Carbon Footprint Analysis of Electrical Energy Use: Case Study Pancasila University

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ABSTRACT

The increase in greenhouse gas (GHG) emissions due to human activities, including electricity consumption, has become a pressing global issue. This study analyzes the carbon emission footprint from electricity use at the Faculty of Engineering, Pancasila University with a quantitative approach based on an inventory of electronic devices and questionnaires. The results show that total carbon emissions reached 1,358.57975 tons of CO_2-eq/Year for CO_2 compounds, 33,964.49376 tons of CO_2-eq/Year for CH_4, and 404,856.7656 tons of CO_2-eq/Year for N_2O. Air conditioner and lighting inventories are the largest contributors every day, reaching 2,350.78 kg CO_2/kWh for AC use and 1,226.07 kg CO_2/kWh for lighting use. The recommended strategy based on the analysis results requires energy efficiency measures and the use of renewable energy, and emphasizes the need for a green campus policy to achieve the SDGs targets.

Keywords: Carbon footprint, electrical energy, CO_2.

INTRODUCTION

Global warming is triggered by Greenhouse Gas (GHG) emissions, especially CO_2 from the combustion of fossil fuels for power generation. The increase in global temperature certainly results in an increase in the concentration of carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and greenhouse gases in the atmosphere so that significant climate change occurs, one of which is an increase in global temperature, considering that more than 75% of the composition of greenhouse gas emissions in the atmosphere is CO2 [1]. In Indonesia, GHG emissions tend to increase with an achievement of 38.77% from 2013 to 2023 [2]. The issue of global warming is increasing day by day. Moreover, environmental degradation in the form of water, soil, and air will affect human health; the loss of biodiversity and the economic sector will also be affected by the environmental damage caused [3].

In addition, there is exploitation of natural materials for the use of electrical energy considering that the use of electrical energy currently tends to experience a fairly rapid increase. Electricity consumption in Indonesia always increases every year, for example in 2023 there was a fairly rapid increase from 2022 by 1,173 kWh/ Capita to 1,337 kWh/ Capita so that electrical energy consumption certainly contributes to greenhouse gas emissions [4]. One of the sectors contributing to GHG is the use of electrical energy, where the largest CO_2 emissions contributed from the use of electrical energy activities, especially in buildings, have a percentage of 70% [5]. The energy sector in activities in buildings is used for lighting, cooling and heating, as well as electronic goods that require electrical energy sources. In daily activities, the electrical energy used will produce CO_2 carbon emissions, so the more activities carried out, the more energy will be used and the larger the carbon footprint will be[6].

Activities that increase carbon emissions include production processes in the manufacturing industry, the use of electric vehicles, and the service industry, which requires electricity. Service industry activities are also related to education, as education requires supporting facilities such as computers, lighting, air conditioning, and laboratories to support practical work.

At the Faculty of Engineering, Pancasila University, the use of electrical energy as a campus with a faculty of Sustainable Development Goals (SDGs) still tends to be unavoidable, starting from the use of computers in laboratories, laptops that require electricity sources, machines used to support

practicums, elevators , lighting, air conditioning for staff and classes, the use of laptops to the need for electrical energy in each study program room that produces CO_2 gas. as the largest contributor to the greenhouse gas effect. Based on the sustainability score on the Pancasila University campus, as found on the Faculty of Engineering SDGs Center website (Figure 1), the value of energy and climate change is 1,340 with a maximum of 2,100 [7]. This condition indicates that energy use has the potential to impact the sustainability of the campus environment. The resulting climate change and air quality will certainly have a significant impact on comfort on campus, and solutions are needed to improve comfort on campus.
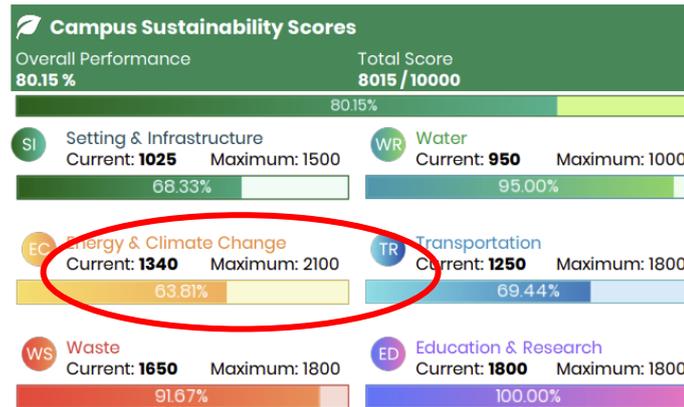

Figure 1. Energy Use in the Faculty of Engineering, Pancasila University

Figure 1 shows that the Faculty of Engineering at Pancasila University actually has excellent sustainability performance, with a total achievement of 80.15% of the maximum score of 100%. This indicates that many aspects of sustainability have been implemented effectively. However, the Energy and Climate Change indicator has the second lowest achievement, at 63.81% of the maximum total. This indicates that the campus's performance in the energy and climate change aspects is quite good, but there is still room for significant improvement. To improve this, the faculty can implement policies regarding energy efficiency systems by reducing unnecessary electricity use, implementing energy management through regular energy audits or energy monitoring systems, using renewable energy, and creating carbon emission reduction policies.

Higher education is committed to providing an example of environmental responsibility by establishing environmentally friendly policies and practices in accordance with the objectives of the sustainability program in the future [8]. In an effort to support the green campus sustainability program, one step that can be taken is to analyze the carbon footprint resulting from energy use activities on campus which is calculated based on its usage. Calculation of the carbon footprint is carried out as a first step that can be used as a basis and strategy towards carbon neutralization [9]. This study aims to analyze the consumption of electrical energy generated from the use of lights, Air Conditioners, elevators, Central Processing Units (CPUs) and computers, other electronic equipment that requires an electrical energy source (excluding machines in the laboratory), for example printers, Uninterruptible Power Supply (UPS), dispensers, refrigerators, Liquid Crystal Displays (LCDs), televisions, network tools (access points, switch routers), servers, laptop use from the results of the questionnaire and the canteen area (showcase, freezer, hexos, and fans). By calculating a carbon footprint, universities or faculties can estimate electricity usage, which will impact operational costs. Furthermore, this research can encourage sustainable environmental policies to support the achievement of the Sustainable Development Goals (SDGs) and serve as climate mitigation within the university or faculty environment.

RESEARCH METHODS
Material

This research requires inventory data which includes the number of lamps, namely 1,613 units, the number of Air Conditioners as many as 248 units, the number of lifts as many as 2 units, the number

of CPUs and computers as many as 437 units, other electronic equipment that requires an electrical energy source (not including machines in the Laboratory), such as printers as many as 82 units, the number of dispensers as many as 28 units, refrigerators as many as 5 units, LCD as many as 83 units, televisions as many as 27 units, network equipment (access points as many as 61 units, switch routers as many as 44 units), servers as many as 9 units, UPS as many as 213 units, and canteen area (showcase as many as 6 units, freezer as many as 6 units, exhaust as many as 12 units, and fans as many as 6 units). In addition, obtained from the results of a questionnaire to 100 respondents to find out the use of laptops in the faculty area and the acquisition of the questionnaire resulted in 100 respondents using laptops in the faculty area. Furthermore, the emission factor multiplier used is 0.87 Kg CO_2 / kWh sourced from the use of electrical energy according to the Ministry of Energy and Mineral Resources Directorate General of Electricity [10]. Meanwhile, the Global Warning Potential (GWP) value for radiation over a 100-year period has been determined by the Intergovernmental Panel on Climate Change (IPCC) with a value for carbon dioxide gas (CO_2) of 1, methane gas (CH_4) of 25 and nitrous oxide gas (N_2O) of 298 [11].

Method

This research uses a descriptive quantitative approach that aims to calculate carbon emissions from the use of electrical energy in the Faculty of Engineering, Pancasila University. This method is applied through systematic stages, starting from problem identification, followed by literature studies and field observations as the basis for developing a theoretical framework. After the theoretical framework is developed, the next stage is data collection, which is carried out through two approaches: an inventory of electronic devices to determine their technical specifications, and a questionnaire distribution to identify user behavior in using these devices. Data from both approaches are combined to calculate energy consumption. After obtaining energy consumption data, emission factors are applied based on the type of energy used to calculate the carbon footprint. Next, the calculation results are analyzed and discussed to identify the largest emission sources and determine appropriate mitigation measures. The final stage is drawing conclusions and providing recommendations based on the analysis results to support carbon emission reduction strategies in the campus environment. The research methodology is shown in Figure 2.

The study done in the Faculty of Engineering, Pancasila University, where data collection was conducted on April 14, 2025 to May 30, 2025 within 5 working days for 8 hours per day. The calculated carbon emission sources include the use of electrical energy (indirect emissions or scope 2) such as lights, Air Conditioners, elevators, Central Processing Units (CPUs) and computers, other electronic equipment that requires electrical energy sources (excluding machines in the laboratory), for example printers, Uninterruptible Power Supply (UPS), dispensers, refrigerators, Liquid Crystal Displays (LCDs), televisions, network tools (access points, routers, switches), servers, laptop use from the questionnaire results and the canteen area (showcases, freezers, exhaust, and fans).
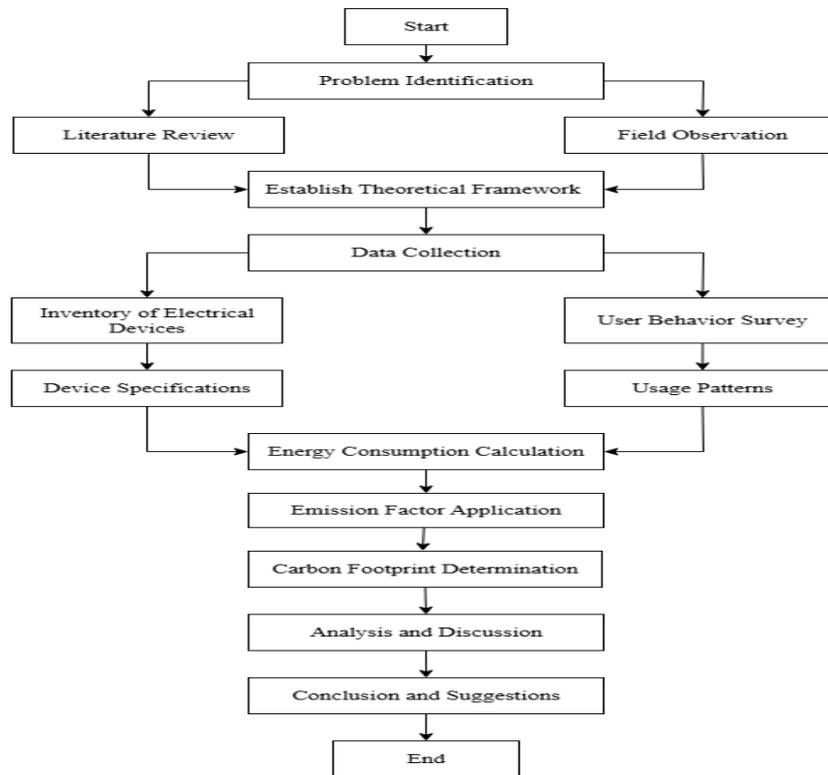
Figure 2. Research Methodology Flowchart

Data analysis

Analysis of research This that is focus on calculations emission carbon produced from use energy electricity which includes use lights, Air Conditioner, elevator, Central Processing Unit (CPU) and computer, other electronic equipment that requires electrical energy source (excluding machines in the laboratory), for example printer, Uninterruptible Power Supply (UPS), dispenser, refrigerator, Liquid Crystal Display (LCD), television, network tools (access point, router, switch), server, laptop usage from questionnaire result and canteen area (showcase, freezer, hexos, and fan). From the inventory data obtained, the specifications of electronic goods will be known starting from brand, type, material, capacity, and number of watts released. After knowing the number of watts released, the results of the amount of electrical energy consumption released in daily activities with 8 working hours every day will be obtained in kilowatt-hour (kWh) units. Based on the results of energy consumption released per day, then a calculation will be made by multiplying the emission factor that has been determined for electrical energy which is $0.87 \, Kg \, CO_2 / kWh$ and the GWP value based on greenhouse gases that will be analyzed. The following is the formula that will be used to calculate the amount of electrical energy used per day and the formula for calculating carbon emissions with an emission multiplier factor [12] [13].

$$\text{Energy (kWh)} = \frac{P \times t \times n}{1000} \tag{1}$$

Information:
- P = Electrical power of the device (in watts)
- t = Time of use per day (in hours)
- n = Number of units/devices
- 1000 = Conversion from watts to kilowatts (1 kW = 1000 watts)

$$CE = \sum A \times EF \times GWP_{100} \tag{2}$$

Where:

CE   = Carbon Emission (CO_2-eq)
$\sum A$ = Total Activity or Consumption (CO_2 / kWh)
EF   = Emission Factor (CO_2 / kWh)
GWP   = Global Warming Potential

RESULTS AND DISCUSSION

The use of electrical energy is certainly inseparable from daily activities in the campus environment and is of course directly related to inventory assets that use electrical energy as their driving force. Inventory data is collected from recording electrical equipment assets used in the Faculty of Engineering environment, including various types of equipment such as AC with various capacities, CPU and computers, printers, servers, network tools (access points, routers, switches), LCD projectors, lighting, UPS, refrigerators, dispensers, elevators, showcases, hexos, freezer and The fans in the engineering canteen. Each piece of equipment is identified by the number of units, which is then used to identify the electrical power (watts). This inventory data is the primary basis for calculating the total electrical energy consumption in the faculty. The following is a recapitulation of the total amount of electrical energy used in the Faculty of Engineering, Pancasila University.

Table 1. Summary of Inventory Amounts

Information	Amount (Unit)
Air Conditioning	248
CPU and Computer	437
Switch Router	44
LCD	83
TV	27
Access Point	61
Server	9
Printer	82
UPS	213
Refrigerator	5
Dispenser	28
Light	1613
Elevator	2
Canteen	30
Laptop	100
Total	**2982**

Once inventory data is obtained, the brand and specifications will show the average wattage output during use. For example, consider the AC usage shown in Table 2.

Table 2. Results of *Air Conditioner Power* Usage Calculations

Asset Type	Brand and Type	Average (Watts)	Amount (Unit)	Output (Watts)	Output (kWh)
Split AC	Daikin 3/4 PK	750	5	3,750	3.75
Split AC	Daikin 1/2 PK	425	3	1,275	1,275
Split AC	Daikin 2 PK	1900	63	119,700	119.7

Table 3. Results of Air Conditioner Power Usage Calculations (Continued)

Asset Type	Brand and Type	Average (Watts)	Amount (Unit)	Output (Watts)	Output (kWh)
Split AC	Panasonic 1 PK	900	28	25,200	25.2
Split AC	Daikin 1 PK	900	10	9,000	9
Split AC	Panasonic 1.5 HP	1300	21	27,300	27.3
Split AC	Besch 1.5 HP	1400	1	1,400	1.4
Split AC	Sharp 1.5 HP	1340	27	36,180	36.18
Split AC	LG 1.5 PK	1500	4	6,000	6
Split AC	LG 2 PK	1900	1	1,900	1.9
Split AC	Season 1 PK	900	1	900	0.9
Split AC	General 1 PK	1300	3	3,900	3.9
Split AC	General 1.5 HP	1300	6	7,800	7.8
Split AC	National 1.5 HP	1300	7	9,100	9.1
Split AC	Panasonic 2 PK	1900	18	34,200	34.2
Split AC	Panasonic 3/4 PK	750	3	2,250	2.25
Split AC	Fuji 1.5 PK	1300	23	29,900	29.9
Split AC	Daikin 1.5 PK	750	24	18,000	18
Amount		**21,815**	**248**	**337,755**	**337,755**

Based on the results in Table 3, there are 248 AC units in inventory with varying specifications and types. The wattage output also varies depending on the type. The calculation results are obtained by multiplying the inventory quantity by the average wattage output. An example calculation is as follows, referring to Formula 1.

$$\text{Energy (kWh)} = \frac{P \times t \times n}{1000}$$
$$= \frac{750 \text{ watt} \times 8 \text{ jam} \times 5 \text{ unit}}{1000}$$
$$= 30 \text{ kilowatt-hours (kWh)}$$

From the results of the calculation recapitulation, the power output for the use of 248 AC units is 337,755 watts or equivalent to 337.755 kilowatt-hours (kWh). If the AC is used for one day during working hours of 8 (eight) hours, the energy consumption or power output is 2,702.04 kWh which is obtained from the result of multiplying the amount of power in kWh units by the hours of use.

After all inventories have been calculated and the results of the calculation of the power expended for each type of inventory or asset are obtained, the following is a recapitulation of the use or expenditure of power expended in watts, kWh, with 8 hours of use per day, as well as the carbon emissions produced for each asset expended.

Table 4. Summary of Electrical Energy Usage Power

Information	Output (Watts)	Output (kWh)	8 Hour Result (kWh)	Emission Results (Kg CO2 / kWh)
air conditioning	337,755	337,755	2702.04	2,350.78
CPU and Computer	112,655	112,655	901.24	784.08
Switch Router	646.5	0.6465	5,172	4.50
LCD	21,382.5	21,3825	171.06	148.82
Television	3,660	3.66	29.28	25.47
Access Point	642	0.642	5,136	4.47
Server	2,241	2,241	17,928	15.60
Printer	1,423.5	1.4235	11,388	9.91
UPS	121,345	121,345	970.76	844.56
Refrigerator	635	0.635	5.08	4.42
Dispenser	12,500	12,500	100	87
Light	176,160	176,160	1,409.28	1,226.07
Elevator	16,750	16.75	134	116.58
Canteen	3,210	3,210	25.68	22.34
Laptop	6,188	6,188	18,564	16.15
Amount	**817,193.5**	**817,1935**	**6,506,608**	**5,660,7490**

Emission results are calculated using formula 2 without a GWP multiplier. The following is an example of an AC inventory calculation.

CE $= 2072.04$ kWh x 0.87 Kg CO $_2$ / kWh
        $= 2,350.78$ Kg CO $_2$ / kWh

Based on the overall inventory results in Table 2, the data was then plotted in a bar chart to facilitate analysis. The bar chart, shown in Figure 3, shows the resulting emissions.
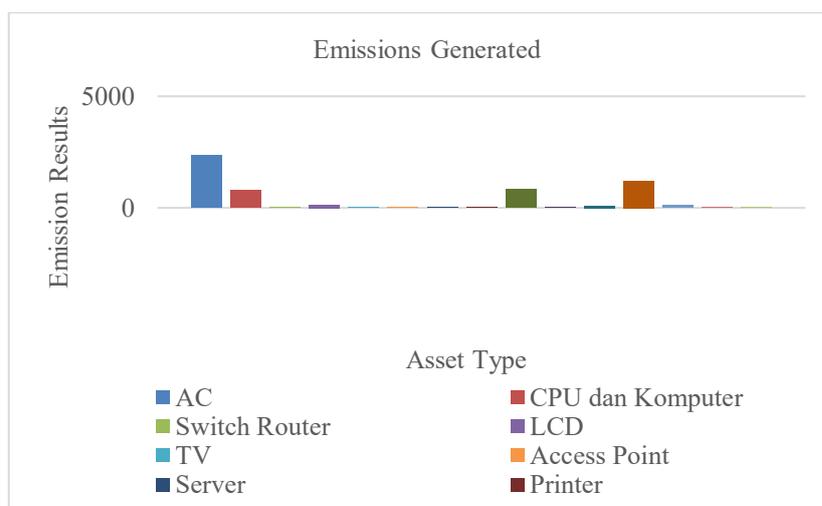

Figure 3. Emissions Generated

Based on Figure 3, it can be seen that the asset that produces the highest emissions is the AC with an emission value of 2,350.78 Kg CO_2 / kWh. Then, in second place are lights as a significant contributor to emissions, namely 1,226.07 Kg CO_2 / kWh . In third place is the UPS which contributes an emission value of 844.56 Kg CO_2 / kWh. The UPS functions to supply backup power and remains active as long as the electricity network is connected, so the energy consumed is also quite large. Next, there are CPUs and computers which are in fourth place with emissions of 784.08 Kg CO_2 / kWh , indicating that daily work activities that depend on computers also play a role in high energy cosumption. In addition, LCDs also contribute emissions in a not insignificant amount, namely 148.82 Kg CO_2 / kWh and elevators of 116.58 Kg CO_2 / kWh.

In addition, several assets show relatively low emissions, such as *switch routers,* printers, servers, *access points,* TVs, refrigerators, dispensers, laptop use, and the canteen area, which have emission values below 100 kg CO_2 / kWh. These low emissions could be caused by limited operating hours, infrequent use, or relatively low electrical power. Therefore, overall, the results of this calculation indicate that to reduce emissions, the main focus needs to be on devices that operate constantly and consume large power, such as air conditioners and lighting.

Furthermore, based on the results of the analysis of Table 2 regarding the recapitulation of power from the use of electrical energy in the inventory in energy units (kWh) for 8 hours of use, the next step is to calculate the use of energy produced during a year by multiplying the results of energy use per day by the total working days of 20 working days each month for 12 months, the following are the results of the calculation.

Energy Consumption = 6,506.608 kWh/ Day x 20 Working Days x 12 Months
= 1,561,585.95 kWh/Year

Carbon emissions were calculated using an emission factor of 0.87 kg CO_2/kWh, which is the standard emission factor for electricity use in Indonesia's Java, Madura, and Bali regions, based on the electricity source and the GWP value based on the type of compound involved. The carbon emissions were calculated using Formula 2, with the following calculation results:

1. Carbon emissions (CE) from electrical energy consumption with GWP for CO_2

    CE = 1,561,585.95 kWh/ Year x 0.87 Kg CO $_2$/ kWh x 1

    = 1,358,579.75 Kg CO_2-eq/ Year

    $$= \frac{1.358.579,75 \; Kg \; CO_2\text{-eq/ Tahun}}{1000}$$

    = 1,358.57975 Tons CO_2-eq/ Year

2. Carbon emissions (CE) from electricity consumption with GWP for CH_4

    CE = 1,561,585.95 kWh/ Year x 0.87 Kg CO_2/ kWh x 25

    = 33,964,493.76 Kg CO_2-eq/ Year

    $$= \frac{33.964.493,76 \; Kg \; CO_2\text{-eq/ Tahun}}{1000}$$

    = 33,964.49376 Tons CO_2-eq/ Year

3. Carbon emissions (CE) from electricity consumption with GWP for N_2O

    CE = 1,561,585.95 kWh/ Year x 0.87 Kg CO_2/ kWh x 298

    = 404,856,765.6 Kg CO_2-eq/ Year

    $$= \frac{404.856.765,6 \; Kg \; CO_2\text{-eq/ Tahun}}{1000}$$

    = 404,856.7656 Tons CO_2-eq/ Year

Based on the calculation results, the total carbon emissions resulting from the use of electrical energy in the Faculty of Engineering, Pancasila University, in units of Tons of CO_2-eq/ Year are 1,358.57975 for the GWP value of CO_2 compounds , which means that for one year, electrical activities in the faculty produce around 1,358.57975 tons of carbon dioxide, which is the main greenhouse gas from the combustion of fossil energy, namely electrical energy. Furthermore, emissions of 33,964.49376 Tons of CO_2-eq/ Year are obtained for the GWP value of CH_4 compounds, the results are higher because the GWP of methane is 25 times that of GWP CO_2. Furthermore, emissions of 404,856.7656 Tons of CO_2-eq/ Year are obtained. For the GWP value of the N_2O compound, even though the N_2O gas produced is small, its GWP is high, 298 times that of CO_2, so it contributes to the total equivalent emissions very dominantly.

Based on the assumption of inventory usage for 8 hours per day, however, in practice in the field some inventories, for example the use of AC and lights, are said to exceed or fall short of the assumed time limit, so this study is estimative, meaning the calculation of carbon emissions is not based on exact data, but rather an approach based on rational assumptions and supporting data. It should be understood that not all emissions from the use of inventory that uses electrical energy at the Faculty of Engineering, Pancasila University are directly released into the atmosphere as carbon dioxide (CO_2). Some emissions may be released into the air, while others can be decomposed or reabsorbed through the natural carbon cycle [14].

In addition, based on the findings in Figure 3 regarding the emissions produced, it shows that the largest source of carbon emissions comes from the use of Air Conditioners (AC) and lights. The resulting emissions from these two sources reach 3,576.85 Kg CO_2 / kWh per working day, so a mitigation strategy is needed to reduce these carbon emissions. Strategies that can be implemented to reduce emissions from the use of AC and lights include replacing energy-saving technologies such as replacing conventional lamps with LED lamps and using ACs with more efficient inverter technology. Meanwhile, an IoT system can also be implemented through the installation of motion sensors and automatic timers connected to the network, so that electrical devices will only be active when needed. For example, the implementation of a smart lighting system that automatically turns on only when the room is detected as active, or an AC management system that automatically adjusts the room temperature based on the number of people in it. With this approach, energy use can be reduced significantly and the resulting carbon emissions can be reduced sustainably.

Based on the strategies described to reduce electricity use from air conditioning and lighting, the Faculty of Engineering has implemented a system that uses LED lights, but conventional lights are still widely used in the faculty building. Meanwhile, the use of inverter AC is still uneven. The use of IoT systems using sensors or smart lighting systems that automatically turn on when a room is detected as active has not yet been implemented. The smart lighting system has only been implemented on the second floor of the corridors of academic and leadership rooms. The application of smart lighting systems should be implemented throughout the building, especially in classrooms. The implementation of smart lighting systems, according to literature, can reduce electricity use by 30% to 60%. This will certainly have a significant impact on the commitment to climate mitigation. Meanwhile, the faculty has not yet implemented an automation system policy for air conditioning use. However, if automation systems are implemented in air conditioning, for example with motion sensors or thermistors, according to literature, energy savings can reach 20% to 50% [15].

Furthermore, to reduce the carbon footprint from the emission target of 29% to 31.89% by conducting independent efforts and from 41% to 43.20% with international assistance by 2030, Indonesia is committed to the struggle for climate mitigation in the world, where the commitment is stated in the Nationally Determined Contribution (NDC). In addition, the Enhanced NCD is aligned with the long-term low-carbon and climate resilience strategy of 2050 and the vision to achieve net zero emissions by 2060 [16]. One of the national strategies is to encourage the use of renewable energy, energy efficiency, waste management, and tree planting through the net zero emissions program by 2060, which is then expanded to the regional, institutional and even higher education institutions.

Based on the agreed commitment, educational institutions or universities must also implement a campus sustainability system. This sustainability system refers to the Sustainable Development

Goals (SDGs), where the implementation of a sustainability system at universities can contribute to achieving climate mitigation goals. This is certainly one of the universities' responsibilities towards the environment to create comfort. As part of a responsible university, the Faculty of Engineering at Pancasila University plays a crucial role in educating and implementing environmental awareness, including the issue of carbon footprint.

Furthermore, universities and other higher education institutions play a crucial role in promoting decarbonization and sustainable development, as their social and educational roles are inseparable from training future leaders, as well as their energy consumption and resource use. For example, in the United States, universities are responsible for approximately 2% of total GHG emissions, equivalent to emissions from commercial aircraft or landfills. Therefore, achieving carbon neutrality in the higher education sector can have a significant environmental impact [17]. To achieve carbon neutrality, several important factors are involved, such as spatial planning, utilization of renewable and clean energy, energy systems, building thermal envelopes, environmentally friendly transportation, energy management and control, and performance related to human behavior. Furthermore, the application of smart technology and the implementation of control technology or Internet of Things systems will certainly provide real-time development information data.

CONCLUSION

The results of the calculation of carbon emission footprints from the use of electrical energy sourced from the use of AC, CPU and computers, switch routers, LCD, TV, access points, servers, printers, UPS, refrigerators, dispensers, lights, elevators, canteens, and the use of laptops in the Faculty of Engineering, Pancasila University in units of Ton CO_2-eq/ Year were obtained at 1,358.57975 Ton CO_2-eq/ Year for the GWP value of CO_2 compounds. Furthermore, carbon emissions were obtained at 33,964.49376 Ton CO_2-eq/ Year for the GWP value of CH_4 compounds and emissions were obtained at 404,856.7656 Ton CO_2-eq/ Year for the GWP value of the compound N_2O.

ACKNOWLEDGMENT

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