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ESTIMATION OF THE CARBON FOOTPRINT OF CAMPUS ACTIVITIES AT THE FACULTY OF SCIENCE AND TECHNOLOGY, UNIVERSITAS JAMBI, AFTER THE COVID19 PANDEMIC

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Abstract

Introduction: *The Covid19 pandemic altered campus activity patterns, impacting energy use and transportation. As operations resumed, universities became significant contributors to carbon emissions. Without intervention, these emissions risk accelerating environmental harm. This study estimates the post-pandemic carbon footprint of campus activities to provide a foundation for emission reduction strategies at the Faculty of Science and Technology, Universitas Jambi.* ***Methods:*** *This quantitative descriptive study used surveys and observations at Universitas Jambi (2023) with 132 respondents via stratified sampling. Emissions were estimated using GHG Protocol scopes 1–3 and IPCC 2019 factors. Carbon-related variables were analyzed and mapped using Vensim to visualize interrelations in campus emission activities.* ***Results and Discussion:*** *The post-pandemic carbon footprint of campus activities at the Faculty of Science and Technology, Universitas Jambi, totaled 490.9 tons CO_2-eq in 2023. Scope 2 emissions from electricity use dominated at 78.54%, followed by Scope 3 (commuting and paper usage) at 20.29%, and Scope 1 at 1.16%. Transportation, particularly student commuting, was the largest contributor within Scope 3. Scenario simulations using Vensim revealed that carpooling and car-free day programs could reduce emissions significantly. Behavior-based interventions, including energy-saving practices and digital document usage, were identified as effective strategies to improve sustainability in daily academic operations.* ***Conclusion:*** *The findings support the development of targeted emission reduction strategies aligned with post-pandemic campus conditions. Its integrated approach contributes a data-driven framework for sustainable policy planning, especially for post-pandemic institutions in tropical and developing country contexts.*

INTRODUCTION

Carbon footprint is the total greenhouse gas emissions produced by individuals and institutions that are calculated and expressed as carbon dioxide equivalents (1). Carbon footprint is a measure of the total amount of carbon dioxide emissions resulting from the activity or accumulated use of products in everyday life (2). Carbon footprints can be generated from various emission sources, such as the use of fossil fuels in the form of petroleum and natural gas that can produce carbon dioxide (3). Carbon emissions are a significant cause of climate change (4). Climate change is a worldwide issue, caused by the emissions of Greenhouse Gases (GHG) of which the dominant contributor is Carbon Dioxide (CO_2). The amount of GHG produced by any higher institution can be quantified using carbon footprint estimation (5). Additionally, the concentration of carbon dioxide in the environment is measured as carbon dioxide equivalent (CO_2-eq) (6).

While carbon footprint can be calculated for any particular area or population, it is also common to calculate carbon footprint for university campuses (7). The existence of universities has an impact on the environment due to the daily activities carried out by universities (8). Various campus activities produce CO_2 emissions that have a direct or indirect impact on the

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environment. Universities as providers of educational institutions contribute to greenhouse gas emissions generated from the use of electronic devices and consumption of fuel oil (BBM) in using motorized vehicles to and from campus (9). Although the energy, industrial, and transportation sectors remain the largest contributors to global emissions (accounting for more than 70% of total CO_2 output universities are increasingly recognized as strategic actors in the transition to a low-carbon future (10). Their role extends beyond emissions: they shape sustainable behavior, foster environmental awareness, and serve as living laboratories for climate solutions (11). Studies at President University and Universitas Andalas have demonstrated the measurable impact of academic environments on emissions and mitigation potential through canopy absorption and sustainable transportation practices (12-13). If these emissions are not effectively monitored and mitigated, they can exacerbate the adverse effects of climate change, including extreme weather events, environmental degradation, and health risks to the broader population. Moreover, as institutions that shape future generations, universities bear a critical responsibility to lead by example in environmental stewardship. The lack of action in reducing emissions at the university level may undermine both national sustainability policies and global climate commitments. Therefore, many sectors, including universities have initiated GHG management systems and focused on reducing carbon emissions (14).

The Faculty of Science and Technology (FST) is the location of carbon footprint estimation research from campus activities. FST is one of the many contributors to the carbon footprint at the Universitas Jambi (UNJA). FST has 14 study programs and is among the faculties with the most study programs at UNJA, making it a representative sample for estimating the university's carbon footprint. Within FST, there are lecture activities, laboratory usage, campus administration, transportation, canteen activities, and other operations, all of which are closely linked to the carbon footprint generated. After Covid19, an additional lecture building was constructed at FST to support academic activities. Any additional activity that requires energy or produces CO_2 contributes to the carbon footprint. Some studies have calculated the carbon footprint before and during the Covid19 pandemic and observed a significant decrease (15). For example, the total carbon footprint at the Faculty of Mathematics and Natural Sciences, Semarang University, was 10,670.25 tons CO_2-eq/month before the pandemic, whereas during the Covid19 pandemic, it decreased to 4,312.27 tons CO_2-eq/month (16). A study at a Philippine university reported substantial declines in Scope 3 emissions, particularly from commuting and paper consumption (17). At Cornell University, emissions dropped markedly due to the reduction in campus operations during lockdown (18). A Brazilian university found that online classes significantly reduced daily environmental impacts compared to face-to-face delivery (19). Universiti Malaysia Perlis (UniMAP) documented a notable drop in electricity and transportation emissions during the pandemic (20). Similarly, Sakarya University in Turkey experienced measurable decreases in its overall campus carbon footprint (21). Research on Chinese universities showed that online education had a clear role in reducing academic-related carbon emissions (22). Studies at McGill University in Canada also highlighted behavioral shifts in travel during the pandemic that contributed to lower greenhouse gas emissions (23).

Generally, teaching and learning activities from school to university are conducted directly or face to face between teachers and students, both in classrooms and in the learning environments (24). The Covid19 pandemic has brought many changes to human life, such as changes in activities and movement patterns (25). Post-pandemic, student and staff activities have also changed, leading to adjustments in the lecture and campus administration systems. After the Covid19 pandemic, lecture and campus administration activities can be carried out offline, online, and hybrid which can streamline the lecture system and can support the reduction of the carbon footprint of campus activities. However, these new patterns may also reintroduce or intensify emission sources such as transportation and electricity consumption. Without proper monitoring, the rebound of campus activity could contribute to elevated CO_2 emissions, which not only drive climate change but also deteriorate air quality and increase health risks such as respiratory and cardiovascular diseases. Despite the availability of carbon footprint assessments at the university level, there is a lack of specific, post-pandemic data at the faculty level to inform localized mitigation strategies. Carbon footprint calculation is a relevant Decision Support tool that allows university organizations to measure and communicate the environmental effects of their activities (26). This research aims to determine the CO_2 emissions generated from campus activities at FST after Covid19, so that strategies can be implemented to reduce CO_2 emissions from these activities.

METHODS

This research applies a quantitative descriptive approach aimed at measuring and describing the post-pandemic carbon footprint of campus activities at the Faculty of Science and Technology, Universitas Jambi.

The study was conducted over a 12-month period, from January to December 2023. This research uses both primary data and secondary data. Primary data collection was obtained through questionnaires, interviews, and observations, while secondary data was obtained from university documentation. The research sample consists of the FST population, which includes students, lecturers, and staff, selected using a stratified random sampling method. In this method, not all individuals in the population are included in the sample, but only a certain number. The total population of FST UNJA in 2023 was 2879 people with a sample size of 132 people. The sample size with a 10% margin of error, yielding a manageable and statistically acceptable number of respondents from the faculty population. The number of samples used is calculated using the Slovin formula as follows:

$$n = N / (1 + N \propto^2)$$

Description:
- n : Number of study area samples (people)
- N : The population size in the study area (people)
- $\propto$: Degree of error (10%)

The most widely used guidelines for calculating a carbon footprint are the GHG Protocol Standards, developed by the World Resources Institute (WRI) and the World Business Council for Sustainable Development (WBCSD) (27). Based on the Greenhouse Gases Protocol (GHG protocol), the carbon footprint is measured based on 3 scopes. Scope 1 (direct GHG emissions) accounts for GHG emissions from sources owned or controlled by the organization, Scope 2 (electricity indirect GHG emissions) accounts for GHG emissions from the generation of purchased electricity consumed by the organization and Scope 3 (other indirect GHG emissions) is an optional reporting category that includes emissions that are a consequence of the activities of the organization but occur from sources not owned or controlled by the organization (28). In this study, these three scopes also served as the primary framework and measurement instrument for identifying the determinants of high carbon emissions. Data is then collected by scope and calculations are performed based on the International Panel on Climate Change (IPCC) (29).

Scope 1 includes CO_2 emissions from the use of LPG originating from canteen activities as well as from the operational vehicles of the faculty. To determine the carbon footprint value from CO_2 emissions originating from transportation activities and LPG use, the following equation can be used:

$$CO_2 \text{ emission} = \text{Consumption}_{fluel} \times NK_{fluel} \times FECO_{2\,(fluel}$$

$$CO_2 \text{ emission} = \text{Consumption}_{LPG} \times NK_{LPG} \times FECO_{2\,(LPG)}$$

Description:
- Emission : Total emission CO_2
- $\text{Consumption}_{fluel}$: Fuel consumption (l)
- Consumption_{LPG} : LPG consumption (kg)
- NK CO_2 : The calorific value of CO_2 by fuel type (MJ/l or MJ/kg)
- FE CO_2 : CO_2 emission factors by fuel type (kg/MJ)

Scope 2 includes CO_2 emissions resulting from the faculty's electricity consumption activities over one year. The total electricity consumption is calculated using an audit method to determine the electricity consumption used in the FST building by calculating the total load usage of the electrical equipment used. To obtain the total load usage, the following equation is applied:

$$\frac{\text{electric load x number of hours of use x working days}}{1000}$$

For the calculation of carbon emissions generated from electricity consumption activities, the following equation can be used:

$$CO_2 \text{ emission} = FE \times \text{Electricity consumption}$$

Description:
- CO_2 emission : CO_2 gas emissions ($kgCO_2$-eq)
- FE : CO_2 emission factor (0,774388897 $kgCO_2$/kWh)

Scope 3 includes CO_2 emissions from the transportation activities of students, lecturers, and staff, as well as paper usage by students, lecturers, and the operations of FST UNJA. The carbon footprint calculation from transportation activities is the same as the carbon footprint calculation for operational vehicles. For the calculation of CO_2 emissions from paper usage activities, the following equation can be used:

$$CO_2 \text{ emission} = FE \times \text{Paper usage}$$

Description:
- CO_2 emission : CO_2 gas emissions ($kgCO_2$-eq)
- FE : CO_2 emission factor (1,22 $kgCO_2$-eq/kg paper)

The carbon footprint generated from the three scopes originating from various activities at the Faculty of Science and Technology, Universitas Jambi, needs to be reduced to minimize the negative impacts that will be caused. The distributed questionnaire is also used to identify the factors influencing CO_2 emissions from campus activities at the Faculty of Science and

Technology, so that efforts can be made to reduce the generated CO_2 emissions with scenarios that may be implemented at the Faculty of Science and Technology. The questionnaire also includes alternative measures that may be applied to reduce the carbon footprint, which respondents can select.

The questionnaire was distributed directly by the researcher and was created by organizing various indicators into structured questions. By checking the designated answer columns, respondents provide direct answers. The solution provided can take the form of policies that can reduce CO_2 emissions, selected based on the highest average according to the Likert scale and the willingness of respondents, such as behavioural changes to reduce the carbon footprint from the transportation activities of students, lecturers, and staff, electricity usage, and paper consumption. Then, the selected policy alternatives are calculated for their CO_2 emission reduction values to determine the amount of CO_2 emissions that can be reduced.

Each question in the questionnaire was tested for validity and reliability by the researcher. The validity test is used to determine whether a questionnaire is valid or not, a questionnaire is considered valid if its questions can provide information that will be used to assess something. A person's response to a question can be considered realizable if it remains constant or stable over time. The reliability test is used to examine the consistency of the research variables. If the calculated r value is greater than the table r value, then the questionnaire is considered valid, and if the Cronbach's alpha value is 0.6, it is considered reliable (30). This study also employed Vensim PLE 10.2.1, a dynamic modeling and visualization tool, to map interrelated carbon emission variables within the campus system. Vensim allows for the creation of causal loop diagrams that visually represent the feedback relationships between key emission factors such as electricity use, transportation frequency, fuel consumption, and paper usage.

By using this tool, a systems thinking approach was applied to identify reinforcing and balancing feedback loops affecting the carbon footprint at the Faculty of Science and Technology. The purpose of this modeling was to understand the dynamic interactions among activities contributing to CO_2 emissions and to simulate potential reduction strategies. This visual representation supported the formulation of practical recommendations by clarifying which variables exert the most significant influence within the emission system.

The construction of the causal loop diagram was based on validated questionnaire results and emission calculation outputs, ensuring that the model accurately reflected the real conditions on campus. The use of Vensim not only enhances transparency but also supports strategic decision-making for emission reduction planning at the institutional level.

RESULTS

The questionnaire results showed that the calculated r values exceeded the critical r table values, confirming item validity. Reliability testing was carried out using Cronbach's alpha, and the instrument was deemed reliable, with a coefficient exceeding the threshold of 0.6, indicating consistent responses over time and across variables. The sources of the carbon footprint at FST include the transportation of official vehicles, the use of LPG, electricity consumption, transportation of students, lecturers, and staff, as well as paper usage. The total carbon footprint generated from campus activities at FST UNJA is as follows:

The calculation of the carbon footprint for Scope 1 consists of data on the fuel consumption of FST UNJA's operational vehicles and the consumption of Liquefied Petroleum Gas (LPG) over a one-year period. The fuel consumption of FST UNJA's operational vehicles in 2023 was 58.37 litres. The data on the purchase of fuel for FST UNJA operational vehicles over the course of one year comes from the fuel expenditure reports for Pertamax-type fuel. The fuel consumption of operational vehicles is done by estimating the fuel consumption used only for trips on campus. The use of fuel for operational vehicles is done by estimating the fuel consumption used only for trips on campus. The calculation of fuel consumption is obtained by dividing the distance from the UNJA gate to FST by the fuel requirement (km/l) and then multiplying it by the frequency of trips to campus. It is assumed that operational vehicles operate for 5 days a week. The total fuel consumption data of operational vehicles obtained is then inserted into equation 2 to obtain the CO_2 gas emission value as the carbon footprint generated from the transportation activities of FST UNJA operational vehicles in 2023. The carbon footprint from the transportation activities of FST UNJA'S operational vehicles, such as official cars, in 2023 was 0.13 tons CO_2-eq.

The use of LPG from campus activities is primarily from the canteen, which consists of six stalls using 3 kg LPG cylinders. Data on LPG usage over one year was obtained through questionnaires distributed to vendors in the FST UNJA cafeteria. The calculation of the carbon footprint from LPG usage activities is carried out based on equation 3, expressed in kg/month. LPG consumption is calculated during both active and holiday periods, with the canteen operating from Monday to

Saturday on average. The LPG consumption of each kiosk varies, as not all canteens process and cook their food on campus some kiosks also cook their food at home. The highest carbon footprint is contributed by the Bina Jaya cafeteria and the Padila cafeteria, which process and cook food on campus, thus consuming more LPG. Other canteens produce lower emissions because the cooking and processing of food are not done directly in the canteen instead, they are pre-processed at home, and only the reheating of food is done on campus. The total LPG usage at FST UNJA in 2023 was 1872 kg. The total carbon footprint from each kiosk at FST UNJA during 2023 was 5.59 tons CO_2-eq. Overall, scope one generated a carbon footprint of 5.72 tons CO_2-eq. The carbon footprint of each kiosk can be seen in Figure 1.

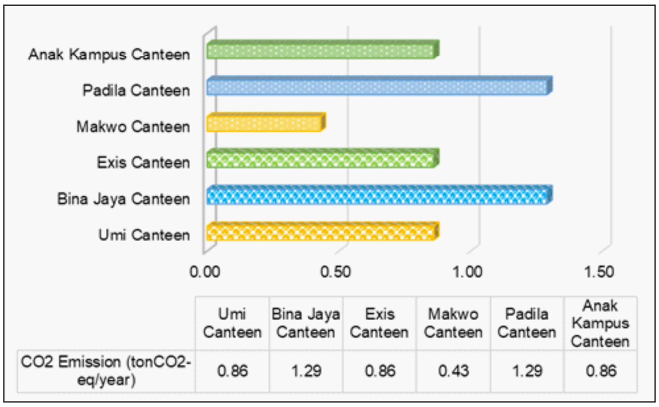

Figure 1. Carbon Footprint of the FST UNJA Canteen

Electricity consumption at FST UNJA in 2023 amounted to 498,504.34 kWh. The total carbon footprint from electricity usage in Building A, Building B, and the FST UNJA cafeteria over the course of a year was 386.04 tons CO_2-eq. The large data on electricity usage was obtained using the audit method, which involves listing all electrical appliances and then multiplying their power (watt) by the duration of use. Each electrical appliance is recorded, then the duration of its usage is estimated and multiplied by the appliance's power rating, resulting in the electricity consumption for each used appliance. The audit method was conducted because FST UNJA does not have its own meter but instead uses the main substation that covers the electricity consumption of all faculties and buildings at UNJA.

The calculation of the Scope 3 carbon footprint includes transportation activities and paper usage by students, lecturers, and staff at FST UNJA. The calculation of the carbon footprint from transportation activities obtained from the questionnaire includes data on the types of transportation modes frequently used, types of fuel, distances travelled, and the frequency of trips to campus. The carbon footprint from burning fossil fuels depends on both the amount and type of fuel used. Fuel usage data is converted into Mega Joules (MJ) by multiplying the calorific value by the emission factor. Most students, lecturers, and staff use motorcycles as their mode of transportation for commuting to and from campus. The percentage of transportation mode selection can be seen in Figure 2.

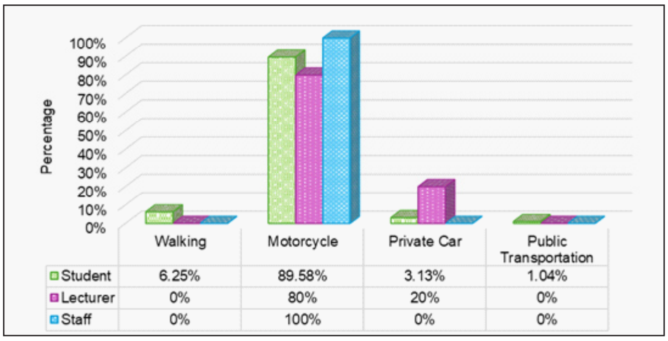

Figure 2. Percentage of Transportation Mode Selection

The carbon footprint generated from transportation activities by students, lecturers, and staff for the year 2023 is 84.71 tonCO_2-eq/year. The fuel consumption of each mode of transportation was obtained by dividing the distance from the UNJA gate to FST by the fuel requirement (km/l) for the mode of transportation used, and then multiplying it by the average frequency of respondents traveling to campus each week. The average frequency of trips to campus made by students, lecturers, and staff also affects the carbon footprint produced. During the active lecture period, the frequency of trips to campus by students tends to be more frequent compared to during the lecture break. Meanwhile, for lecturers and staff, the frequency of trips to campus tends to be not much different because during the lecture break, lecturers and staff still carry out their duties on campus. The calculation of the carbon footprint from the transportation activities of students, lecturers, and staff is done using equation 2. There are 35 weeks of active lecture periods in 2023, 14 weeks of lecture breaks, and the remaining 4 weeks include national holidays (Eid and New Year). The even semester of 2022/2023 starts in February – June 2023 and the odd semester of 2023/2024 starts in August – January 2024. From the 84.71 tons of CO_2-eq/year generated from the transportation activities of students, lecturers, and staff, 77.34 tons of CO_2-eq/year are contributed by students. The carbon footprint generated from the transportation activities of students, lecturers, and staff can be seen in Figure 3.

The data required to calculate the carbon footprint from paper usage activities includes the type of paper used and the amount of paper usage expressed in units of rim/year. The carbon footprint from paper usage activities can be calculated by knowing the percentage of paper selection used by each respondent, then multiplying it by the average paper usage by students, lecturers, and staff over the course of a year. The type of paper used is HVS A4 70 GSM and HVS A4 80 GSM paper, which are used as support for lectures and office work. The amount of paper usage in reams is converted into weight units (kg) to calculate its emissions. Similar to transportation activities, students are the largest contributors to the carbon footprint from paper usage, accounting for 13.52 tons CO2-eq out of the total 14.48 tons CO2-eq produced. This is primarily due to the significantly larger student population compared to lecturers and staff. In addition, the demand for paper is also very high among students, such as for assignments in hard copy (print out), report writing materials, final projects, notes, and others. The carbon footprint from paper usage activities can be seen in Figure 4.

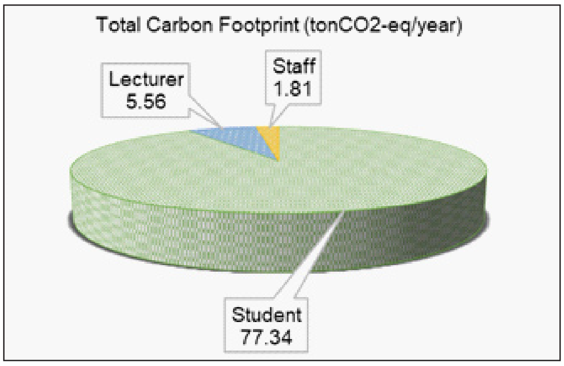

Figure 3. Carbon Footprint of Transportation Activities of Students, Lecturers, and Staff

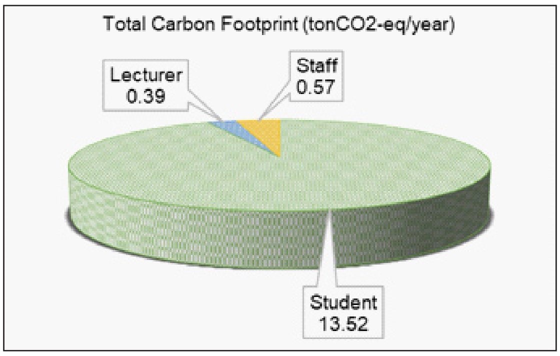

Figure 4. Carbon Footprint of Paper Usage Activities

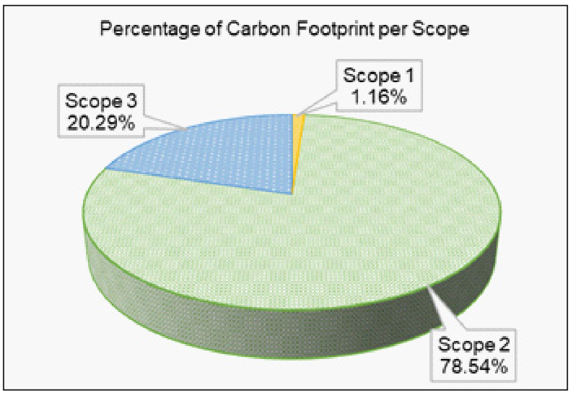

Figure 5. Percentage of Total Carbon Footprint per Scope

The carbon footprint from paper usage by students, lecturers, and staff from January to December 2023 at FST UNJA is 14.48 tonCO_2-eq. Overall, scope three generates a carbon footprint of 99.16 tonCO_2-eq.

Based on the carbon footprint emission calculations that have been conducted previously, the total carbon footprint emitted by campus activities at FST UNJA is 490.9 tons CO_2-eq. The total carbon footprint value obtained is the sum of the carbon footprints from scope 1, scope 2, and scope 3. The results and contributions from each scope can be seen in Table 1.

Table 1. Total Carbon Footprint from Campus Activities at the Faculty of Science and Technology, Universitas Jambi

Scope	Sector	Percentage		CO_2 Emission (tonCO_2-eq)	
Scope 1	Operational Fuel Consumption	0.03	1.17	0.13	5.72
	LPG Consumption	1.14		5.59	
Scope 2	Electricity Usage	78.63	78.63	386.04	386.04
Scope 3	Transportation for Students, Lecturers, and Staff	17.25	20.29	84.68	99.16
	Paper Consumption	2.95		14.48	
Total				**490.9**	

To reduce the carbon footprint generated from various campus activities, several strategies can be implemented by the university. The proposed scenario for students, lecturers, and staff to reduce the carbon footprint from transportation activities includes using private vehicles with more than one person, implementing a car-free day system, and walking to campus for those living ≤2 km from the campus. To reduce electricity consumption, it can be done by minimizing electricity use and implementing a paperless program to reduce paper usage. The total carbon footprint reduction calculation from the transportation sector can be seen in Table 2.

Table 2. Recap of Transportation Sector Reduction Efforts

Sector	CO_2 Emission (tonCO_2-eq)	Reduction Scenario	Reduction Efforts	Reduction Result (tonCO_2-eq)	
Transportation Sector (Students, Lecturers, and Staff)	84.71	Passengers more than one	32.8	43.3%	45.1
		Car free day Program	6.81	7.1%	
Total			**39.61**	**50.4**	**45.1**

The comparison of carbon footprint values before, during, and after the Covid19 pandemic is presented in Table 3. The pre-pandemic value (2018) was obtained from previously published research that estimated emissions at the Faculty of Science and Technology, Universitas Jambi (31). The pandemic period data (2020–2021) were calculated using an estimation approach developed by the authors, based on the actual institutional conditions at the time, such as fully online lectures, shift-based staffing, non-operational campus vehicles, and the closure of canteens and laboratories.

These calculations followed the same methodological approach based on the GHG Protocol and IPCC emission factors.

Table 3. Total of Carbon Emissions Across The Pandemic Time Period at the Faculty of Science and Technology, Universitas Jambi

Scope	Sector	2018 ($tonCO_2$-eq)	2020 ($tonCO_2$-eq)	2023 ($tonCO_2$-eq)
Scope 1	Operational Fuel Consumption	6.22	0	0.13
	LPG Consumption	5.96	0	5.59
Scope 2	Electricity Usage	100.3	8.024	386.04
Scope 3	Transportation for Students, Lecturers, and Staff	427.38	29.92	84.68
	Paper Consumption	16.25	0.8125	14.48
Total		**556.11**	**38.75**	**490.92**

The carbon footprint mapping at FST UNJA is illustrated using Vensim PLE 10.2.1, which can be accessed through the website https://vensim.com/. Vensim is a visual modelling software that enables the conceptualization, documentation, simulation, analysis, and optimization of dynamic system models. In Vensim PLE, users can easily and flexibly create simulation models using causal loop diagrams and stock flow diagrams (32). In the causal loop diagram, there are positive feedback loops and negative feedback loops. Positive feedback loop is an increase in one variable that also causes an increase in another variable, while a negative feedback loop is an increase in one variable that will cause a decrease in another variable. The Vensim mapping of the FST carbon footprint can be seen in Figure 6.

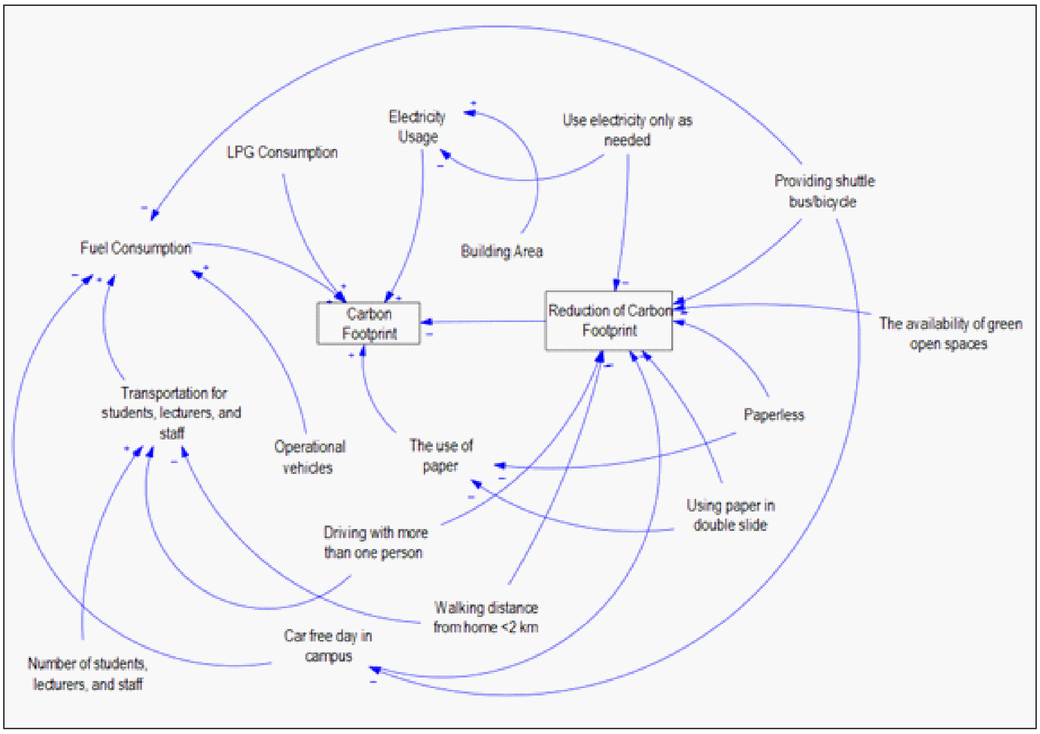

Figure 6. Mapping the Carbon Footprint of FST

DISCUSSION

Carbon footprint is a general term used to describe the total amount of greenhouse gas emissions from individuals or organizations responsible (33). The carbon footprint calculated at FST UNJA based on the IPCC uses tier 2, where greenhouse gas estimates are based on activity data occurring at FST. Every activity carried out by humans requires energy, which will subsequently produce emissions. The more activities are performed, the more energy is needed, and thus the greater the emissions produced (34). The results confirm a sharp rebound in emissions compared to the pandemic period (2020–2021), with total emissions reaching 490.9 tons CO_2-eq in 2023—an increase of over 12 times from the pandemic-era low of 38.75 tons CO_2-eq.

Power generation using thermal plants requires the combustion of fossil-based fuels which contribute significantly to the emission of carbon dioxide (CO_2) (35). By estimating electricity consumption in kilowatt-hours (kWh), CO_2 emissions from electricity usage can be determined. The amount of CO_2 emissions is then calculated by multiplying the total kWh by the CO_2 emission factor.

The carbon footprint comes from electronic equipment and laboratory tools that use electricity as their power source. The electricity consumption at FST UNJA is quite high (accounting for 78.54% of total emissions), not only due to the increasing number of lecture buildings but also because of the intensive academic activities, office work, and laboratory activities that require a significant amount of electricity, which also contributes to the carbon footprint generated. The majority of the studies that are calculating the carbon footprint found that, regarding energy consumption, electricity consumption was the biggest most significant contributor (36). This trend mirrors findings at institutions like Cornell University and UniMAP where the return of in-person learning and infrastructure expansion led to dramatic increases in electricity demand. At FST, expanded building operations and laboratory activities post-Covid played a central role in this rise.

Aside from electricity, transportation is another key contributor to carbon emissions. Globally, vehicles are responsible for 23% of all greenhouse gas emissions. In developing nations where older vehicles lacking efficient emission reduction mechanisms are still prevalent, the contribution of vehicles to this total is significantly higher (37).

In Figure 2, it can be seen that for the selection of transportation modes by students, lecturers, and staff, the majority use motorcycles as their means of travel to campus. As many as 96 respondents from FST UNJA students, 89.58% of them use motorcycles, 6.25% use cars, 3.13% use private cars, and only 1.04% use public transportation. The choice of transportation modes among 20 faculty respondents showed that 80% used motorcycles and the remaining 20% used private cars, while all 16 staff respondents (100%) used motorcycles as their mode of transportation for activities on campus. The choice to use public transportation and walk is very minimal, due to the considerable distance from the residences of students, lecturers, and staff, and the inadequate public transportation facilities available for commuting to campus. Walking is generally only practiced by students who live around the campus with a distance of less than 2 km from their residence.

As shown in Figure 3, it can be seen that students are the main contributors to the carbon footprint from travel activities to and from campus. This is influenced by the larger student population, which amounts to 2,734 people, compared to 101 lecturers and 44 staff members. Additionally, the average emissions from each vehicle are also affected by the number of passengers using that vehicle. On average, both students, lecturers, and staff members drive alone to campus. Before the Covid19 pandemic, the travel activities of students, lecturers, and staff were one of the largest contributors to the carbon footprint produced by the university. The carbon footprint research conducted during the Covid19 pandemic showed a significant decrease in carbon emissions from transportation activities due to regional quarantine policies and travel restrictions, which required students to study from home, resulting in a reduction in emission levels (38). A preference for motorcycles and solo travel—driven by convenience and infrastructure limitations—aligns with mobility patterns seen in studies from Turkish and Chinese universities

Universities are significant producers of greenhouse gases due to the high mobility of the academic community and the energy consumption required to support various activities (39). From Table 1, it can be seen that the carbon footprint from campus activities at FST UNJA is primarily generated from electricity usage, amounting to 386.04 tons CO_2-eq or 78.54% of the total carbon footprint produced in 2023. Then in second place is Scope 3, which produces a carbon footprint of 99.16 tons CO_2-eq (20.29%). Scope 1 is the lowest contributor, generating a carbon footprint of 5.72 tons CO_2-eq or only 1.16% of the total carbon footprint produced from January to December 2023. Percentage of Total Carbon Footprint per Scope can be seen in Figure 5. The same thing also happens on American and European campuses where the highest contribution comes from the use of supporting facilities such as electricity and heat generators during the cold season. which was then continued with an automotive journey (40).

Feedback from each variable is illustrated in Figure 6. For example, an increase in paper usage by students, lecturers, and staff leads to a higher carbon footprint. The higher the intensity of paper usage, the larger the carbon footprint produced will be. To reduce the amount of paper consumption generated from campus activities, it can be done by implementing a paperless program (storing documents in electronic form) and using double-sided paper, which can increase paper efficiency by 50%, thereby reducing the carbon footprint generated from paper usage activities.

The carbon footprint emissions analysed in this study originate from fuel consumption of campus operational vehicles, transportation activities of students, lecturers, and staff, LPG consumption, electricity usage, and paper usage. As presented in Table 3, the carbon footprint during the pandemic period (2020–2021) was significantly lower (38.75 tons CO_2-eq) due to full online learning, minimal staff presence, closure of facilities, and inactive operational vehicles. In contrast, post-pandemic emissions in 2023 rose sharply to 490.92 tons CO_2-eq, primarily due to increased electricity demand (Scope 2) and resumed commuting activities (Scope 3). This increase coincided with a growth in the number of students and staff, as well as the addition of new academic buildings starting in 2022, which contributed to greater energy usage and mobility.

Recognizing these challenges, several reduction strategies have been proposed to address key emission sources. The results of the carbon footprint calculation that have been conducted are then used as a basis to provide several alternative reduction efforts to reduce the generated carbon footprint. Reduction efforts to decrease the carbon footprint include providing sufficient green open spaces to help absorb CO_2 emissions. Providing shuttle buses or bicycles, implementing a car free day system, carpooling, and walking for those living ≤2 km can reduce the carbon footprint from transportation activities. Reduction of the carbon footprint from the electricity consumption sector can be achieved by adopting energy saving behaviours and implementing a paperless program to reduce paper usage.

Carbon footprinting is a technique to find an aggregate of all GHGs as CO_2-eq, emitted directly or indirectly from different anthropogenic activities (41). Anthropogenic greenhouse gas emissions need to be cut to limit climate change. Thus, universities, in the same way as citizens and companies, are starting to raise awareness about this issue and to take action to reduce their carbon footprint (42). Reducing the carbon footprint generated by campus activities at FST UNJA can be achieved by proposing alternatives in the form of policies or behavioural changes. Based on the carbon footprint calculations that have been conducted, the carbon footprint value from campus activities at FST UNJA has been obtained. By conducting a carbon footprint analysis, it can serve as a basis for strategies to reduce the carbon footprint. One way to reduce the carbon footprint is by planting biomass, which can decrease the carbon footprint because biomass source plants can capture carbon dioxide through photosynthesis (43). Preserving native forests on campus can also contribute to carbon removal (44). In addition, there are several alternatives that the university can implement to reduce its carbon footprint. The feasibility of these recommendations also takes into account the willingness of respondents to participate in carbon reduction efforts. Improving classroom ventilation systems can also indirectly reduce a campus' carbon footprint (45). Using technology in virtual teaching and learning activities can significantly reduce the carbon footprint (46). The decarbonization of electricity on campus program can help reduce the carbon footprint by more than 60 percent (47-48). Apart from changes on the campus side, government policies and incentives play an important role as a catalyst so that the campus reaches zero carbon (49).

Based on this research, the recommendations provided can be applied to the transportation sector, electricity usage, and paper consumption. Reduction efforts in commuting activities to campus can be achieved by walking for those living ≤ 2 km from campus, carpooling, and implementing a car-free day system. Thus, the number of vehicles entering the campus will decrease, and it will also reduce the carbon footprint produced. The implementation of reduction efforts by carpooling can reduce approximately 32.8 tons of CO_2-eq/year. Before the carbon footprint reduction efforts, the carbon footprint generated from the transportation activities of students, lecturers, and staff was 84.71 tons CO_2-eq/year. By implementing the scenario of carpooling, the total carbon footprint generated can be minimized to 51.91 tons CO_2-eq/year, which is 43.3% of the carbon footprint value before the reduction efforts were made. The calculation of carbon footprint reduction results using the car free day strategy during the active lecture period is only conducted once a week for the frequency of respondents' trips to campus. During the lecture break, only lecturers and staff are assumed to go to campus using the Trans Siginjai public transportation.

The implementation of a car-free day system once a week and the recommendation to walk to campus for those living ≤2 km from campus can reduce 6.81 tons of CO_2-eq/year. The initial carbon footprint before the implementation of the car free day system was 84.71 tons CO_2-eq/year, which decreased to 77.9 tons CO_2-eq/year after the reduction. If we look at the average responses from the respondents, the choice of reducing efforts by walking to campus tends to lean towards disagreement. The reasons given are the hot and dusty weather, as well as time efficiency, leading them to prefer using motor vehicles to get to campus. A significant 63.64% of respondents reported commuting to campus alone in personal vehicles, whether motorcycles or cars. The recap of carbon footprint reduction efforts from the transportation sector by proposing carpooling and implementing a car-free day system amounts to 39.61 tons CO_2-eq or 50.4% of the total carbon footprint value before reduction efforts were made.

Accurate carbon footprint assessment and the utilization of real-time applications play a crucial role in achieving sustainable performance, enabling policymakers to meet the Sustainable Development Goals (SDGs) (50–53). Based on the assessment conducted, electricity usage has been identified as the largest contributor to the carbon footprint in FST. Several proposed reduction efforts received positive responses from respondents, with a general agreement on their implementation. To minimize electricity consumption, various measures can be adopted, such as turning off or hibernating computers and laptops when not in use for more than 60 minutes, as well as switching off electrical equipment like lights, projectors, and air conditioners after a room has been used. Additionally, unplugging phone or laptop chargers once the battery is fully charged can help conserve energy. Another important step is setting the air conditioner (AC) temperature to a minimum of 24℃-27℃, in accordance with the energy-saving policy regulated by the government (54). By implementing these strategies, electricity usage can be effectively reduced, contributing to a lower carbon footprint and a more sustainable environment.

Based on the results of a questionnaire distributed to 132 respondents regarding their willingness to reduce the carbon footprint from paper usage, the majority agreed to take reduction efforts. These efforts can be implemented through a paperless program, which includes several key actions. One approach is storing files as electronic documents instead of relying on paper-based archives. Additionally, using electronic mail for various purposes, such as sending invitations, can help minimize paper consumption. Another effective step is submitting final projects or internship reports exclusively in soft file format. Furthermore, in academic activities like submitting assignments or preparing reports, using both sides of the paper (double-sided printing) can significantly cut down paper usage. By adopting these measures, individuals can effectively reduce their carbon footprint, contributing to a more sustainable environment.

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AUTHORS' CONTRIBUTION

FJA: Conceptualization, Methodology, Software, Validation. WMNF: Data curation, Visualisation, Writing-Original draft preparation. HV: Investigation, Validation, Writing- Reviewing and Editing.

CONCLUSION

The study successfully quantified the post-pandemic carbon footprint of campus activities at the Faculty of Science and Technology, Universitas Jambi. In 2023, total CO_2 emissions reached 490.9 tons CO_2-eq, with Scope 2 contributing the highest share (78.54%) due to increased electricity use following the return of in-person activities and infrastructure expansion. Scope 1 and 3 contributed 1.16% and 20.29%, respectively. Compared to during-pandemic conditions, emissions have rebounded yet remain lower than pre-pandemic levels, reflecting hybrid learning and adjusted mobility patterns. Based on mapping analysis and respondent input, recommended efforts to reduce the carbon footprint from campus activities at the Faculty of Science and Technology can reduce it by 39.61 tons CO_2-eq. This can be achieved by implementing carpooling (32.8 tons CO_2-eq) and through the car free day program (6.81 tons CO_2-eq). For electricity consumption, it can be done by implementing energy-saving behaviours and applying a paperless program to reduce paper usage. Vensim modeling helped visualize systemic interactions between activity variables, providing a dynamic basis for policy development. By integrating empirical measurements, participatory planning, and system dynamics modeling, this study can support evidence-based decision-making toward greener, more sustainable academic environments. These findings provide a practical foundation for emission reduction strategies, aligning with the study's objective of supporting sustainable campus operations.

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