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https://doi.org/10.5109/7326999

出版情報：Evergreen. 11 (4), pp.3684-3692, 2024-12. 九州大学グリーンテクノロジー研究教育センター
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Leveraging Carbon Footprint Derivatives in Challenging the Effective Implementation of Sustainable Transportation

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(Received May 8, 2024; Revised September 9, 2024; Accepted December 17, 2024).

Abstract: Carbon footprint detection in transportation sector can be applied through measuring vehicle emissions, analyzing vehicle travel patterns through GPS monitoring, monitoring fuel consumption accurately through a fleet management system. The purpose of this study is to find derivatives of the carbon footprint concept in the transportation sector that have the potential for knowledge development. This study uses mix approaches, including bibliometric analysis to find several new concepts and analytical hierarchy process to follow up on findings that are recommended as new as a step in developing knowledge. Data comes from journal publications in the last five years obtained through searches on Google Scholar based on analysis of scientific literature. The results of study found that several derivatives of the carbon footprint concept in transportation sector which have the potential to be novel in the study include material footprint, urban mobility, energy footprint, energy demand, public transport, green transportation, environmental degradation, environmental impact, carbon capture, carbon neutrality and energy efficiency. Concept derivatives that are a priority and are expected to be developed more widely and have high novelty value include energy efficiency, carbon neutrality and green transportation. This study recommends further development of priority concept derivatives to be studied more significantly in order to accelerate the implementation of low carbon in supporting sustainable transportation.

Keywords: carbon footprint; sustainable transportation; energy efficiency; carbon neutrality; green transportation

1. Introduction

Various efforts to reduce carbon dioxide emissions in the transportation sector have become increasingly interesting studies and have attracted much attention from academics and public awareness[1)], it is important to increase public awareness in developing a green economy to achieve sustainable development[2)], need to use hydrogen energy to replace fossil fuels and achieve net zero carbon emissions[3)], as global industrialization and the transportation sector advance, the study of carbon emissions is becoming a global concern[4)]. The three main modes of transportation for the movement of people or goods have a negative impact on the environment because they contribute to carbon and energy footprints based on the life cycle of transportation practices[5)]. Transportation is capable of eliminating comparative ecological advantages that help reduce greenhouse gas emissions and environmental impacts on supply chains[6)]. Digitalization of the carbon footprint contributes to sustainable development in line with the sustainable development goals (SDGs) which are expected to be able to ensure industrial and economic transition in adapting to climate change and advancing environmentally friendly economic growth[7)]. The carbon footprint is assessed based on the amount of carbon dioxide from various activities through calculating the amount of greenhouse gas emissions produced[8)]. The focus on industrial transformation through low carbon implementation needs to be adopted by various countries in order to achieve net-zero carbon[9)]. The carbon footprint produced in various activities causes a greenhouse effect which has an impact on the earth's temperature increasing and resulting in a lot of heat being retained by the earth which makes the earth's temperature warmer[10)]. Carbon footprint calculations are carried out by measuring human activities that have an impact on the environment through calculating the by-products or greenhouse gases produced[11)]. Carbon footprint produces greenhouse gases or CO2 emissions which are the impact of transportation activities, industry, forest degradation in the form of pollutant gases, the construction industry is the main contributor to greenhouse gas effects which have an important role in global warming[12)].

Some of the problems faced in efforts to reduce the carbon footprint in implementation in the value chain are due to limited resources, financial constraints, lack of technical knowledge in understanding emissions[13]. Another problem is that efforts to prevent the severity of disease as an effort to overcome decarbonization are still having difficulty being implemented because they have not been able to analyze the relationship between carbon footprints and the development of chronic diseases[14]. Several solutions for minimizing carbon footprints have been implemented in various countries, including efforts to use the XGBoost-TPE model which was built to increase the level of trust through identifying the most influential features that have an impact on model output for assessing household carbon footprints[15]. Solutions developed related to carbon emissions analysis can be carried out through life cycle assessment models to help reduce emissions[16]. Comprehensive life cycle assessment and focus on climate change to measure the carbon footprint by comparing the carbon footprint of conventional VCRS with alternative phase-change material based cold storage systems (PCCSS)[17]. A dynamic life cycle is applied to evaluate regulations towards a sustainable transport infrastructure system to measure the energy and carbon footprint by the difference between existing and newly built assets[18]. Systematic carbon footprint calculations were carried out to minimize the contribution of transportation to global climate change by using the MATLAB program to calculate uncertainty-based carbon footprints and a Monte Carlo simulation model for carbon footprint analysis based on parameters within reliable ranges[19].

It is hoped that the derivative concepts found can be applied for further development in the development of knowledge and technology for academics and researchers. A transportation system that utilizes future alternative energy such as hydrogen energy to become environmentally friendly energy that contributes to reducing CO_2 emissions[6]. Reducing carbon emissions can be applied to sustainable transportation strategies to reduce global warming and prevent extreme climate change[20], decarbonizing especially metal production by implementing a digital transition due to complex operations[21], developed a dynamic threshold model of an inverted U-shaped validation cave that examines the relationship between energy structure and digital infrastructure[22], necessary to carry out heterogeneity analysis through business grouping[23], need to strengthen the integration of digital technology through green technology innovation and environmental, social and governance performance[24]. The purpose of this study is to find derivatives of the carbon footprint concept in the transportation sector that have the potential for knowledge development.

2. Method

Mixed methods are applied in this study by combining qualitative and quantitative approaches. The qualitative approach is developed through bibliometric analysis to identify trends and patterns in the concept of carbon footprint in the transportation sector. While the Analytical Hierarchy Process (AHP) was used to execute the quantitative approach. An in-depth review of trends and patterns in bibliometric analysis is conducted in the transportation sector. VOSviewer is qualitative approach that can be applied in journal analysis[25], able to collect information according to studies in research[26], easy to understand through visualizations presented based on collected journal publications[27]. Identification of journal publications on the carbon footprint concept can track the derivation of the concept according to the specified publication time span and has the opportunity to obtain the latest research concepts that have relevance to the study being carried out. The journal publication period is a reference for obtaining in-depth research studies[28]. A collection of journals obtained in the 2019-2023 publication period was carried out through a search on Google Scholar. The total number of journals collected during the last five years of publication was 996 scientific journals. Derived topics on the carbon footprint concept are directed at developing knowledge and technology.

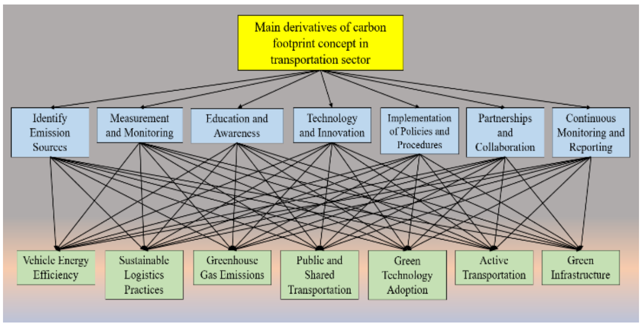

Fig. 1: Carbon footprint hierarchy in transportation sector.

Furthermore, this analysis also uses AHP which develops methods for complex decision making presented in Fig.1. The AHP method applied can be optimized by disclosing criteria and describing alternatives in the elaboration of the carbon footprint concept analysis. Hierarchy is a model developed in arranging the stages of AHP[29]. The criteria that make up AHP in the analysis of the carbon footprint concept are described in several ways, including identifying emission sources, measurement and monitoring, education and awareness, technology and innovation, implementation of policies and procedures, partnerships and collaboration, continuous monitoring and reporting. Meanwhile, several alternatives that make up the AHP hierarchy include vehicle energy efficiency, sustainable logistics practice, greenhouse gas emissions, public and share transportation, green technology adoption, active transportation, and green infrastructure. The visualization results in AHP analysis are able to explain the flow of assessment and sequence in decision making through in-depth analysis, especially the carbon footprint concept. AHP is applied in carbon footprint studies in the transportation sector in order to choose appropriate alternatives.

3. Result and discussion

The carbon footprint concept which is presented visually in the form of networks and densities is implemented through bibliometric analysis to obtain new findings which are expected to contribute to the development of new knowledge in accordance with this study. The next step taken to obtain priority findings is to select three recommended alternatives by applying AHP. Based on data collected by scientific journal publications on the carbon footprint concept in the last five years, it is hoped that analysis results can be obtained to develop new knowledge in the form of derivative concepts related to carbon footprint in the transportation sector.

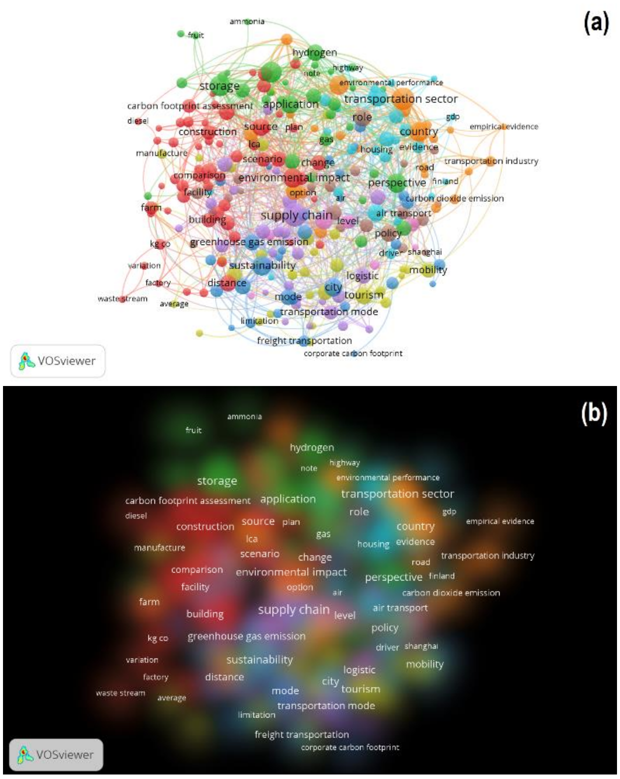

Fig. 2: Network visualization (a), density visualization (b) in carbon footprint.

The derivation of carbon footprint topic is presented in a visualization of the network produced in support of green transportation policies according to the categories of color, size and links to existing nodes which is shown in Fig. 2. Similarities in the topics studied are marked with the same color. Larger the size of node formed, the greater the number of publications. There is a relationship between the concepts studied which are united through interrelated links. Topic findings visualized through nodes show various topics that have been widely studied or topics that have the potential to be new and need to be followed up to encourage the development of research on carbon footprint. The visualization results shown can be used as important information in tracking research development according to the desired topic, especially related to the carbon footprint concept in supporting the development of green transportation. Based on the visualization obtained in this study, several derivatives of the carbon footprint concept were found that have the potential to have novel value and need to be followed up in this study, including vehicle energy efficiency, sustainable logistics practices, greenhouse gas emissions, public and share transportation, green technology adoption, active transportation, and green infrastructure.

Table 1. Top ten citation rankings on the carbon footprint concept.

TC	CPY	Title	Journal	Publisher	Year	Authors
378	126.00	The nexus between urbanization, renewable energy, trade, and ecological footprint in ASEAN countries	Journal of Cleaner Production	Elsevier	2020	S Nathaniel, SAR Khan[30)]
340	113.33	The role of financial development and globalization in the environment: accounting ecological footprint indicators for selected one-belt-one-road initiative countries	Journal of Cleaner Production	Elsevier	2020	S Saud, S Chen, A Haseeb[31)]
337	168.50	Blockchain technology and the circular economy: Implications for sustainability and social responsibility	Journal of Cleaner Production	Elsevier	2021	A Upadhyay, S Mukhuty, V Kumar[32)]

319	106.33	Towards the systematic reporting of the energy and carbon footprints of machine learning	The Journal of Machine Learning Research	ACM Digital Library	2020	P Henderson, J Hu, J Romoff, E Brunskill[33]
263	87.67	Stepping up and stepping out of COVID-19: New challenges for environmental sustainability policies in the global airline industry	Journal of Cleaner Production	Elsevier	2020	J Amankwah-Amoah[34]
241	80.33	Strength, microstructure, efflorescence behaviour and environmental impacts of waste glass geopolymers cured at ambient temperature	Journal of Cleaner Production	Elsevier	2020	R Xiao, Y Ma, X Jiang, M Zhang, Y Zhang[35]
232	77.33	Impact of coronavirus (COVID-19) pandemic on air transport mobility, energy, and environment: A case study	International Journal of Energy Research	Wiley Online Library	2020	S Nižetić[36]
228	76.00	Mitigating the carbon footprint and improving productivity of ruminant livestock agriculture using a red seaweed	Journal of Cleaner Production	Elsevier	2020	RD Kinley, G Martinez-Fernandez, MK Matthews[37]
225	75.00	Contradictions of the climate-friendly city: new perspectives on eco-gentrification and housing justice	International journal of urban and regional research	Wiley Online Library	2020	JL Rice, DA Cohen, J Long[38]
203	101.50	The Mediterranean diet and health: A comprehensive overview	Journal of internal medicine	Wiley Online Library	2021	M Guasch-Ferré, WC Willett[39]

TC= Total Citation; CPY= Citations Per Year

Journal publications on the carbon footprint concept ranked in the top ten based on the number of citations can be shown in Table 1. One indicator that determines the quality of research is marked by the number of citations, although other factors must still be considered, including the relevance of the problem, validity and methodology. To measure the impact of the research carried out, one indicator that can be applied is knowing the number of citations, so that the higher the citations obtained, the research produced will have a significant impact and contribute actively to the dissemination of knowledge. It is believed that the citation rankings published and known by the authors will be able to encourage increased creativity and innovation in developing knowledge and technology, especially in the concept of carbon footprint. Based on the citation ranking, it can be seen that the number of citations will potentially be large if the research conducted can be published in quality journals and publishers such as Elsevier, ACM digital library and Wiley online library. For this reason, so that published papers can be widely cited by other parties, it is important to publish manuscripts that are recorded in publisher databases such as Elsevier[40], ACM digital library[41,42] and Wiley online library[43]. The results presented are important to understand that quality journals and publishers have an important impact in disseminating new knowledge and have great potential to disseminate the novelty obtained, including studies related to carbon footprint.

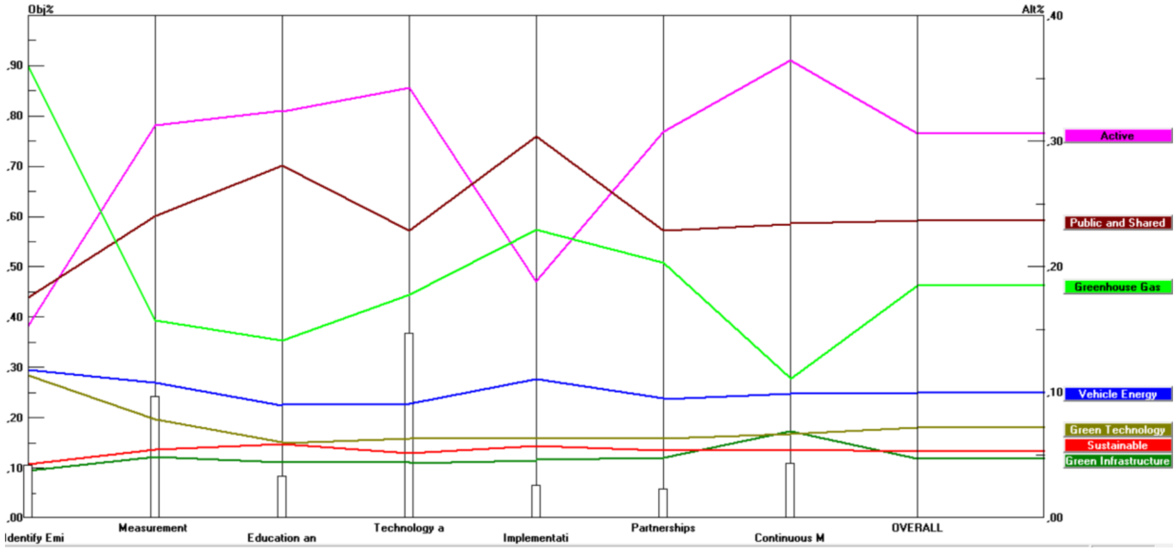

Fig. 3: Measuring performance sensitivity on the carbon footprint concept.

One of the indicators in measuring AHP can be identified by describing performance sensitivity in order to measure the weight value of criteria to determine alternative selection. AHP is able to improve the quality of decision making and is able to reduce uncertainty in carrying out evaluations, in this case to determine criteria and alternatives[44]. Measurement of weights and efforts to make comparisons between criteria used to calculate the ranking of alternatives. This measurement aims to determine several of the most sensitive factors to obtain priority values in the derivative assessment of the carbon footprint concept. The three main priorities in measuring performance sensitivity include active transportation, public and shared transportation and greenhouse gas emissions. The presentation of performance sensitivity measurement results is shown in Fig. 3 which shows that active transportation gets the highest priority in the measurement results of the carbon footprint concept based on dominant criteria including continuous monitoring and reporting, technology and innovation and measurement and monitoring.

Fig. 4: Dynamic sensitivity measurement on the carbon footprint concept.

Dynamic sensitivity measurements are shown in Fig. 4 which illustrates the comparison of various indicators that are between the criteria and comparing various indicators that are between alternatives. The sensitivity results show that based on the seven criteria used to achieve the goal of deriving the carbon footprint concept, one of the dominant criteria in this measurement is the implementation of policies and procedures criteria. This criterion has the greatest contribution in measuring various alternatives at 36.4% compared to other criteria used. Apart from that, the results of dynamic sensitivity measurements also found the alternative that had the most dominant value shown in the active transportation alternative. The highest assessment of the active transportation alternative is marked by a contribution value of 30.6%. Based on the results of dynamic sensitivity measurements, it can be predicted that there is potential for active transportation as an alternative that will be used as a priority and has the potential to be the main choice in this study. These results show the strong potential that active transportation will become the main choice for the development of green transportation in the future.

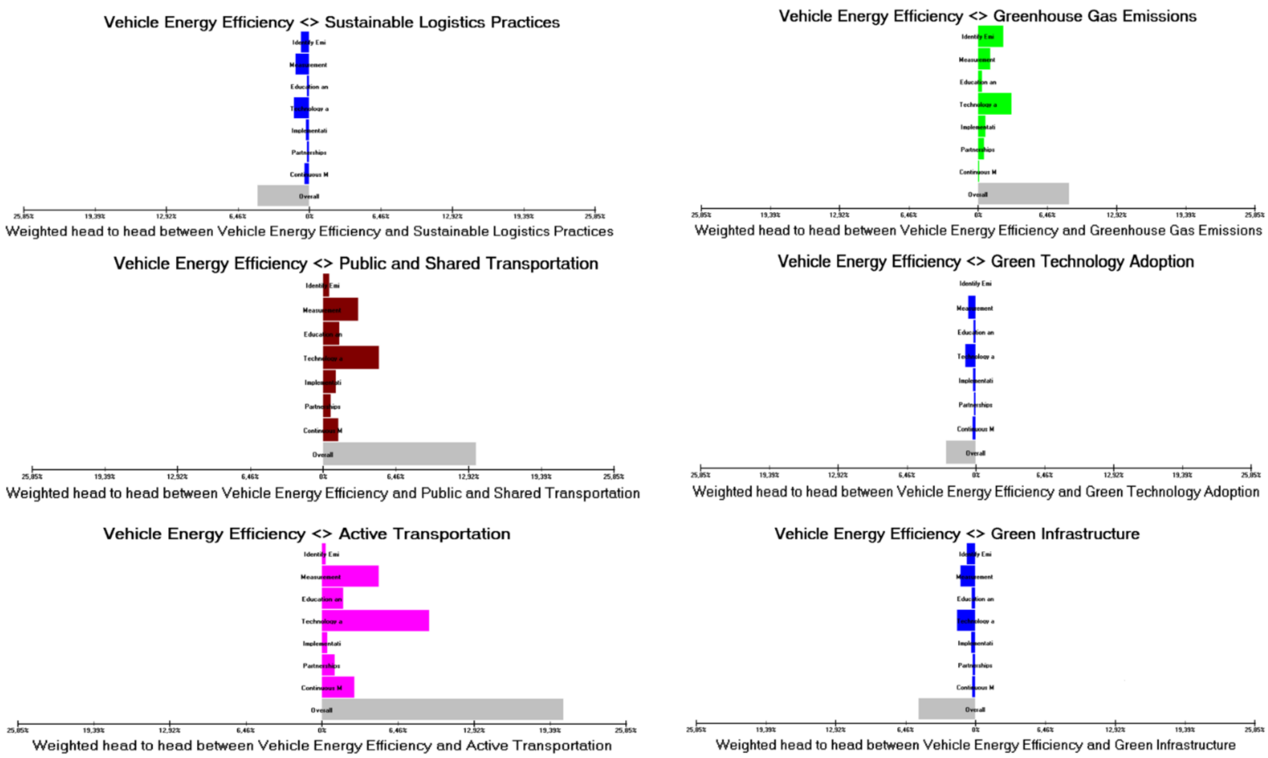

Fig. 5: Head-to-head sensitivity measurement on the carbon footprint concept.

Head-to-head sensitivity applies direct comparisons between the alternatives being tested and matching them between the alternatives used. Head-to-head sensitivity in the context of carbon footprint focuses on the ranking of alternatives through direct comparison between indicators of the alternatives being tested. Head-to-head sensitivity measurements are able to determine preferences or obtain a priority scale in decision making based on relative comparisons. The measurements are carried out by directly comparing the assessment of several alternatives including vehicle energy efficiency, sustainable logistics practices, greenhouse gas emissions, public and share transportation, green technology adoption, active transportation, and green infrastructure. The head-to-head sensitivity found can be seen that active transportation is the alternative studied which has the greatest sensitivity value when compared to other alternatives shown in Fig. 5. These results show that active transportation is the superior option and has a high priority in the context of carbon footprint.

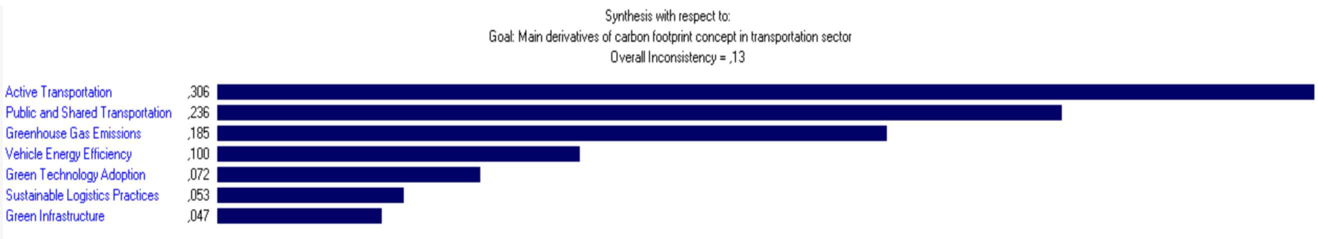

Fig. 6: Synthesis based on priority on the carbon footprint concept.

The synthesis carried out refers to priorities calculated by comparing indicators to criteria or alternatives that are in accordance with the hierarchy created in the AHP analysis shown in Fig. 6. This synthesis is carried out by combining the weight values obtained or knowing the priority measures for the elements being studied so as to produce an assessment that can be considered in decision making. The results of this measurement produce a priority order for several alternatives which are measured according to the number of alternatives used in measuring the derivative carbon footprint concept. Active transportation, public and shared transportation and greenhouse gas emissions are the three main priorities resulting from this measurement. These three priority alternatives are the main findings in this research as derivatives of the carbon footprint concept and have the potential to be novel and important for this derivative concept to be developed further in the future. However, four other alternatives such as vehicle energy efficiency, sustainable logistics practice, green technology adoption and green infrastructure are also important concept derivatives even though they are not a priority in this study.

Active transportation such as walking and cycling not only reduces carbon emissions, but also encourages healthy lifestyles and improves people's quality of life. Encouraging more people to use active transportation can reduce dependence on motorized vehicles, which are one of the main sources of greenhouse gas emissions. Optimizing the use of public and shared transportation can reduce the number of private vehicles on the road, which has the potential to reduce traffic congestion, reduce fuel consumption, and reduce greenhouse gas emissions. In addition, an efficient and integrated transportation system can improve accessibility and mobility, especially for more vulnerable groups in society. Reducing greenhouse gas emissions is one of the main goals of sustainable transportation policies. By focusing on emissions, this study can provide important insights into how to reduce the negative impacts of transportation on the environment. Measuring and prioritizing greenhouse gas emission reductions helps in achieving climate change mitigation targets and ensuring that the transportation sector plays an active role in addressing this global challenge. These three priorities are not only relevant to the concept of carbon footprint, but also provide a basis for developing more holistic and sustainable transportation policies. In the long term, further development of these derivative concepts can create more efficient and effective innovations and solutions in creating an environmentally friendly and healthy transportation system for the community.

Furthermore, the novelty obtained in this research found three main derivatives of the carbon footprint concept that can be implemented effectively in sustainable transportation in the future, including active transportation, public and shared transportation, and greenhouse gas emissions. Carbon footprint can be revealed through the development of input-output analysis or life cycle assessment[45)]. For this reason, these three new concept findings are recommended to be followed up by researchers or academics in developing carbon footprint derivatives in their future development. The three new concepts that are part of the carbon footprint derivative have high relevance to the development of sustainable transportation which is in line with sustainable development goals.

4. Conclusions

The findings obtained in this research are a derivative of the carbon footprint concept which has important value to be followed up in the development of knowledge and technology in pushing green transportation into the future. The three main topics found in this study have a great potential to become novelty in developing knowledge on the carbon footprint concept, including active transportation, public and shared transportation and greenhouse gas emissions. These findings highlight the importance of developing infrastructure and policies that support active transportation, such as walking and cycling. This finding not only helps reduce carbon emissions but also promotes overall public health. As a derivative of the carbon footprint concept, focusing on active transportation contributes significantly to reducing personal and collective carbon footprints. In addition, the study found that public and shared transportation can play a significant role in reducing greenhouse gas emissions, by promoting the use of public transportation and car sharing systems, energy consumption and emissions can be significantly reduced. One of the most important findings is the identification and measurement of greenhouse gas emissions from various modes of transportation. By understanding the main sources of emissions, more effective mitigation measures can be designed to reduce the carbon footprint in the transportation sector which is important for global policies in the fight against climate change. Meanwhile, the other four topics consisting of vehicle energy efficiency, sustainable logistics practice, green technology adoption and green infrastructure as concept derivatives have not yet become a priority but have great potential to be studied more deeply by academics and researchers in order to develop knowledge and technology, especially in encouraging related understanding carbon footprint and implementation of a transportation system that prioritizes the use of green transportation which is in line with the implementation of sustainable transportation.

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