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Low-Carbon Food Consumption for Solving Climate Change Mitigation: Literature Review with Bibliometric and Simple Calculation Application for Cultivating Sustainability Consciousness in facing Sustainable Development Goals (SDGs)

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ABSTRACT

Low-carbon food consumption is defined as the selection of a diet that is done by people that aims to reduce greenhouse gas emissions due to excessive energy use. Greenhouse gases are the main cause of climate change. Thus, it is needed mitigation for climate change through education to make changes in mindset and habits. This study aims to investigate students' sustainability consciousness through low-carbon food consumption by using simple calculation applications. The research used is a research and development method with 53 pre-service teachers. The data collections are analyzed by simple calculation percentages. The results describe that the sustainability consciousness of pre-service teachers has already in excellent results either in sustainability knowingness, sustainability attitude, and sustainability consciousness through low-carbon food consumption learning topics using simple calculation applications. it can be interpreted that learning the topic of low-carbon food consumption can lead pre-service teachers to make a change in their lifestyle starting from choosing the menu of their plates to reduce greenhouse gases indirectly as climate change mitigations. It can be concluded that low-carbon food consumption could promote preservice teachers' sustainable consciousness. This study also supports strategies facing Sustainable Development Goals (SDGs) issues.

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1. INTRODUCTION

Low-carbon food consumption is predicted to reduce global green-house gases (Lindroos *et al*., 2023; Hallström *et al*., 2021; Melina *et al*., 2016; Boehm *et al*., 2018). Low-carbon food consumption is defined as the selection of a diet that aims to reduce greenhouse gas emissions due to excessive energy use (Melina *et al*., 2016). The principles of low-carbon food consumption include consuming less food that will produce high greenhouse gas emissions, buying food in moderation, choosing local food that is in season, increasing consumption of fresh food with simple processing, reducing food packaging, and reducing food waste (Lin & Lin, 2014). Based on these considerations, according to De Pee *et al*., (2021), Indonesia needs to develop a healthy and sustainable diet and food to improve public health and environmental sustainability. The pattern This diet is a challenge to implement in Indonesia because only a small proportion of people are aware of the link between their food choices and their carbon footprint. Understanding the relationship between food diets and climate change through education needs to be made available to the public (Jay *et al*., 2019).

Factual data shows that the environmental mitigation about reducing greenhouse gases is mostly concerned with only transportation, waste products, and using renewable energy (Abulude *et al*., 2022; Setyani *et al*., 2023). In reality, the food and agricultural sectors also contribute big emissions indirectly. Carbon emissions which produced indirectly because of the supply chain, energy consumed from farmland, and retail energy that contribute to one product when it is in consumer hands. Those descriptions and the flow must be realized by the people in the society to cultivate their sustainable consciousness to reduce greenhouse gases and climate change. Sustainable consciousness means the knowledge, attitude, and behavior toward sustainability action especially in low-carbon education. Low-carbon food consumption is included in low-carbon education areas that have the same direction to reducing green-house gases as climate change mitigation.

One of the solutions is in education by introducing the low-carbon food consumption topic in environmental learning (Keisyafa *et al*., 2024; Olowoyeye, 2022; Ahsan, 2022; Ahsan, 2023; Satria and Nandiyanto, 2022; Nurnabila *et al*. 2023; Bansur *et al*., 2024). The higher education sector is already an important pillar in the battle against climate change, with researchers contributing to our understanding of the phenomenon and its consequences while also teaching students and society (Manullang *et al*., 2021). However, many universities recognize the importance of behaving more sustainability within their institutions (Danzer *et al*., 2021; Chiaverina *et al*., 2022; Getzingeret *et al*., 2019; Vásquezet *et al*., 2015; Yañez *et al*., 2019). In Indonesia, low-carbon food consumption is rarely implemented in the learning process. A few research about low-carbon food consumption as low carbon diet are conducted in higher education at universities (Imaniar *et al*., 2022) and other parts of the world also still a few to discuss low-carbon food consumption implemented in learning (Harrer *et al*., 2021; Li *et al*., 2024). Thus, this research provides new insight into low-carbon food consumption immersed in education, especially in environmental learning. However, it is needed to investigate the evolution of low carbon especially low-carbon food consumption particularly in education, professionals frequently use existing research trends, such as bibliometric studies, which entail meta-analysis research incorporating bibliographic contents and article citations from journals and other scientific works. Bibliometric research has been undertaken in a variety of areas, including low-carbon cities (Wang *et al*., 2023), Low carbon economies (Wang *et al*., 2022), low-carbon energy (Zhang *et al*., 2021), and power-plant energy (Meng *et al*., 2021). We present a comprehensive collection of bibliometric literature, as shown in **Table 1**, together with references to previous bibliometric research and our inquiries into prior

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bibliometric analysis. Computational mapping analysis using a bibliometric approach specifically focused on understanding publication trends in low carbon theme using the Scopus database becomes the basis for conducting this research to be convinced that the theme of low carbon is still a hot topic that must be developed more and is needed in research trends in Indonesia, especially in the world. This is particularly true for bibliometric analyses conducted within the past ten years (2014-2024) using the VOSviewer application.

Table 1. Previous research on bibliometric analysis.

Author	Title	Result
Shidiq *et al.* (2021)	The use of simple spectrophotometer in STEM education: A bibliometric analysis	The study, which used the VOSviewer program, discovered that modified spectrophotometers are commonly used in chemistry and STEM education, presenting opportunities for future research and resolving concerns.
Hamidah *et al.* (2020)	A bibliometric analysis of covid-19 researches using VOSviewer	The scope of COVID-19 research was analyzed using the Scopus tool VOSviewer, which demonstrated a significant increase in publications between 2019 and 2020.
Setiyo *et al.* (2021)	The concise latest report on the advantages and disadvantages of pure biodiesel (B100) on engine performance: Literature review and bibliometric analysis	A bibliometric review of 127 papers demonstrated the benefits of B100, a diesel engine fuel; nevertheless, it also asks for additional research on engine sizes, raw materials, and testing circumstances.
Soegoto *et al.* (2022)	A bibliometric analysis of management bioenergy research using vosviewer application	The study utilized VOSViewer to assess 180 papers on bioenergy management from 2017 to 2021, finding research topics and suggesting how they could be merged with other fields of study.
Mudzakir *et al.* (2022)	Oil palm empty fruit bunch waste pretreatment with benzotriazolium-based ionic liquids for cellulose conversion to glucose: Experiments with computational bibliometric analysis	The study investigates the use of benzotriazolium salt-ionic liquids (ILs) as solvents in oil palm EFB waste processing using VOSviewer. This study reveals their maximal solubility, as well as an increase in cellulose crystallinity and lignin content.
Santoso *et al.* (2022)	Management information systems: bibliometric analysis and its effect on decision making.	The study, which included 120 administrative personnel from Bandung, investigated how management information systems influenced decision-making in archives. The findings demonstrated excellent levels of quality and efficacy, and bibliometric analysis highlighted current trends in this field of research.
Nordin (2022)	Correlation between process engineering and special needs from bibliometric analysis perspectives.	Between 2017 and 2021, VOSviewer, a process engineering tool for mapping analysis, saw a drop in publications on "process engineering special demands".
Bilad (2022)	Bibliometric analysis for understanding the correlation between chemistry and special needs education using VOSviewer indexed by Google.	An examination of articles on chemistry and special education using VOSviewer and Publish or Perish revealed that publications decreased in 2017 but increased in 2021.

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Table 1 (Continue). Previous research on bibliometric analysis.

Author	Title	Result
Riandi *et al.* (2022)	Implementation of Biotechnology in Education towards Green Chemistry Teaching: A Bibliometrics Study and Research Trends	With journals as the most common source, the study's bibliometric analysis of research trends on biotechnology in education showed four study concept potentials, emphasising the importance of teaching green chemistry in schools.
Nordin (2022)	A bibliometric analysis of computational mapping on publishing teaching science engineering using VOSviewer application and correlation.	A study that looked at teaching, science, and engineering research using the VOSviewer and Perish apps discovered a significant decline due to pandemic conditions.
Wirzal & Putra (2022)	What is the correlation between chemical engineering and special needs education from the perspective of bibliometric analysis using VOSviewer indexed by google scholar?	A research study on the association between chemical engineering and special needs used the VOSviewer software to assess 800 relevant papers between 2018 and 2022.
Nandiyanto & Al Husaeni (2021)	A bibliometric analysis of materials research in Indonesian journal using VOSviewer	A bibliometric examination of research on Indonesian materials was carried out using VOSviewer, and the results revealed that "acid" attracted the most attention from 2016 to 2021, with 43 publications and 8 international linkages.
Maryanti *et al.* (2022)	Sustainable development goals (SDGs) in science education: Definition, literature review, and bibliometric analysis.	The bibliometric analysis, a critical tool in science education, provides a full understanding of the subject, emphasizing its importance in promoting research on the SDGs.
Nandiyanto & Al Husaeni (2021)	A bibliometric analysis of chemical engineering research using VOSviewer and its correlation with covid-19 pandemic condition.	Despite a drop in research since 2019, chemical engineering uses VOSviewer software for bibliometric analysis, which provides useful insights into research patterns and themes.
Al Husaeni (2022)	Computational bibliometric analysis of research on science and Islam with VOSviewer: Scopus database in 2012 to 2022.	In a study on science and Islamic research, VOSviewer was used for bibliometric analysis, revealing a decline in research, particularly in Indonesia and Malaysia. This study also gave useful references for future research.
Al Husaeni (2022)	Bibliometric analysis of briquette research trends during the Covid-19 pandemic.	An evaluation of 973 relevant publications on briquettes was conducted using VOSviewer, bibliometric analysis, and data mapping; the findings revealed a reduction in research during the past three years due to the COVID-19 epidemic.
Ragadhita & Nandiyanto (2022)	Computational bibliometric analysis on publication of techno-economic education.	A study on science and Islamic research using data from the Scopus database from 2012 to 2022 using VOSviewer for bibliometric analysis discovered a decrease in research, primarily in Indonesia and Malaysia.
Al Husaeni (2022)	How to calculate bibliometric using VOSviewer with Publish or Perish (using Scopus data): science education keywords	VOSviewer, which has 200 papers from 2013 to 2023, is an effective tool for analyzing bibliometric data and provides simple, step-by-step insights into research advances in scientific education.

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Table 1 (Continue). Previous research on bibliometric analysis.

Author	Title	Result
Supriyadi & Dahlan (2022)	Constructionism and constructivism in computational thinking and mathematics education: bibliometric review	The study used bibliometric analysis to identify prolific authors and often cited scholars by examining the surge in publications on constructionism, constructivism, computational thinking, and mathematics education.
Supriyadi *et al*. (2022)	Bibliometric analysis from local instruction theory research	The Scopus database was used to conduct a bibliometric analysis of 29 scientific articles on local instruction theory published between 2009 and 2020, with Sriwijaya University having the greatest scientific influence and Indonesia producing the most documents.
Supriyadi *et al.* (2023)	Geometry in ethnomathematics research publication: bibliometric analysis	Despite ongoing challenges, the bibliometric analysis of ethnomathematics research revealed its potential to promote learning interaction activities and conceptual comprehension in geometry.
Febriandi *et al*. (2023)	Research on algebraic thinking in elementary school is reduced: a bibliometric analysis	VOSviewer, a bibliometric technique, was used to analyze 996 papers between 2012 and 2021, demonstrating a reduction in algebraic thinking research and offering significant suggestions for future study.
Supriyadi *et al*. (2023)	Global trend of ethnoscience research: a bibliometric analysis using Scopus database	A survey of the Scopus database revealed that ethnoscience research has expanded dramatically over the last 50 years, indicating potential future research possibilities. This bibliometric study indicated future areas for ethnoscience research.
Supriyadi *et al*. (2023)	Didactical design research: a bibliometric analysis	Scopus provides bibliometric analysis of DDR publications by identifying study subjects, authors, sources, nations, affiliations, and the most cited papers. This analysis revealed a significant increase in DDR programs from 2015 to 2022.
Hayati & Hirawan. (2023)	Computational bibliometric analysis on adaptive gamification using Vosviewer	A bibliometric analysis of adaptive gamification using the VOSviewer program revealed an increase in research between 2019 and 2020 and a decrease in 2021.
Hayati & Hirawan. (2023)	Computational bibliometric analysis on adaptive gamification using Vosviewer	A bibliometric analysis of adaptive gamification using the VOSviewer program revealed an increase in research between 2019 and 2020 and a decrease in 2021.
Nandiyanto *et al*. (2023)	Particulate matter emission from combustion and non-combustion automotive engine process: review and computational bibliometric analysis on its source, sizes, and health and lung impact	This study examines the increasing trend of scientific papers on particulate matter found using multiple criteria, including the most cited, publisher, author, country, and affiliation.

Low-carbon food consumption or low-carbon diet also needs a proper calculation to compile a menu in one portion to know the classification of food that is harmless or harmful to the environment. Several websites and applications have already been developed for calculating food carbon emissions (Wu *et al*., 2024; Pandey *et al*., 2011; Vergé *et al*., 2013). Some of them only show the comprising the food products beef, pork, fish, fats, and oil

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(Becker *et al*., 2023; Getzinger *et al*., 2019; Alromaizan *et al*., 2023; Schulman *et al*., 2021). However, no one made it with the total amount of carbon emission with the classification of environmental impact, and also no one made it simpler and students could understand it easier. Thus, this research aims to investigate students' sustainability consciousness through low-carbon food consumption by using simple calculation applications about low-carbon food consumption. This study could become a new insight into low-carbon food consumption areas to cultivate people's sustainable consciousness and as the foundation for a sustainable society through education. This study also supports strategies facing Sustainable Development Goals (SDGs) issues.

2. LITERATURE REVIEW

2.1. Low-carbon Food Consumption

Low-carbon food consumption is a food environment strategy that might be used to encourage the consumption of foods associated with reduced greenhouse gas emissions, resulting in more sustainable eating habits. It has been claimed that many of the ingredients now associated with health concerns are also included in foods with a high environmental impact, therefore adopting a 'healthy' diet may also help to reduce greenhouse gas emissions. Similar efforts to combat the rise of diet-related diseases in the industrialized world focus on changing the food environment to increase the intake of 'excellent' foods while decreasing the consumption of 'unhealthy' foods. Interventions include food labeling (Crippa *et al*., 2021), food tariffs (Vallgårda *et al*., 2014), advertising limitations (Scarborough *et al*., 2013), and food reformulation (Wyness *et al*., 2012). The food system has been identified as a significant driver of climate change. The main sources of greenhouse gas emissions include nitrous oxide (N_2O) from soils, methane (CH_4) from animal enteric fermentation, and carbon dioxide (CO_2) from land use change, such as deforestation. (Grosu, 2024). Manure management, mineral fertilizer production, rice cultivation, and energy use on farms all contribute to emissions, as do post-farm operations like processing, packing, storage, distribution, and waste management. With increased awareness of climate change, measuring the carbon footprint of food products has become popular among researchers and businesses seeking to detect the impact of their products on global warming and convey the carbon footprint of their products to customers.

The association between greenhouse gases, low-carbon food consumption, and healthiness is figured out by five studies that examined the green-house gases and health consequences of diets (Biesbroek *et al*., 2014; Soret *et al*., 2014; Tilman & Clark, 2014; Aleksandrowicz *et al*., 2016; Hallström *et al*., 2017). Two of these studies focused on reduced meat or dairy intake and identified a consistent link between lower greenhouse gases and better health outcomes (Quam *et al*., 2017; Aleksandrowicz *et al*., 2016). However, the remaining three studies looked at diets based on cost, emissions, and a combination of nutrition and greenhouse gases, and found either an inconsistent relationship between greenhouse gases and health outcomes, or that a lack of concern for low-carbon food consumption was associated with an increased risk of noncommunicable diseases. Food that has a high impact on the environment does not necessarily have the worst nutrition for the body. It depends on the ingredients of the food itself. Ingredient means the nutritional content of food, such as macronutrients and micronutrients. Several studies discovered significantly contradictory results regarding the relationship between lowered greenhouse gases and reduced nutritional content. The majority of dietary patterns revealed a reduction in levels of salt and saturated fat in diets with reduced greenhouse gases. This could be

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attributed to a drop in meat consumption in reducing greenhouse gas diets or low-carbon food. Low-carbon food product in general is shown in **Figure 1**.

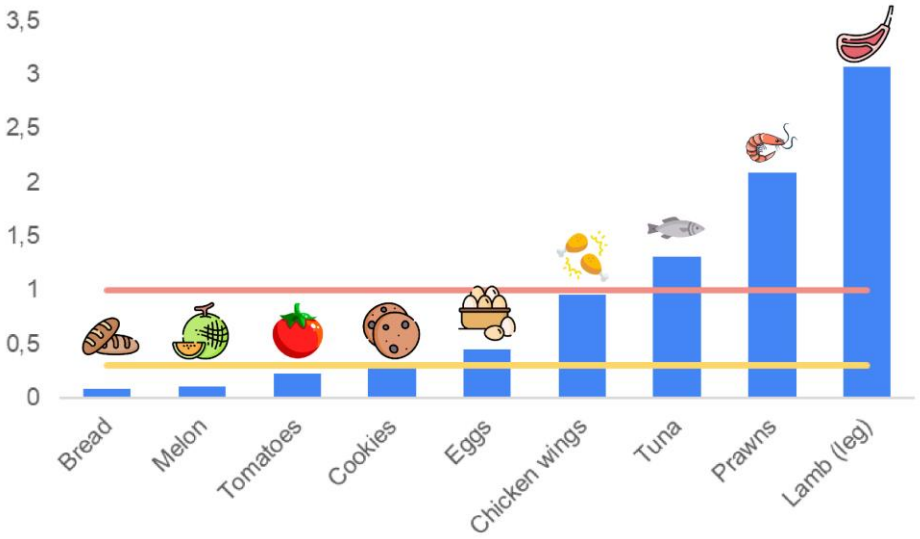

Figure 1. Low-carbon food product.

However, we found that a decrease in micronutrient content in the diet was more often associated with a decrease in greenhouse gases than an increase in micronutrient content, with more cases where a low-carbon consumption or diet was associated with a decrease in major micronutrients than an increase in micronutrients. Similarly, to the negative relationship discussed between major macronutrients, this may be due to the decreased consumption of animal products and especially dairy products in low-carbon diets, which may be due to diets with reduced consumption of meat and dairy products. Fe was the only micronutrient that had an association between increased micronutrient levels and greenhouse gas reductions. Zn levels, on the other hand, were found to be lower in people on a low-carbon diet or low-carbon food (Springmann *et al*., 2021; Eini-Zinab *et al*., 2021). These findings identify micronutrients as a crucial area of concern when advocating for a low-carbon diet. Health concerns associated with micronutrient deficiencies are rising worldwide, and future research and policy should take steps to guarantee that environmentally-focused dietary recommendations do not disregard micronutrient requirements (Donati *et al*., 2016).

2.2. Sustainability Consciousness for Climate Change Mitigation in Food Sector

Climate change has already had a bad impact on ecosystems, freshwater resources, and human health. While climate change cannot be entirely averted, the most severe consequences can be mitigated by significantly reducing the amount of heat-trapping gases released into the atmosphere. The act of reducing greenhouse gases released into the atmosphere to slow climate change is called climate change mitigation. As a significant contributor to greenhouse gas emissions, the food manufacturing business or food sector must establish climate targets and track emissions. In addition to addressing global emissions, it is vital to account for and incorporate emissions across the value chain when setting emissions targets (Stoddard *et al*., 2021). Despite this enormous contribution, there has been little focus on how the food industry might address the carbon issue.

Sustainability consciousness is an important predictor for the successful implementation of sustainability projects. Changing citizens' knowledge, attitudes, and behaviors is an important step towards achieving sustainable development. Ensuring a sustainable future

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requires cultivating a long-term feeling of awareness among citizens. Sustainability consciousness based on low carbon education is one of the climate change mitigations through people's notions, behavior, and attitudes through sustainable development framework, for instance, environment, social, and economic areas (Gericke *et al*., 2019; Gulzar *et al*., 2023). Sustainability consciousness also could be cultivated in low-carbon food consumption as a sector that is an indirect contributor to greenhouse gases. That is important to build the habit of considering choosing the menu in daily life wisely for reducing greenhouse gases. Food production is mostly driven by consumption, which is directly tied to consumer eating patterns (de Oliveira Padilha *et al*., 2022; González-García *et al*., 2018; Parashar *et al*., 2020). Changes in food consumption may thus reduce greenhouse emissions in the production chain if people move from high-carbon emissions to low-carbon emissions foods (Xu *et al*., 2022).

Climate change mitigation has a protocol to protect the environment. The protocol arranges for the company to be aware carbon footprints' flow of their product. It is figured by the scope of carbon emissions. The scope of carbon emissions is divided into three categories. Scope 1 covers direct emissions from a company's own or controlled sources. This includes on-site energy sources including natural gas and gasoline, refrigerants, emissions from combustion in owned or controlled boilers and furnaces, and emissions from fleet vehicles (cars, vans, trucks, and hospital helicopters). Scope 1 emissions also include process pollutants generated during industrial activities and on-site manufacturing (such as factory odors and chemicals). Scope 2 is indirect emissions from purchased or acquired energy, such as electricity, steam, heat, or cooling, produced off-site and consumed by the reporting enterprise. For example, power purchased from a utility provider is generated offsite, so it is classified as indirect emissions. Scope 3 indirect emissions means emissions from upstream and downstream activities. The example of scope carbon emission in making milk powder. It is made for all the people including the owner until consumers understand and make mitigation for choosing products wisely for environmental impact as sustainability consciousness in society. Therefore, the flow of carbon emission that emits into the atmosphere could be explained as shown in **Figure 2**. It is described as cows becoming meat from crops and farmland life has already emitted methane as greenhouse gases, then it is distributed to cattle slaughtered industry which uses the energy power plan for cut the cow. Continue to the storage which uses a cooler to emit the amount of greenhouse gases of CFC. They are transported by transportation which consumes gasoline and emits greenhouse gases from combustions. Then, the meat arrives at the supermarket or market to meet the buyer. Thus, the food could have its carbon emission classifications.

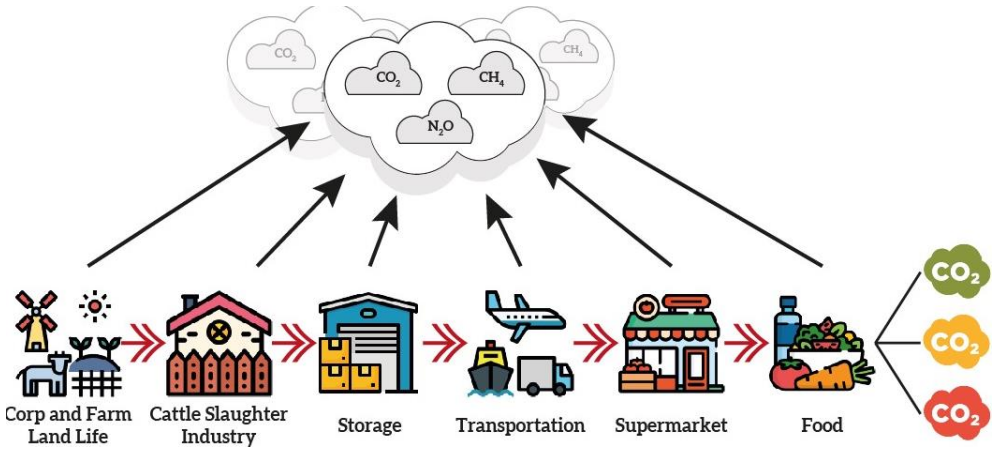

Figure 2. The flow of carbon emission on food products.

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3. METHODS

3.1. Bibliometric Analysis Method

This study used a bibliometric analysis strategy. The bibliometrics theory guides each analysis, which uses statistics and mathematics to statistically analyze, explain, and visualize the research subject. Identifying current status and critical points might help predict future research trends and hotspots. The research process involved five steps: keyword selection, data collecting, data processing and analysis, and result analysis and conclusion. The research steps for bibliometric analysis for this research are presented in **Figure 3**. Detailed information how to use bibliometric is explained elsewhere (Al Husaeni & Nandiyanto, 2022; Azizah *et al*., 2021).

This research uses the keywords "low carbon" AND “education”. Keywords are used to select relevant articles. Articles are selected based on specified keywords, using the abstract and title as references. The review covered the years 2014-2024. On 10 January 2024, Those articles are searched at scopus.com and the result shows 568 related articles with open-access journal selections during 10 years of publication. Data collected is kept in *.csv formats. The VOSviewer software uses the *.ris format for data mapping. VOSviewer is an application that helps map search results. VOSviewer performs two analyses: coauthorship and co-occurrence. The analysis results are presented as a visual map. We employed two methods of visualization: network and overlay. Co-authorship analysis evaluates the relationship between articles based on their number of co-authors. Authors tend to collaborate more when their points of view are similar. Co-occurrence analysis visualizes the occurrence of a word term using a map. This analysis uses the binary word count approach.

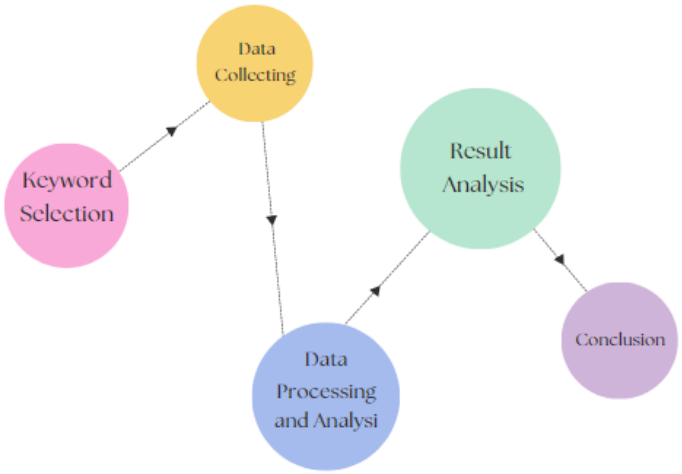

Figure 3. The research steps for bibliometric analysis.

3.2. Data Collection Method

The research used is the research and development method with the Analyze, Design, Develop, Implement, Evaluate model. The subject is 53 pre-service teachers at of private university in Bogor, Indonesia. Five boys and 48 girls. The data of this research are taken by deep observation, semi-structured interviews, and a sustainable consciousness questionnaire adopted from Gericke (2019) that has 27 statements to know the consciousness of respondents to sustainability for low carbon education. The questionnaire uses using Likert scale which consists of four scales, i.e. strongly agree, agree, disagree, and strongly disagree. The other instrument is the validation of the development of a low-carbon food consumption

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calculation application. Before the questionnaire is given to the students, they develop a low-carbon food consumption calculation application. Then, it is validated by three experts, i.e. the media expert, the content expert, and the technology expert. Then, it trials the pre-service teachers to see the readability of the user.

3.3. Teaching Method

The research has been done through several steps which are observed deeply through the Science, Technology, Engineering, and Mathematics (STEM) learning approach.

(i) The pre-service teachers are given the problem related to their daily menu which could contribute to the greenhouse gas indirectly and they have to be identified whether the food is harmful or not for the environment.
(ii) Then, they recreate the menu which is harmless for the environment through the STEM learning approach.
(iii) They design the menu based on scientific knowledge with technological and engineering activity by calculating food carbon footprint on low-carbon food consumption simple calculation application. That application (calculator) allows them to know whether their menu has a low impact on the environment, medium, or high impact on the environment by a color indicator in the total amount of food carbon emissions part. Green color indicator for low impact on the environment as a range of 0.00 $kgCO_2^e$ – 0.29 $kgCO_2^e$; yellow color indicator for medium impact on the environment as a range of 0.3 $kgCO_2^e$ – 1 $kgCO_2^e$; and red color indicator for high impact to the environment as a range of 0.3 $kgCO_2^e$ – 1 $kgCO_2^e$. The menu has to fit the criteria for instance based on local ingredients, have a low to medium impact on the environment, and be affordable.
(iv) After designing the menu, they make the menu as a solution for reducing carbon emissions and as their menu for lunch during the semester.
(v) Then they disseminate their menu to their friend, lecturers, and society around them for trials and make it low-carbon food consumption.
(vi) After that, they assessed their sustainability consciousness through the sustainability consciousness questionnaire for low-carbon education.

4. RESULTS AND DISCUSSION

4.1.Bibliometric Analysis Results

Bibliometrics has been utilized to aid study analysis in a variety of fields (Al Husaeni & Nandiyanto 2023; Fatimah *et al*., 2022; Maryanti *et al*., 2022). This study employed bibliometric analysis to better understand the present research trend in low carbon consumption. Between 2014 and 2024, 568 articles were published with research on Low carbon in education. The titles, abstracts, and article data were screened for relevance to the study themes specified. **Figure 4** depicts the evolution of research in low carbon. In general, fewer studies were conducted between 2014 and 2024, but the trends in this research are increasing. There were 37 articles published in 2014, 34 in 2015, 31 in 2015, 48 in 2017 and 2020, 44 in 2018, 53 in 2019, 72 in 2021, 79 in 2022, 115 in 2023, and 7 in 2024.

The low carbon education research identified 568 related terms with at least three occurrences. We select only the most relevant terms in three times attempts. We create three types of bibliometric visualization maps: network, overlay, and density. It visualizes the network of publications on low-carbon education from 2014-2024. The network visualization displays link strength, which indicates the strength of a relationship. In network analysis, higher link strength values indicate stronger relationships between terms. Each term on the network is grouped into 4 clusters regarding low-carbon education with different colors. There are red, blue, green, and

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yellow. The clustering also has been done not only for related abstracts and keywords but also for the country that is works comes from. It is also has been clustered by the same four colors, i.e., red, blue, green, and yellow.

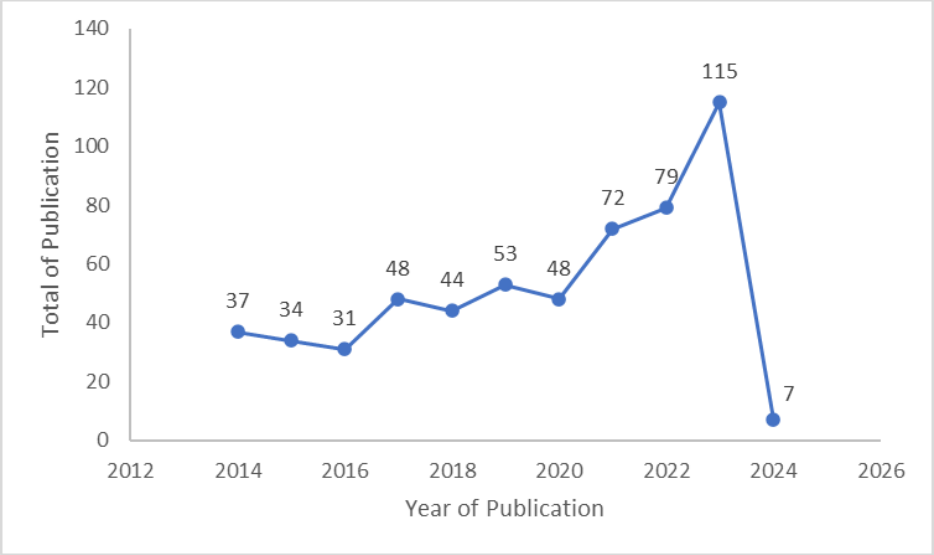

Figure 4. The development of low-carbon publication.

Visualization of color density indicates that brighter yellow colors and larger circle sizes correlate with increased frequency of word appearance. Interest in the phrase is increasing. Research on a term reduces as its color fades and approaches the backdrop color. Low Carbon Education research frequently uses the phrases carbon, sustainable development, low carbon, education, and engineering education. There is no one has discussed low-carbon food consumption in education. This shows that the research on low carbon in education has already increased, but not too many researchers have deeper about this issue, especially in Indonesia. It is proven that the data for the author from Indonesia for this expertise in this issue are only four. By using scopus.com, there are Permanasari, A., Abdullah, A.G., Hamidah, I., and Hudha, M.N.

4.2. Low-Carbon Food Consumptions Simple Calculation Application

The development of a low-carbon food consumption simple calculation application has several steps. In the first step, we analyze the problem that appears from the students that they are confusing how to calculate their menu by simple calculation and gain more understanding to relate it to their daily life. Then, we design the simple calculation of low-carbon food consumption application. Thus, we find the data on global data mining about food carbon footprint. We sorting out which products relate to ingredients in Indonesia. We analyzed the environmental impact of food categories used by merchants. Food classifications become more detailed as they progress from the department (e.g., "Bakery") to Aisle (e.g., "Croissants, Brioche, and Pastries") to Shelf. The main material focuses on the products offered. Each supermarket has its classification system. We divided products into eight categories based on aisle and shelf location: beverages, fruits, vegetables, and nuts; cereals and bread; snacks, sweets; kitchen accessories; prepared foods; dairy, eggs, meat; and plant-based alternatives. This facilitates the comparison of similar and potentially substitutable meals. This food's carbon emissions score included the calculation of greenhouse gases (GHG), distribution, and water land used. All the scores are classified as the environmental impact as shown in **Figure 5** for the foundation to develop the low-carbon food simple calculation application. Those classifications are based on the amount of food carbon emission per 100 g.

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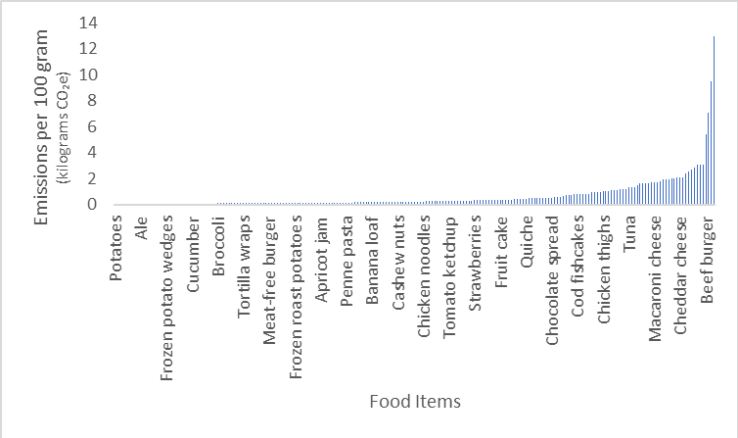

Figure 5. The classification of foods' carbon emission toward environmental impact.

After collecting the data on food carbon emissions, then we develop an application for calculating the total emissions as simple and easier to understand for students. The part of the low-carbon food simple calculations application is developed as a table in an Excel spreadsheet. There are included numbers for numbering the item, ingredients are for the name of the product that we used as the menu, the total is the amount of product that we used in the menu, units are the units of product amount (e.g. in grams), amount of carbon emissions per product, and the total amount of food carbon emissions as the total of food carbon emission that we used on the menu. The application is simple as it is to make students more understanding and easier to calculate the carbon footprint on the menu that they created. These applications use the VLOOKUP formula to know the food classification for its impact on the environment. We use VLOOKUP to find information in a large spreadsheet or to search for the same sort of information again. VLOOKUP functions similarly to a phone book, beginning with known data, such as a person's name, and progressing to unknown data, such as their phone number. VLOOKUP stands for 'Vertical Lookup'. It is an Excel or spreadsheet function that searches for a specified value in one column (the 'table array') and returns a value from another column in the same row. A VLOOKUP function consists of four components: the value to be looked up; the range in which we want to find the value and the return value; and the number of columns within the stated range that holds the return value. 0 or FALSE indicates an exact match with the desired number, while 1 or TRUE indicates an approximate match. The syntax is VLOOKUP([value], [range], [column number], [false or true]). The formula on this application is =if(ISBLANK(C7);"";D7*VLOOKUP(C7;Data!$A$2:$C$212;3;false)) and at the end of the total amount of food carbon emissions use the formula of the sum.

Based on this application, the food carbon footprint that has been classified based on carbon emissions which impact to environment in the earlier steps, are figured out in this application when we put the data of food by the total of ingredients that we input in the application. For example, a beef burger of 100 g has an amount of carbon emission is 5.3976 $kgCO_2^e$ which is represented by red color, which means that beef burger has a high impact on the environment or can be called harmful to the environment. On the other hand, there is the product that is represented by yellow color means that the product has a middle impact on the environment, for instance, 5 g of almond milk is 0.328 $kgCO_2^e$. The green color represents the product that has a low impact on the environment, for instance, potatoes with 0.0207 $kgCO_2^e$ per 100 grams. By using this application, allows pre-service teachers to calculate and classify the menus that they have chosen for meals and consider the environment. Besides knowing that the menu classifications they have created can have an

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impact on the environment, they also know that the products they choose in their menu have carbon emission equivalence with how many liters of gasoline consumption, how many smartphones are charged, and how many kilometers a passenger car travel (see **Tables 2, 3,** and **4**).

Table 2. Data equivalencies of foods carbon emissions (low carbon emissions).

Product	Emissions per 100gram ($KgCO_2^e$)	Number of Smartphones Charged	Liter of Gasoline Consumed	Kilometer Driven by an Average Gasoline-Powered Passenger Vehicle
Flour	0.0044	1	0.0	0.02
Potatoes	0.0207	3	0.0	0.09
Onions	0.0363	4	0.0	0.15
Almond butter	0.0387	5	0.0	0.16
Frozen sweet potato fries	0.041	5	0.0	0.17
Oat milk	0.0453	6	0.0	0.19
Apple juice	0.0458	6	0.0	0.19
Limes	0.0463	6	0.0	0.19
Almond milk	0.0656	8	0.0	0.27
Frozen potato wedges	0.0665	8	0.0	0.28
Cucumber	0.0847	10	0.0	0.35
Sourdough bread	0.0851	10	0.0	0.36
Meat-free nuggets	0.0862	11	0.0	0.36
Bananas	0.0873	11	0.0	0.37
Bread	0.0879	11	0.0	0.37
Cabbage	0.089	11	0.0	0.37
Soy milk	0.0893	11	0.0	0.37
Broccoli	0.0897	11	0.0	0.38
Kale	0.0903	11	0.0	0.38
Peppers	0.0919	11	0.0	0.38
Avocados	0.0921	11	0.0	0.39
Asparagus	0.0926	11	0.0	0.39
Pears	0.0926	11	0.0	0.39
Pineapple	0.0932	11	0.0	0.39
Carrots	0.0935	11	0.0	0.39
Watermelon	0.0969	12	0.0	0.41
Sweetcorn	0.0971	12	0.0	0.41
Garden peas	0.1004	12	0.0	0.42
Spinach	0.1009	12	0.0	0.42
Tofu	0.1021	12	0.0	0.43
Melon	0.1057	13	0.0	0.44
Cider	0.1082	13	0.0	0.45
Quinoa	0.1139	14	0.0	0.48
Chia seeds	0.1221	15	0.1	0.51
Beans	0.1373	17	0.1	0.57
Egg noodles	0.1382	17	0.1	0.58
Vegetarian chilli con carne	0.1429	17	0.1	0.60
Breakfast cereal	0.1493	18	0.1	0.62
Poppadoms	0.1501	18	0.1	0.63
Pancakes	0.1548	19	0.1	0.65
Porridge (oatmeal)	0.1555	19	0.1	0.65
Kiwis	0.1614	20	0.1	0.68
Penne pasta	0.1625	20	0.1	0.68
Spaghetti	0.1646	20	0.1	0.69

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Table 2 (Continue). Data equivalencies of foods carbon emissions (low carbon emissions).

Product	Emissions per 100gram ($KgCO_2^e$)	Number of Smartphones Charged	Liter of Gasoline Consumed	Kilometer Driven by an Average Gasoline-Powered Passenger Vehicle
Popcorn	0.1814	22	0.1	0.76
Sugar	0.1852	23	0.1	0.77
Sunflower seeds	0.1934	24	0.1	0.81
Dairy-free cheese	0.1976	24	0.1	0.83
Tomatoes	0.2272	28	0.1	0.95
Mushrooms	0.2353	29	0.1	0.98
Walnuts	0.2416	29	0.1	1.01
Tomato ketchup	0.261	32	0.1	1.09

Table 3. Data equivalencies of foods carbon emissions (middle carbon emissions).

Product	Emissions per 100gram ($KgCO_2^e$)	Number of Smartphones Charged	Liter of Gasoline Consumed	Kilometer Driven by an Average Gasoline-Powered Passenger Vehicle
Yogurt	0.3112	38	0.1	1.30
Peanuts	0.3146	38	0.1	1.32
Strawberries	0.3242	40	0.1	1.36
Coconut milk	0.332	41	0.1	1.39
Butter	0.3325	41	0.1	1.39
Cookies	0.3357	41	0.1	1.40
Peanut butter	0.3435	42	0.1	1.44
Fruit cake	0.3452	42	0.1	1.44
Sunflower oil	0.3661	45	0.2	1.53
Ice cream	0.3662	45	0.2	1.53
Cow's milk	0.3703	45	0.2	1.55
Rice	0.3926	48	0.2	1.64
Biscuits	0.3989	49	0.2	1.67
Eggs	0.4437	54	0.2	1.86
Lettuce	0.4926	60	0.2	2.06
Prawn crackers	0.4933	60	0.2	2.06
Olive oil	0.5185	63	0.2	2.17
Sausage rolls	0.585	71	0.3	2.45
Salmon fishcakes	0.6506	79	0.3	2.72
Spaghetti bolognese	0.7835	96	0.3	3.28
Chicken sausages	0.8164	100	0.3	3.42
Grapes	0.8279	101	0.4	3.46
Raspberries	0.8371	102	0.4	3.50
Chicken breast	0.9272	113	0.4	3.88
Chicken wings	0.9583	117	0.4	4.01
Chicken thighs	0.9982	122	0.4	4.18

Referring to the beef steak product listed above which is in red means that it has a big impact on the environment. Beef steak also produces the carbon emissions per 100 g is equal to 12.9748 $KgCO_2^e$. It is equivalent to charging 1.583 mobile phones, consuming 1.5 liters of gasoline, and the equivalent of driving a car passenger 54.28 km. However, products that include green color are harmless to the environment, for instance, kiwis with 0.1614 $KgCO_2^e$. It is equivalent to charging 20 mobile phones, consuming 1.5 liters of gasoline, and the equivalent of driving a car passenger 0.68 km. This makes people aware of its impact on the

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environment. People should be intrigued to change their habit of choosing the menu on their plate wisely. This can also be linked to nutrition and health issues. Some research suggests that there is no link between consuming fewer carbon-emitting foods and improved health (Quam *et al*., 2017; Aleksandrowicz *et al*., 2016). However, others suggest that a low-carbon consumption or diet will improve our health as long as the micronutrients in our food are provided to our bodies (Donati *et al*., 2016). Thus, our bodies are healthy, our environment is protected and we can indirectly slow down climate change.

Table 4. Data equivalencies of foods carbon emissions (high carbon emissions).

Product	Emissions per 100gram ($KgCO_2^e$)	Number of Smartphones Charged	Liter of Gasoline Consumed	Kilometer Driven by an Average Gasoline-Powered Passenger Vehicle
Salmon	1.0413	127	0.4	4.36
Milk chocolate	1.08	132	0.5	4.52
Tuna	1.3075	160	0.6	5.47
Mackerel	1.3606	166	0.6	5.69
Mozzarella cheese	1.6233	198	0.7	6.79
Coffee beans	1.6825	205	0.7	7.04
Tea	1.7621	215	0.8	7.37
Blue cheese	2.0106	245	0.9	8.41
Coffee pods	2.03	248	0.9	8.49
Dark chocolate	2.062	252	0.9	8.63
Prawns	2.0911	255	0.9	8.75
Parmesan cheese	2.4016	293	1.0	10.05
Instant coffee	2.8784	351	1.2	12.04
Lamb (leg)	3.0741	375	1.3	12.86
Lamb casserole	3.0877	377	1.3	12.92
Lamb chops	3.0902	377	1.3	12.93
Beef burger	5.3976	659	2.3	22.58
Beef meatballs	7.0787	864	3.0	29.61
Beef mince	9.5035	1159	4.1	39.76
Beef steak	12.9748	1583	1.5	54.28

Calculation in the data equivalence of the amount of carbon emissions per product with the number of cell phones charged covers the amount of energy required to fully charge a drained smartphone battery and keep it charged all day. According to Ferreira *et al*. (2011), it takes about 2 hours to fully recharge a smartphone battery. Maintenance mode power, often known as the power consumed while the phone is completely charged but the charger remains plugged in, is 0.13 Watts (Shenker *et al*., 2023). To get the amount of energy used to charge the smartphone, subtract the energy consumed in "maintenance mode" (0.13 W multiplied by 22 hours) from the 24-hour energy consumed (14.46 Wh). The equivalence of product carbon emissions with how many liters of gasoline consumption by conversion ratio for CO_2 emissions is 8.887 g per gallon of petrol consumed (Güzel & Alp, 2024). Gallon petrol would be converted to liters first, as one gallon equals 3.785 liters. To calculate the number of grams of CO_2 emitted per gallon of petrol combusted, multiply the heat content of the fuel by the kg CO_2 per heat content of the fuel. This calculation means that 100% of the carbon in petrol gets transformed into CO_2 (Edwards & Trancik, 2022; Heagle *et al*., 2023). The equivalencies of products' carbon emission with how far the passenger vehicle converting carbon dioxide emissions-to-total greenhouse gas emissions ratio for passenger vehicles is 0.993. The carbon dioxide emissions per gallon of motor petrol are 8.89 10-3 metric tonnes, as calculated in the gallons converted to liters of petrol consumed section. To compute annual

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greenhouse gas emissions per mile translated to kilometers, the following approach was used: The carbon dioxide emissions per liter of gasoline were divided by the average fuel efficiency of automobiles to compute the carbon dioxide emissions per kilometer driven by a typical passenger vehicle. Carbon dioxide emissions were then split by the ratio of carbon dioxide emissions to total vehicle greenhouse gas emissions, which includes vehicle methane and nitrous oxide.

Low-carbon food consumption calculation application has been developed, then it is implemented as a trial to the students through learning low-carbon food consumption topics. In the evaluation, this application needs improvement on the display to add some more pictures to make it more interesting. It has already simple and pre-service teacher more understanding of low-carbon food consumption and how to calculate their menus. There is also the display about equivalencies of carbon emissions per product. Thus, it is more relatable to their daily life. Another evaluation is to add some more data which unrecorded products such as domestic products that require further analysis to determine their carbon emission value.

4.3. Students' Demographic

Table 5 figures students' demography based on gender and educational background. Educational background has a high influence on the students' learning toward the topics that commonly use STEM (science, technology, engineering, and mathematics) approach. Two main aspects of students' demography are used as assessments to measure students' readiness for low-carbon food consumption learning. Each student has various educational backgrounds. This finding supports the notion that students' educational background and gender are influenced by their sustainable consciousness through low-carbon food consumption learning topics. These data were also utilized to assess intelligence and determine the optimum learning strategies (Hidayat *et al*., 2020; Nandiyanto *et al*., 2018).

Table 5. Students' demographic data.

No	Aspect	Score (%)	Remarks
1	**Gender**		
	Male	90.6	Students' Sustainability Consciousness
	Female	9.4	For Low-carbon food
2	**Educational Background**		
	Social	37.7	
	Science	49.1	
	Linguistic	5.7	
	Engineering	7.5	

4.4. Students' Sustainability Consciousness through Low-Carbon Food Consumption

After developing the application of low-carbon food consumption calculation applications to calculate the carbon emissions that are on the menu, the pre-service teacher and students are divided into several groups to identify the problem that is given by the lecturer. They have to identify the daily favorite menu whether that is harmful to the environment or harmless to the environment. When they have already the data, they should discuss it with their group to re-arrange the menu which has a low to medium impact on the environment, has good nutrition, and is affordable. They should use the low-carbon food consumption simple calculation application to calculate their menu and determine which categories their foods are included. Thus, they could have their consciousness of the sustainability of low-carbon

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education and their low-carbon food consumption through its topics in the learning using the STEM learning approach.

During the lesson, all the group has their new low-carbon menu. One of them created a new menu, named Tallow Doughnut. The tallow doughnut is made from 200 g of steamed potatoes (0.0414 $KgCO_2^e$), 150 g of eggs (0.66555 $KgCO_2^e$), 20 g of sugar (0.03704 $KgCO_2^e$), and 300 grams of flour (0.0132 $KgCO_2^e$). They calculated the ingredients in low-carbon food with simple calculation applications. However, the tallow doughnut meets the criteria of a food that has a medium impact on the environment with a total amount of food carbon emissions of 0.75719 $KgCO_2^e$. Based on those results, the value of the total amount of carbon emissions could be equivalencies to 3.17 kilometers driven by an average gasoline-powered passenger vehicle, 92 smartphones charged, and 0.3 Liter of gasoline consumed. Besides this value, the tallow doughnut also has 480 kcal/portion, which means that all the nutrition such as carbohydrates, proteins, and minerals is already included in one portion of the tallow doughnut. This is also affordable to buy by the people who need fast food for breakfast and also as a souvenir of indigenous food from Bogor, Indonesia. These are all results that have been done by the pre-service teacher to arrange the low-carbon food menu. They have already noticed that food is an important point to be considered as an indirect carbon emissions contributor. It is proven by the low-carbon food consumptions of pre-service teacher results that has shift to the positive way. They consume more meat-based food product before learning pertaining low-carbon food consumptions, while after learning process during semster, their habit changed to consume plant-based food product.

The results of pre-service teachers' sustainability consciousness for low-carbon education are described in **Figure 6** which contains three main aspects i.e. sustainability knowingness, sustainability attitude, and sustainability behavior. For each main aspect, there are three dimensions of sustainable development, there are environmental, economic, and social. Pre-service teachers are assessed and the results are calculated by the percentages.

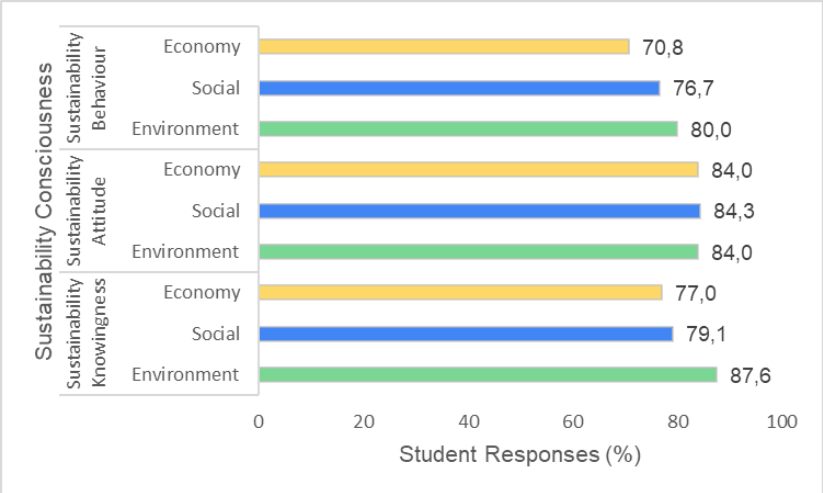

Figure 6. Students' sustainability consciousness results.

According to the data, pre-service teachers' sustainability knowledge about the environment has already in an excellent result. They already know what low-carbon food consumption is, how to calculate the menu as low-carbon food consumption, how their consumptions could impact to the environment, and convert the menu to its nutrition. While for their knowingness pertaining social and economy is not as good as the environment. Pre-service teachers are still confused about how to calculate the menu, and how to explain low-carbon food consumption to others. Because they are new to what low-carbon food

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consumption is. Thus, it is natural that they still lack the knowledge to link low-carbon food consumption with social and economic indicators. Similar to the results of sustainability behavior, the environmental and social aspects are more prominent. Through interviews with several pre-service teachers, they stated that after doing this low-carbon food consumption project using a STEM learning approach, they became more critical and careful in choosing their daily food so as not to have a bad impact on the environment. The factors of choosing learning topics and learning approaches greatly affect student learning outcomes in terms of knowledge, attitudes, and behavior (Thahir *et al*., 2020; Astuti *et al*., 2021). STEM learning has a very positive impact on student learning outcomes and makes them think more critically (Hartini *et al*., 2020; Sirajudin & Suratno, 2021). Moreover, in the calculation application, there is an equivalent value of carbon emissions with aspects relating to their daily lives such as cellphone charging, vehicle mileage, and gasoline consumption. As for the economic aspect, they still do not really think about it, even though the food is a bit expensive, but it is good for the environment and health, then they will still buy it.

Unlike the sustainability attitude, all aspects of the environment, society, and economy, have equally good points. attitude itself is a person's mindset or feelings that are reflected in behavior. Attitude can change according to the circumstances experienced by a person while behavior tends not to change. Educational background also plays play important role in these results, pre-service teacher who has educational backgrounds in social and science has the most numbers. It could be figured out that all the science and social content that are included in this learning, have already been mastered. Thus, it can be interpreted that learning the topic of low-carbon food consumption can lead pre-service teachers to decide to change their lifestyle starting from choosing the menus of their plates. If this decision is continuously made, it may become a behavior or habit. High knowledge, attitude, and behavior can succeed in the goal of reducing greenhouse gases as mitigation of climate change (Venkataramanan *et al*., 2020), especially through low-carbon food consumption.

Finally, this study adds information how to teach students as researchers did previously (Suherman et al., 2023; Al Husaeni et al., 2022; Fauziah et al., 2021; Al Husaeni et al., 2024) This study also supports strategies facing SDGs issues.

5. CONCLUSION

Based on the results, the mitigation of climate change through low-carbon food consumption learning could be successful. It is proven by the sustainability consciousness of pre-service teachers has already in excellent results either in sustainability knowingness, sustainability attitude, and sustainability consciousness through low-carbon food consumption learning topics using simple calculation applications. The low-carbon food simple calculation applications are feasible to use in learning related to low-carbon ideas, especially in food and agriculture. This application is simple and students are easier to understand about low-carbon food topics. Pre-services' low-carbon food consumption has positively shifted from meat-based food to plant-based food.

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7. AUTHORS' NOTE

The authors state that there are no conflicts of interest in the publishing of this work. The authors certified that the data and the paper are original and free of plagiarism.

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