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Research Article

Bibliometric Analysis of Carbon Footprint Studies Within the Scope of Sustainability

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ABSTRACT

Today, the world climate is undergoing negative changes as a result of the unconscious use of resources, increasing energy demand and anthropogenic effects resulting from the development of industry. Climate changes occurring on a global scale are long-term and bring with them many irreversible consequences. Various improvement activities are based on sustainability in the fight against global climate change. To ensure environmental sustainability, practices are carried out in industrial areas to determine carbon footprints and reduce carbon emissions accordingly. One of the important steps taken in this context is the European Green Deal action plan, which is the roadmap for the green transformation required by the Paris Climate Agreement of the EU, to which Turkey is also a party. The European Green Deal aims to make Europe the first carbon-neutral continent in 2050 and to bring carbon emissions in the atmosphere back to pre-industrial revolution levels. In line with this goal, activities aimed at carbon footprint studies have gained serious momentum. This study aims to determine the current status of carbon footprint studies on a global scale, their progress and their distribution on a country basis through bibliometric analysis. Bibliometric analysis is a social network analysis that guides researchers regarding the interactions of existing studies and future studies. 1305 indexed journal articles published between 2020 and 2024 were downloaded via the Web of Science database and analyzed. Network maps and graphs showed correlations between keywords, countries, and journals. Researchers in China and America have made significant contributions to this field. It is seen that the studies examined serve sustainability development goals and that the studies mainly target climate action with 722 articles.

1. Introduction

Today, the need for energy is increasing as a result of increased consumption and unconscious consumption of energy resources. The inability to curb fossil fuel use contributes to climate change and its negative effects. Global climate change; due to global warming, air movements, precipitation, humidity and other climate factors are affected, causing the climate to change rapidly within a short period, typically 15–20 years [1]. In order to prevent this negative impact, many countries on a global scale need to work in cooperation.

The European Union has presented many international legislative studies to combat global climate change [2-5]. In this context, the European Green Deal is an implementation that complements the 2030 Sustainable Development Goals [6]. The European Green Deal aims to have a sustainable economy and combat climate change by determining the strategic goals of the European Union [7].

The European Green Deal is a strategic plan that supports the EU's global sustainability, climate action and green transformation efforts with various action plans and policies [8]

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The European Green Deal includes the protection of biodiversity, clean energy applications, sustainable industry, sustainable agricultural applications, green construction sector, circular economic approach, environmentally friendly transportation and sustainable food systems [9]. One of the European Green Deal targets is to achieve zero carbon neutrality in the atmosphere by 2050. It aims to ensure balance in the atmosphere through various methods such as carbon footprint reduction and carbon regulation mechanisms [10].

Sustainability is the ability to meet current generations' needs while also considering future generations' needs, encompassing environmental, social and economic dimensions [11]. Transforming Our World: In line with the goals of the 2030 Agenda for Sustainable Development, reducing the carbon footprint, transitioning from fossil fuels to renewable energy and achieving carbon neutrality targets are of strategic importance on a global scale [12, 13]. Especially the identification of the carbon footprint and the reduction of carbon emissions, along with energy efficiency and green transition efforts, constitute the most critical elements in line with the Sustainable Development Goals (SDGs) [14].

In recent years, significant research has been conducted on carbon footprint, green transition and sustainability [15-17]. A comprehensive analysis is needed to determine the directions of the studies carried out in these areas and to direct the studies that will contribute to achieving sustainable development goals. One of the analysis methods that provides a roadmap for properly determining the field of study and showing the interaction processes in the research is the bibliometric analysis method [18]. It enables the analysis of academic studies within a certain period of time by evaluating them in terms of different criteria and using various statistical methods and numerical data [19]. Bibliometric analysis is a powerful tool for assessing the research trends of studies conducted in a selected field, and many studies have been carried out using this analysis method [20-25]. When examining bibliometric studies related to carbon footprint research, which plays a significant role in combating global climate change, it has been observed that researchers emphasize the importance of resource management, energy efficiency, and green transition efforts [18, 25]. In this study, bibliometric analysis was conducted using the Web of Science database to examine publications related to carbon footprint, particularly in the field of environmental engineering. The study also evaluates the alignment of these publications with the Sustainable Development Goals (SDGs).

2. Materials-Methods

In this study, the Web of Science (WOS) database, which includes different disciplines and provides up-to-date data, was used as a search engine. Web of Science is one of the transparent and most reliable bibliometric analysis tools used to conduct research analysis and visualize this analysis. It is also considered one of the most comprehensive scientific databases worldwide [26]. Bibliometric analysis, which enables the examination of academic studies according to various criteria, serves as a guiding tool for researchers by allowing them to select studies within a specific time frame, thereby providing a roadmap for future descriptive studies [19].

In bibliometric analysis, distance-based maps are used when it comes to investigating the relationships between data, while graphic-based maps are used when it comes to presenting only existing data. For graph-based mapping, software such as Kamada-Kawai, Fruchterman-Reingold, and Pathfinder Networks are used, while for distance-based mapping, tools like VOSviewer and Vxord are employed. Vosviewer is the most preferred software with the best performance quality [27, 28]. VOSviewer generally uses data obtained from bibliometric databases such as Web of Science, Scopus, Google Scholar. Analyzes such as co-authorship, co-citation links, citation relationships of publications and journals, and keyword groups are carried out [29]. In the analyses carried out in the Vosviewer application, data can be uploaded in different file formats. In this study, the numerical data obtained from the study through a bibliometric

analysis were interpreted using the Microsoft Excel program and visualized with social network analysis maps made via the VOSViewer program.

The search was conducted in the Web of Science database in November 2024. The search was done by selecting the " environmental engineering" category among the articles published in "2020-2024". The publications were searched using the term "article" to identify original studies with significantly higher scientific acceptability. Publications in the form of book chapters, reviews and conference papers were excluded from the analysis due to criteria. Also, searches were customized by selecting three indexes: Emerging Sources Citation Index (ESCI), Social Science Citation Index (SSCI), and Science Citation Index (SCI).

Since the importance of environmental sustainability and sustainability studies in the fight against global climate change is significant, the search used the keyword "sustainability". It was determined that there were 8539 pieces of data as a result of the necessary customizations when searching with the keyword "Sustainability". Then, since the focus of the study is carbon footprint, studies on "carbon footprint" were scanned in the WOS database after the search with the keyword sustainability.

3. Results and Discussion

Bibliometric mapping of the studies published on sustainability and carbon footprint, which have an essential place in the fight against climate change, was made with the help of the VOSviewer program. Studies carried out in the field of sustainability were evaluated on a country basis and in terms of keyword analysis. Keyword analysis of carbon footprint studies, which is the main focus of the study, the publishing company of the study, country-based distribution, publication year and quarterly indicator of the journal in which the publication was published were discussed in detail. Additionally, within the scope of the European Green Deal compliance process, the extent to which carbon footprint studies contribute to sustainable development goals has been examined.

3.1. Examination of publications on sustainability

The search made by typing "sustainability" in the Web of Science database determined that there were 8539 articles. Keyword analysis of sustainability studies carried out in the department of environmental engineering was carried out and words related to the subject of sustainability were identified. Figure 1 shows the network analysis visual of the keywords found in the articles. The size of the shapes in the image is directly proportional to the frequency of use of the keyword. The size of the nodes in the resulting maps symbolizes the number of articles published on sustainability. The largest node represents the most work.

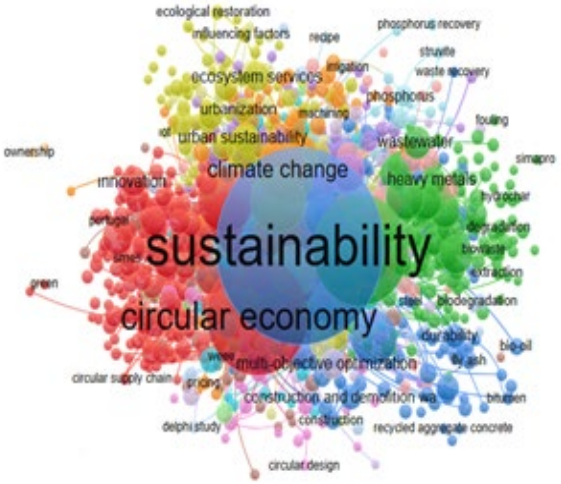

Figure 1. Bibliometric network analysis of keywords of published articles on sustainability

When the cross-country bibliometric network analysis of published articles on sustainability was examined, it was determined that the words “circular economy”, “wastewater treatment”, “climate change”, “environmental sustainability”, “greenhouse gas emissions”, “sustainability development”, “recycling” were the most used keywords in these studies in Figure 1. It has been determined that sustainability-themed studies in the Department of Environmental Engineering are highly related to these issues.

A bibliometric network analysis of cross-country publications was carried out to determine

the global distribution of studies conducted within the scope of sustainability. As seen in Figure 2, the majority of articles on sustainability were published in the People's Republic of China. Countries such as Brazil, Australia, India, Italy, and Japan publish more in this field than other countries. The distribution of studies carried out under the umbrella of sustainability by country is given in Figure 3.

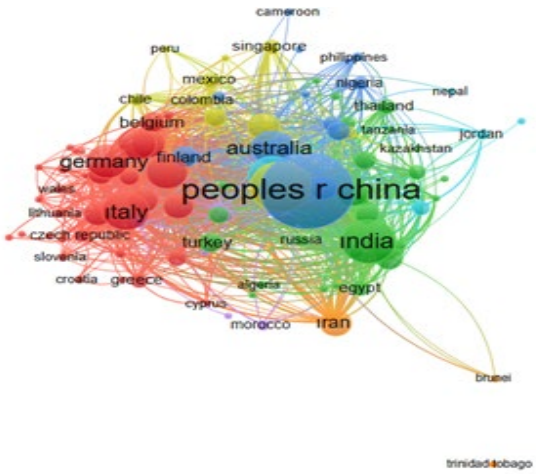

Figure 2. Cross-country bibliometric network analysis of published articles on sustainability

It is stated that articles on "sustainability" have been studied more intensively in the countries shown in darker colors in Figure 3. In comparison, lighter-color countries have published fewer articles on this subject.

Figure 3. Cross-country bibliometric network analysis of published articles on sustainability

3.2. Examination of publications on carbon footprint

Carbon footprint shows the damage caused to the environment as a result of human activities and is a measure of greenhouse gases that cause global warming. Carbon footprint is expressed as the total carbon dioxide (CO_2) emissions caused directly or indirectly by an activity [30]. Carbon footprint studies are directly related to energy consumption and resource use. Increasing energy efficiency and effective use of resources are the most important steps for environmental sustainability. Industrial organizations ' carbon footprint reduction and environmental sustainability efforts play an important role in the fight against climate change. Since the carbon footprint and sustainability studies have gained momentum after the European Green Deal came into force, 2020-2024 was chosen as the search year in this study. The studies related to the 'carbon footprint' were examined, and 1305 data records were obtained. As seen in Table 1, the minimum number of published articles on the subject is 206 and occurred in 2020. The border carbon regulation mechanism, which comes into force as of 2023, imposes obligations on industrial sectors determined as priority areas [31]. For this reason, an increase in carbon footprint studies is observed in 2024.

Table 1. Distribution of carbon footprint studies by years

Years	Article
2024	282
2023	268
2022	272
2021	277
2020	206

Journal impact factor (Q value) is a measure used to determine a journal's ranking in the academic field and is associated with indicators of academic success. Impact factor is the method used to evaluate the relative impact of a journal. It is the average number of times articles published in the last 2 years were cited in journal citation reports. It has been used as a journal impact factor for the selection of journals since 1961, with the emergence of the Science Citation Index [18].

In addition to the impact factor, many journals also use criteria such as "usage factor" and "h-index". Databases such as Web of Science, Scopus, Google Scholar use h-index and impact factor parameters to evaluate journal quality. Journals are ranked under different subject headings every year, and the publications in the first 25% of the ranking are grouped as Q1, those in the second quarter are grouped as Q2, those in the third quarter are grouped as Q3, and those in the last quarter are grouped as Q4 [32, 33]. Q values of articles on carbon footprint: 1305 articles in the Web of Science database were examined and the information in Table 2 was obtained. Q values were analyzed to understand the quality of published studies on carbon footprint and their value in terms of information content production.

Table 2. Q values of articles presenting carbon footprint

Quartile	Article
Q1	1039
Q2	202
Q3	53
Q4	11

As seen in Table 2, it was observed that publications with Q1 value were in majority. Articles in the Q1 category constitute 79.6%, articles in the Q2 category constitute 15.48%, articles in the Q3 category constitute 4.06% and articles in the Q4 category constitute 0.84%.

The majority of articles in the Q1 category means that the studies conducted in this field are valuable regarding information and content. At the same time, the increase in carbon footprint studies in the European Green Agreement harmonization process and the contribution of studies on improvement activities to the literature are of great importance in this process. The originality of the articles and their publishability in Q1 journals are high.

3.3. Bibliometric analysis of carbon footprint articles

The country-based distribution of articles written on carbon footprint in the Web of Science database between 2020 and 2024 is shown in the Figure 4.

It has been determined that the People's Republic of China did the most work. Since fewer studies have been done on this subject in Turkey compared to countries such as China, America and England, the clustering here is very small. The People's Republic of China ranks first with 369 articles. The United States ranked second with 185 articles, and Spain ranked third with 112 articles. England, Italy and Australia follow these countries. A bibliometric visualization of the most used keywords in articles on carbon footprint is shown in Figure 5.

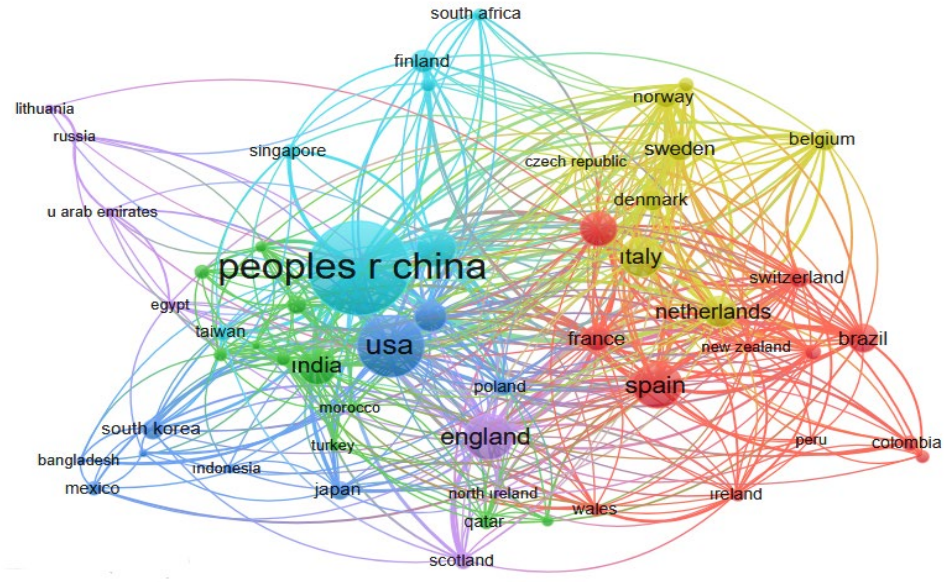

Figure 4. Country-based distribution of carbon footprint studies

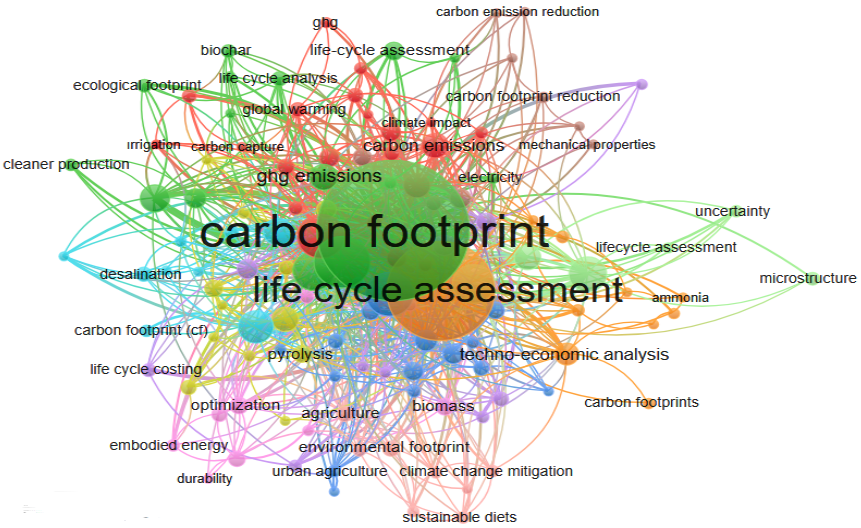

Figure 5. Distribution of "Carbon footprint" keyword network

The most frequently used keywords in articles on carbon footprint have been visualized bibliometrically and are given in Figure 5. As seen in this visualization, the most common keywords in articles on the subject of "carbon footprint", other than the keyword carbon footprint, are "life cycle assessment", "carbon emission", "greenhouse gas emission", "global warming", "water footprint", "environmental footprint". The analysis of the institutions where articles on carbon footprint are published and the bibliometric links between institutions are given in the Figure 6. Chinese Acad Sci, Bejing University, Guangdong Techno University and Michigan University have mainly published.

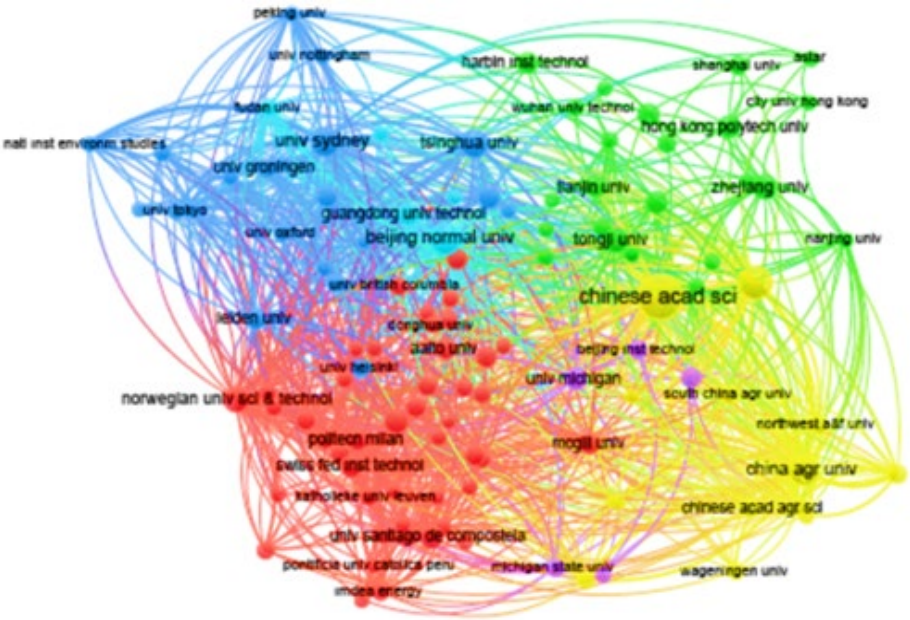

Figure 6. Bibliographic network of publishing institutions and organizations

3.4. Investigating the compatibility of carbon footprint studies with sustainable development goals

As a result of the decrease in natural resources and the negative effects created by global climate change, the concepts of sustainability and sustainable development have gained importance. The term sustainability originates from the science of ecology. It refers to the conditions required for the ecosystem to ensure its own continuity in the long term [34].

Sustainability is acting to meet the needs of today while ensuring that future generations can meet their own need [35].

Sustainable development covers economic and social development types that protect and improve the environment and social equality. Therefore, supporting sustainability with activities for the benefit of the environment, economy and society and keeping the gains at the highest level are among the priority targets [8]. To ensure economic, social and environmental sustainability, 17 basic goals were determined by the United Nations in 2015 within the frameworkof the basic principles of human, world, prosperity, peace and partnership [36].

The European Green Deal is a process that guides the fight against global climate change and the achievement of sustainable development goals. The European Union Green Deal and the Sustainable Development Goals complement each other [37]. In this study, the compatibility of carbon footprint studies, which have an important place in the European Union Green Deal harmonization process, with sustainable development goals was analyzed (Table 3). According to the article analysis results, the articles mainly serve climate action's 13th sustainable development goal. It was observed that the goal it served the least was the 10th goal, which is the reduction of inequality. The data obtained from the study determined that the sustainable development goals, which consist of 17 sub-goals in total, served 15 sub-goals.

Table 3. Distribution of articles on carbon footprint in the context of Sustainable Development Goals

Sustainable Development Goals	Article
13 Climate action	722
12 Responsible Consumption And Production	671
07 Affordable And Clean Energy	505
11 Sustainable Cities And Communities	378
15 Life on Land	333
06 Clean Water And Sanitation	327
09 Industry, Innovation And Infrastructure	315
14 Life Below Water	284
02 Zero Hunger	241
03 Good Health And Well-Being	193
08 Decent Work And Economic Growth	101
04 Quality Education	20
01 No Poverty	3
05 Gender Equality	1
10 Reduced Inequalities	1

According to the data, it is determined that 722 articles serve the purpose of climate action, 671 articles serve the purpose of responsible consumption and production, 505 articles serve the purpose of appropriate and clean energy, 378 articles serve the purpose of sustainable city and community, and 333 articles serve the purpose of life on land. It is determined that the purposes that the articles on carbon footprint serve the least are quality education with 20 articles, end poverty with 3 articles, gender equality with 1 article, and reducing inequality with 1 article.

Carbon footprint studies are an indispensable step in the fight against climate change. Providing clean energy, reducing the use of fossil fuels and using more sustainable energy sources are important steps in minimizing carbon emissions. For this reason, the concepts of clean energy and carbon footprint are associated.

4. Conclusion

Within the scope of sustainability, between 2020-2024, studies with carbon footprint keywords in the field of environmental engineering were evaluated using the bibliometric analysis method. As a result of the data obtained, it was determined that 8539 articles were published in the search on sustainability and 1305 articles were published in the search on carbon footprint in the Web of Science database. 14.44% of the articles using the sustainability keyword were written on the sub-topic of environmental sustainability. Apart from this, the articles included are studies on economic and social sustainability, the other main components of sustainability. Along with the European Green Deal and the 2030 Sustainable Development Agenda, combating climate change, carbon emission reduction targets, and green transformation have gained significant importance. Therefore, it is essential to expand studies on carbon footprint and shed light on new research, identifying gaps in the literature. As a result of the data obtained, it has been observed that most of the studies in this field are conducted in China and the United States.

In our country, it has been determined that there are fewer studies compared to other countries; however, it is anticipated that with the intensification of carbon emission reduction efforts as part of the European Green Deal compliance process, there will be an increase in studies in the fields of carbon footprint and sustainability. An analysis of the keywords in articles on carbon footprint reveals that most studies focus on life cycle analysis. Life cycle analysis evaluates a product's environmental impacts in all its processes, from raw material to finished product. Carbon footprint is among the environmental impacts evaluated in the life cycle analysis and is an important component in the life cycle analysis.

In this context, conducting life cycle analysis studies shows that efficient results can be achieved regarding carbon footprint reduction. The distribution of carbon footprint studies by country, changes over the years, other keywords used together, and the Q values of the published journals were examined. It is determined that 79.6% of the Q values are published at the Q1 level. From here, it is thought that global publications on carbon footprint are sufficient and reliable in terms of information and content production. Countries' sensitivity to combating climate change varies depending on their level of development and geographical situation. For this reason, the distribution of studies on the subject by country and the institution conducting the study varies depending on these factors.

Sustainability plays an important role in determining international development goals as it is directly related to global climate change. Sustainable development is a phenomenon shaped not only by economic factors but also by environmental and social factors. Climate change, depletion of natural resources and degradation of biodiversity threaten long-term sustainable development goals.

Therefore, carbon footprint and carbon emission reduction studies have an important role in achieving sustainable development goals. When the relationship between articles on carbon footprint and sustainable development goals was examined, it was determined that most of the studies served the purpose of climate action. The other articles addressed in the study have been found to align with the sustainable development goals, including the responsible consumption and production goal, the affordable and clean energy goal, the sustainable cities and communities goal, and the life on land goal.

As a result of examining the relationship between carbon footprint studies and the Sustainable Development Goals, it has been determined which specific goals these studies are targeted towards. The obtained results will serve as a guide for industry professionals in the process of developing business strategies that incorporate the SDGs. It is anticipated that carbon footprint studies will be more compatible with the goals of climate action, clean energy, clean water and sanitation, responsible consumption and production, and sustainable cities. However, it is of great importance that sector professionals prioritize sustainable development goals that are least served by carbon footprint studies and present an integrated approach to sustainability-carbon footprint studies. Especially, the social and environmental issues need to be studied in an integrated manner to increase their compatibility with the goals of combating poverty, education, gender equality, decent work and economic growth, which are areas least served by carbon footprint studies.

On the other hand, in order to increase societal awareness in the fight against climate change and guide carbon emission reduction efforts, it is crucial to conduct sustainability and carbon footprint studies and ensure their visibility across all areas that impact society.

Article Information Form

Authors' Contribution

RSA: Concept/Design, Data Colleciton, Data Analysis, Writing, Critical Review of Content, Literature Review; HD: Concept/Design, Data Colleciton, Data Analysis, Writing, Critical

Review of Content, Literature Review; AA: Concept/Design, Data Analysis, Writing, Technical Support; Critical Review of Content, Literature Review.

The Declaration of Conflict of Interest/ Common Interest

No conflict of interest or common interest has been declared by authors.

Artificial Intelligence Statement

No artificial intelligence tools were used while writing this article.

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