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CARBON FOOTPRINT - IMPORTANT DRIVER OF CLIMATE CHANGE GENERATED BY THE FOOD INDUSTRY

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Abstract

In the context in which one of the biggest problems affecting the environment worldwide is that of global warming, the study of carbon footprint, greenhouse gases and their effects is of utmost topicality. Current statistics show that agriculture and the food industry are some of the sectors with a significant carbon footprint, resulting in the need for conclusive studies to provide solutions to reduce it. The main purpose of this study is to concentrate on the results of research undertaken in this area. Thus, the thorough analysis of studies published in the main databases shows that the food industry contributes significantly to the accumulation of greenhouse gases in the atmosphere, the main sources of emissions being agricultural practices, crop rotation, waste management, etc. The urgency of adopting sustainable practices and mitigation strategies in the food industry to minimize the carbon footprint is underlined. Research not only highlights the urgent need to address the environmental impacts of the food industry, but also provides an essential basis for developing policies and strategies for implementing sustainable agricultural practices.

Key words: *agriculture, carbon footprint, food industry, greenhouse gases.*

INTRODUCTION

The intensification of climate change is evidenced by a constellation of environmental perturbations, including extreme weather events, deterioration in air quality, diminished agricultural yields, accelerated sea level rise, and the proliferation of infectious diseases. These converging environmental challenges pose a significant threat to the achievement of long-term socio-economic sustainability, particularly in regions with limited adaptive capacity. The preponderance of carbon emissions, primarily driven by anthropogenic activities, is widely recognized as the principal driver of climate change (IPCC, 2013). Extensive international cooperation has led to the prioritisation of reducing carbon emissions at national level. Measuring carbon emissions is essential to ensure sustainable development. The carbon footprint stands out as an effective tool in this regard, providing a scientific way to assess human impact on the environment. Carbon footprint analysis facilitates the identification of significant emission areas, providing a basis for specific measures and regular monitoring. Fighting climate change and promoting sustainable development requires a comprehensive global approach with a focus on reducing carbon emissions. The carbon footprint plays an important role in this process, providing a solid foundation for strategic decision making (Shi & Yin, 2021).

Connecting different levels of carbon consumption through carbon footprinting provides a unified baseline for diverse research perspectives (He et al., 2019; Shi & Yin, 2021). This is essential to facilitate collaboration and develop a coherent global approach to tackling climate change.

The quantification of carbon footprints offers a compelling rationale for its adoption as a tool to harmonize stakeholder efforts and objectives across diverse sectors. By providing a common unit of measurement, the carbon footprint allows emissions from different sectors and regions to be better compared.

Building upon the concept of ecological footprint, introduced by Rees (1992) and further explored by Wackernagel et al. (1999), the carbon footprint serves as a crucial metric for quantifying greenhouse gas emissions associated with specific activities and products.

Challenges associated with a lack of standardized definitions for carbon footprint have been documented by Matthews et al. (2008). Inconsistencies can hinder collaboration and result in difficulties comparing research findings. To address this issue, the following definition was adopted: carbon footprint is a metric that quantifies the total direct and indirect greenhouse gas (GHG) emissions associated with a product or activity throughout its life cycle.

This definition emphasizes consumer responsibility and considers emissions generated at all stages of a product's life, from production to consumption to disposal. Addressing the carbon footprint is essential to assess the full impact of human activities on the environment and identify opportunities to reduce greenhouse gas emissions (Shi & Yin, 2021).

Food industry: A major contributor to greenhouse gas emissions?

GHG greenhouse gas verification plays a crucial role in assessing an organization's greenhouse gas emissions, providing a detailed picture of its environmental impact. This process includes accurate emission assessment, transparent reporting, and identification of critical emission points through standardised procedures. Companies' awareness of geographically significant emission zones facilitates the implementation of efficient and cost-effective strategies for mitigating their emissions (Clark & Tilman, 2017).

The agricultural and post-production stages of the food system are recognized as prominent contributors to anthropogenic greenhouse gas (GHG) emissions (Tubiello et al., 2022). Emissions occur at various stages, from agricultural and livestock production to food processing, transport, and consumption. (Tubiello et al., 2021) report a noteworthy decline in agricultural land-use emissions between 1990 and 2018. Conversely, energy consumption-related emissions, particularly within the food production sector, are anticipated to rise soon.

To tackle the climate impact of the food system, a holistic approach is needed comprising:

- Implementing sustainable agricultural practices, such as reducing the use of chemical fertilisers and pesticides, can significantly contribute to reducing emissions.
- Reducing energy consumption and food waste in the food industry can significantly reduce GHG emissions.
- Adopting a more sustainable diet with a reduction in meat and dairy consumption can have a significant impact on emissions from the food system.

Thus, a significant increase in emissions from the food industry, especially from energy consumption, is predictable.

Greenhouse gas verification is a process that allows the identification of major sources of emissions and facilitates the implementation of reduction strategies. The international landscape for greenhouse gas (GHG) emissions accounting features a diverse array of established standards. Each standard possesses a distinct focus and scope, catering to specific needs within the emissions management process.

The Greenhouse Gas Protocol (GHG Protocol), being the first protocol developed to do so, provides a comprehensive framework for emissions accounting. The protocol classifies emissions into three categories: Scope 1 (direct emissions), Scope 2 (indirect emissions from purchased energy) and Scope 3 (indirect emissions from the value chain). This classification allows a detailed understanding of emissions throughout the life cycle of food.

ISO 14064 standard (ISO 14064-1, n.d.) is based on the GHG Protocol and provides specific guidelines for quantifying and reporting GHG emissions at the organizational level. ISO 14067 (ISO 14067, n.d.) complements ISO 14064, focusing on quantifying and reporting the carbon footprint of products.

Within the vast array of international standards for GHG accounting, PAS 2050 stands out as a specialized tool for life cycle assessment (LCA) of product emissions. This standard is complemented by STEP 2060 (successor to PAS 2060 according to Liu et al., 2023), which offers a framework specifically designed to achieve carbon neutrality within the context of products or operational activities (PAS 2060 - Carbon Neutrality, n.d.).

The selection of an appropriate standard hinges on an organization's specific objectives, resource constraints, and degree of commitment to sustainability and emissions reduction.

Responsible choices: The environmental impact of food packaging

Packaging serves as a critical element within the food supply chain, safeguarding the integrity of foodstuffs during long-distance transportation.

This multifaceted function encompasses protection against spoilage and contamination, thereby extending shelf life and facilitating efficient handling and distribution.

Packaging materials and weight can significantly influence greenhouse gas emissions. Heavier packaging can lead to higher GHG emissions due to transportation (Xu et al., 2015).

The selection of packaging material is a crucial decision with major environmental consequences. The choice of alternative materials may have less impact. According to a study conducted by (Humbert et al., 2009; Poovarodom et al., 2012) plastic can be a more sustainable option for certain food products, reducing GHG emissions by about 30%, retort cups over metal cans can be a greener alternative to tuna packaging, reducing GHG emissions by 10-22%, and recyclable stainless steel can be a highly sustainable option for beer packaging, reducing GHG emissions by 93-96%, better than glass or plastic.

In addition to the packaging material, its weight also influences the GHG emissions generated. The use of lightweight packaging, such as ultralight glass bottles, can significantly reduce emissions related to production and transport (Martins et al., 2018). Research by Point et al. (2012) demonstrates the potential for significant emissions reduction. For instance, a 30% weight reduction in a wine bottle can lead to a 4-23% decrease in GHG emissions. Material selection also plays a crucial role. While plastic packaging typically generates emissions exceeding 3 kg CO_2-eq/kg (Schenker et al., 2021), cellulose-fibre alternatives boast a lower footprint of less than 1.5 kg CO_2-eq/kg. However, cellulose-based packaging may require combining materials to achieve similar protection levels, potentially negating some weight-related benefits (Schenker et al., 2021). Design optimization, reduced material thickness, and the incorporation of recycled materials present further opportunities to minimize the environmental impact of fibre packaging. In conclusion, strategic selection of packaging materials and weight reduction strategies offer significant avenues for the food industry to lessen its environmental footprint.

MATERIALS AND METHODS

This study investigates the evolution of scientific publications on carbon footprint using the Scopus database. The analysis encompasses articles published between 2012 and 2023, identified through a search string targeting titles, abstracts, and key words containing "carbon footprint" [TITLE-ABS-KEY ("carbon footprint")]. The search retrieved articles published from 2002 to 2024, with a focus on the period 2012-2023 (PUBYEAR > 2012 AND PUBYEAR < 2024). Limiting the document type to research articles [LIMIT-TO(DOCTYPE,"ar")] yielded a total of 18,836 publications. To exclude the possibility of review articles in the analysis, specific query criteria (AND NOT "review") were added, resulting in a result of 3813 articles outside the field of interest of the study.

A systematic review was conducted to analyze the retrieved publications. This review involved a multifaceted segmentation of the data by year, source, author, affiliation, country/territory, domain, and document type. Bibliometric indicators, including total publications, citations, CiteScore, and h-index, were employed to assess and compare the articles.

RESULTS AND DISCUSSIONS

CF Research Impact: An Evaluation Based on Publications and Citations

For a determined period of 10 years, more precisely between 2013 and 2023, a total of 15,023 research articles in the field of carbon footprint were published (Figure 1). There has been exponential growth since 2013, which shows the growing interest of researchers in this field. Carbon footprint research enjoys a significant expansion, with numerous research groups around the world actively involved in various fields. Analysis of the fields reveals the major concern for environmental issues as the focus of carbon footprint studies. This aspect is highlighted by the significant share of publications classified in areas such as: environmental sciences (29.4%), engineering (12%), energy (10.4%) and social sciences (5.2%). Moreover, the multidisciplinary nature of the carbon footprint field is evidenced by the existence of more than 200 classified publications in fields such as arts and humanities, neurosciences, or dentistry. This demonstrates the significant impact of carbon footprint and greenhouse gas issues across multiple areas of activity.

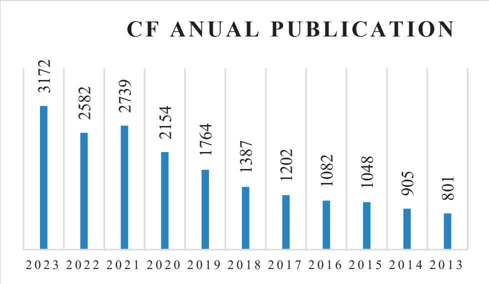

Figure 1. Evolution of the number of publications based on the key word in 2013-2023

The linguistic analysis highlighted the diversity of publications, identifying 22 languages used. English stands out as the dominant language, with a total of 14,619 articles. Chinese (192 articles), German (56 articles), Spanish (54 articles), Russian (41 articles) and French (40 articles) follow. Other languages, such as Portuguese, Polish, Italian, Turkish, Korean, and Japanese, were used in a smaller number of publications.

The journal productivity analysis identified 10 top journals owned by 7 distinct publishers (Table 1). Elsevier stands out as the main editor, with 2 magazines in the top 10, totalling 4 publications. The remaining articles were published by publishers such as Academic Press, American Chemical Society, MDPI, Public Library of Science and Springer Nature.

Table 1. Top 10 most productive carbon footprint journals with their most cited article

Journal	Total publications	Total citations	CiteScore 2022	The most cited article	Times cited	Publisher
Science of the Total Environment	8.468	479.285	16,8	Detection of microplastics in human lung tissue using µFTIR spectroscopy	326	Elsevier B.V.
Journal of Cleaner Production	4.444	351.758	18.5	The Dynamic Impact of Digital Economy on Carbon Emission Reduction: Evidence City-level Empirical Data in China	184	Elsevier Ltd
Journal of Environmental Management	2.782	102.717	13.4	Combined role of green productivity growth, economic globalization, and eco-innovation in achieving ecological sustainability for OECD economies	142	Academic Press
Environmental Science and Technology	2.100	102.167	16.7	Outside the Safe Operating Space of the Planetary Boundary for Novel Entities	400	American Chemical Society
Sustainability (Switzerland)	13.600	281.274	5.8	A Global Assessment: Can Renewable Energy Replace Fossil Fuels by 2050?	211	MDPI
Resources, Conservation and Recycling	544	42.404	20.3	Challenges toward carbon neutrality in China: Strategies and countermeasures	606	Elsevier
International Journal of Environmental Research and Public Health	7.185	241.049	5.4	Digital Economy Development, Industrial Structure Upgrading and Green Total Factor Productivity: Empirical Evidence from China's Cities	154	MDPI
Plos One	15.413	377.961	6	The mental health of university students during the COVID-19 pandemic: An online survey in the UK	137	Public Library of Science
Waste management	529	33.490	15.1	Opportunities and challenges for the application of post-consumer plastic waste pyrolysis oils as steam cracker feedstocks: To decontaminate or not to decontaminate?	86	Elsevier Ltd

The detailed analysis identified Science of the Total Environment as the most prolific journal, with an impressive 8468 articles. The next positions in the ranking are occupied by Journal of Production Cleaner (4444 articles), Journal of Environmental Management (2782 articles) and Environmental Science and Technology (2100 articles).

The 2022 CiteScore report highlights a CiteScore greater than 5 for all journals analyzed. The Journal of Cleaner Production has the highest score of 18.5, while the International

Journal of Environmental Research and Public Health has the lowest score of 5.4.

The influence of CiteScore in the decision of authors to select appropriate journals for publication of significant papers is acknowledged. CiteScore, the Elsevier-Scopus alternative to Clarivate Analytics impact factor, provides a measure of journal impact based on citation data from Scopus.

While CiteScore offers valuable insights, it should not be the sole factor guiding author selection. A comprehensive evaluation should also encompass the journal's ability to disseminate research to the targeted readership and its potential to advance the field.

Bibliometric analysis of countries using VOSviewer

Figure 2 illustrates the distribution of countries/ territories by region. The visualization within VOSviewer employs line thickness to depict the collaborative relationships between countries. Thicker lines indicate stronger collaborative ties between nations positioned closer together within the map. The map contains 68 nodes representing countries. The size of the nodes reflects the number of co-authors in each country. Links between nodes indicate collaboration between countries in scientific publications. The US is the central node, with the largest number of co-authors and links to other countries.

China, Germany, the UK, and France are also important nodes, with large numbers of co-authors and links. There is significant collaboration between countries in Europe, North America, and Asia. There is less significant collaboration between countries in Africa and Oceania.

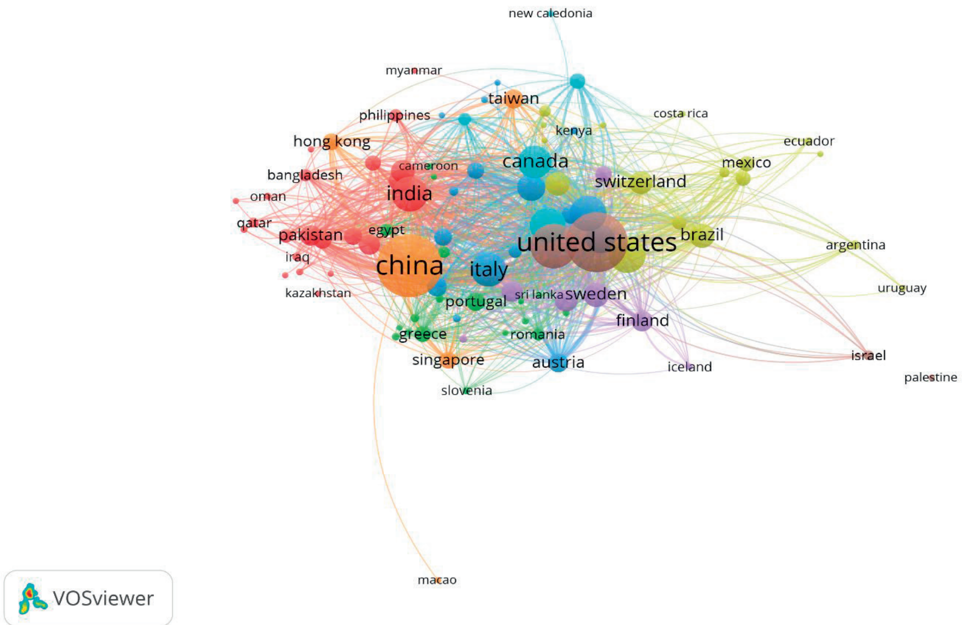

Figure 2. A screenshot of the bibliometric map created based on co-authors with the network visualization

The U.S. is a world leader in scientific collaboration, with an extensive network of co-authors around the world. China, Germany, Britain, and France are also important players in scientific collaboration. There is a significant regional divide in scientific collaboration, with closer collaboration between countries in similar geographical regions.

In terms of limitations, the map is based on a specific dataset of scientific publications and may not reflect collaboration across all research areas. The size of the nodes reflects only the number of co-authors and does not consider the quality of the collaboration.

The generated map can be used to identify trends in scientific collaboration over time. For example, an increase in collaboration between Asian countries can be observed in recent years. It can also be used to identify opportunities for collaboration between countries. For example, a country with a small number of co-authors could collaborate with a country with many co-authors to increase its visibility in scientific research. Another use of the map is to identify factors influencing scientific collaboration, such as geographical distance, language, and culture.

The VOSviewer map of co-authors by territory provides an overview of scientific collaboration globally.

CONCLUSIONS

The urgent need to reduce greenhouse gas emissions in the food industry is obvious.

Implementing effective strategies along the food value chain is essential to combat climate change. Using sustainable packaging materials and reducing the amount of packaging used can significantly contribute to reducing the carbon footprint generated by the food industry.

Collaborating with research organizations to develop new low-emission technologies is another important direction.

Policymakers have a crucial role to play in promoting the necessary changes. The adoption of policies aimed at reducing emissions from the food industry is essential. Stimulating the development and deployment of low-emission technologies must be a priority. Educating the public about the importance of reducing the carbon footprint of food is another important aspect.

Consumers can play a significant role in reducing the carbon footprint of the food industry. Choosing products with a lower carbon footprint, such as vegetables, reducing food waste and separate collection are actions with major impact.

Interest in the field of carbon footprint has increased considerably in the last 10 years, evidenced by the significant number of publications in the field. The U.S. holds a leading position in global scientific collaboration, with important collaboration also between countries in Europe, North America, and Asia.

The VOSviewer map provides an overview of scientific collaboration globally. This map can be used to identify trends, opportunities and factors influencing carbon footprint collaboration.

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