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Sustainable practices to mitigate environmental wastage in food supply chain: A review

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Abstract
As the global population continues to rise, the food industry faces increasing scrutiny for its environmental impact, specifically regarding carbon footprints. The study aims to provide a holistic understanding of the carbon footprints in the food industry, examining the complexities associated with agriculture, food processing and food packaging, transportation and distribution as well as consumption of food. The research methodology employed a meticulous approach to data collection. Both online databases, including peer-reviewed journals, conference papers, and reputable publications, as well as offline resources such as books and reports, were scrutinized. A set of carefully chosen keywords, encompassing terms like "carbon footprints," "food industry," "sustainability," and more, were employed to ensure a thorough examination of relevant articles. The literature review uncovered that the sustainable practices in agriculture, eco-friendly and innovative food processing and packaging strategies as well as innovative transportation emerged as pivotal areas for mitigating carbon emissions. The synthesis of diverse studies allowed for the identification of emerging trends and successful initiatives, offering a roadmap for future sustainable practices. In conclusion, this review underscores the pressing need for a paradigm shift in the food industry towards sustainable practices. The synthesis of information from various sources emphasizes the importance of collaborative efforts across the supply chain. While challenges persist, the study provides a foundation for informed decision-making and a call to action for stakeholders to collectively work towards a greener and more sustainable future for the food industry.

Keywords: Carbon footprints, Food industry, Food processing, Food packaging, Sustainability

Introduction
The prevailing consensus among the scientific community unequivocally affirms that our climate is undergoing profound changes, and the primary driver of this transformation is attributed to human activities (Anttonen *et al*. 2023: 100139) [2]. The global food industry, an integral component of human civilization, stands at a critical juncture as it grapples with the imperative to address its substantial environmental impact (Climate Seed, 2023). Amidst the growing concerns of climate change and ecological degradation, the concept of carbon footprints has emerged as a pivotal metric in evaluating the sustainability of various sectors (Baek & Pride 2014: 6–10) [3], and the food industry is no exception (Shabir *et al*. 2023: 100215; Kumar & Chakabarti 2018: 19–44) [24, 16].

The background of this review study stems from the realization that the production, processing, transportation, and consumption of food collectively contribute significantly to greenhouse gas emissions and environmental degradation (Shabir *et al*. 2023: 100215) [24]. The intricate web of activities involved in bringing food from farm to table encompasses practices that, if left unchecked, can exacerbate climate change and deplete natural resources (Metabolic, 2021) [19].

Food production is responsible for more than a quarter (26%) of the total global greenhouse gas emissions. Approximately half of the Earth's habitable land is utilized for agriculture, defined as land that is free from ice and deserts. Agriculture accounts for 70% of the world's freshwater withdrawals, and a significant 78% of global ocean and freshwater eutrophication is attributed to agricultural activities, referring to the pollution of waterways with nutrient-rich water. Livestock constitutes a substantial portion of non-human mammal biomass, comprising 94%. This indicates that the combined weight of livestock is 15 times greater

than that of wild mammals. When considering only land-based mammals, this proportion increases to 97%. Furthermore, poultry livestock constitutes 71% of bird biomass, highlighting that the collective weight of poultry livestock surpasses that of wild birds by more than threefold (Ritchie 2022) [23].

Historically, the food industry's focus has been on meeting the escalating demands of a burgeoning global population, often at the expense of environmental considerations. Conventional agricultural practices, reliance on fossil fuels for transportation, and extensive packaging have led to a substantial carbon footprint, posing a threat to the delicate balance of ecosystems. As societies increasingly recognize the urgent need for sustainability, the food industry is under increasing pressure to reassess its practices. The understanding that unchecked carbon emissions contribute to global warming, altered weather patterns, and other adverse environmental effects has catalyzed a paradigm shift towards more environment friendly and sustainable practices within the sector.

It is evident that the path to sustainability requires a holistic approach, encompassing all facets of the food supply chain. Therefore, this review study aims to navigate through the complex landscape of carbon footprints within the food industry.

Aims of the study

- To analyze the contribution of different stages of the food supply chain- agriculture, food processing, packaging, transportation, and consumption- to carbon emissions.
- To identify and evaluate sustainable practices in agriculture that can mitigate carbon emissions in the food industry.
- To assess the impact of eco-friendly and innovative food processing and packaging strategies on reducing carbon footprints.
- To synthesize emerging trends, successful initiatives, and case studies that demonstrate the effectiveness of sustainable practices in reducing carbon footprints.
- To provide recommendations for collaborative efforts among stakeholders in the food industry for promoting sustainability and reducing environmental impact.

Methodology

This study adopts a comprehensive literature review approach to analyse the environmental impact of the food industry, with a focus on carbon footprints. The study synthesizes data from a wide range of sources to provide a holistic understanding of sustainable practices and strategies to mitigate carbon emissions across the food supply chain. A thorough search was conducted across several peer-reviewed journals, conference proceedings, and reputable publications using online databases such as Scopus, Web of Science, and Google Scholar. Books, industry reports, and government publications related to the food industry and environmental sustainability were also reviewed. A set of carefully chosen keywords, encompassing terms like "carbon footprints," "food industry," "sustainability," and more, were employed to ensure a thorough examination of relevant articles.

Inclusion Criteria

- Articles published within the last 10 years to ensure current data and trends.
- Studies that focus on carbon emissions in different stages of the food supply chain.
- Research papers and case studies on sustainable practices in agriculture, processing, packaging, and distribution.

Exclusion Criteria

- Data from unreliable sources
- Studies focussing solely on carbon prints outside food industry

Synthesis of Data

- **Thematic Analysis:** The literature was thematically categorized based on the stages of the food supply chain—agriculture, food processing, packaging, transportation, and consumption. Each theme was analysed for its contribution to carbon emissions and its potential for sustainability improvements.
- **Content Analysis:** Sustainable practices in agriculture, innovative food processing, eco-friendly packaging, and transportation methods were evaluated for their effectiveness in reducing carbon footprints.

Synthesis of Results

- A synthesis of diverse studies was performed to identify overarching trends, gaps in existing research, and successful initiatives in the food industry's efforts to reduce carbon emissions.
- The data reviewed was mapped to current industry practices to assess alignment with sustainable development goals (SDGs).

Limitations

- The methodology acknowledges potential limitations, including the reliance on secondary data and the challenges of obtaining real-time or region-specific data for certain food industry practices.
- Additionally, the evolving nature of sustainable technologies may require continuous updates in the field.

Carbon Footprints in the Food Industry

Ecological Footprint accounting measures how much nature's resources we use and how much nature can supply. It calculates the area of land needed for things like food, livestock, timber, and cities, as well as the capacity to absorb waste like carbon emissions. It looks at both demand (what we use) and supply (what nature can provide). Demand includes resources consumed and waste generated, while supply refers to the productive capacity of ecosystems. (Global Footprint Network, 2024).

A carbon footprint refers to the cumulative greenhouse gas (GHG) emissions, both direct and indirect, associated with an individual, organization, event, or product. This measurement is derived by adding up emissions at every stage of a product or service's life cycle, encompassing material production, manufacturing, usage, and end-of-life considerations. Throughout the life cycle, various GHGs, such as carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O), may be released, each possessing distinct capacities to trap heat in the atmosphere. These variations are factored in through the global warming potential (GWP) of each gas, resulting in the expression of a carbon footprint

in units of mass of carbon dioxide equivalents (CO_2e) (Carbon Footprint Factsheet, 2023).

The carbon footprints in the food industry represent the total amount of greenhouse gas emissions, particularly carbon dioxide (CO2), associated with the production, processing, transportation, and consumption of food. This metric provides a comprehensive measure of the environmental impact of the entire food supply chain, from farm to table.

- **Agriculture and Land Use:** The cultivation of crops and livestock is often associated with emissions from the use of fertilizers, pesticides, and machinery. Additionally, land-use changes, such as deforestation for agriculture, contribute to carbon emissions.
- **Food Processing:** Energy-intensive processing methods contribute to the carbon footprint.
- Food Packaging: The manufacturing of non-renewable packaging material and disposal of packaging materials also play a role.
- **Transportation and Distribution:** The transportation of raw materials to processing facilities, as well as the distribution of finished products to retailers and consumers, involves the combustion of fossil fuels, leading to carbon emissions.
- **Retail and Consumption:** Energy use in retail operations and the preparation of food at home contribute to the carbon footprint. Additionally, food waste at the consumer level results in unnecessary emissions from the decomposition of organic matter in landfills.

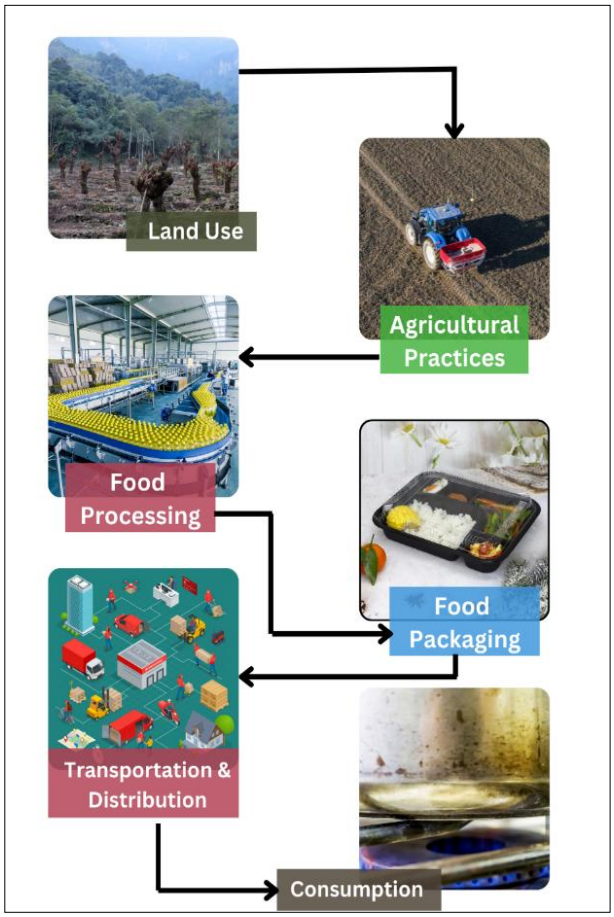

Fig 1: Overview of Food Supply Chain

Sustainable practices in Food Supply Chain

Sustainable Practices in Agriculture and Land Use

Agroecology is a holistic and interconnected approach to agriculture that integrates ecological principles, social values and economic dimensions to create sustainable and resilient farming systems (Agroecology Europe, 2024). It emphasizes the importance of understanding and harnessing ecological processes to enhance agricultural productivity while minimizing negative environmental and social impacts.

Eco-friendly and Sustainable food processing and packaging

Traditional packaging materials, such as plastics, contribute significantly to environmental pollution. In response, the industry is increasingly exploring alternative materials, including biodegradable plastics, compostable materials, edible packaging, and plant-based packaging derived from renewable resources. These materials aim to minimize the environmental impact of packaging waste, reduce dependence on fossil fuels, and promote a more circular and sustainable approach to packaging (Moshood *et al*. 2022: 100273) [20].

Transportation and Distribution

The transportation and distribution phase of the food supply chain plays a pivotal role in determining the overall environmental impact of the food industry. Sustainable practices in this domain are essential for reducing carbon emissions, optimizing resource use, and fostering an eco-friendlier approach (Mastos & Gotzamani 2022: 2295) [18].

Consumption and Consumer perspectives

The retail and consumer perspectives are pivotal in influencing the sustainability of the food industry. By incorporating eco-friendly practices in retail operations and fostering consumer awareness, the industry can promote and encourage sustainable choices. Additionally, the role of labeling and certifications emerges as a crucial factor in guiding consumers towards more environmentally conscious decisions.

Table 1: Sustainable practices in Food supply chain

Stage	Sustainable Practices		Reference
Agriculture and Land Use (Tripathi *et al*. 2015: EC Agriculture 2.1, 241–248; Wezel *et al*. 2020)	Biodiversity Integration	the intentional inclusion of a variety of crops, trees, and livestock within agricultural systems	(Feledyn-Szewczyk *et al*. 2016)
	Crop Rotation and Polyculture	break pest and disease cycles while enhancing soil health	*(De La Maza 2024)*
	Natural Pest Management	reduce reliance on synthetic pesticides and contribute to healthier ecosystems	(Reddy 2017)
	Conservation Agriculture	includes minimal tillage and cover cropping, are central to preserving soil structure, water retention, and carbon sequestration.	
	Local Adaptation	recognizing the significance of aligning farming practices with specific ecological conditions	(De La Maza 2024)
	Agroforestry	incorporating trees into agricultural settings, provides benefits such as improved microclimates and additional income sources for farmers	(Pantera *et al*. 2021: 767–774)
	Soil Health Management	through practices like composting and reduced tillage, promoting overall soil fertility.	
Food processing and packaging	Energy-Efficient Processing Technologies	prioritize the adoption of energy-efficient technologies, such as advanced heating and cooling systems, solar-powered equipment, and innovations in food preservation methods.	(Sovacool *et al*. 2021: 110856).
	Waste Reduction and Circular Economy Approaches	emphasize the reduction, reuse, and recycling of materials to minimize waste. This involves designing packaging that can be easily recycled or repurposed, implementing efficient waste management systems, and fostering a closed-loop approach where by-products are utilized as resources.	(Energy 2023)
Transportation and Distribution	Sustainable Transportation Options	adoption of low-emission vehicles, such as electric or hybrid trucks, to reduce greenhouse gas emissions during transportation. Additionally, optimizing logistics to minimize empty backhauls, utilizing alternative fuels, and incorporating fuel-efficient technologies contribute to a more sustainable and energy-efficient transportation network.	(Mastos & Gotzamani 2022: 2295)
	Local and Regional Sourcing Strategies	By prioritizing the procurement of food from nearby producers, the industry can minimize the distances traveled and decrease transportation-related emissions. Collaboration with local farmers, cooperatives, and distributors fosters a sense of community and strengthens regional food systems	(Majewski *et al*. 2020: 4853)
	Cold Chain Optimization for Reduced Energy Consumption	Implementing energy-efficient refrigeration technologies, such as advanced insulation materials and temperature monitoring systems, can significantly decrease the overall energy demand of the cold chain Furthermore, adopting renewable energy sources to power refrigeration units and exploring innovations like cryogenic refrigeration technologies contribute to a more sustainable and environmentally friendly cold chain	(Gao 2019: 032007) and (Gupta *et al*. 2021: 4850–4854).
Consumption and Consumer perspectives	Eco-friendly Practices in Retail Operations	adopting energy-efficient lighting and equipment, optimizing store layouts to minimize energy consumption, and implementing waste reduction strategies. Sustainable packaging initiatives, such as offering bulk purchase options and reducing single-use plastics, contribute to a reduction in overall environmental impact.	(Coelho *et al*. 2020: 100037)
	Consumer Awareness and Behavior Towards Sustainable Choices	educating consumers about the environmental impact of different food choices, the significance of local and seasonal produce, and the benefits of sustainable packaging. Engaging in marketing campaigns that highlight the ecological footprint of products can empower consumers to make informed decisions aligned with their values. Encouraging practices such as reusable shopping bags and containers further cultivates a culture of sustainability among consumers	(Han 2021: 1021–1042) and (White *et al*. 2019: 22–49)
	Role of Labeling and Certifications in Promoting Sustainability	with environmentally friendly attributes, such as organic, fair trade, or carbon-neutral certifications. Clear and informative labeling that communicates the product's sustainability credentials	(Cook *et al*. 2023: 3837)

Future Outlook

The future of the food industry is poised for transformation through the integration of emerging technologies and innovations. This includes advancements in precision agriculture, where technologies like drones, sensors, and data analytics optimize resource use, enhance crop yields, and minimize environmental impact. Biotechnological innovations, such as gene editing for crop improvement and

alternative protein sources, have the potential to revolutionize food production. Additionally, blockchain technology can enhance traceability and transparency in the supply chain, ensuring ethical and sustainable sourcing practices. Embracing these technologies can pave the way for a more efficient, resilient, and sustainable food industry.

Climate change, resource scarcity, and the increasing global population pose significant challenges to sustainable food production. The industry must grapple with the need to adapt to changing climatic conditions, reduce water usage, and address the social and ethical implications of food production. However, these challenges also present opportunities for innovation and collaboration. Sustainable farming practices, circular economy approaches, and community engagement can unlock new possibilities for addressing these challenges and creating a more sustainable and equitable food system.

Conclusion

The examination of various facets within the food industry, from production to retail, highlights the critical importance of transitioning towards a more sustainable and environmentally conscious model. The key findings from this comprehensive review underscore the need for immediate action to address the challenges posed by climate change, resource depletion, and environmental degradation.

Throughout this review, key findings have emphasized the interconnectedness of sustainable practices within the food industry. From adopting eco-friendly agricultural methods and energy-efficient processing technologies to promoting responsible consumption and waste reduction, each aspect contributes to the overall goal of building a more sustainable and resilient food system. The incorporation of agroecological principles, circular economy approaches, and the utilization of emerging technologies emerges as a pathway towards mitigating the environmental impact of food production and consumption.

Crucially, the journey towards a sustainable food industry necessitates collaborative efforts from all stakeholders involved. Farmers, processors, retailers, consumers, and policymakers must work hand-in-hand to implement and promote sustainable practices. The review underscores the significance of partnerships, knowledge sharing, and shared responsibility. By fostering collaboration, the industry can leverage collective expertise and resources to overcome challenges and drive positive change.

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