Journal of Agriculture and Food Research 21 (2025) 101937

Contents lists available at ScienceDirect

Journal of Agriculture and Food Research

journal homepage: www.sciencedirect.com/journal/journal-of-agriculture-and-food-research

Exploring consumer behaviour on carbon labelled food products: Evidence from a survey on the case of sandwich production and consumption in UK

Noor Imran [a], Mukesh Kumar [b], Sandeep Jagtap [a,c,*], Hana Trollman [d], Sumit Gupta [e], Guillermo Garcia-Garcia [f]

[a] Sustainable Manufacturing Systems Centre, Cranfield University, Cranfield, UK
[b] Department of Mechanical Engineering, Ganga Memorial College of Polytechnic, Harnaut, India
[c] Division of Engineering Logistics, Lund University, Lund, Sweden
[d] School of Business, University of Leicester, Leicester, UK
[e] Department of Mechanical Engineering, Amity University, Noida, India
[f] Department of Chemical Engineering, University of Granada, Granada, Spain

ARTICLE INFO

Keywords:
Life Cycle Assessment (LCA)
Carbon labelling
Carbon footprints
Consumer perception
Food industry

ABSTRACT

By assessing carbon footprints and raising awareness of carbon labelling, the food sector is setting long-term targets to reduce carbon emissions and accelerate the transition to low-carbon food production. Carbon labelling, also known as carbon labelling, informs customers about a product's production, distribution, and disposal carbon emissions. This study examines how customers view carbon labelling and how it affects their purchases. The study also examines the complex food industry, identifying the biggest carbon emitters and proposing sustainable alternatives. The study collects qualitative and quantitative data using mixed methodologies. An overview of the literature shows how carbon labelling promotes sustainable consumption. Life Cycle Assessment (LCA) is used to evaluate two sandwich recipes' carbon footprints, focusing on emissions per item. LCA results indicated that carbon footprint of a cheese and mayonnaise sandwich ranged between 700 and 750 g CO_2 eq, while a ham and cheese sandwich ranged between 1053 and 1070 g CO_2 eq., and the primary contributors for these emissions were ingredient production, packaging and energy consumption. A sandwich maker partnership simplifies case study data collection, providing a complete carbon footprint analysis throughout production. This study suggests ways to minimise food industry carbon emissions for a sustainable future. Consumer knowledge and relevance of carbon labelling vary, according to our results. Survey findings revealed that 68.6 % of respondents recognise the significance of carbon labelling, however, only 26.9 % reported that their purchasing decisions are influenced by carbon labelling. This indicated a gap between consumer awareness and behavioural change. Consumers are concerned about carbon footprints; thus, carbon labels affect shopping decisions differently. This study suggests that consumer education, standardisation of carbon labelling and recipe modifications could increase effectiveness of carbon labelling in the food industry and its potential to change consumer behaviour towards greener choices and lower carbon footprints.

1. Introduction

In recent years, resource consumption and climate change have risen to the ranks of the greatest global challenges [1]. Global warming is one of the biggest environmental threats to human progress [2]. As the global population is predicted to surpass 10 billion by 2050, the world's food systems will be faced with immense pressure to adapt to a changing climate, lessen their environmental footprint, and satisfy the increasing calorie demands of this rising population [3]. The food production sector generates approximately 34 % of global greenhouse gas emissions, contributing an estimated 18 gigatonnes of CO_2 eq. yearly [4]. And meat and dairy sector is responsible for 60 % of these emissions, emphasising the urgent need for more sustainable dietary choices. Given the significant role of food production in global carbon emissions, reducing the environmental impact of food choices is critical. Carbon labelling has emerged as a strategy to inform consumers about the carbon footprint of their purchases, thereby fostering sustainable consumption. Recent studies indicate that carbon labelling can positively

* Corresponding author. Sustainable Manufacturing Systems Centre, Cranfield University, Cranfield, UK.
E-mail address: sandeep.jagtap@tlog.lth.se (S. Jagtap).

https://doi.org/10.1016/j.jafr.2025.101937
Received 18 September 2024; Received in revised form 19 April 2025; Accepted 20 April 2025
Available online 21 April 2025

influence consumer behavior. For instance, a study conducted in Sweden found that carbon labels on food products led to a 10–15 % reduction in the purchase of high-emission foods [5]. Similarly, a UK supermarket study revealed that 72 % of consumers expressed interest in carbon-labelled products, but 89 % found the labels difficult to interpret [6]. This demonstrates the potential and limitations of carbon labelling in encouraging sustainable food choices. In the UK, it is estimated that over 11.5 billion sandwiches are consumed annually, on which half of those being prepared at home and the other being purchased ready-made that are mostly pre-packaged (Guenther, 2023). Thus, understanding how carbon labelling influences sandwich choices provides a practical and impactful case study for assessing the effectiveness of carbon footprint labelling in reducing emissions. The general public is concerned about the impact of food on the environment caused by all the steps needed to make, transport, and consume it. It is needed to propose innovative solutions that could mitigate these consequences while also providing consumers with the knowledge they need to make informed choices [7]. The idea of carbon labelling for food products has been stimulated by the requirements of ecological sustainability and responsible consumption. The goal of carbon labelling is to empower consumers to make decisions that are in line with their ecological ideals by revealing the carbon footprint of a good throughout its entire life-cycle. A comprehensive strategy to reduce carbon emissions throughout the food supply chain is required due to the interdependence of the production of food, consumption habits, and environmental impact.

Carbon food labeling in the UK presents potential as a sustainability instrument; nevertheless, its efficacy relies on mitigating consumer uncertainty, establishing clear and uniform labeling, and enhancing awareness and education [8]. Moreover, governments must evaluate the international ramifications of carbon labeling to prevent inequitable disadvantages for exporting nations. A coordinated strategy combining business, government, and consumers is crucial to enhance the efficacy of carbon labeling in promoting sustainable food choices [9]. The importance of studying consumer behavior is important thus, the purpose of this study is to examine the carbon footprint of different sandwiches along with exploring the consumer perception on carbon labelled products. The unquestionable need to close the gap among consumer behaviour and the effects of food consumption on the environment is what drives this research. The necessity of revolutionising food production processes is becoming more and more obvious due to the growing world population and the pressing urgency of climate change. Carbon labelling offers a viable strategy by giving consumers concrete information regarding the carbon emissions associated with the foods they consume. This study also aligns practices with the UN Sustainable Development Goals 7, 12, and 13, so that a more resilient and sustainable future can be visualized.

The aim of this study is to evaluate carbon footprint of sandwiches through carbon labelling and also evaluate the consumer perception regarding carbon labelling. This study is effective to test the acceptability of solutions in industry as well as society.

The objectives listed below will be followed in order to fulfil the study's intended aim:

RO1: To identify the carbon footprints of sandwich production.
RO2: To propose a carbon labelling approach for sandwiches in the UK.
RO3: To study consumer responses to carbon labelling of sandwiches.

A thorough examination of the existing body of literature has been undertaken to gain a comprehensive understanding of carbon footprint analysis and the intricate landscape of consumer perceptions related to carbon labelling. A strategic partnership has been established with a case company, a sandwich manufacturer, to facilitate the acquisition of critical data pertaining to their complex production cycle. This collaborative effort aims to facilitate an in-depth analysis of carbon footprints by employing a robust Life-Cycle Assessment (LCA) methodology. Concurrently, a meticulously designed survey has been deployed to gauge the level of consumer awareness concerning carbon labelling. This survey serves as a vital instrument for unravelling the intricate layers of consumer perceptions, shedding light on their attitudes in the context of food products. It is important to note that due to the presence of sensitive and proprietary data within the ambit of this study, a rigorous non-disclosure agreement (NDA) was formally executed. This legal arrangement ensured the safeguarding of commercially restricted information, maintaining the confidentiality and integrity of the invaluable data provided by the case company.

This paper has six sections. In the first section, the background of the study is explained along with the research objectives. In the second section the existing literature is discussed. The method used to achieve the goals established for this study is presented in Section 3. Section 4 comprises the results of the survey and the carbon footprints identified in the research. Section 5 discusses the main findings of the study. Finally, Section 6 states the conclusions of the study and future recommendations.

2. Literature review

This review is based on publications that were identified from Scopus, Science Direct, and Web of Science online databases, and ten websites found to be relevant using snowballing from the references of the identified publications. Studies were identified in the databases by searching article titles, summaries, and keywords for the terms: "carbon labelling", "carbon offset" OR "carbon offsetting", "carbon labelling: food", "carbon footprint labels", "consumers perception", "CO_2 emission", and "Carbon labelling countries". This resulted in 247 articles. Out of the 247, 35 studies were found to be relevant based on a review of abstracts and conclusions of the studies. Relevant studies were those that considered consumers in relation to carbon labelling.

2.1. Theoretical background

A new practice called carbon labelling for foods aims to inform consumers about the carbon footprint connected to the manufacturing, processing, and transportation of food products. It is a means of expressing how an item will affect the environment in terms of greenhouse gas emissions. The idea of carbon labelling is in line with the rising popularity of sustainable consumption as well as the call for greater openness in the food sector [10]. Consumers can make informed decisions that take into account how their purchases will affect the climate by looking for carbon labels on food products [11]. The energy required for production, changes in land usage, farming practices, transportation, and packaging are just a few of the variables that make up a food product's carbon footprint. In order to measure these variables and determine the overall emissions connected with a particular food item, LCAs are frequently carried out [12]. Only a few studies have been conducted in regard to food product carbon labelling. Overall research has already been conducted suggesting that carbon labels, particularly for individuals who care about the environment, may have an impact on consumer buying decisions [13].

An emerging strategy to inform consumers about the carbon footprint associated with their food choices is carbon labelling for food products using Life Cycle Assessment (LCA). The existing research on carbon labelling for food products using the LCA approach and consumer perception is examined in the following review of the literature. The goal is to explain how LCA is used to calculate carbon footprints, explore the prospects and limitations, and suggest possible directions for further research. This review will also explain current knowledge on consumer perception of carbon labelling in the food industry and the challenges faced by industries [14]. Numerous food items, such as vegetables, meat, dairy, grains, and processed foods, have had their carbon footprints evaluated in studies. The heterogeneity in carbon

emissions across the food system can be highlighted by using LCA to compare various food varieties, production processes, and supply chains [15,16]. The application of LCA to the carbon labelling of food products offers important insights into the effects of the food system on the environment.

2.2. Food carbon labelling

Carbon labelling is essential for lowering agri-food industry carbon emissions, with corporations setting long-term goals and short-term remedies. This procedure is difficult to implement due to expenses, lack of resources and budget, and carbon offsetting scepticism. However, governments offering free or subsidised certifications/verifications and technical help, especially for supply chains, enable enterprises to financially adopt relevant practices [17]. Urban Chinese consumers' willingness to pay (WTP) for carbon-neutral-labelled beef products influences their purchasing of low-GHG (greenhouse gas) food goods. A study indicated that customers pay 28.92 CNY/500 g more for carbon-neutral-labelled beef, and a substitution impact occurs when both the label and the imported characteristic are present [18]. Promoting carbon labelling on high-carbon agricultural goods in transitional nations like China, especially beef, would help agri-food systems reach carbon neutrality. A random inquiry in four first-tier Chinese cities found 88.39 % of customers would buy carbon-labelled items [16]. Higher emitters may be forced to change their practices due to price and availability of reduced GHG-emitting activities.

Labelling is one of the best ways to encourage sustainable consumption, yet multi-labels on food goods might reduce its impact. Research findings into the promotion of sustainable food consumption advise producers to avoid comparable labelling in the same front-of-pack and utilise marketing to reduce customers' zero-sum bias [16]. Carbon labelling helps consumers understand food lifecycle carbon dioxide emissions and promote low-carbon consumption. Data from a study of Chinese university students suggest that price is the main factor in buying carbon-labelled milk products, the premium effects willingness to pay, and students are prepared to pay up to 3.2 % [13].

Most phases of the Food Supply Chain (FSC) are inefficient and thus Miranda-Ackerman & Azzaro-Pantel [19] studied Green Supply Chain Network Design (GSCND) which includes carbon labelling. A genetic algorithm was used to implement a multi-objective optimisation strategy on orange juice production, showing that CO2 emission minimisation as an objective function during the GSCND process and techno-economic criteria improve FSC environmental performance compared to organic and conventional orange juice production.

Carbon labelling is essential for alerting customers about food's carbon footprint and encouraging lower-carbon purchases. A cross-cultural study by Roa-Goyes & Pickering [20] revealed that carbon footprint and carbon label knowledge gaps differed by nation, gender, and education. The relative preference ratings of labels varied with education level. To assess carbon labelling effectiveness chances, life cycle assessment for food total carbon footprints (CF) were used. Product sustainability and carbon emissions information is in demand in New Zealand's export markets [9]. His survey indicated that customers in Australia and New Zealand want sustainable labelling. The findings of this study may aid manufacturers' labelling policies. A novel technology-based carbon label on food product was explored, and carbon labelled bread was valued at $4 per 20 oz., somewhat cheaper than conventional and organic bread [21]. Targeting non-white, liberal, well-educated, and climate change-savvy consumers would boost consumer valuation for the unique carbon labelled bread.

2.3. Carbon labelling from consumer perspectives

The purpose of carbon labelling is to inform consumers so they may make educated decisions. However, without extra information, consumers find it extremely difficult to understand the indicated emissions levels. In a particular study, the researcher conducted a survey involving 428 customers of UK supermarkets [6]. The findings revealed a significant consumer interest in carbon labels, as indicated by a substantial preference rate of 72 %. However, the study also highlighted a noteworthy challenge: a considerable 89 % of respondents expressed confusion in comprehending and interpreting these labels. Several studies indicate that carbon labelling can influence consumer behavior, particularly among environmentally conscious individuals [5,13]. However, many of these studies rely on hypothetical purchase scenarios rather than actual consumer decision-making in real shopping environments. Additionally, research findings on willingness to pay for carbon-labelled products are mixed, with some studies showing a positive effect [18] and others highlighting consumer scepticism and the 'attitude-behavior gap' [22]. This study extends previous research by examining real purchasing motivations and awareness gaps through a structured consumer survey, while also incorporating quantitative carbon footprint data to provide tangible, product-specific insights.

This confusion primarily arose due to issues related to inadequate communication and the saturation of the market [5]. Consumers might encounter difficulties in understanding carbon labels due to the utilization of unconventional units, complex calculations, and technical terminology. To address this challenge, the adoption of easily understandable labels that are visually engaging and offer informative context can serve as a solution. The UK's carbon food labeling initiative has been gaining attention as a tool to promote sustainable consumption and reduce carbon emissions [6]. However, consumers in the UK face challenges in understanding and interpreting carbon labels effectively due to poor communication, lack of standardization, and confusion caused by multiple sustainability labels [9,23]. The effectiveness of carbon labels depends on factors such as label design, consumer education, and perceived credibility. UK may face trade disadvantages without standardized assessment methods, highlighting the need for international collaboration in developing fair and consistent carbon labeling frameworks [8,23]. Simplifying labeling schemes and improving consumer education could enhance the effectiveness of carbon labels in promoting low-carbon consumption [8].

The success of carbon labelling hinges on fostering consumer trust. A recent study underscores that the difficulty in accessing products with carbon labels results from consumer scepticism toward the certification process [5].

2.4. Public perception of carbon labelling

Panzone et al. [24] explains public perception of the carbon footprint of supermarket products in their study and whether it has a long-term impact on lowering carbon emissions. In the study, they explain how carbon labelling can encourage product manufacturers to take greater care in creating ecologically friendly goods. The study concentrated on defining carbon labelling for the general public, engaging the general public in discussions on environmental commitment, and lastly exploring the impact of policies relating to carbon labelling.

In another study, Hartikainen et al. (2014) explain the public perception of people in Finland and how they view carbon labels. Although many people are familiar with the name associated with carbon labelling, they do not necessarily grasp what it means. Many people had the impression that they would choose products with low carbon emissions, but their choices will actually be influenced by their understanding of carbon emissions and the harm they cause. The study found that consumers knew very little to nothing about carbon labelling and its implications, so more research is required to fully comprehend this phenomenon. The findings of this survey indicated that carbon labels were fairly intriguing and significant because 90 % of respondents thought that knowing a product's carbon footprint would have at least a little influence on their decisions. However, a number of variables, including the relative lack of priority consumers place on environmental friendliness in comparison to other food features (such as price and

quality), suggest that carbon labels currently do not appeal to many consumers.

Consumer education is desperately needed due to the lack of knowledge about product carbon footprints and the environmental effects of food, and this type of study should be repeated once consumers receive such education. The largest grocery chain in the UK TESCO has expressed its disappointment that other top retailers did not follow its example, which prevented their carbon label from achieving critical mass. Tesco's Carbon Reduction Labelling strategy was introduced in cooperation with the Carbon Trust [25]. Tesco, however, informed The Grocer (magazine) that it had ended the study because it had discovered that conducting research for each product required several months' worth of work. "We expected that other retailers would move quickly to do it as well, giving it critical mass, but that hasn't happened," said Tesco's climate change director, Helen Fleming [26].

In another study by Rondoni, & Grasso [27], it was explained that only a small amount of research has examined consumer attitudes and actions in relation to food product carbon labelling. However, research indicates that carbon labels could have an impact on consumer purchase decisions, particularly among those who care about the environment [10,28].

2.5. Carbon labelling used in various countries

Carbon labelling initiatives have been introduced in various countries, with the UK leading efforts through the Carbon Trust's Carbon Reduction Label and PAS 2050 [29]. Sweden, France, and Japan have also developed similar programs. While these efforts highlight the global push toward sustainable food labelling, the effectiveness of these initiatives remains varied, particularly due to consumer confusion, lack of standardization, and limited empirical testing on actual purchasing behavior [5,23]. Our study contributes by providing a focused assessment of how carbon labelling influences consumer choices within a specific, high-consumption food category (sandwiches) in the UK.

2.6. Challenges in implementing carbon labelling

Implementing carbon labelling initiatives faces several challenges that can impact their effectiveness. In the study, it is explained that the verification and communication of a product's carbon impact depends heavily on certification and standards. The potential financial burden connected with obtaining certificates is one of the major challenges. Compliance with strict standards may require the investment of a significant amount of money in infrastructure, and technology, and increases inventory [30]. The reason behind the difficulty in obtaining products with carbon labels stems from a lack of trust in the certification process. Similarly, it has been observed that one of the underlying causes for the limited success of organic food sales is the inadequacy of transparent and reliable information provision [5]. The initial global GHG standard, known as PAS 2050 [31], effectively established a standardised method for measuring carbon emissions. The study also addressed the carbon footprint of products in relation to ozone-depleting substances, providing specifications and guidelines for measurement [2].

2.7. Life cycle assessment

LCA provides a comprehensive and standardized approach for assessing the environmental impact of products throughout their entire life cycle, including raw material extraction, production, use, and end-of-life. By incorporating LCA into carbon labelling, consumers can obtain accurate and reliable information about the carbon emissions associated with a product, enabling informed purchasing decisions [32]. The idea of the carbon footprint was introduced in 1960 but still the exact definition is not clear and a lot of debate is happening [33]. LCA as a measure of a product or service's environmental impact over the course of its full life cycle, from the procurement of raw materials to disposal [34]. The study also states the importance of detecting and quantifying the environmental effects connected to the production of food, processing, transportation, and disposal [35].

2.8. Carbon footprint

The primary objective of carbon labelling is to diminish carbon footprints by cultivating a heightened consumer preference for products characterized by reduced emissions. Incorporating carbon labels onto merchandise stimulates enterprises to curtail their carbon emissions across the entire lifecycle of their products, encompassing procurement, manufacturing, transportation, and disposal phases. This incentivizes businesses to adopt environmentally friendly technologies and production methodologies, thus advancing the objectives of environmental sustainability [36]. In the realm of sustainable product selection, carbon labelling furnishes consumers with the empowerment to opt for items that possess diminished carbon footprints, thereby fostering patterns of consumption that are ecologically sustainable. Through the provision of transparent insights into a product's environmental impact, carbon labels empower consumers to harmonize their choices with their inherent values of sustainability. This in turn fuels the demand for products that are ecologically responsible, bolstering sustainable industries and propelling the market toward a broader spectrum of sustainable alternatives.

It is ensured that the focus goes beyond carbon emissions alone, embracing broader environmental problems, and supporting sustainable practises along the value chain by incorporating eco-friendly sustainability principles into carbon labelling programmes. We can promote a more complete approach to eco-friendly sustainability and hasten the transition to a greener future by combining carbon labelling with other sustainable measures, such as the adoption of renewable energy, waste reduction, and sustainable sourcing [37].

2.9. Practicality of carbon labelling

This study addresses the issue of whether carbon labelling will help UK citizens choose their purchases more wisely or, more generally if it will help the country move towards a low-carbon future [23]. The study also states carbon foot printing and labelling rules, which are undoubtedly significant but primarily top-down in nature, will assist but not necessarily drive a decarbonised food chain. When carbon foot printing policy requirements are optional, it could be challenging to mobilise sincere efforts to successfully reduce carbon emissions and promote proactive environmental behaviour [6]. One study [2] indicates that one of the largest environmental issues that could obstruct human development is global climate change. The usefulness of carbon labelling can be seen by the adoption of product category criteria to enable accurate comparisons within the same product category was one key evolutionary leap, according to a look back at the development of carbon labelling schemes [2]. And tier-based rating and grading, a popular benchmarking technique in ecolabelling programs, has lately been incorporated into carbon labelling programs. These evolutionary changes may increase the legitimacy and transparency of carbon labelling programs.

While existing studies have explored consumer attitudes toward carbon labelling (e.g., Ref. [5,6]), they often focus on general perceptions rather than examining actual purchasing behaviors. Furthermore, much of the current research is based on self-reported preferences rather than real-world decision-making scenarios. Another key limitation in prior studies is the lack of empirical carbon footprint calculations for specific food categories, particularly ready-made food products like sandwiches. This study addresses these gaps by (1) combining quantitative LCA-based carbon footprint assessments with survey-based consumer perception analysis, (2) focusing on a specific and widely consumed food product (sandwiches), and (3) evaluating how carbon

labels influence real purchasing intentions rather than just stated preferences. By bridging these gaps, our research provides a more application-driven understanding of the role of carbon labelling in shaping sustainable food choices.

3. Methodology

This section focuses on the methodology employed to investigate carbon labelling with consumer perception. The process encompassed several crucial stages, including the attainment of ethical clearance, reviewing the relevant literature, and paving the way for the systematic collection of data through both surveys, observations, and interviews as shown in Fig. 1. The obtained data was then subjected to statistical and thematic analysis, generating significant findings that contributed towards the objectives of this study (See Fig. 1).

3.1. Research methodology approach

The research approach used was action design research (ADR) [38] since the main objective of the study focused on a practical problem and its solution. The action research design was utilized to study carbon labelling for user groups to understand their motivations, their backgrounds, and their social skills and needs to identify design principles. Multiple data collection techniques, including surveys, observations, and interviews, were deployed to generate significant results.

3.2. Case study

The case company selected for this study is a prominent UK-based sandwich manufacturer specializing in 'food-to-go' products. The company was chosen due to its significant market presence, well-established sustainability goals, and its proactive approach to reducing carbon emissions within the food production lifecycle. This selection allowed access to crucial production data, facilitating accurate Life Cycle Assessment (LCA) of their sandwich products. Two sandwich types, namely a P1 = "Ham and Cheese Sandwich" and a P2 = "Cheese and Mayonnaise Sandwich", were selected based on their popularity among UK consumers, representing some of the highest selling varieties within the company's product range. Additionally, these sandwiches provide a meaningful comparison between meat-containing and vegetarian options, enabling insights into the differential impacts of ingredients on carbon footprints. The manufacturing cycle of production is analysed in the study along with awareness of consumer perception in the consumer for a sustainable future.

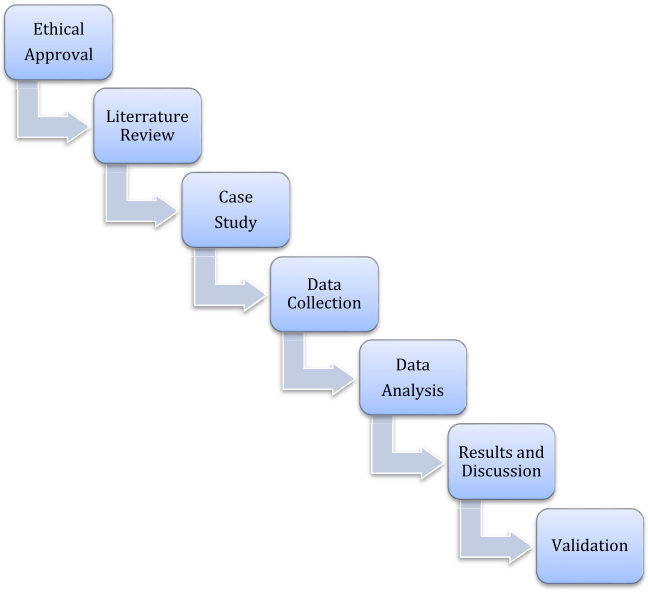

Fig. 1. Research methodology approach.

Sandwich manufacturing was analysed: the ingredients of a Ham and Cheese Sandwich comprising 2 slices of medium bread, 1 slice of ham, 30 g of cheese, and mayonnaise. On the other hand, the Cheese Sandwich consists of 2 slices of medium bread and 30 g of cheese. Bread is kept at ambient temperature and is supplied daily whereas ham and cheese are kept in a chiller where the temperature is $< 5\ ^{\circ}C$ and are supplied on a weekly basis. After preparation, each sandwich is cut diagonally and both halves are placed side by side in a triangularly shaped cardboard container weighing 10 g.

3.3. Data collection

The participants included in the study were mainly stakeholders of the industry along with consumers. A total of 89 participants were engaged in the study to mark their responses on a survey that focused on consumer perceptions and attitudes towards carbon labelling. As noted by Ref. [39], for relational survey design, the sample size should not be less than 30 as a necessary requirement. A total of 89 responses were collected, representing an approximate response rate of 45 % from the total approached individuals (approx. 200 invited). The sample of 89 respondents may not be sufficient however, to hold the efficacy of the survey author make face-to-face discussion during data collection to avoid confusion in providing response and hence get appropriate response. This hybrid approach ensured clarity of responses, mitigated misinterpretation risks, and improved response quality. While participants were broadly representative of typical sandwich consumers, deliberate efforts were made to achieve demographic diversity in terms of age and gender. A sample of 89 respondents out of a population of 200, yielding a response rate of 45 %, is sufficient for this study, especially considering Gupta and Jagtap [40] successfully conducted their research with a lower response rate of only 20.21 % from various experts. In this study, qualitative and quantitative data are collected through interviews, surveys, and observations to achieve the objectives.

3.4. Life cycle assessment

Life Cycle Assessment (LCA) is a standardized methodology that analyses all the resources consumed and all emissions to air, water, and soil, at each stage in the production, use, and disposal of products [14]. The present study was carried out to estimate the emissions impact of two types of ready-made sandwich production. At many phases of food production, qualitative data was collected on CO_2 emissions. A semi-structured interview was conducted with the company to analyse different emission factors, interviews were conducted with:

- Purchasing Manager
- Innovation and Technical Director

The main questions consist of the production cycle of the product, waste management, packaging, and energy consumption. An analysis of sandwich production was studied to develop questionnaire environmental LCA data collection to calculate the CF of sandwiches for sustainability and that will lead to enabling carbon labelling as well in the future. The collected data includes material usage, energy usage, and production cycle. CF analysis was carried out using a "field-to-gate" methodology [41] which was performed in accordance with the documents: ISO 14067 [42], ISO 14044 [43], and PAS 2050 [31].

In "field-to-gate" methodology includes processing, assembly, manufacturing, and packaging. In this study, the analyses include unit stages: ingredient preparations, assembly, cutting, and packaging. The functional unit was defined as 'one individual sandwich serving prepared for immediate consumption,' standardized by using two slices of medium-sized bread with consistent ingredient portions and packaging

methods across variants. This definition ensured comparability of carbon footprints between sandwich types. Sandwich types (Ham and Cheese, Cheese and Mayonnaise) were selected based on their popularity among UK consumers and clear contrast between vegetarian and non-vegetarian options. Variants with alternative protein sources (e.g., chicken, plant-based) were excluded due to limited data availability, supply chain complexity, and the study's focus on a clear initial comparison. Future research could incorporate these additional variants for broader analysis.

The current study employs a 'field-to-gate' LCA methodology, explicitly focusing on ingredient preparation, sandwich assembly, cutting, and packaging stages. Transportation, ingredient processing, and consumption phases have been deliberately excluded from this study due to practical constraints primarily driven by proprietary data limitations imposed by the Non-Disclosure Agreement (NDA), logistical complexity, and the specific aims of the research.

Transportation and ingredient processing stages involve complex, geographically dispersed supply chains, and data availability constraints prevented accurate quantification within this study's timeframe. Similarly, consumption and post-consumption stages were considered outside the immediate control and direct influence of the case company, limiting actionable insights.

Despite these exclusions, this study provides valuable initial insights into significant emission hotspots within sandwich production. The identified emission factors, such as ingredient choice, packaging, energy usage, and waste management, offer practical opportunities for direct intervention by food producers.

Future research, building upon these preliminary findings, should extend the scope to incorporate the currently excluded stages—transportation, ingredient processing, and end-of-life impacts—to achieve a comprehensive cradle-to-grave assessment. Such an extended LCA would offer deeper insights into the full environmental impacts and further inform robust sustainability strategies for food manufacturers.

Two recipes of general types of ready-made sandwiches were considered. Their compositions are detailed in Table 1, based on their own market research. These recipes were chosen because of consumer preferences and as guided by data availability for the ingredients. The number of ingredients used in each sandwich recipe is relatively small, with mayonnaise being common to both recipes. The mass of the sandwich ranges from 128 to 199 g, with bread accounting for almost half of the total mass. In turn, the energy content of the sandwich ranges from 279 up to 546 kcal (1169–2286 kJ) approximately.

The system boundaries for both sandwiches include the production of agricultural products and packaging materials, processing of ingredients, preparation of sandwiches, packing, and disposal of food waste.

3.5. Survey

An online survey created on Qualtrics was conducted to better understand the general habits of consumers and their perception of carbon labelling. The survey provided a deeper insight into why consumers think in a certain way and provided general responses on a Likert-type scale. Likert-scale questions were specifically designed to measure key variables including consumer awareness, perceived importance, influence on purchasing, understanding, and trust towards carbon labelling. Questions were adapted and refined from previously validated survey instruments used in prior research on consumer perceptions of sustainability labels [5,6]. Prior to full deployment, questions were pre-tested with a small consumer panel (n = 10) to ensure clarity, comprehension, and reliability. The survey was a structured questionnaire that focussed on collecting quantitative data on consumer perceptions.

The survey included questions that assessed the following aspects:

a. **Awareness**: Determine the level of consumer awareness regarding carbon labelling for food products, including sandwiches.
b. **Importance**: Identify the importance consumers place on carbon labelling when making sandwich purchasing decisions.
c. **Influence**: Explore whether carbon labelling influences consumer choices and whether it affects brand loyalty.
d. **Understanding**: Assess consumers' understanding of carbon labelling and its implications.
e. **Trust:** Evaluate the level of trust consumers have in carbon labelling information provided by brands.
f. **Behavioural Change:** Determine whether carbon labelling prompts consumers to change their sandwich purchasing behaviour.

3.6. Data analysis

The partial and total carbon footprints (CFs) were calculated using data obtained from carbon footprint measurement apps, as well as previously published literature on the calculation of carbon emissions from sandwich and production data. Conversely, the survey results were examined using statistical techniques including descriptive statistics, frequency distribution, and Pearson correlation analysis to measure consumer opinions and detect relationships among factors. The data analysis was conducted using Qualtrics, the correlation was determined using SPSS, and the heat map was generated using Jupiter Notebook using the C-burn python package.

4. Results

This section comprises results obtained from the collection of qualitative and quantitative data for the study.

4.1. Life cycle assessment

The results are collected for sandwich preparation, waste generation, energy usage, and packaging excluding the rest of the standard Life Cycle Assessment (LCA) stages. The other stages such as ingredients processing, weighing, transportation, and consumption, were beyond the scope of this study. Moreover, Non-Disclosure Agreement (NDA) further limited the scope of presenting some of the data but approximate values are given.

4.1.1. Mass of one serving of commercially prepared sandwiches

The results for the mass of the ready-made sandwiches are presented in Table 2. The results indicate that ham and cheese sandwiches have more mass than cheese and mayonnaise sandwiches. This is because of the inclusion of ham slices.

Table 1
Recipes of sandwiched studied for LCA.

No	Sandwich	Ingredients
1	Cheese sandwich	two slices of square bread, cheese, and mayo
2	Ham and cheese sandwich	two slices of square bread, ham, cheese, and mayo

Table 2
Mass of ingredients for read-made sandwiches based on one serving.

No	Sandwich type	White Bread (g)	Ham (g)	Mayonnaise (g)	Cheese (g)	Total mass (g)
1	Cheese sandwich	80	0	16	30	126
2	Ham and cheese sandwich	80	38	16	30	164

4.1.2. Carbon footprint of one serving commercially prepared sandwiches

Carbon footprints were calculated using the online carbon footprint calculator 'My Emissions' (https://myemissions.green), a widely used and validated tool based on peer-reviewed data and industry-standard emission databases. This calculator incorporates emission factors considering Global Warming Potential (GWP) of primary greenhouse gases, including CO_2, CH_4, and N_2O, as per IPCC guidelines. The reliability of this tool has been confirmed by multiple industry and academic studies assessing food product emissions. The results for CF (g CO_2 eq.) of the ingredients only of the ready-made sandwiches are presented in Table 3. The results indicate that ham and cheese sandwich have higher CF (625 g CO_2 eq) as compared to cheese and mayonnaise sandwich which has CF (373 g CO_2 eq). The cheese contributed the highest CF followed by ham and white bread. Mayonnaise had the lowest CF among all ingredients.

After ingredients including the other stages, the Cheese and mayonnaise sandwich has a carbon footprint approximately ranging from 700 g CO_2 eq – 750 g CO_2 eq whereas the ham and cheese sandwich CF ranges from 1053 g CO_2 eq – 1070 g CO_2 eq approximately. The significant difference in carbon footprints between the Ham and Cheese sandwich and Cheese sandwich primarily stems from ham production, which involves resource-intensive processes, high emissions from animal farming, and indirect emissions from feed production and land-use changes. Cheese production, while also resource-intensive, generally involves fewer emissions compared to meat products, especially processed meats like ham. The packaging consisting of a cardboard container weighing approximately 10 g contributes around 5.2 % of the carbon footprint whereas the energy usage contributes around 13 %–15.2 % approximately. Considering industry trends towards sustainability, adopting biodegradable, compostable, or recycled packaging materials presents a tangible opportunity to further reduce environmental impact. On the other hand, waste management has a 7 % impact on the carbon footprint. Due to the signed NDA, the exact measured data is not shown. The exclusion of transportation, ingredient processing, and consumption phases may result in an underestimation of the true carbon footprint of sandwiches. These stages, particularly transportation and ingredient processing, are typically significant contributors, especially for emissions-intensive ingredients such as cheese and ham. Hence, results presented should be interpreted as conservative estimates of total carbon footprints.

4.2. Consumer perception on carbon labelling

The results of the consumer perception study were generated through quantitative analysis of data obtained by the participants. The quantitative responses recorded on the survey were assessed through the SPSS version 22 and Qualtrics Survey Software. The responses to the survey were categorized into the following variables:

4.2.1. Demographic variables

The participants in the survey were analysed by calculating the mean differences across the two categorical variables; age and gender (see Fig. 2). The survey recorded responses from 89 participants ranging from age 15 to 60+ years. Most of the participants ranged from age 31 to 45 (37.08 %, n = 33). The remaining participants aged 15–30 years (31.46 %, n = 28), 46–60 years (16.85 %, n = 15), and 14.61 % participants aged above 60 years (n = 13). The survey responses were also measured across the different categories of gender among which 51.7 % constituted female participants, making it a majority (n = 46). Other participants included males (43.8 %, n = 39) and 4.5 % of the participants preferred not to say (n = 4).

Table 3
Carbon footprint of ingredients used in ready-made sandwiches based on one serving.

No	Sandwich type	White Bread	Ham	Mayonnaise	Cheese	Carbon footprint (g CO_2 eq.)
1	Cheese sandwich	86	0	64	264	373
2	Ham and cheese sandwich	86	252	64	264	625

4.2.2. Consumer awareness

The next six questions on the survey focussed primarily on consumer perceptions regarding carbon labelling as shown in Fig. 3. Most of the people agreed on the level of awareness regarding carbon labelling for food products (strongly agree = 11.2 %, n = 10; somewhat agree = 36 %, n = 32). The remaining participants neither agreed nor disagreed (28.1 %, n = 25); however, 24.7 % disagreed that the company from where they were purchasing is taking any action to reduce the product's carbon footprint (somewhat disagree = 21.3 %, n = 19; strongly disagree = 3.4 %, n = 3).

4.2.3. Importance of carbon labelling

Regarding identifying the importance of carbon labels on food products to reduce the carbon footprint, the majority of the participants agreed (strongly agree = 32.6 %, n = 29; somewhat agree = 36 %, n = 32), 18 % of participants neither agreed nor disagreed (n = 16) and the remaining disagreed (somewhat disagree = 10.1 %, n = 9; strongly disagree = 3.4 %, n = 3) (Fig. 4).

4.2.4. Effectiveness of carbon labelling

Most participants agreed that carbon labelling is a good idea (76.4 %, n = 68) (Fig. 5). The observed gap between high consumer awareness of carbon labelling (76.4 %) and its relatively limited influence on purchasing decisions (26.9 %) aligns with existing literature [6,22]. Factors such as price sensitivity, accessibility issues, confusion regarding label interpretation, and prioritization of taste and convenience likely explain this disparity.

4.2.5. Impact of carbon footprints on consumer's buying criteria

On a question assessing the consumer's understanding and importance of a product's carbon footprint if compared with other buying criteria while grocery shopping, the participants differed in their responses, making a majority of participants who agreed (42.7 %, n = 38) while 29.2 % did not agree (n = 26) (Fig. 6). The weak correlation between positive perceptions of carbon labels and actual purchasing behaviour suggests opportunities to improve label design. Simpler, visually intuitive systems (e.g., traffic-light schemes or clearer numeric indicators), already successful in sectors like energy efficiency labelling of appliances, could increase consumer comprehension and translate awareness into meaningful actions.

4.2.6. Influence of carbon footprints on consumers

Around 40 % of the participants disagreed with getting influenced by the carbon footprint on a product, revealing the impact of carbon footprint on consumer's buying decisions, suggesting economic factors, notably price sensitivity and perceived product quality, dominate consumer decision-making over sustainability concerns. Future labelling strategies should integrate economic incentives or clear value propositions to encourage actual behavioural change. However, only 26.9 % of participants agreed to get influenced by the carbon labels on products (Fig. 7).

4.2.7. Consumers' trust in carbon foot printing

Most participants (70.8 %, n = 63) trusted a company that had worked to reduce the carbon footprint of products (Fig. 8).

Fig. 9 shows the item-to-total correlation of six items excluding the two demographic variables. The results showed a positive and significant Pearson correlation between the survey items. These correlation

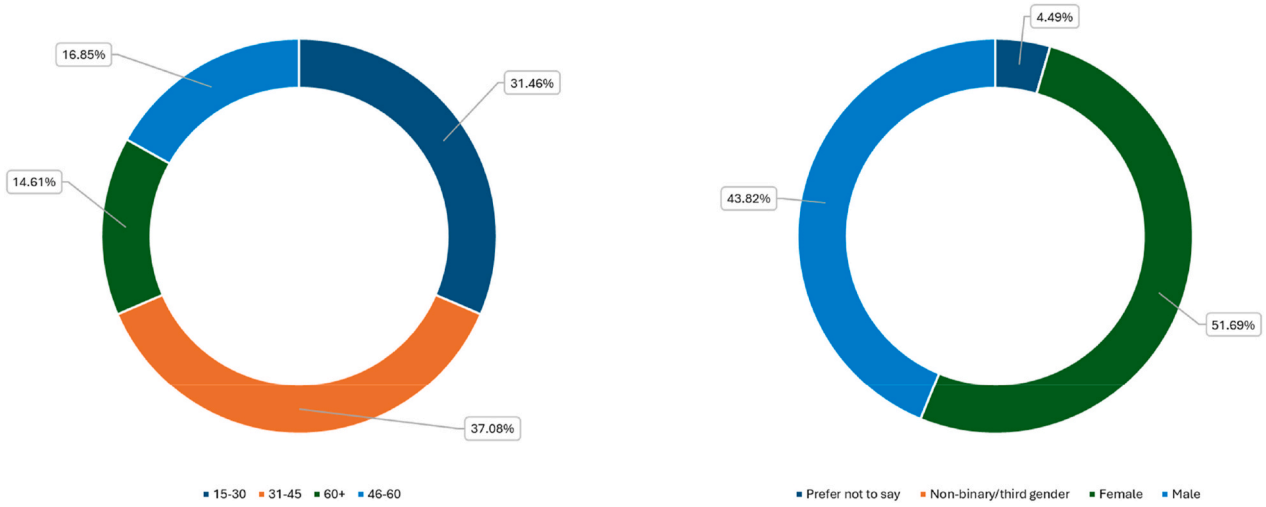

Fig. 2. Age (left) and gender (right) of participants.

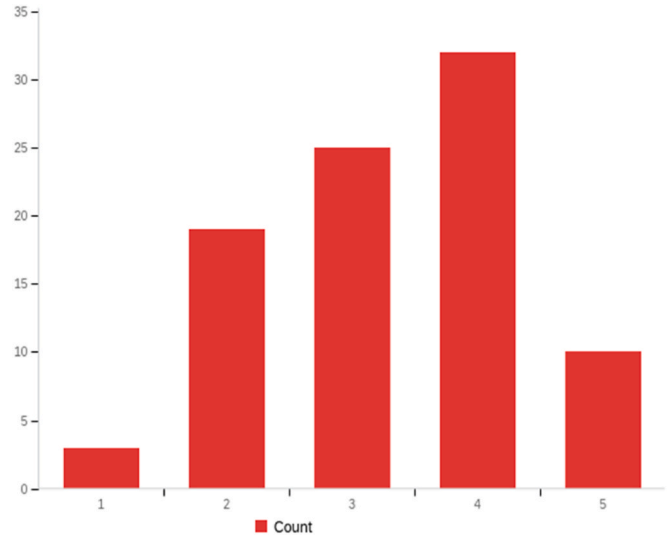

Fig. 3. Consumer awareness.

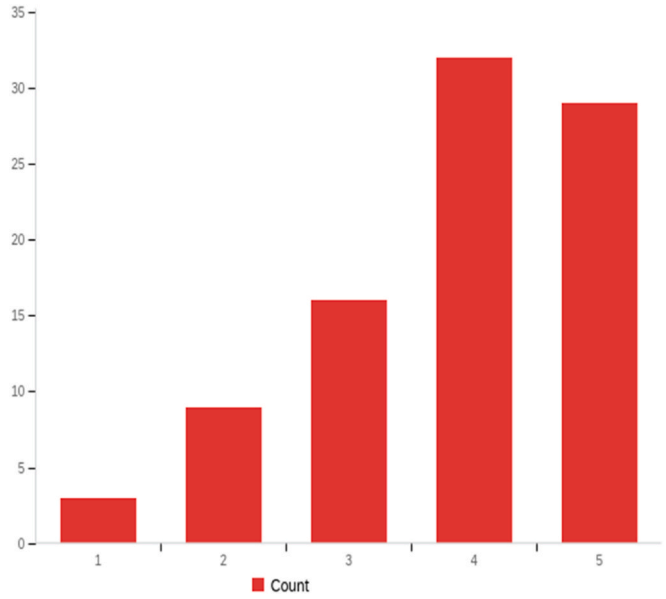

Fig. 4. Importance of Carbon labelling.

coefficients suggest that participants who perceive carbon labelling as important are more likely to believe that companies are taking action to reduce carbon footprints, that carbon labels influence their buying decisions, that there is higher awareness about carbon labelling, and that they have a more positive attitude toward carbon labelling as a whole.

Fig. 9 depicts a heat map between the survey questions other than the demographic questions. It shows that all the survey items are positively correlated with each other. Overall, the significant correlation coefficients suggest various consumer perceptions about carbon labelling and carbon footprinting on food products; however, the item-to-total correlation between the general consumer perception of carbon labelling and the usefulness of carbon footprinting (Question 4) suggests a positive but weak linear relationship (0.27) with Question 3. Moreover, Question 5 shows a weak correlation as well. This indicates that even though participants may have a strong perception regarding carbon labelling and its importance, they lack perception regarding the usefulness of recognized labels on products for reducing carbon footprints. However, Question 3 represents an ideally positive correlation against the total, suggesting that the participants agreed that the company from which they are purchasing is taking action to reduce its carbon footprint. On the other hand, Questions 4 and 5 show a strong correlation of 0.62. Similarly, Questions 7 and 6 show a strong correlation of 0.70, which means the consumer has strong awareness and perception of carbon labelling and recognisable labels on food products related to carbon emissions.

5. Discussion

This section of the study focuses on the findings associated with the main objectives of the study. Carbon labelling informs consumers about the food's carbon footprint and encourages the purchase of low-carbon items. A cross-cultural study by Roa-Goyes & Pickering [20] identified carbon footprint and carbon label awareness gaps by nation, gender, and education level. The emerging concept of carbon labelling for food products, aimed at informing consumers about the environmental impact of manufacturing, and processing, aligns with the growing trend of sustainable consumption and the demand for transparency in the food industry variables such as production energy, land use changes, farming methods, transportation, and packaging collectively define a food product's carbon footprint. Although limited studies exist on food product carbon labelling, initial research suggests that such labels, particularly for environmentally conscious individuals, can influence

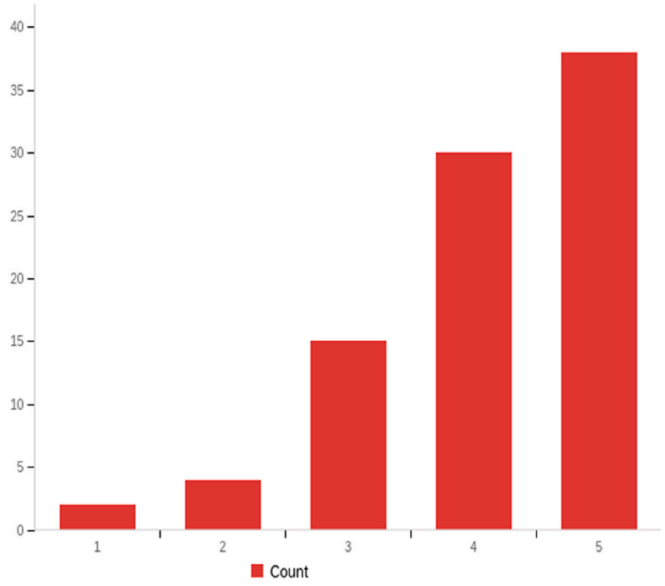

Fig. 5. Effectiveness of Carbon labelling.

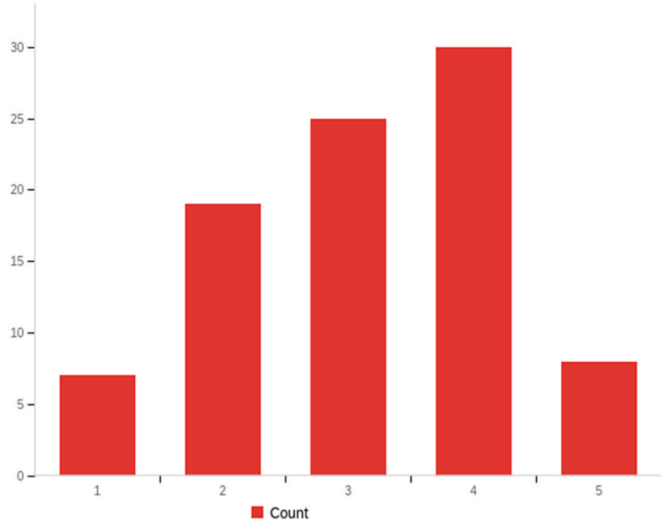

Fig. 6. Impact of Carbon footprint on buying criteria.

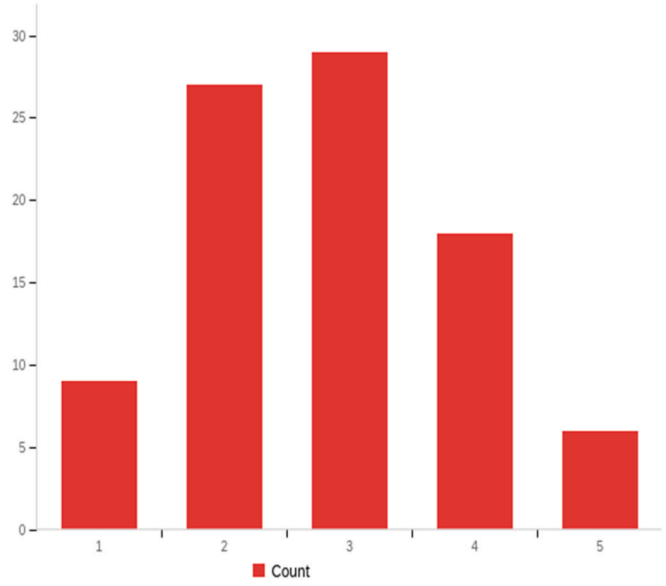

Fig. 7. Carbon footprint influence.

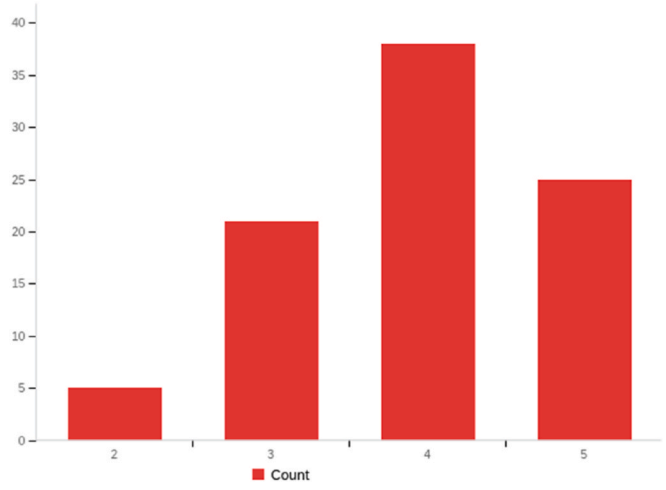

Fig. 8. Consumer's Trust In carbon labelling.

consumer purchasing behaviours. The present study explored the utilization of Life Cycle Assessment (LCA) for carbon labelling in the food industry. Moreover, the study also addresses consumer perceptions of carbon labelling and the challenges faced by the food industry. The omission of transportation and ingredient processing stages from this LCA likely results in an underestimation of the true carbon footprint, particularly for resource-intensive ingredients like cheese and ham, which typically have complex and emissions-heavy supply chains. A sensitivity analysis considering industry-average emission factors suggests that these excluded stages could increase the reported carbon footprints by approximately 15–25 %. This highlights the importance of including full life-cycle assessments ('cradle-to-grave') in future studies to provide more accurate environmental insights and inform comprehensive sustainability strategies.

The literature suggested that various studies have evaluated the carbon footprints of different food items, including vegetables, meat, dairy, grains, and processed foods. By using LCA to compare diverse food types, production methods, and supply chains, the heterogeneous nature of carbon emissions across the food system becomes evident. Incorporating LCA into carbon labelling provides consumers with accurate and consistent information about product-related carbon emissions, empowering them to make well-informed purchasing decisions. Integrating LCA into carbon labelling ensures consumers have access to reliable information about a product's carbon footprint. Notably, there remains ongoing debate around the precise definition of carbon footprint.

Consumer behavior about sustainability is influenced by various factors, as evidenced by survey data obtained. These biases may result in inconsistencies between consumers' intentions and their actual purchase behavior. Prominent biases including social desirability bias, the attitude-behavior gap, recollection and cognitive biases, as well as survey framing and response bias. We observed that consumers are fully aware of sustainable diets and environmentally friendly diets, but they do not consistently implement them. These biases result in customers exaggerating their dedication to sustainability while disregarding the impact of price, convenience, and product availability on their choices. Moreover, behavioral interventions and consumer education can assist customers in making informed decisions without misunderstanding. Consumer readiness to swap high-emissions meat products with lower-emissions protein goods was also examined, and the traffic light

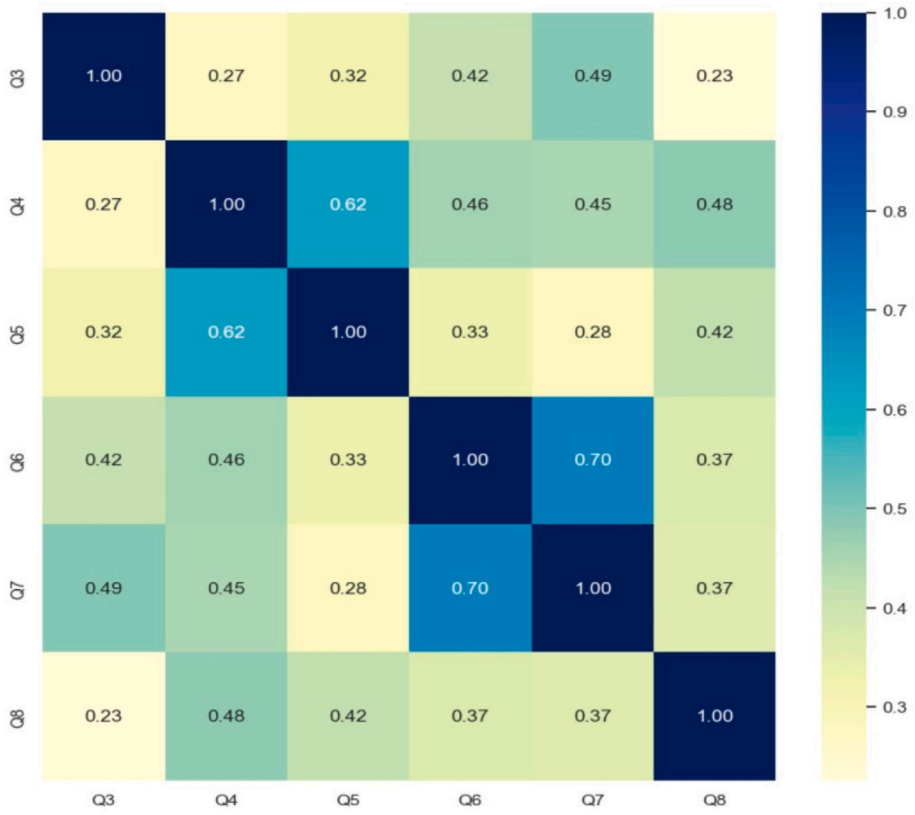

Fig. 9. Heat map.

carbon label affected choosing behaviour. A hybrid auction-consumption experiment examined university students' purchase intention and willingness to pay for carbon-labelled food [13]. The findings indicated that price drives the purchase of carbon-labelled milk products, the premium effects willingness to pay, and students are willing to pay up to 3.2 %. Finnish consumers liked hearing about food goods' carbon footprints, with 90 % saying it would influence their purchase. Perceived carbon label content demands vary. The agri-food sector needs carbon labelling to promote sustainable consumption and reduce greenhouse gas emissions. UK carbon foot printing and labelling are voluntary food system decarbonisation activities. Consumer desire for carbon labels is great, yet 89 % of 428 UK grocery buyers are confused about them. Due to market expansion and insufficient communication. Most consumers would respond favourably to more carbon labelling, but it is unlikely to transform food systems. Data reveals that a fragmented and chaotic market strategy limits a cohesive governmental attempt to decarbonise food systems through voluntary carbon footprinting and labelling. Consumers may wish to choose product based on their carbon footprint. Effective links between food policy and food market players are essential to promote a focused and consistent carbon labelling strategy, allowing consumers to make educated choices and eliminating the need for retailers to rely on demand side supply chain to meet carbon reduction objectives.

5.1. Primary sources of carbon emissions in food industry

The study findings also focussed on identifying some important sources of carbon emissions in the food industry. By evaluating the previous information gathered by literature review, the study identified that the food industry is a significant contributor to carbon emissions, with various stages of the food supply chain generating greenhouse gases. One of the high carbon emission sources is cheese as well as the poultry items such as meat ham, and chicken. Some primary sources of carbon emissions in the food industry, as implied by previous research, revealed that food industries including agriculture, Energy-intensive processes used in food processing and manufacturing, such as heating, cooling, and packaging, production of packaging materials, such as plastic, paper, lead, and metal contribute significantly to the carbon emissions.

5.2. Carbon footprint

The sandwich has a significantly higher environmental footprint than other food products. However, improvement in the production system could reduce several million tons of CO_2 from getting into the atmosphere. The greatest contributor to the CF of ham and cheese is the agricultural production and processing of ingredients. Generally, shop sandwiches that incorporate meat, cheese, and prawns each contribute the equivalent of at least 1200 g CO_2 [44]. Due to its inherent nature, single-use paper-based packaging can be easily recycled and turned into high-quality secondary products.

5.3. Recipe modification

The carbon footprint of the sandwich can be lowered by modifying the recipe, for example using wholewheat bread instead of white. We can lessen the amount of mayonnaise in the sandwich which will lower the carbon footprint and also make it a healthier option as it would have less fat [44]. Switching to whole wheat bread and reducing mayonnaise content could potentially reduce sandwich emissions by approximately 10–15 % per serving, as these ingredients exhibit lower carbon intensities. While these changes appear beneficial, consumer acceptance testing is recommended to evaluate market feasibility and acceptance. Cheese significantly contributes to the carbon footprint, since 30 g of cheese has 264 g CO_2 eq. Another alternative is removing the ham and use a plant-based substitute instead, since meat has a very high carbon

footprint [45,46]. In general, switching to plant-based diets is a good solution to lower carbon footprint of diets.

5.4. Waste management

As the company is not capable of managing their own waste, they transfer their waste to another company. This requires energy as well as transportation. To lower the footprint, waste management should be incorporated in the company.

5.5. Renewable energy

According to the observations, no renewable energy resources are used. Solar panels should be installed which can lower energy consumption and also the carbon footprint [34]. They further suggest in their findings that to reduce the environmental carbon footprint impact renewable energy shift is necessary. On the other hand, energy-efficient appliances should be used, which can lower the carbon footprint and lead a more resilient future.

5.6. Wastewater

The water is not recycled or managed within the company which gives a very high amount of CF, Insufficient water recycling and management practices have been identified as significant contributors to elevated carbon footprints within the context of this study. Proper water management should be introduced which will be able to lower the carbon footprint in a significant amount and will lead to a sustainable future.

5.7. Consumer perception regarding carbon labelling

The quantitative data collection tool was a survey generated to record and quantify various perceptions and compare the importance, awareness, impact and trustfulness of companies that promoted carbon labelling for food products. The survey results revealed a range of attitudes and behaviours among participants concerning carbon labelling for food products. While many participants expressed awareness and perceived importance of carbon labels, there were differences in the extent to which such labels influenced buying decisions. These findings underscore the complex interplay between consumer perceptions, knowledge, and purchasing behaviours in the context of sustainable consumption. Proper awareness is needed to engage the general public in reducing their own carbon footprint. This initiative could aim to enhance consumer understanding of carbon labels and promote their integration into purchasing decisions, contributing to more environmentally conscious consumption patterns. The observed high consumer awareness yet limited behavioural impact of carbon labelling aligns closely with international findings. For instance, similar studies in Finland found consumers expressing strong interest but exhibiting low actual influence on purchase behaviour due to competing priorities like price and quality [22]. Similarly, studies from China revealed high stated willingness-to-buy carbon-labelled products but significant gaps in actual buying decisions, largely due to cost and confusion around label interpretation [16]. This consistency highlights a global challenge where awareness alone is insufficient, suggesting that effective carbon labelling strategies must address practical barriers to consumer behaviour change. The limited influence of carbon labels on actual consumer purchasing behaviour observed in this study aligns with findings from previous research [6,22].

The observed weak correlation between strong consumer perceptions of carbon labelling and actual purchasing behavior highlights the need for more effective communication strategies. Label clarity and visual simplicity are crucial; successful examples from energy labelling of household appliances, such as the widely recognized ‘traffic light’ or A-to-G rating systems, illustrate how intuitive designs significantly influence consumer behaviour [28]. Adopting similar visually intuitive labels, clearly indicating environmental impact levels, could bridge the existing gap between awareness and action in carbon labelling for food products.

In contrast, carbon pricing mechanisms and environmental taxes have demonstrated greater effectiveness due to their direct economic impact on consumer choices, immediately affecting prices and driving behavioural change. Implementing complementary policies, such as financial incentives for lower-carbon products or targeted carbon taxes on high-emission foods, could significantly enhance consumer responsiveness to carbon labels and stimulate more sustainable purchasing behaviours. Tax reductions for low-carbon products could also be considered for effectively implementing carbon labelling.

5.8. Challenges in implementing carbon labelling

Despite the obvious benefits of carbon labelling in products, some companies are still reluctant to implement it. The main reason for this appears to be the difficulty of carrying out the appropriate carbon footprint assessments required before implementing carbon labelling. A large amount of data and complex calculations are required, which has a significant cost associated with it. This is an important reason why large and profitable companies, mainly in developed countries, are the most likely to use carbon labelling. In addition, the whole process needs to be transparent enough to ensure that carbon claims are verifiable.

6. Conclusion

The current study identifies the consumer perception on the carbon labelled sandwiches. The concept of carbon labelling for food goods developed as a viable strategy for promoting sustainable consumption by informing consumers about their environmental effect. The data also revealed that life cycle evaluations can estimate carbon emissions from food production, transportation, and disposal. This approach helps consumers comprehend the complicated relationships between food choices and environmental impact, enabling them to make smart choices. Accepting carbon labelling and integrating it with LCAs is a vital step towards a more responsible and ecologically conscious food business as we tackle the problems of climate change. A robust and greener food system is achieved by addressing emissions from transportation, processing, and agriculture and improving resource management and efficiency.

Moreover, in this study it has been concluded that the Cheese and Mayonnaise sandwich comprises approximately 700 g CO_2 eq – 750 g CO_2 eq on the other hand Ham and cheese sandwich comprises approximately 1053 g CO_2 eq – 1070 g CO_2 eq. The major contribution to carbon footprint is by food production followed by other things such as waste, packaging etc. Beyond the immediate findings, this study underscores the critical role of carbon labelling in fostering a consumer-driven transition to low-carbon food consumption. While carbon labels provide valuable information, their effectiveness depends on consumer comprehension, standardization of labelling frameworks, and supportive policies that incentivize sustainable choices. The results suggest that increasing consumer education and accessibility of carbon footprint data could enhance engagement with carbon-labelled products.

Additionally, consumer education initiatives—such as public awareness campaigns and simplified, visually intuitive labelling—can bridge the gap between carbon footprint awareness and purchasing behaviour. Governments can further incentivize low-carbon food choices by providing subsidies or tax benefits for products with lower emissions, particularly plant-based alternatives. The integration of digital technologies, such as QR codes linking to Life Cycle Assessment (LCA) data, can enhance transparency and allow consumers to make informed decisions based on real-time data. Lastly, industry accountability and reporting mechanisms should be strengthened, requiring

food producers to regularly disclose their carbon emissions and adopt sustainable production practices. By implementing these policies, carbon labelling can evolve from an informational tool into a driver of tangible environmental change, encouraging both businesses and consumers to contribute to a more sustainable food system.

The study's research into consumers' opinions on carbon labelling found a range of attitudes and behaviours, highlighting the complex connection between consumers' awareness, perceived importance, and choices regarding sustainable consumption. The consumer study has deepened the understanding of current consumer perceptions regarding the environmental impacts of food, carbon footprints, and carbon labelling. Consequently, there is a clear need to educate consumers about carbon labels, helping them better comprehend their significance and realize how altering their food consumption habits can positively impact the environment and climate. While consumers have demonstrated awareness of healthier choices leading to better outcomes, purchasing decisions remain complex when multiple criteria are involved.

To facilitate wider implementation of carbon labelling within the industry, governments must encourage businesses to adopt this practice, primarily through new policies that require companies to assess and report their carbon footprint. Consumers increasingly demand transparency in this area, empowering them to push businesses towards adopting carbon labelling. From a policy perspective, this study emphasizes the necessity of a multi-faceted approach to enhance the effectiveness of carbon labelling in promoting sustainable food choices. Standardized carbon labelling guidelines should be developed collaboratively by policymakers, industry stakeholders, and regulatory bodies to ensure consistency, transparency, and consumer trust.

7. Future work

In the future, possible advancements in LCA technique can greatly advance the precision and thoroughness of carbon footprint evaluations in the food sector. Extending the LCA's system boundaries to include a more thorough analysis of the full food supply chain i.e., cradle to grave and by providing more data is LCA will be improved. The LCA technique can provide a more comprehensive view of the carbon emissions related to food products by taking into account upstream and downstream processes, such as ingredient production, packaging. This will provide clear picture of carbon footprint for sandwiches to the consumer. The idea of carbon labelling of food products could also be extended to other products as it greatly improves the transparency of carbon emission to consumers. Future research should explore longitudinal consumer studies to assess the long-term impact of carbon labels on real purchasing behaviours and investigate the feasibility of integrating carbon labelling with broader sustainability policies in the food industry. A multi-stakeholder approach is essential to bridge the gap between awareness, behaviour, and tangible environmental impact. Moreover, modern technology can be used by businesses to monitor and optimise the flow of commodities, cut waste, and assure transparency such as sustainable supply chains and innovative eco-packaging. As a result, there could be an increase in consumer confidence and more environmentally friendly sourcing methods.

CRediT authorship contribution statement

Noor Imran: Writing – review & editing, Writing – original draft, Validation, Methodology, Investigation, Formal analysis, Data curation. **Mukesh Kumar:** Writing – review & editing, Writing – original draft, Investigation, Formal analysis, Data curation. **Sandeep Jagtap:** Writing – review & editing, Writing – original draft, Visualization, Supervision, Resources, Project administration, Investigation, Funding acquisition, Conceptualization. **Hana Trollman:** Writing – review & editing, Writing – original draft, Investigation, Formal analysis. **Sumit Gupta:** Methodology, Formal analysis, Data curation, Conceptualization. **Guillermo Garcia-Garcia:** Writing – review & editing, Writing – original draft, Investigation, Formal analysis.

Ethical approval application

Ethical approval for this research was granted by Cranfield University's Ethical Review Board (approval reference: CURES/18779/2023). Participants were recruited voluntarily, with informed consent obtained prior to data collection. Data privacy was rigorously maintained through anonymization procedures, with identifiable details excluded from analysis and publications. Additionally, a Non-Disclosure Agreement (NDA) was signed with the participating company to safeguard proprietary production data, ensuring confidentiality and integrity throughout the research process.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

Guillermo Garcia-Garcia acknowledges the Grant 'Marie Skłodowska-Curie Actions (MSCA) Postdoctoral Fellowship' with Grant agreement ID: 101052284.

Data availability

Data will be made available on request.

References

[1] A. Acampora, L. Ruini, G. Mattia, C.A. Pratesi, M.C. Lucchetti, Towards carbon neutrality in the agri-food sector: drivers and barriers, Resour. Conserv. Recycl. 189 (2023) 106755.
[2] P. Wu, B. Xia, J. Pienaar, X. Zhao, The past, present and future of carbon labelling for construction materials–a review, Build. Environ. 77 (2014) 160–168.
[3] S. Madhanaroopan, *Characterizing Net Life Cycle Greenhouse Gas Emissions And Environmental Performance Of Organic Field Crops In Ontario and Quebec* (Master's Thesis, University of Waterloo, 2023.
[4] M. Crippa, E. Solazzo, D. Guizzardi, F. Monforti-Ferrario, F.N. Tubiello, A.J.N. F. Leip, Food systems are responsible for a third of global anthropogenic GHG emissions. Nat Food 2 (2021) 198–209.
[5] E. Röös, H. Tjärnemo, Challenges of carbon labelling of food products: a consumer research perspective, Br. Food J. 113 (8) (2011) 982–996.
[6] Z. Gadema, D. Oglethorpe, The use and usefulness of carbon labelling food: a policy perspective from a survey of UK supermarket shoppers, Food Policy 36 (6) (2011) 815–822.
[7] S. Sala, S.J. McLaren, B. Notarnicola, E. Saouter, U. Sonesson, In quest of reducing the environmental impacts of food production and consumption, J. Clean. Prod. 140 (2017) 387–398.
[8] L. Sirieix, M. Delanchy, H. Remaud, L. Zepeda, P. Gurviez, Consumers' perceptions of individual and combined sustainable food labels: a UK pilot investigation, Int. J. Consum. Stud. 37 (2) (2013) 143–151.
[9] M. Guenther, C.M. Saunders, P.R. Tait, Carbon labeling and consumer attitudes, Carbon Manag. 3 (5) (2012) 445–455.
[10] R. Zhao, S. Zhong, Carbon labelling influences on consumers' behaviour: a system dynamics approach, Ecol. Indic. 51 (2015) 98–106.
[11] P. Upham, L. Dendler, M. Bleda, Carbon labelling of grocery products: public perceptions and potential emissions reductions, J. Clean. Prod. 19 (4) (2011) 348–355.
[12] Y. Haddad, Y.A. Yuksek, S. Jagtap, S. Jenkins, E. Pagone, K. Salonitis, Eco-social sustainability assessment of manufacturing systems: an LCA-based framework, Procedia CIRP 116 (2023) 312–317.
[13] R. Zhao, M. Yang, J. Liu, L. Yang, Z. Bao, X. Ren, University students' purchase intention and willingness to pay for carbon-labeled food products: a purchase decision-making experiment, Int. J. Environ. Res. Publ. Health 17 (19) (2020) 7026.
[14] R.U. Ayres, Life cycle analysis: a critique, Resour. Conserv. Recycl. 14 (3–4) (1995) 199–223.
[15] A. Detzel, M. Krüger, M. Busch, I. Blanco-Gutiérrez, C. Varela, R. Manners, E. Zannini, Life cycle assessment of animal-based foods and plant-based protein-rich alternatives: an environmental perspective, J. Sci. Food Agric. 102 (12) (2022) 5098–5110.
[16] M. Xu, B. Lin, Towards low-carbon economy by carbon label?: survey evidence from first-tier cities in China, Environ. Impact Assess. Rev. 97 (2022) 106902.

[17] Y. Xie, Y. Su, F. Li, The evolutionary game analysis of low carbon production behaviour of farmers, government and consumers in food safety source governance, Int. J. Environ. Res. Publ. Health 19 (19) (2022) 12211.
[18] X. Chen, S. Zhen, S. Li, J. Yang, Y. Ren, Consumers' willingness to pay for carbon-labeled agricultural products and its effect on greenhouse gas emissions: evidence from beef products in urban China, Environ. Impact Assess. Rev. 106 (2024) 107528.
[19] M.A. Miranda-Ackerman, C. Azzaro-Pantel, Extending the scope of eco-labelling in the food industry to drive change beyond sustainable agriculture practices, J. Environ. Manag. 204 (2017) 814–824.
[20] S. Roa-Goyes, G.J. Pickering, Promoting a sustainable diet through carbon labeling of food: insights from young consumers in the Americas, Sustain. Prod. Consum. 44 (2024) 179–187.
[21] S. Lin, X. Jin, J. Gao, Z. Qiu, J. Ying, Y. Wang, W. Zhou, Impact of wheat bran micronization on dough properties and bread quality: Part II–Quality, antioxidant and nutritional properties of bread, Food Chem. 396 (2022) 133631.
[22] H. Hartikainen, T. Roininen, J.M. Katajajuuri, H. Pulkkinen, Finnish consumer perceptions of carbon footprints and carbon labelling of food products, J. Clean. Prod. 73 (2014) 285–293.
[23] G. Edwards-Jones, K. Plassmann, E.H. York, B. Hounsome, D.L. Jones, L.M. i Canals, Vulnerability of exporting nations to the development of a carbon label in the United Kingdom, Environ. Sci. Pol. 12 (4) (2009) 479–490.
[24] L.A. Panzone, A. Ulph, D.J. Zizzo, D. Hilton, A. Clear, The impact of environmental recall and carbon taxation on the carbon footprint of supermarket shopping, J. Environ. Econ. Manag. 109 (2021) 102137.
[25] R. Smithers, Consumers push businesses on the green agenda, The Guardian (2009) [Online]. Available: https://www.theguardian.com/money/2009/jun/19/carbon-footprint-product-research. (Accessed 19 August 2023).
[26] I. Quinn, Frustrated Tesco ditches eco-labels, Grocer 28 (2012).
[27] A. Rondoni, S. Grasso, Consumers behaviour towards carbon footprint labels on food: a review of the literature and discussion of industry implications, J. Clean. Prod. 301 (2021) 127031.
[28] J. Thøgersen, K.S. Nielsen, A better carbon footprint label, J. Clean. Prod. 125 (2016) 86–94.
[29] P.S. Mallaburn, N. Eyre, Lessons from energy efficiency policy and programmes in the UK from 1973 to 2013, Energy Efficiency 7 (2014) 23–41.
[30] P. Brenton, G. Edwards-Jones, M.F. Jensen, Carbon labelling and low-income country exports: a review of the development issues, Dev. Policy Rev. 27 (3) (2009) 243–267.
[31] Equans, PAS 2050 | EQUANS UK & Ireland. https://www.equans.co.uk/pas-2050. (Accessed 19 August 2023).
[32] A.A. Jensen, *Life Cycle Assessment (LCA): a Guide to Approaches, Experiences and Information Sources* (No. 6), European Environment Agency, 1998.
[33] M. Karwacka, A. Ciurzyńska, A. Lenart, M. Janowicz, Sustainable development in the agri-food sector in terms of the carbon footprint: a Review, Sustainability 12 (16) (2020) 6463.
[34] M. Kumar, V.K. Choubey, A. Deepak, V.V. Gedam, R.D. Raut, Life cycle assessment (LCA) of dairy processing industry: a case study of North India, J. Clean. Prod. 326 (2021) 129331.
[35] I. Shabir, K.K. Dash, A.H. Dar, V.K. Pandey, U. Fayaz, S. Srivastava, R. Nisha, Carbon footprints evaluation for sustainable food processing system development: a comprehensive review, Future Foods 7 (2023) 100215.
[36] A. Schwenkenbecher, Is there an obligation to reduce one's individual carbon footprint? Crit. Rev. Int. Soc. Polit. Philos. 17 (2) (2014) 168–188.
[37] S.J. Kühne, E. Reijnen, L. Laasner Vogt, M. Baumgartner, Can carbon labels encourage green food choices? Front. Psychol. 13 (2023) 902869.
[38] M.K. Sein, O. Henfridsson, S. Purao, M. Rossi, R. Lindgren, Action design research, MIS Q. (2011) 37–56.
[39] A. Delice, The sampling issues in quantitative research, Educ. Sci. Theor. Pract. 10 (4) (2010) 2001–2018.
[40] S. Gupta, S. Jagtap, Unlocking digital growth: overcoming barriers to digital transformation for Indian food SMEs, Discover Food 4 (1) (2024) 55.
[41] M. Wróbel-Jędrzejewska, E. Polak, Carbon footprint analysis of ice cream production, Sustainability 15 (8) (2023) 6887.
[42] ISO 14067, (en), Greenhouse gases — Carbon footprint of products — Requirements and guidelines for quantification'. https://www.iso.org/obp/ui/en/#iso:std:iso:14067:ed-1:v1:en, 2018. (Accessed 11 August 2023).
[43] ISO 14044, /Amd 2:2020(en), Environmental management — Life cycle assessment — Requirements and guidelines — AMENDMENT 2'. https://www.iso.org/obp/ui/en/#iso:std:iso:14044:ed-1:v1:amd:2:v1:en, 2006. (Accessed 11 August 2023).
[44] N. Espinoza-Orias, A. Azapagic, Understanding the impact on climate change of convenience food: carbon footprint of sandwiches, Sustain. Prod. Consum. 15 (2018) 1–15.
[45] A. Laca, N. Gómez, A. Laca, M. Díaz, Overview on GHG emissions of raw milk production and a comparison of milk and cheese carbon footprints of two different systems from northern Spain, Environ. Sci. Pollut. Control Ser. 27 (2020) 1650–1666.
[46] L. Grossmann, D.J. McClements, The science of plant-based foods: approaches to create nutritious and sustainable plant-based cheese analogs, Trends Food Sci. Technol. 118 (2021) 207–229.