Results in Engineering 18 (2023) 101054

Contents lists available at ScienceDirect

Results in Engineering

journal homepage: www.sciencedirect.com/journal/results-in-engineering

Review article

A comprehensive review on carbon footprint of regular diet and ways to improving lowered emissions

H. Nabipour Afrouzi [a,*], J. Ahmed [b], B. Mobin Siddique [a], N. Khairuddin [c], Ateeb Hassan [a]

[a] Faculty of Engineering, Computing, and Science, Swinburne University of Technology Sarawak, 93350, Kuching, Malaysia
[b] School of Engineering and Built Environment, Edinburgh Napier University, Merchiston Campus, 10 Colinton Road, Edinburgh, EH10 5DTT, UK
[c] Institut Ekosains Borneo, Universiti Putra Malaysia Bintulu Sarawak Campus, Bintulu Sarawak, 97008, Malaysia

ARTICLE INFO

Keywords:
Carbon footprint
Food-diet carbon emission
Global warming
Renewable energy
Bibliometric analysis

ABSTRACT

In light of the SDG goals, carbon emissions from different food and food-related products have been under serious scrutiny in recent years. Despite the increasing awareness of global warming and the carbon footprint issue, food culture in different societies is difficult to change. Food production and storage are related to food security. The assessment of food-related carbon footprint should be linked with the chain of food lines rather than food items per se. It is obvious that much of the carbon emission is contributed by the production of it, packaging, storage, transportation, modification, quality control, and other related logistics. Therefore, this research investigated the correlation between food consumption and carbon footprint in the two types of diets and different populated regions. A systematic literature review combined with a bibliometric analysis approach was taken to construct the discussion. It studied the sources of carbon footprint and the life cycle of daily diet consumption and compared the carbon footprint of animal and plant-based diets. An evaluation of carbon footprint from various dietary patterns in India, China, and Italy was qualitatively carried out based on the published data in different scientific databases, and quantified values were discussed. Animal-based protein diets, especially meat, were found to have a higher contribution of carbon footprint; rice, however, contributes the highest among the plant-based diets. The bibliometric analysis pointed to the academic engagement on food-related carbon footprint issues across the globe and the scope of improvement. This review will help researchers to construct a thematic framework, and policymakers reorient the policy implementation.

1. Introduction

Access to appropriate nourishment is a basic human need that is influenced by a variety of social, political, and economic circumstances. Human health and well-being are influenced by a well-balanced and full diet. The impact of dietary patterns on obesity, heart disease, and other diet-related health issues is well understood. The choice of one type of food over another has immediate implications in the supply chain, as well as environmental, economic, and social issues related to the manufacturing process [1].

On the other hand, Carbon Footprint (CF) is favourably designated to indicate the number of greenhouse gases emitted directly or indirectly by certain activities or parties and is widely heard in society nowadays. CF is usually determined through greenhouse gas assessment and is expressed in equivalent tons of carbon dioxide (tCO_2e) [2]. Calculating a country's CF is one of the most effective methods for assessing carbon emissions from all sectors of the economy, including daily home activities [3]. The per capita CF varies depending on the economic growth of each country [4]. Higher-income countries like the United States, Canada, and Australia emit the most carbon, averaging 15–29 tons per capita per year. The second category, which produces moderate levels of emissions, includes Japan, South Korea, and many EU member states with annual emissions of roughly 10–12 tons per capita. Most of the world's developing countries fall into a third category, with average emissions of less than 4 tons. Malaysia's carbon emissions per capital are increasing and reaching over 8 tons per year. With a per capital income of 6.6 per year, it is classified as being above upper middle-income [5]. CF of a product can be determined using the greenhouse gas assessment. GHG emissions and climate change are heavily influenced by agricultural and food production [9]. Although carbon dioxide (CO_2) is the dominant greenhouse gas that primarily accounts for CF, other greenhouse gases such as methane (CH_4) and nitrous oxide (N_2O) also

* Corresponding author.
E-mail address: HAfrouzi@swinburne.edu.my (H. Nabipour Afrouzi).

https://doi.org/10.1016/j.rineng.2023.101054
Received 15 December 2022; Received in revised form 17 March 2023; Accepted 26 March 2023
Available online 27 March 2023

contribute to CF. CO_2 is mainly emitted from processes such as the burning of fossil fuels and various agricultural activities, while landfill sites contribute to the increase of CH_4, and N_2O is released from refrigerant gases and industrial and farming processes [10].

CF is directly linked to climate change, which causes environmental issues and food security to become common concerns worldwide. The ever-growing global population has resulted in an increasing demand for resources and subsequently intensified crises related to food and energy. Undeniably, the growth of food consumption has also raised pressure on the environment. According to Ref. [11], the impact of food consumption on CF is one of the most important issues that have been intensely discussed over the years. Therefore, this paper will provide an insight into the CF developed by our regular diet, which involves five stages: extraction, processing, transportation, usage, and disposal. This paper also compares the CF developed by different diets and regions while providing possible mitigation strategies to alleviate the issue. According to Ref. [12], nature's ecosystems and the well-being of humanity are deeply threatened by climate change. Therefore, changes in food consumption patterns must be made by every party to reduce the emission of greenhouse gases and, thus, provide a better ecosystem for future generations [11,12].

On the other hand, greenhouse gases (GHG) like Sulfur Dioxide, nitrogen dioxide, and carbon dioxide have all been identified as major contributors to global climate change, which has garnered a lot of attention. Carbon dioxide is the most prevalent of these gases, prompting researchers to investigate carbon reduction and mitigation measures. On the other hand, GHG emissions produced by growing, rearing, farming, processing, transporting, storing, cooking, and disposing of the food we eat are referred to as food's CF. Changing the diet can have a significant influence on the CF, resulting in pollution reduction, cleaning the environment, and slowing down global warming. As a result, that was the inspiration to write this article in the first place. Secondly, the review articles or research papers on this topic are available with limited understanding of the knowledge. Thus, the second motive for writing this review article was to improve the existing research on carbon emissions and to fill the knowledge gaps in the field.

Furthermore, food production includes various stages, and all those stages require energy and resources to be used at different levels. Due to the usage of energy and materials, carbon emission is also a fact, and therefore, CF increases. But worldwide human race shares different food menus and cuisine, so everyday food preparation as well contribute to increasing the CF. Therefore, considering the demographic of the most prevalent diet may be a good way to track the carbon release and thus may lead to estimating the burden of CF. Moreover, Life Cycle Assessment (LCA) is a standard procedure for the comprehensive evaluation of environmental effects. It is increasingly utilized to analyze the connections between environmental challenges and food security issues and to assess agricultural and food systems. By considering the fate of emissions and tying them to categories of consequences on local, regional, and global ecosystems, LCA offers and evaluates quantitative indicators of potential environmental repercussions. In this sense, strengthening the techniques employed is a potentially effective strategy. The popularity of Chinese, Indian, and Italian cuisine is high and altogether covers more than half of the world's diet, so considering the carbon cost of those cuisines cumulatively can help us to get a fair estimation of the carbon emission due to diet and food-related activities.

Since humans have a wide dietary pattern and food choices, researchers have often chosen to find the CF of specific crops and food or preparation of a specific food. However, to get a complete idea of how much carbon burden is contributed by foods, especially for the largest demographic consumers, this paper endeavours to get the full picture by collecting data from various scientific sources. Although calculating and labelling CF for different foods and food products are complex decision-making and subject to different research set-ups [7]. So, a consensus approach for various parameters was taken to evaluate the overall CF burden of food consumed. Many research studies have ventured to assess the CF of different food items separately, but a holistic approach to cover the whole cuisine from across the cultural or ethnic choices has not been reported yet. To fill this void, this research uses an exhaustive strategy to analyze three main cuisines from China, India, and Italy, which account for about 60% of the world's diet. Besides, this work focuses on providing a deeper understanding of CF generation at every stage of food production, starting from raw materials to final food products, which is scarcely found in the literature. Moreover, suggestions are made to reduce the CF at every stage of food production, which is a significant literary contribution and may lead to other research scopes in the future. Additionally, the role of the circular economy in mitigating CF in a regular diet is also presented in the discussion section.

2. Source and impact of carbon footprint

CF is produced in every stage of food consumption, from, and lastly, disposed of (Fig. 1). Moreover, each stage contributes a different amount of CF. Therefore, this section will investigate the source of CF in every stage and, thus, provide the impact of these CFs on the environment. This first step in the food production lifecycle is the extraction of raw materials, which involves the cultivation of crops and the raising of animals for food. This stage can contribute to carbon emissions using fossil fuels in machinery, fertilizers, and other agricultural inputs. After the agricultural production stage, the food is processed and packaged for distribution and consumption. This stage can also contribute to carbon emissions with energy-intensive processes, such as refrigeration, heating, and transportation.

The third step involves the transportation of food from the processing and packaging facilities to retail stores and other points of sale. Transportation emissions are a significant contributor to the CF of food production, especially when food is transported long distances. The fourth step is acquisition and consumption, which involves the preparation and consumption of food by individuals. Energy use during cooking and refrigeration of leftovers also contribute to the CF of food production. Finally, the disposal of food waste is an important step in the lifecycle of food production. When food waste is sent to landfills, it produces methane, a potent greenhouse gas that contributes to climate change.

2.1. Extraction of raw materials

The growth of the human population has led to higher food consumption and has hence doubled agricultural production. The rapid growth of such products has subsequently decoupled emissions in the process. According to Ref. [13], the agricultural sector contributes to approximately 13.5% of the total global anthropogenic greenhouse gas emissions and accounts for 25% of the total CO_2 emission. It is currently the second-largest greenhouse gas emitter after the energy sector. Although CH_4 is the main pollutant that comes from the agricultural sector, a significant amount of nitrous oxide (N_2O) and carbon dioxide (CO_2) are counted as well. Agricultural food production, however, can be categorized into two types: vegetable food production and animal food production [13,14].

CF is sourced from different activities involved in crop production. Such activities include land preparation, sowing of crops, irrigation, fertilizer, and pesticide applications, harvesting, threshing, and seed processing. Emissions are embodied in agricultural inputs such as fertilizers, pesticides, and soil conditioners. However [15], highlighted that fertilizer is the largest source of greenhouse gas emissions in total agricultural emissions. Such emissions range from fossil fuel mining to post-fertilizer use in the agricultural field. Nonetheless, CO_2 is emitted from the direct energy use of fossil fuel-powered machinery for farming, such as harvesters, tractors, threshers, and grain cleaning systems. The use of electricity for irrigation activities, such as channel and sprinkle drip, also indirectly contributes to CF since all technologies that generate electricity emits CO_2 in certain stages of their life cycle [13,15].

Animal food production at the farm level, also known as the primary

Fig. 1. Lifecycle of food consumption.

production, is where most emissions and uses of resources take place [16]. The main inputs of primary products include the process where livestock and poultry are raised. Emission sources of primary production are enteric fermentation by livestock, manure storage and handling, direct on-farm energy use, and production of used fodder [17]. However [18], argued that the direct emissions derived from the respiratory process of livestock and poultry in the form of CO_2 should also be considered as the source of CF despite the trivial contribution. Nonetheless, United Nations Environment Programme (2008) revealed the emissions from the production of 100 kcal of food, which shows that the food that contributed to the highest emissions is shrimp (3.0799 $kgCO_2/J$), followed by mutton (2.5900 $kgCO_2/J$), beef (1.3789 $kgCO_2/J$), and pork (0.9026 $kgCO_2/J$) (Fig. 2) [18].

Fig. 2 also proves that animal food (feed) production has a higher contribution to CF than vegetable production in overall food production. In fact, it is estimated that livestock activities have contributed to 18% of the anthropogenic greenhouse gas emissions measured in CO_2 equivalent directly and indirectly [18]. Now that all the foods and feeds are fully extracted, they will then be sent to food processing industries to undergo processing and packaging before being distributed to the retailers.

2.2. Processing and packaging

It is important for food to undergo this stage as it helps to reduce the disease present within the food. Raw food tends to rot or spoil easily, causing it to be contaminated by moulds or bacteria that may be harmful to the consumer's health. Both processing and packaging are essential for preparing the food before distributing them to the retail stores. The processing stage here refers to the slaughtering process, while the packaging stage refers to how food is packaged in order to sustain its quality.

In the slaughtering process, the animal is processed into other products, which in turn will be packaged and sent away. The products are categorized either for consumption or destruction [16]. It is a common practice to adapt the use of polylactic acid-based materials in the packaging stage. The products of polylactic acid (PLA) materials are synthetic plastics that are one of the sources which contribute to the emission of CO_2, which is a major contributor to global warming [19].

Food packaging is used to protect food during their shelf-lives, in turn, provides the customers' food with expected safety and quality. Since packaging plays a vital role in determining the shelf-life of the food, the materials chosen in food packaging must be able to preserve the food regardless the environmental factors [19]. stated that the basic elements of good packaging are freshness conservation, identification of food, and convenience for storage and distribution. According to Ref. [20], packaging of food accounts for 10% of the total emission of CF for food production, where the value is approximately 655 lb CO2e per year per American, but to use SI unit lb is converted into kg and therefore, the converted value is 297 kg of CO_2e per year per American. Moreover, it was also mentioned that aluminium cans and foil, and cartons are two of the largest contributors. This is due to the fact that more CF was emitted per pound of packaging as compared to other materials such as glass bottles and containers, steel cans, paper bags, plastic soda bottles, plastic milk bottles, and plastic bags [20]. Fig. 3 shows the stark differences between different packaging materials in relation to CO_2 emission.

Even though aluminium cans and foils, and cartons contribute the most CF, they are not as widely used as plastic and polystyrene. Plastic and polystyrene are mostly produced from crude oil and fossil fuels. The production of plastic takes 4–5% portion of the annual crude oil consumption. Not only are these materials made from unrenewable resources, but they also have a negative impact on the environment when considering their end-of-life. One example would be expanded

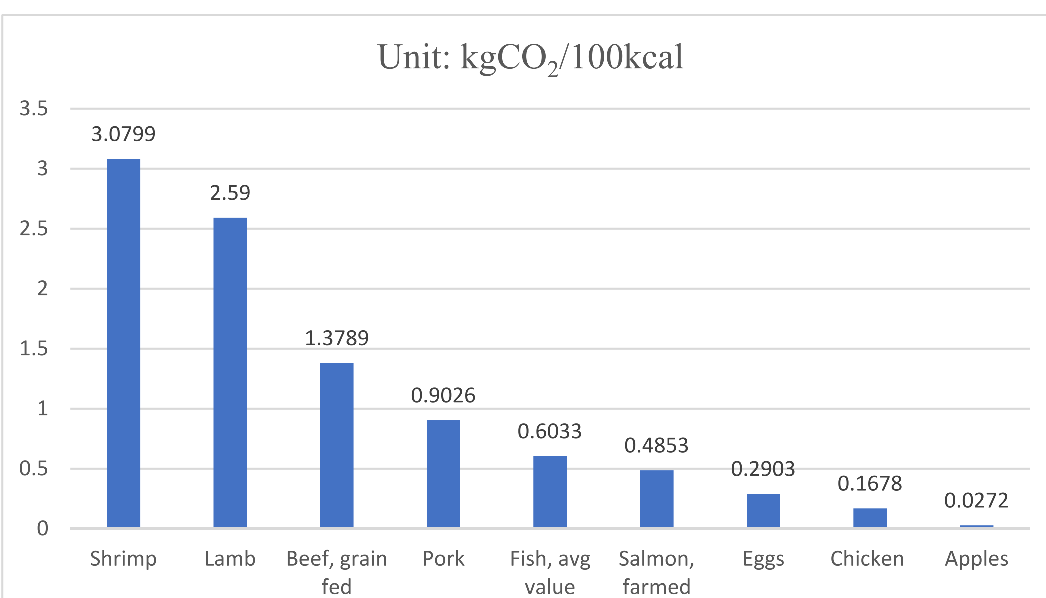

Fig. 2. Carbon Emission of different food production [18].

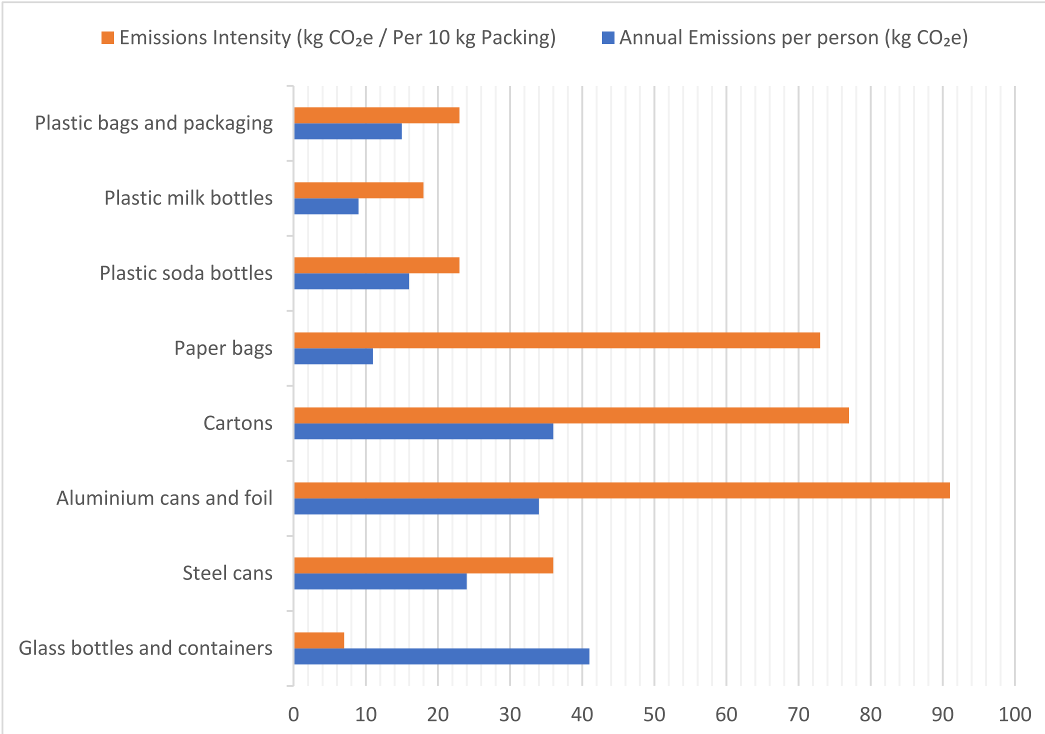

Fig. 3. Life Cycle Packaging emissions.

polystyrene (EPS) trays to package fresh meat [19]. Since the container absorbs blood from the meat, the container is inhabited by microorganisms which makes it more suitable to be disposed of through a landfill instead of recycled. Moreover, containers and packaging were responsible for 31% of U.S. municipal solid waste in 2008, making these materials the highest percentage among solid waste [21].

During material selection, environmental aspects such as land use and non-renewable energy should be taken into consideration instead of solely on the availability and manufacturing cost of the materials. With the increasing environmental awareness of the public, more research studies are being carried out to study biopolymers as an alternative to conventional plastic and polystyrene in food packaging. Some of the more successful examples are polylactic acid (PLA) and polyethylene terephthalate (PET). Not only are they biodegradable, but they are also healthier for consumers since it is less likely for biopolymer packaging to produce carcinogenic components through chemical reactions. On the other hand, the biodegradability of biopolymer packaging solves the problem of conventional packaging, which oftentimes can't be achieved by recycling conventional packaging since it is not biologically and economically convenient as the method of disposal. In terms of CF, it is found that CF produced by polystyrene packaging is 78% higher than that of PLA through life-cycle assessment [19].

An assessment regarding the application of CF was carried out on quantifying the GWP_{100} (100-year Global Warming Potential) in relation to the life cycle of PLA trays for packaging food. In the making of PLA, many GHGs are produced; as a result, an overview of each greenhouse gas contributed to the atmosphere is listed in Table 4. GWP_{100} is expressed in terms of per kg emission, and it's calculated through the amount of emitted or removed multiplied by associated GWP_{100}. In this context, the Functional Unit (FU) was selected to use as a parcel containing 1 kg of trays to be delivered to users for food packaging [19].

From the studies, it's discovered that the production process of 1 kg of PLA trays emits a total of 4.826 kg CO_{2eq}, which in turn accounts for 61.26% of GWP_{100} contribution to the atmosphere in total and 11.16% of GWP_{100} comes from the electricity consumption for production, 14.33% emits from transportation, and other miscellaneous contribution from other processes and materials.

In association with the GHGs in Table 1, it can be seen in Tables 1 and 2 that the GHG with the highest impact is CO_2 in terms of GWP_{100}. Table 1 shows that 83.7% of GWP_{100} comes from carbon dioxide fossil fuels, with the amount 4.039 $kgCO_{2eq}$ against the total 4.826 $kgCO_{2eq}$ [19].

Regarding the CF of food packaging, there are four main stages of the food packaging life cycle to be considered: (1) preparation of raw materials, (2) container fabrication, (3) delivery, and (4) end-of-life. There are some boundaries if the qualitative approach is to be used. For instance, the containers are to be delivered to retailers all over the world; hence there is high variability between the data collected from place to place. Also, it is difficult to collect precise data about their end-of-life disposal due to the sheer amount of daily waste disposal. Due to the limitations stated, the modelling approach is more suitable for investigating the CF of food packaging. Life-cycle assessment (LCA) is particularly a popular choice for CF assessment of any kind [19–21].

2.3. Transportation and distribution of food

Transportation of food from one place to another can be performed through land transportation, ships, or even airplanes. Therefore, the CF produced from how food is distributed and transported can be a major issue for the entire globe.

The food mile, a measurement of the distance required to transport food from where it is produced to where it is consumed, is a critical

Table 1
The types of GHGs [19].

GHG	GWP_{100} per kg emission ($kgCO_{2eq}/kg_{GHG}$)
Carbon Dioxide	1
Methane	25
Nitrous oxide	298
Hydrofluorocarbons	124–14800
Per-fluorocarbons	7390–12200
Sulfur hexafluoride	22,800

Table 2
Amount of most impacting GHGs – Values in kg_{GHG} [19].

GHG	Total Amount	Polylactide granulate, at plant	Butane-1, 4-diol, at plant	Lubricating oil, at plant	Electricity ([a])	Heat ([b])	LDPE bags	HDPE bags	PLA-granulate supply	Auxiliary material supply	PLA-tray delivering	PLA-tray composting
Carbon dioxide fossil	4.039	2.46	1.83E-01	1.92E-04	3.91E-01	1.07E-01	3.61E-02	5.21E-02	6.65E-01	4.80E-03	1.17E-01	2.44E-02
Dinitrogen monoxide	1.295E-03	1.10E-03	2.44E-06	3.81E-09	1.79E-06	1.47E-06	4.97E-07	7.51E-07	3.37E-05	3.61E-07	7.63E-06	1.46E-04
Methane, biogenic	9.034E-03	1.36E-04	2.16E-06	2.71E-09	6.18E-07	2.22E-07	2.47E-06	3.23E-06	3.40E-06	2.58E-08	6.15E-07	8.89E-03
Methane, fossil	8.397E-03	5.22E-03	1.62E-04	6.42E-07	8.80E-04	6.60E-04	1.55E-04	1.53E-04	9.22E-04	6.42E-06	2.03E-04	3.77E-05

[a] Medium voltage, at grid (+imports).
[b] From natural gas burned in a condensing modulating boiler with nominal power <100 kW.

element in analyzing the emission of CF. According to Ref. [22], the longer the food is travelled, the greater the energy is used, and so do the carbon emissions. Moreover [23], investigated that the food mile has increased significantly for the past ten years and believed that it would keep increasing. With that being said, studies have shown that the community's awareness of this issue is still not as noteworthy as it should be. Moreover [24], has found out that approximately 21.5% of the nominated consumers in the UK consider the impact of food mile while buying food, and in fact, 5.6% of the nominated consumers buy food with regards to the country of origin. Contrary to the claim by Refs. [24,25] discovered that consumers tend to ignore information regarding food miles while buying food, although the information is provided. Therefore [25], concluded that it is insufficient to urge consumers to buy food by considering the food mile information provided.

Furthermore [26], as well emphasized the importance of transport and pointed out that the food mile is an important factor for CF and emission. According to Ref. [27], transportation is the biggest contributor to global warming in the United States (U.S.) and most of the developed countries. Based on the calculation of CO2 emissions from transportation for the year 2017 performed by the U.S. Department of Energy (DOE), the emissions were found to be more than two billion metric tons. In the case of food transportation, they investigated that food transportation may be responsible for about 50% of the total carbon emissions. This 50% of carbon emissions involve all the transportation used in the food supply chain (Fig. 4) [27].

It is also noticeable that different modes of transport contribute to a different amount of CF [27]. mentioned that the four basic transport modes for shipping a huge quantity of food in most developed countries are rail, trailers, ships, and air cargo. Therefore, the increased use of transportation has inevitably led to a dramatic increase in the emission of CO_2 in 2002 with an amount of 19 tonnes which is a 12% increment from the year 1992 [23]. reported that the air cargo mode of food transportation pollutes the environment the most, and its usage has been increasing steadily every year since it started. Studies have also been done on the emission of CF from different food transportation modes in the UK. The transportation modes include heavy goods vehicles (HGV), cars, vans, sea transportation, and air transportation. In 2010, UK HGV had the highest CO_2 emission of 29%, followed by car (23%), sea transportation (15%), air transportation (12%), and overseas HGV (12%) (refer to Fig. 5) [27].

It's good to note that carbon emission differs for food items to transport to the same distances based on their types. Packaging is a part of this issue as liquid or semi-solid food items need more intense packaging, which contributes to the increase of CF. At the same time, meat or animal-based food products need to be transported at a regulated temperature which also impacts the carbon release to the environment. However [8], showed that the production and processing of several food items contribute about 82% of the total carbon emission, followed by cooking and transportation come in 3rd place.

2.4. Food acquisition and consumption

CFs are contributed during the use of food as well, be it acquisition, preparation, or consumption of food. Thus, this section will investigate each process of food usage and carbon emissions. The acquisition of food involves the action of purchasing food from the store with

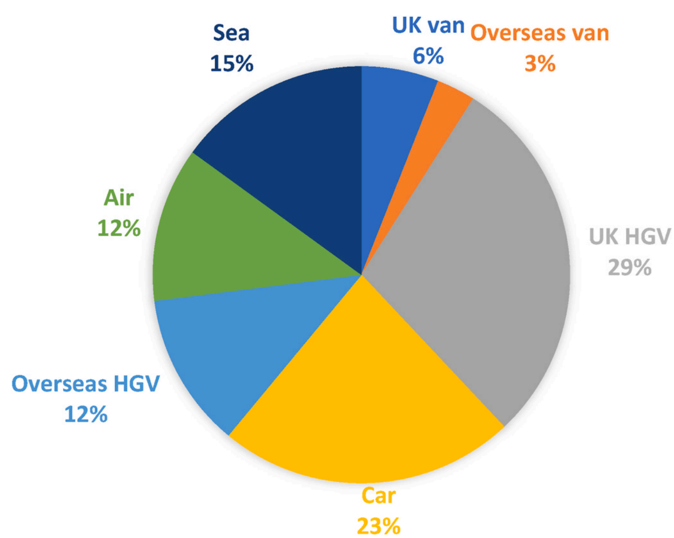

Fig. 5. Tabulation of CF emission from different modes of transportation.

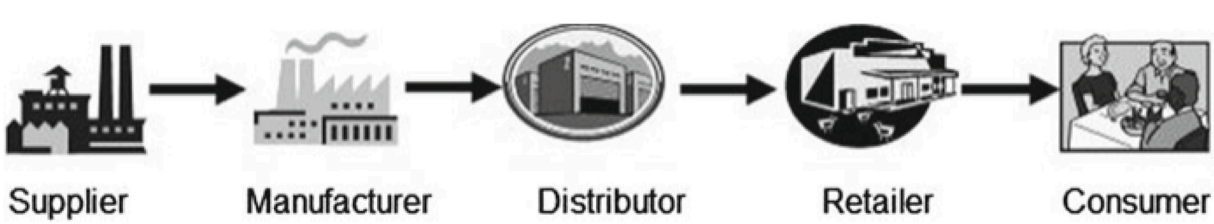

Fig. 4. Food supply chain [27].

transportation. According to Ref. [28], the acquisition of food has the most influence on the emission of CF due to the use of motorized vehicles to transport the food from and to the store. He further mentioned that this particular action emitted 9.54 × 10^8 kg in Norway, exceeding the CF emitted from the use of freezers, electric stoves, and ovens [28]. The preparation of food involves the action of cleaning, prepping, and cooking. These actions combinedly contributed 105 MJ per kg, which is due to the loss of energy during the process of preparation [29]. This value then leads to a high emission of CF which is approximately 447 kg CO_2-e per household for a year [28].

According to Ref. [20], although the production and transportation of ingredients are responsible for most of the CF emissions, the energy used to transform these ingredients into edible food is one of the major contributors too. This stage involves storage, cooking, and clean-up. According to a study done by Ref. [15] in China, it was determined that the CF imparted solely from the consumption of food was 379.6 kg per capita per year. Furthermore, it was also reported that the amount of energy used in the kitchen occupied about 15% of the average CF emitted by Americans. Besides, consumption of food occurs either in the home or in food services restaurants, bars, food trucks, catering companies, and some other establishments that serve food and beverages [29].

By looking into a smaller picture, it was examined that the CF produced between eating at home and dining out is different, whereby emissions are higher when dining out. It was further explained by the dietary pattern difference where the food prepared outside tends to contain fatter content and lesser carbohydrate. However, it was also found that the dietary pattern in China, be it eating at home or dining outside, exceeds the recommended diet with regards to CF emission, which is set at 0.72 kg per capita for one meal [29]. On the other hand [30], studied the relationship between price and CF emission of food and found out that every dollar spent on food leads to an approximated CF emission of 0.7–1.6 g N. Using the information from the studies of [15, 30], it can be theorized that dietary habit is a major factor towards the emission of CF.

On the other hand, an analysis of the CF emitted by home kitchen usage has also been performed [20]. It was found that refrigeration emitted the most CF annually per household, with a value of 653.17 kg (refer to Fig. 6). Besides, it was also mentioned that old fridges or freezers tend to emit more CF due to the reduction in efficiency through their lifespan [20].

In addition, the industry of food and beverages in British Columbia (BC) consists of more than 12,500 businesses where approximately 153,000 people are employed. Moreover, it was investigated that more than 450,000 tonnes of CO_2e were produced merely from this sector in BC.

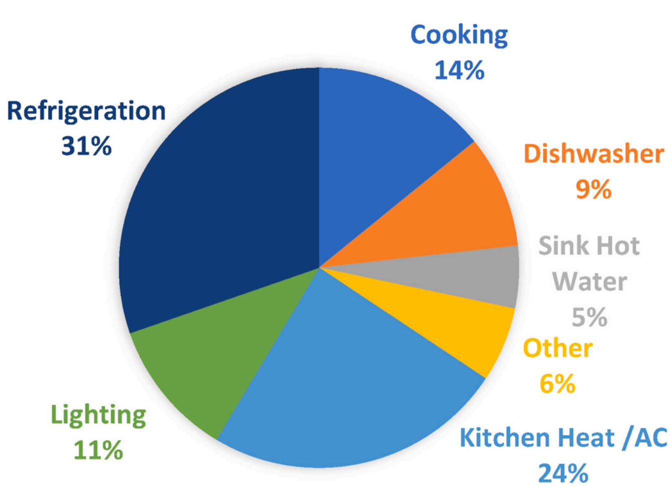

Fig. 6. CF emission by preparation of food.

From this section, it can be seen that the acquisition of food tends to emit a higher amount of CF between the preparation and consumption of food. Therefore, it is advisable to acquire food through other methods instead of transportation, and these methods will be discussed in the later section [30].

2.5. *Food waste*

Food waste has been a critical issue for a long time, but not many initiatives have been taken to resolve this issue other than composting. It was investigated that roughly 40% of food is wasted in the U.S., and at the same time, there are approximately 20% of Americans are struggling to have a decent meal. This section will look into the scale of food waste.

The study done by Ref. [31] investigated that there are about 1.3 billion tonnes of food waste produced per year [32]. further suggested that the global CF of annual food waste is about 3.3 Gt CO_2 equivalents (CO_2e). Food waste occurs at all stages along the food supply chain (FSC), such as extraction, processes of production, distribution, and food waste produced at home or retail [33]. The composting of food wastage, however, contributes to the increased emission of methane and CO_2, leading to global warming [34]. In total, 90 tonnes of food waste were generated annually per retail store, where each store produced an associated CF wastage of 2500 t CO_2-e. This amount corresponds to 46% of the overall wastage from both meat and bakery stores. Other sectors, such as hypermarkets, agriculture, industrial, etc., generated a maximum food waste of 15% annually, which can be considered low compared to other sectors [31]. According to Ref. [35], the main cause of food waste is serving waste. The food services centre is the biggest contributor to food waste production. Based on the data regarding the generation of waste collected by the Danish Government in 2013, it was found that there is at least 60% of the food waste was generated by the food service sector [36]. This is due to the leftovers from the customers' plates, the self-service buffet, and the overproduction of food. Furthermore, it was investigated that the total amount of food waste accounts for 67% of the total waste produced in corporate offices and facilities. These sources of food waste here are the company's self-service canteen and food that was either brought by the employees or delivered by food delivery services. On the other hand, there is a report regarding the level of source-sorted food waste where it was found that food waste produced in households was higher as compared to office areas. For instance Ref. [38], found out that the level of source-sorted food waste in residential areas is 35% higher than in food service sectors in Sweden. Despite that, the amount of waste generated in the food service sector could be significantly higher than in households in the long run, as according to Ref. [36], the amount of waste generated is highly dependent on the number of workers and members in both the food service sector and households.

Thus, it indicated that the food service sector generates the highest percentage of food waste, which eventually contributes the most to CF.

2.6. *Impact on carbon footprint*

Based on what was discussed in the previous sections, despite the fact that extraction of raw materials, processing and packaging of food, usage of food, and food waste contributes a lot towards the total emission of CF, the distribution of food was identified to be the biggest contributor. This is mainly due to the use of transportation, which consumes a massive amount of fuel as compared to other stages. As mentioned earlier, food distribution is accountable for 50% of the total carbon emissions. If mitigations were to be implemented to improve how food is transported, it is certain that CF would be significantly reduced. These mitigations will be discussed in the later sections.

3. Methodology

This article is written using two different approaches. First, a comparison of CFs between regular diets and then diets and sources in different regions is presented. A systematic Literature Review (SLR) was done based on the available literature and academic resources published in this field. After that, information on improvements in lowering CFs is explained. The information collected can be divided into two main parts: logistics and consumption. Collection and management of Food and related materials were covered under logistics, where data ranging from raw materials extraction to waste production were considered. The carbon emission from the extraction and transportation of various food products from the sources to the processing facilities was collected from various published research based on certain amounts and categories of food items. The transportation through land, sky, and sea medium was discussed for both animal, and plant-based foods and food waste disposal was considered as well. Consumption, however, is again divided into a few sections based on cuisine and demographic. Food items are prepared in different ways in different cultures; therefore, the data on carbon emission was collected for food items per processing and cooking as well.

Finally, the data for waste food products was taken for the food that was not consumed before and after the preparation of meals. The data was collected from the municipal waste collection reports for household waste production and industrial production reports as well. The carbon emission from the composting process of kitchen waste or from farming has been grossly estimated based on available data.

Bibliometric analysis was followed to determine global trends in the field and to assess the quality of the work by gathering and evaluating quantitative data on the number of documents published by institutions, countries, research groups, and individuals with the highest scientific productivity.

3.1. Comparison of carbon footprint between our regular diets

Livestock farming has been found to be a major anthropogenic source of pollutants that affects the environment, with GHGs by-products such as CO_2, CH_4, NH_4, and N_2O emitting into the atmosphere. Rearing livestock impacted the environment both directly and indirectly, from the enteric fermentation in ruminant animals and their urinal output to the carbon dioxide emission due to fertilizer production and processing and transportation of livestock products [29].

This section discusses the differences between levels of CF emission of different diets. The two main diets used in this study to compare the level of CF are meat-based diets and plant-based diets. Other additional diets, such as soft-diet, residue-free diets conducted in a hospital, are also considered in the scope of this study.

In the meat-based diet, there is a meat lover who consumes a heavy amount of meat, an average regular meat-eater, and a meat-eaters who refrains from beef. In a plant-based diet, there are vegetarian and vegan. All information obtained in this section is based on data from the United States, the United Kingdom, and Spain [29].

3.1.1. Carbon footprint on meat-based diet

In America, a heavy meat eater's diet contributes 3.3 tons of CO_2e to the atmosphere each year. An average diet, based on a typical American diet, contributes 2.5 tons of CO_2e each year per person. Americans who consume other kinds of meat but avoid beef account for 1.9 tons of CO_2e, which is 1.4-ton CO_2e less in comparison to a meat lover's diet [29].

The diet of an average vegetarian in America contributes 1.7 tons of CO2e yearly to the earth's surface. A vegan's CF accounts for 1.5 tons of CO_2e, making it the lowest CF contributor in the list of diets in the United States [9]. A bar chart, as shown in Fig. 7, was plotted to highlight the different levels of the five diets' CF [29].

For the meat lover, beef consumption is half of the total footprint of a vegan's diet. As seen in the meat-eater but refrain from the beef diet, replacing beef with chicken, fish, and pork in the diet could reduce CF emission by a quarter. The difference between vegetarian and vegan diets comes from replacing dairy consumption with cereals and bread.

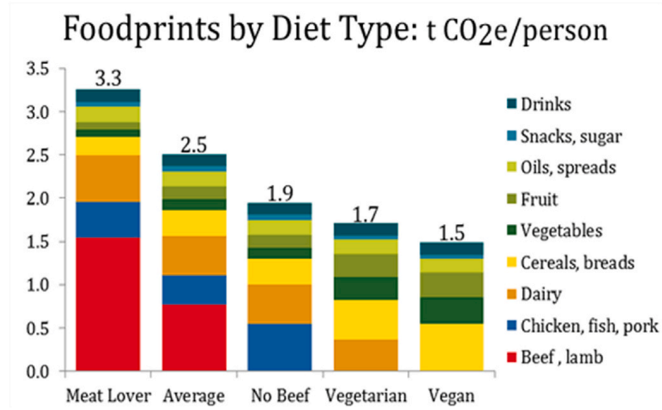

Fig. 7. CF of five diets in the US, in tons of CO_2e per person [37].

The carbon intensity of food consumption is the main reason that the five diet's footprints differ so widely. Before obtaining in terms of tons of CO_2e per person, the CF intensity of each diet is calculated by first converting (kg CO_2e/kg) to (CO_2e/kJ, as shown in Fig. 8.

In Fig. 9, it can be seen that beef, has the highest carbon intensity of food energy, followed by fruits, dairy, and chicken. Beef cattle have the highest level of CF because of the digestive process known as enteric fermentation. In the rumen, a high level of methane is produced as a by-product, which is a GHG that contributes to climate change. Cereals, oils, and snacks, in contrast, are the least carbon-intensive, and they are both part of a vegan-based diet [39].

A case study to evaluate the CF of hospital menus for patients in Spain also shows that beef scores the highest in line for CF index, ranging from 9 to 125 kg CO_2 per kg carcass weight. The reason why beef scores so high is because of the process of fermentation in the rumen of ruminants which produces the GHG methane. It is found in the studies that the production of 1 kg of extensively farmed beef is bad and results in three to four times as many greenhouse gas emissions [40].

The CF level of different parts of the cattle varied and was categorized by typical cuts in stakes, roasts, ground beef, and stew meat. The same studies show that pork produces a medium CF. From the studies, its reported values of around 5 kg CO_2 eq per kg CW are reportedly mainly due to the N_2O emissions from feed production [40].

3.1.2. Carbon footprint on plant-based diet

In a 2014 paper, Peter Scarborough and his team conducted a study on the CF of different diets in the UK. The subjects were 29,589 meat eaters, 15,751 vegetarians, 2041 vegans, and 8123 fish eaters between the ages of 20–79 years old. From this study, a few findings were found. An average heavy meat eater is classified as one who consumes at least 3.5 ounces of meat each day. From the findings, such a diet produced an equivalent amount of 15.8 pounds of carbon dioxide. An average medium meat eater, on the other hand, produces 12.4 pounds of CF. In comparison to a heavy meat eater's diet, an average vegetarian diet produces 8.4 pounds of carbon dioxide each day. That is close to half of as much CF a heavy meat eater diet usually generates. Vegan diets, on the contrary, rank the lowest in footprint level, with the equivalent of 6.4 pounds of carbon dioxide emission per day. The average vegan diet's CF was around 60% lighter than the average meat eater diet in the UK.

The average fish-eater diet, however, is rough as climate-friendly as the average vegetarian diet, with only a small variation of a 2.5% difference [41]. From these four points, one can draw the conclusion that diets lighter in meat will produce a smaller level of CF in general. A bar chart, as shown in Fig. 9, was plotted to show the difference.

3.1.3. Case study: carbon footprint emission of patient's diets in a Spanish hospital

A case study conducted in Spain that seeks to quantify the CF of

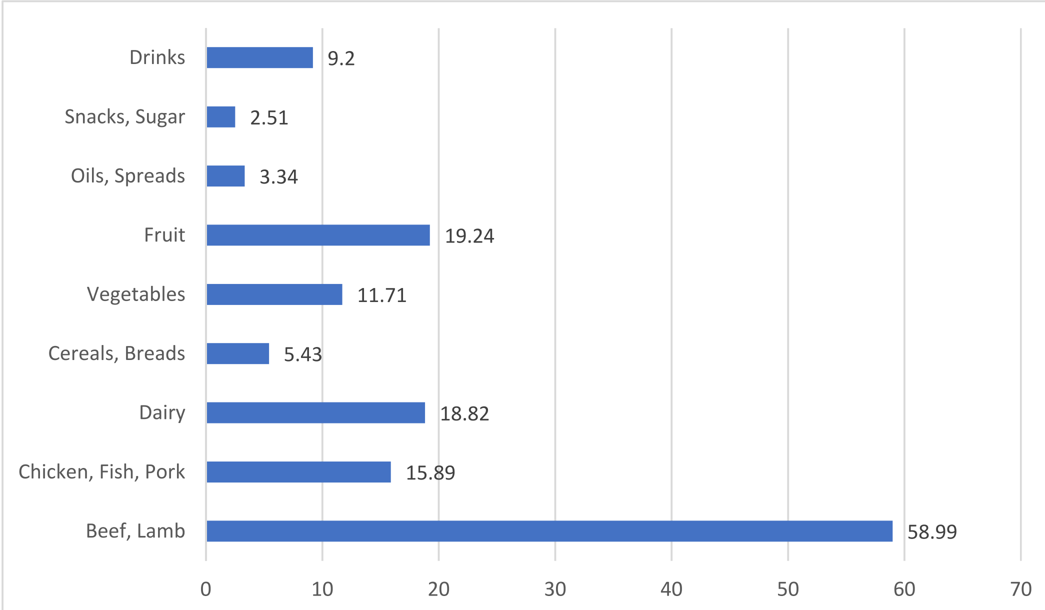

Fig. 8. Carbon intensity of food eaten in terms of grams CO_2e per kiloJoules of five diets in the US [37].

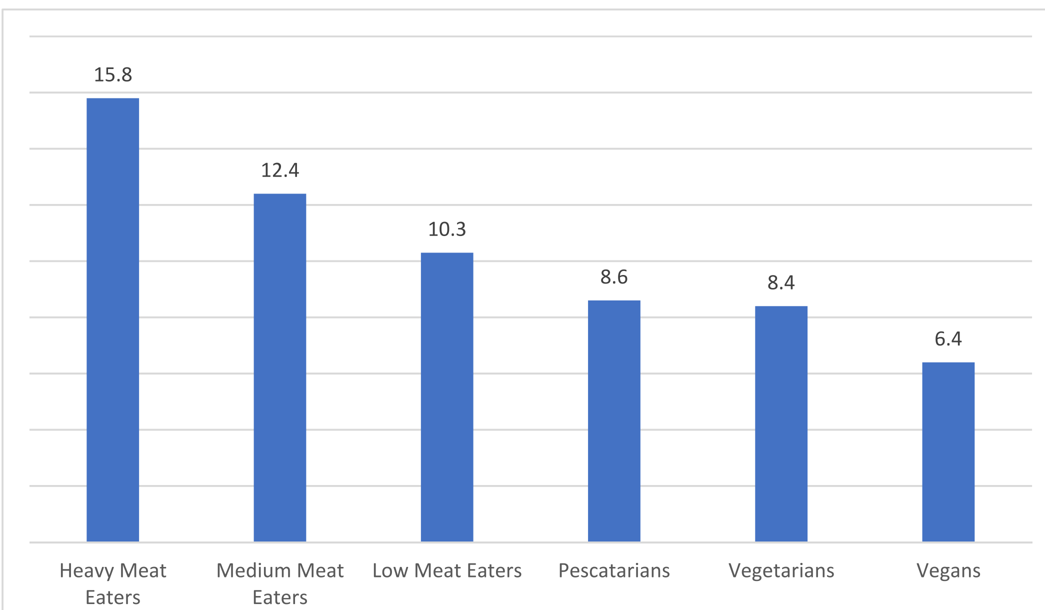

Fig. 9. Various diets' footprint in pounds of CO_2-eq/day [39].

different patient diets in a hospital was selected and used to further contrast the levels of CF of different diets. In this context, CF is defined as the total amount of carbon dioxide emitted (CO_2 eq) expressed in terms of the total amount of GHGs emission, based on the principles of the Global Warming Potentials (GWPs) supplied by the Inter-Governmental Panel on Climate Change (IPCC) [40]. The average carbon dioxide emission per person of a normal diet was based on comprehensive composition data in Juan Ramón Jiménez Hospital in Huelva, Spain [40].

From Table 3, it can be observed that diets high in protein tend to have a higher level of CF. A high protein diet has an 8.112 kg CO_2 eq footprint. A normal basal-based diet has a 5.083 kg CO_2 eq of footprint, and a liquid diet has the lowest footprint level, at 1.652 kg CO_2 eq. Other diets, which are residue-free, hepatobiliary protective, and low-protein diets, have moderately high CF levels but are not as high as high-protein diets.

Among the food which contains a high level of protein, meat is one of the major sources of protein, and previously it is known that diets higher in meat have a higher footprint. This study draws a comparison with the previous studies that diets higher in meat have a higher footprint, and diets higher in protein also contain higher in protein [39].

3.1.4. *Results and findings of different diet footprints*

The rearing of livestock is a major contributor to greenhouse gases and global warming. It is foreseen that the number of livestock rearing and meat production will only increase in the future. As a result, the carbon dioxide production contributing to climate change will also increase, ultimately leading to a rise in global temperatures [29].

The current diet scenario between plant-based and meat-based is not environmentally sustainable, as it is evident from the studies above that

Table 3
Summary of CF in 18 different hospital diets [40].

Menu	CF (Kg CO_2 eq/daily diet)
Normal or basal diet	5.083
Salt-free normal diet	5.081
Liquid diet	1.652
Semi-soft diet	2.781
Soft diet	3.839
Gastroprotective diet	4.696
Liquid anti-diarrhea diet	0.473
Broad anti-diarrhea diet	2.385
Residue-free diet	5.143
Residue-rich diet	4.909
Hepatobiliary protective diet	5.389
Low-protein diet with 20 g of protein	3.028
Low-protein diet with 40 g of protein	4.179
Low-protein diet with 60 g of protein	5.304
High-protein diet	8.112
Hyperuricaemia diet	4.718
Diet for bowel inflammation	5.684
Gastrectomy diet	4.386

a meat-based diet especially containing beef, produces a much higher level of a carbon footprint than a plant-based diet.

From the three different studies conducted, one thing in common that can be observed in diets heavy on meat has the highest level of CF, whereas diets lighter in meat and more inclined towards plant-based have a smaller footprint. The vegan diet has the lowest CF level. Red meat, such as beef, has the highest level of CF among all other meats [29].

3.2. Comparison of carbon footprint between regions: diet

The dietary patterns in every region vary with regard to the content of the food intake. For instance, there are some regions where the citizens consume more plant-based food than other regions and, thus, contribute less towards the CF. This section will investigate the dietary patterns and their contribution towards CF mainly in three regions: India, China, and Italy.

3.2.1. Indian dietary patterns

Indian diet is mostly influenced by religion and tradition. As one of the Hindu religion countries, Most Indian is vegetarian as they avoid taking beef and pork. However, there are still many Indians that implements mixed diet, such as meat mixed with vegetables. According to Ref. [41], Indians mostly consume fresh foods that are produced locally. Livestock and rice production are the main sources of greenhouse gases emission in India. India eats a lot of livestock products, including mutton and milk. However, mutton accounts for the highest demand among Indian food options, followed by rice and milk [42]. Table 4 shows the ingredient needed for the preparation of certain foods that were common in Indian households [43]. According to Ref. [44], among the food consumed in Indian households, mutton produced the highest GHG emission with a value of 482.5 g kg^{-1} CH_4, while rice produced 53.7 g kg^{-1} and milk produced 29.2 g kg^{-1} (Table 5).

In other words, mutton has the highest GWP per calorie food intake (5301 g CO_2 eq. cal−1), followed by egg, milk, and wheat. The result in Table 6 shows mutton is the highest with GHG intensity with regard to the price at the value of 51 g CO_2 eq. Rs.−1, followed by milk (31 g CO_2 eq. Rs.−1) and wheat (19 g CO_2 eq. Rs.−1) [43].

3.2.2. Chinese dietary patterns

This paper has also looked into the comparison of CF distribution of

Table 5
Emission of greenhouse gases due to the production of various food products [44].

Crop/animal product	GHG emission (g kg^{-1})			
	CH_4	N_2O	CO_2	GWP (CO_2 eq.)
Wheat	0.0	0.3	45.0	119.5
Rice, Basmati	43.0	0.2	75.0	1221.3
Pulse	53.7	0.3	82.5	1515.4
Potato	0.0	0.8	83.3	306.8
Cauliflower	0.0	0.1	10.0	24.9
Brinjal	0.0	0.1	12.5	31.1
Oilseed	0.0	1.3	50.0	422.5
Poultry meat	0.0	2.7	50.0	846.5
Mutton	482.5	0.0	0.0	12062.7
Egg	0.0	2.0	1.0	588.4
Milk	29.2	0.0	0.0	12062.7
Banana	0.0	2.0	1.0	71.6
Apple	0.0	1.0	41.7	331.4
Spice	0.0	2.5	100.0	845.5
Fish	25.0	0.3	18.8	718.3

Table 4
Ingredients used for the preparation of foods that were commonly consumed in Indian households [42].

Food Item	No./Quantity	Ingredient (fresh weight, g) (Main)	Water for preparation (g)	Product Fresh weight (g)	Product dry weight (g)
Chapatti	4	100	40	140	90
Bread	2	60	20	80	54
Paratha	2	100	60	220	144
Burger	1	75	25	170	131
Rice (ordinary)	One plate	100	45	145	88
Rice (basmati)	1 plate	100	40	140	88
Dosa	1	50	50	110	53
Idli	1	25	25	50	22
Pulse	1 cup	30	100	140	37
Sambar	1 cup	30	100	155	51
Potato	1 cup	120	25	155	26
Cauliflower	1 cup	100		110	17
Brinjal	1 cup	100		110	13
Poultry meat	One plate	100		120	39
Mutton	One plate	100		130	39
Fish	Two pieces	100		115	33
Egg	1	50		50	25
Omelette	1	50		56	25
Milk	One glass	250		255	33
Curd	1 cup	100		100	10
Lassi	1 cup	50		115	7
Butter	One spoon	10		10	8
Apple	1	100		100	15
Banana	1	100		100	10

Table 6
Emission of greenhouse gases per calorie for food consumption and their emission intensity [43].

Food	GWP of food (g CO2 eq. kg)	Food Value (cal kg-1)	Emission intensity for food value (g CO2 eq. cal-1)	Price of Raw food (Rs. Kg-1)	Emission intensity for the price (gCO2 eq. Rs-1)
Wheat	351	3410	0.10	18	19
Rice	1424	3330	0.43	25	57
Pulse	970	3250	0.30	80	12
Vegetable	171	300	0.57	25	7
Milk	782	680	1.15	25	31
Apple	357	560	0.64	80	4
Sugar	845	4000	0.21	40	21
Oil	423	9000	0.05	70	6
Mutton	12,352	2000	6.18	240	51
Egg	668	1750	0.38	70	10

different diets with regard to human consumption behaviour in China. The different diets are animal-based products and plant-based products. According to Ref. [45], the CF of rice was the highest among plant-based products due to CH_4 emissions from paddy cultivation. Besides, they further elaborated that the CF produced by animal-based products was massive. Thus, this indicates that keeping more vegetables on the menu comparatively helps reduce GHG emissions. The composition of plant-based food and animal-based food is found that the field emission made up to 72% CF, with rice having the highest CH_4 emission of 765.17 g CO_2-eq/kg. On the other hand, the composition of CF for the animal-based product is totally different from other products, where the major carbon emission was generated through chicken, eggs, beef, mutton, and pork processing [45]. Mutton and beef were the biggest contributors to CF emissions as they account for 25,281.91 g CO_2-eq/kg and 20,577.26 g CO_2-eq/kg, respectively, followed by pork and eggs. However, CFs had not been allocated by energy to present the compositions of carbon [46]. Food supply quantity and dietary greenhouse gas emissions in China are found. The animal-based products emitted 1.8 times more CF emissions than plant-based production, particularly beef, chicken, wheat, and mutton, as they contributed the most GHG emission [47]. However [41], suggested that reducing the consumption of these foods will help to cut down the total GHG emission.

3.2.3. Italian dietary pattern

According to Ref. [48], livestock production is the main problem of anthropogenic emissions in Italy. The CF produced was approximately 7.1 Gt CO_2/year. Moreover, beef production accounted for about 2.8 million tons per year, which is 65% of the total livestock production [48]. Italy is found to be the second largest contributor to GHG emissions, accounting for around 6.9% of total anthropogenic emissions in 2011. However, this 6.9% will be increased the beef cattle production activity was widespread in Italy starting in 2014 [49].

In 2017 [50], performed a comparison between feed production, beef production, and manure management and found that beef production generated the highest CF percentage of total CF. In addition, it was further mentioned that there were two types of beef production systems: conventional (CON) and organic (ORG). The calculation of these systems showed that the ORG system produces more GHG emissions than the CON system, where the values were found to be 24.62 kg CO_2 eq/kg live weight and 18.21 kg CO_2 eq/kg live weight, respectively. Thus, it is clearly seen that beef production is principally responsible for the GHG emission from the Italian agricultural industry [50].

3.2.4. Differences between diet structure and Carbon Footprints

Indian diet structure consists of vegetables, mutton, milk, and rice. Out of which mutton and milk contribute to the large amount of GHG emission of 12062.7 GWP. Since India grows a large amount of rice so, when accumulated, it can also contribute a large amount of GHG emissions of 1221 GWP [6]. On the other hand, the Chinese diet consists of mutton, beef, chicken, eggs, and pork. Where mutton and beef are major contributors, with 25.28 kg CO_2-eq/kg meat and 20.57 kg CO_2-eq/kg meat, respectively, GHG emissions. Moreover, the Italians mostly consume beef as their primary source of diet, which is a major contributor to GHG emissions resulting in 7.1 Gt CO_2/year CF.

3.2.5. Section summary

Through the findings of dietary patterns of CF for various countries, CF could be regarded as a crucial indicator in quantifying the impact of foods on global warming. From the discussion above, it was found that animal-based products contributed higher CF as compared to plant-based products. In particular, mutton and beef are the highest CF contributors among animal-based products, with a combined amount of 26,000 g CO2eq/kg. Moreover, citizens of certain countries with a dietary pattern containing high animal protein such as milk, egg, and cheese production were also identified to be a huge CF contributor as compared to countries that implement a vegetarian diet. In contrast, a plant-based diet is 111 times lower CF than animal-based products. CF of plant-based products varied from 223.03 g CO2eq/kg to 1.646 kg CO2eq/kg. Therefore, it is obvious that some parts of the world are contributing to more CF by having an animal-based diet frequently on the menu. To reduce the CF, improving and innovating farming techniques, processing and transportation technologies, and dietary behaviour must be revised by taking collective measures.

3.3. Comparison of carbon footprint between regions: sources

All stages of the dietary supply chain contribute to the emission of CF. However, the level of footprint contribution between countries and regions is different from the footprint contribution of the dietary supply chain. This is due to the differences in the density of population, land availability, monetary capacity, and the effectiveness of mitigating actions undertaken by the countries. Therefore, this section will investigate the source of CF in different countries or regions. Comparisons between countries and regions will be provided, assessing the three sources of CF in the food supply chain, namely extraction of raw material, distribution of food, and food waste.

3.3.1. Crop and livestock production

The CF emissions from the agricultural sector in different countries are highlighted in a dark colour, as shown in Fig. 10. According to the [51], China is the highest contributor of agricultural emissions in the world and is responsible for approximately 750 Mt CO_2e of agricultural emissions. This is followed by Brazil (500 Mt CO_2e), India (475 Mt CO_2e), the United States (450 Mt CO_2e), and Indonesia (175 Mt CO_2e). In terms of per-capita emission, it was found from these same studies that countries with larger livestock populations relative to the human population tend to have a higher per-capita emission. A few examples of countries include New Zealand, Mongolia, Australia, and South America. Agricultural production is categorized into two types for analysis, namely, crop production and livestock production. For comparison, all CFs are measured in kg CO_2e/kg [51].

In China, crop production has contributed from 353.0 Mt CO_2e to 648.8 Mt CO_2e of CF, which has accounted for approximately 60% of the total CF [13]. Paddy rice, wheat, maize, and soybean are the main crops produced in China. Rice paddies were the major contributor to CH_4 emissions from 1979 to 1999 but were superseded using synthetic fertilizers in 2009. The CF produced by crop production in the 30 years had increased from pesticide production, direct use of energy, applications of manure, agricultural film, synthetic fertilizer, agricultural facilities, and reuse of crop residues in the field. According to Ref. [14], the carbon emission of rice production ranked the highest, with 1.571–2.355 kg CO_2e/kg food in 2009. This is followed by fruit production and oil crop production with 0.8012–2.229 kg CO_2e/kg food and 0.320–0.640 kg CO_2e/kg food, respectively [13]. On the other hand, fertilizer use in crop

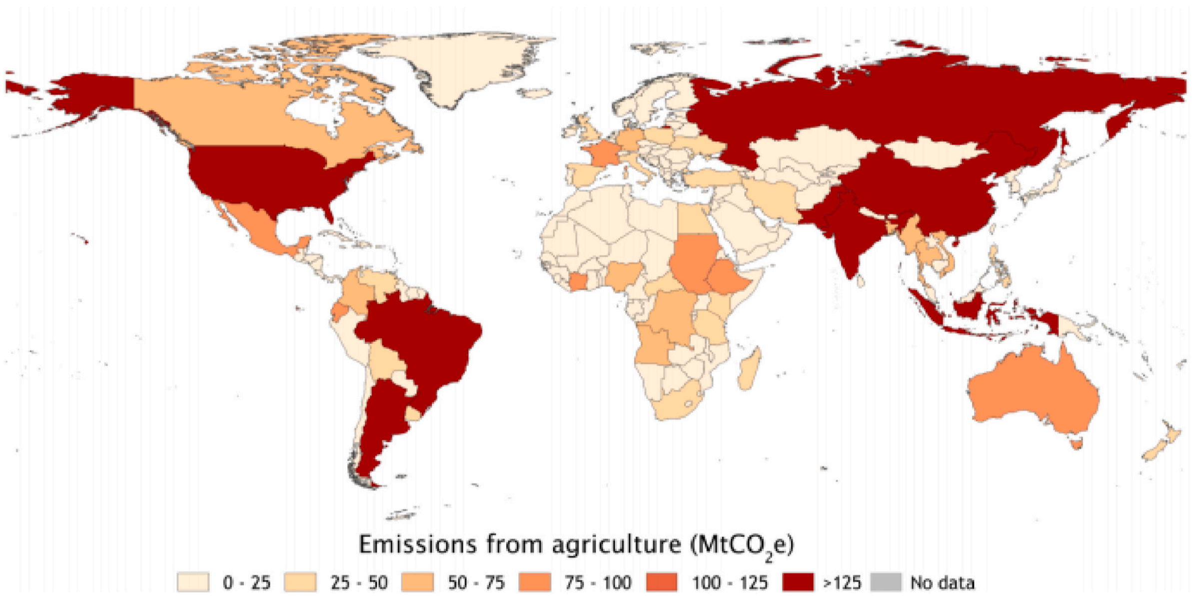

Fig. 10. Emissions from agricultural production in different countries [51].

production has contributed to 57% of the total crop production in China [52]. The application itself has contributed to 44% of the total CF in rice production [53].

In India, agricultural production is one of the main contributors to CF, which has accounted for 18% of the total CF of the country in the past [54]. Rice, a staple food among the people of India, plays a significant role in contributing to CF in crop production, with an average of 5.65 kg CO_2e/kg of food. Other crop productions are cereals, fruits, and vegetables, which account for less than 1 kg CO_2e/kg food production of CF. For example, the production of wheat, as included in cereal, has a CF of 0.34 kg CO_2e/kg food. The main reason for such a high level of CF in rice production is the greenhouse gas CH_4, which emits during the process of rice management. It was also found that the process where continuous flooding of rice paddies generates more CH_4 emissions than the frequent period of water drainage. Other than rice management, the variation in the application of fertilizer is also one of the major sources of CF. However, the application of fertilizer has only contributed to less than 10% of the total CF in rice production. On the contrary, fertilizer use has accounted for 75% of CF in wheat production [41].

Rice has been the staple food for most Asian. With rice as the main crop production for both China and India, the emission of rice production in India (5.65 kg CO_2e/kg food) is found to be higher than the emission from China (approximately 2.45 kg CO_2e/kg food). This may be due to the inefficient rice management technique adopted by India, as mentioned above. Nonetheless, the cropland area of India (115,733 ha) is greater than the cropland area of China (55,874 ha). Subsequently, the net emission of the cropland soil of India (8484 Gg CO_2e) is higher than the net emission of the cropland soil of China (1052 Gg CO_2e) [55].

In China, CF derived from livestock production has accounted for 192.9 Mt CO_2e to 480.2 Mt CO_2e [13]. Beef has the highest CF per food among all livestock products, with an emission of 21.71 kgCO_2e/kg food in 2009. This is followed by mutton and pork, with CF of 20.82 kg CO_2e/kg food and 2.89 kgCO_2e/kg foods in 2009, respectively. The emission is mainly sourced from enteric fermentation and manure management, which accounts for 61.14% of CF. Feeding is also the largest emission source in China. In 2009, the CF accounted for 13.78% of milk production and 33.32% of pig meat production [55].

In India, emissions from livestock production are higher than emissions from crop production [41]. Mutton has the highest emission per food among livestock products, with CF of 45.54 kg CO2eq/kg food. This is followed by poultry meat and egg, both with CF of 2.59 kg CO2eq/kg [54].

Livestock product contributes to more dietary emissions than ruminant meat, even though ruminant meat has the largest emissions per food. Due to low consumption, emission from ruminant meat only accounts for 0.4% of the total emission from agricultural production (12.5%) in India. The emission from livestock production is mainly derived from feed inputs, where for example, the production of milk and poultry falls within the range of 0.8–2.4 kg CO2eq/kg food and 2.5–6.9 kg CO2eq/kg food, respectively. Other sources of emission include manure management and enteric fermentation [41].

In America, emission from livestock production is also higher than emissions from crop production. The highest emission per food is derived from mutton, which accounted for 20.44 kg CO2eq/kg food in 2010 [57]. This is followed by beef and pork, with an emission of 15.25 kg CO2e/kg food and 4.62 kg CO2e/kg food [56]. Beef, as a staple of the American diet, contributes more to dietary emissions with the emission of approximately 31 kg CO2eq/kg food. In terms of livestock production, mutton ranked first in terms of per-food emission in India and America. However, India (45.54 kg CO2eq/kg food) has the highest emission per food than America (20.44 kg CO2eq/kg food) and China (20.82 kg CO2eq/kg food). On the other hand, beef production ranked first among the emission sourced from livestock production in China, with emissions of 21.71 kg CO_2e/kg food. The emission is also higher than the emission from America, with an emission of 15.25 kg CO2eq/kg food [58].

A) CF Mitigation by Crop and Livestock Production

Crop and livestock production can provide some mitigation for each stage of the food life cycle. To quantitatively justify the impact of crop and livestock production on each stage of the food life cycle, we can use the life cycle assessment (LCA) methodology. LCA is a standardized method for quantifying the environmental impact of a product or service throughout its entire life cycle. By applying the LCA methodology to crop and livestock production, we can estimate the greenhouse gas emissions associated with each stage of the food life cycle.

[59] put forth an LCA4CSA methodology that was put to the test in southern Colombia for small-scale family farming systems that produced coffee, cane, and small cattle. The Life Cycle Assessment (LCA) and multi-criteria assessment techniques serve as the foundation for this methodological framework. In this instance, the procedure involved using compost created from coffee processing waste. By taking into

account activities that take place on and upstream of the farm, the assessment at the agricultural system level made it possible to determine the mitigation potential associated with the use of compost (between 22 and 41%). Because of the substantial importation of cereals, it was determined that farms with livestock units might reduce their emissions even more by altering the diets of the animals. For these farms, compost's potential for mitigating climate change was only 3%.

Additionally, to put LCA into a future context [60], devised a method that combines LCA and qualitative scenarios. This method was used for the LCA of a technology created for the FOX project that produces apple juice. In the same study effort, qualitative scenarios for the European agri-food industry in 2035 were developed. When comparing two local alternatives, apple cultivation and energy use for juice processing carry the majority of the environmental impact, regardless of the manufacturing line. Yet, compared to a comparable small-scale stationary apple juice processing plant, FOX technology was 20% more ecologically friendly, whereas adjustments in transportation and operation only had a 5% impact.

3.3.2. Distribution of food

Transportation occurs in almost every stage of the dietary supply chain and has a paramount impact on the emission of the food and beverage sector [61]. Transportation mode is more important than the distance travelled since different modes of transport are powered by different quantities of fossil fuels. Transportation by air has the greatest environmental impact among the food transportation options, although such an option is rarely used. This is followed by the use of heavy vehicles, rail, and sea transportation [62].

In 2003, it was reported that food distribution accounted for approximately 2.5% of the total CO_2 emissions in the UK. On the other hand, car-based food shopping and transportation of domestic food waste have accounted for 0.72% and 0.03% of total CO_2 emissions, respectively, in the UK. Overall, transport associated with the dietary supply chain accounts for approximately 3.5% of the UK's greenhouse gas emissions, excluding food waste disposal in the manufacturing stage.

Transportation has accounted for around 11% of the embodied emissions of typical groceries in America. According to Ref. [62], transportation accounts for approximately 14% of the usage of total energy by the food system of the US. Transportation from private grocery shopping trips and distribution of raw and processed food have accounted for 5% and 9% of energy use, respectively. The contribution of food transportation in relation to the total greenhouse gas emissions of a food product in the US generally represents an insignificant amount of the CF. Transportation of fresh foods by air freight can account for higher weighting in distribution-associated carbon impacts. However, on average, the distribution of completed food products from farms or factories to retail stores accounts for less than 4% of the greenhouse gas emissions of consumed foods in the U.S [62].

In India, emission from food transportation is insignificant, which only contributes to 1% of the total food emission [41]. This is because Indians mostly consume locally produced fresh food. In comparison, there is more share of transportation in Europe and America since processed foods are more common in those countries [63]. The research on the emissions from overseas-sourced food of each country has not been conducted yet, but according to Ref. [64], wheat (2,693,404 tonnes) is the most imported food in the UK, which is followed by maize (2,061, 883 tonnes) and soybeans (1,747,330 tonnes). In the US, most imported foods are bananas (4,547,932 tonnes), wheat (3,386,604 tonnes), and maize (3,309,863 tonnes). In terms of emissions from overseas-sourced wheat, the US can be said to account for higher emissions than the UK due to higher demand for imported foods (Fig. 11). Brazil, however, imports the most wheat among the countries and hence can account for the highest emission of imported wheat [55,63].

3.3.3. Food waste

Food wastage occurs at all stages of the dietary supply chain. The reasons depend on the conditions of each country. On a global scale, a food wastage pattern is visible. Regarding income, regions with high incomes would have higher volumes of food wastage in the processing, transportation, and consumption stages. On the other hand, regions with low income would have food wastage in the production and harvesting stages. Furthermore, the lack of infrastructure, the deficiency of knowledge regarding proper food handling and storage, as well as the unfavourable climatic conditions have favoured food spoilage in low-income countries. Conversely, aesthetic preference and arbitrary sell-by dates have contributed to food waste in countries of higher income [64].

According to Ref. [63], the CF of food wastage was approximately 3.6 Gt CO_2e in 2011, excluding deforestation and management of organic soil related to food wastage. By including land use, the total CF of food wastage is 4.4 Gt CO_2 e per year.

The CF of the seven continents had been studied, and it was found that Asia has the highest CF among the continents. Industrialized Asia, such as Japan, Korea, and China, has the highest CF of food wastage among regions, with approximately 1300 Mt CO_2e of CF in total (refer to Fig. 12). This is followed by South and Southeast Asia, with a total CF of approximately 800 Mt CO_2e. Sub-Saharan Africa, on the other hand, has the lowest CF of food wastage, with a total CF of approximately 190 Mt CO_2e [64].

On a global average, high-income countries have more than two times low-income countries in per capita food wastage footprint on climate. This is the result of the wasteful food distribution and consumption patterns in countries with high incomes. Table 7, in terms of per capita of CF of food wastage, shows that North America and Oceania ranked first, with a total CF of 860 kg CO_2. This is followed by Industrialized Asia, with total food wastage CF of 810 kg CO_2. Among all, Sub-Saharan Africa has the lowest per capita CF of 210 kg CO_2 [64].

3.4. Bibliometric analysis

A thorough literature review is required after a summary of earlier research investigations and their findings. It facilitates researchers' rapid acquisition of a sizable body of information on a certain topic. One of the simplest ways to evaluate a large body of literature is through bibliometric analysis. Researchers can better comprehend the many linkages (such as those between authors, universities, author-citation relationships, and others) as well as the current research trends in a certain field of study with the aid of bibliometric analysis. As a result, using publication data from Scopus, a bibliometric analysis of communication technologies was carried out.

3.4.1. Data source

The bibliometric analysis was carried out by obtaining published records from the Scopus database for the last 20 years. On March 09, 2023, the publications were retrieved from Scopus by using the following keywords and logic operators from the article title, abstracts,

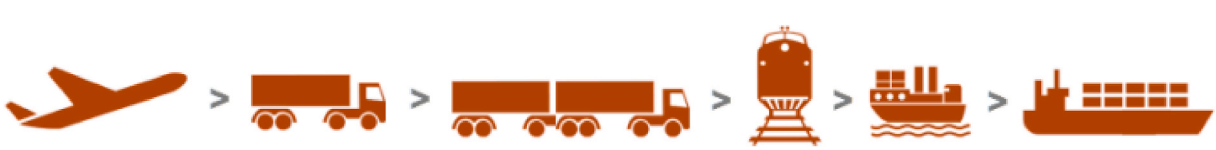

Fig. 11. Impacts of food transportation options in descending order [62].

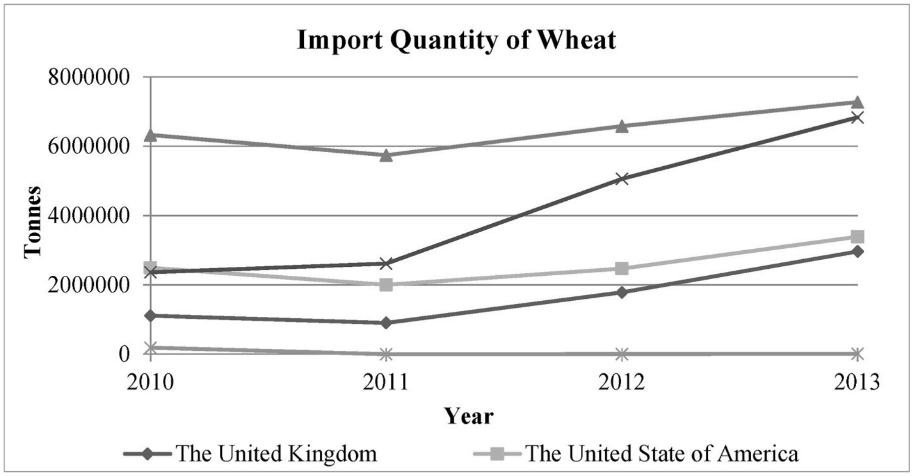

Fig. 12. Import quantity of wheat in the UK, the US, Brazil, China, and India from 2010 until 2013 [55].

Table 7
Per capita CF of food wastage in different regions [64].

Per Capita CF of Food Wastage in different regions (kg.CO_2)						
North America and Oceania	Industrialized Asia	Europe	Latin America	North Africa, Western Asia, and Central Asia	South and Southeast Asia	Sub-Saharan Africa
860	810	680	540	350	350	230

and keywords ("Carbon Footprint" OR "Global Warming" OR "Renewable Energy" AND "Food" AND "Environment"). After searching, a total of 2174 documents were found, and by screening for only journal publications, research articles, review papers, and articles written in English, 1552 documents from Scopus were filtered and included in the analysis. Besides, the information from Scopus was exported in CSV and tab-delimited text file formats, and it contains information about citations, bibliographies, abstracts, keywords, financing, and other things.

3.4.2. Method and process

The bibliometric study was performed using the VOS viewer software, which Van Eck and Ludo Waltman created. It provides a graphical representation of the bibliometric data in the form of maps that is simple to interpret. The bibliometric map's node distances are inversely correlated with their proximity. To put it another way, this information shows that the first pair of nodes are more tightly related than the second pair if the distance between two nodes is smaller than the distance between two other nodes. Based on the connections between authors, universities, and nations that received citations, this software produced several bibliometric maps. In this study, citation analysis is done where the relatedness of items is determined based on the number of items they cite each other. Additionally, a unit of this analysis are authors, universities, and countries. Section 4.2 contains a discussion of the findings of this bibliometric investigation.

4. Discussion

4.1. Improvements in lowering carbon footprint

The world population is predicted to hit 9 billion by the year 2050. As a consequence, the global energy demand would increase by 45%. Looking back now, 30% of food is wasted per day, and it needs to be changed in preparation to embrace the surging population. At the same time, the life cycle of our daily food contributes the most to global CF. In order to improve the current situation, a thorough study of the life cycle of daily diet is carried out, and suggestions are given for each phase [65].

4.1.1. Extraction of raw materials (agricultural production)

Agriculture is the cultivation of animals and plants as the raw materials of food. It is proven that the agricultural sector is the highest CF contributor to the life cycle of the daily diet. In the year 2013, the greenhouse gas (GHG) emissions from the agricultural sector were 1.41 Gt CO_2e, and the highest portion is meat, with 37% [29].

Animal breeding and cultivation produce CF mainly through enteric fermentation (digestion) and manure management. In 2016 [67], suggested that the feeding system could be improved by using less ruminal degradable starch and the chemicals used as a feed additive to slow down the rumen metabolism. The two suggestions above involve slowing down the metabolism and hence, decreasing methane emissions. Another suggestion is to solve the problems of poor fertility and health issues through a genetic approach [66]. However, these are just theoretical ideas with few practical uses due to factors of high costs and inconsistencies involved. One of the more realistic ways is to promote small-scale aggregated farming. It would indirectly reduce the reliance on fossil fuels and has more efficient manure management [29].

Plantation, on the other hand, produces comparably less CF than animal cultivation. The source of CF is mainly from the appliances involved in farming. Improvements could be made to the ready-made appliances to reduce CF produced. One of the ways is to increase fertilizer use efficiency by avoiding excessive fertilization. Next, the water irrigation efficiency in rice paddles is to be increased by optimizing the process. Both suggestions involve efficient resource management and reducing the fossil fuels used to power up machines and appliances [66].

4.1.2. Packaging

Packaging is another life cycle of food that contributes to the emission of GHGs. Packaging plays a vital role in prolonging the shelf life of food. It is important since food wastage leads to the replacement of food, and more CF is produced indirectly. For this study, the packaging materials are limited to conventional plastic and polystyrene since they are the most popular used materials [19].

During material selection, environmental aspects such as land use and non-renewable energy should be taken into consideration instead of solely on the availability and manufacturing cost of the materials. The end-of-life products of the packaging phase are usually disposed of by landfill since they cannot be discomposed naturally and are hard to be recycled. Not to mention that the raw material of both plastic and polystyrene is petroleum, and it is generally known that petroleum is a non-renewable energy. These factors motivate the researchers to find alternatives to the current packaging materials and take environmental impact into consideration.

With the increasing environmental awareness of the public, more research studies are being carried out to study biopolymers as an alternative to conventional plastic and polystyrene in food packaging. Some of the more successful examples are PLA and PET. Not only are they biodegradable, but they are also healthier for consumers since it is less likely for biopolymer packaging to produce carcinogenic components through chemical reactions. On the other hand, the biodegradability of biopolymer packaging solves the problem of conventional packaging, which sometimes recycling is not biologically and economically convenient as the method of disposal. In terms of CF, it is found that CF produced by polystyrene packaging is 78% higher than that of PLA through life-cycle assessment. The advantages of being eco-friendly and healthier for the human body make PLA a superior choice over conventional plastic and polystyrene. The higher manufacturing cost and less material abundance of PLA are the obstacles to be solved if this direction is to be taken [19].

4.1.3. Transportation

The transportation phase refers to the process of transferring food from one origin to the final consumer. An imported apple produces a lot more CF than a locally supplied apple since an imported apple is air freighted.

The CF of the transportation phase could be reduced through transport optimization strategies. In this context, fuel use could be optimized in different ways. One of the ways is to optimize the distribution route by distributing the food from customer to customer in the shortest distance. Next, the fuel efficiency of the vehicles should be optimized. Opting toward low-emission fuels, which include biofuels for high-performance engines, should be enforced across nations and renewable energies to generate power otherwise [65]. On the other hand, the transportation should be changed from airfreighting to shipping if possible. Although shipping takes more time, it costs cheaper, and it produces three times less CF compared to airfreighting [66].

Eco-friendly fuels should be considered as alternatives to petrol since they produce comparably less CF. For instance, compressed natural gas and biofuels such as bioethanol and biodiesel could be used. The disadvantage of using compressed natural gas is that less torque is produced by the engine, and hence it is harder for the vehicle to climb up a slope. However, it provides sufficient torque for the vehicles to transport food on the straight road.

Furthermore, the use of fuels could be reduced by purchasing fuel-efficient or electric hybrid vehicles for food transportation. It is estimated that an electric car emits half the GHGs per mile of a vehicle in the U.S. today. The initial car price might be more expensive; however, the fuel saved is significant in the long run, and fewer negative impacts are caused on the environment [66].

4.1.4. Consumption

The consumption of food might not be the biggest CF contributor. However, it might produce the biggest improvement if changes are to be made since everyone is a food consumer. The first step to being made as an individual is changing food preferences to the ones that produce less CF. In this context, an individual could follow a balanced intake of livestock products and choose white meat instead of ruminants (beef and lamb). Red meat produces an extra 150% of GHG throughout its life cycle as compared to chicken and fish [67]. Also, an individual could reduce meat consumption. In the year 2014, 60% of maize was used as livestock feed, and it caused a discrepancy between demand and supply [29]. By lowering global meet demand, not only the situation above is solved, but the CF could also be reduced at the same time. In 2014 [68], estimated that GHG emissions would be decreased by 19% by replacing a quarter to half per cent of meat in daily diet with plant-based food.

An individual also could contribute by changing the current lifestyle to a more beneficial one. One of them is choosing locally produced food instead of imported food. Air freighted food produces high CF during the transportation phase, and it should be avoided. Besides, the number of shopping trips should be reduced by buying food for the whole week to reduce CF of transportation. Also, the freshness of food should be prioritized to ensure its long shelf-life and minimize food wastage. On the other hand, dining at home instead of in a restaurant should be practised since it is easier to control the way of cooking and the type of food. For instance, the electronic stove is used instead of conventional natural gas stoves, and meat intake is reduced. These practices might not be seemed significant, but the reduced CF can add up to a large amount over the years [68].

Food intake is still greatly associated with social and cultural values. It might be difficult to make sudden changes in a short period. However, gradual changes over the years are good enough to make beneficial impacts, and every individual should try their best to contribute [69].

4.1.5. Waste disposal

Waste disposal is the management of end-of-life products from the life cycle. In the context of food, the leftover from the consumption phase and the plastic from packaging are some examples of food waste. The most common way to dispose of them is by landfilling due to their unsuitability to be recycled, or else more efforts will be needed to recycle them. Not only do the wastes emit GHGs such as carbon dioxide and methane into the environment, but they also cause pollution to the air, soil, and water.

The most practical way to reduce waste disposal is by reducing the waste itself. In this context, the habit of 3 R (Reduce, Reuse, and Recycle) should be practised by everyone. Food waste could be reduced by ensuring the freshness of the food and storing the food appropriately. Also, the practice of using a reusable container instead of polystyrene and a shopping bag instead of a plastic bag could effectively reduce waste production. Lastly, the waste should be recycled if feasible. The papers, plastics, bottles, and cans should be separated from the food waste to ease the recycling process. Through recycling an aluminium can, 90% of the production energy is reduced, and 9 kg of carbon dioxide is prevented for recycled aluminium per kg [70].

It is known that reducing waste disposal through landfill could effectively reduce the CF and prevent pollution to the environment. Hence, everyone has a responsibility in this matter. The government should subsidies the local recycling factories and encourage the habit of recycling through education and public speech. Also, a recycling bin should be prepared to collect food waste. As for the individual, we should prevent the open burning of food waste since the act emits GHGs into the environment. Categorizing the food waste properly could ease the process of classifying waste for recycling [70].

4.1.6. A change in diet

From the discussion above, a comparison of CF can be drawn for our regular diet, which indicates that diets higher in animal protein produces the highest CF level. Therefore, to improve the existing diet-based CF scenario, the consumption of a large amount of meat, beef, could be reduced. The protein diet, however, can be replaced with chicken, fish, and pork, which are found to have less CF. Evidently, adopting a vegetarian-friendly diet will help to reduce the level of CF, thus slowing the pace of global warming [40]. However, opting for an all-vegetarian diet all over the region might not be a very practical suggestion.

Therefore, much focus can be given to the logistics and the production process of food. We need to rethink the materials and production chain to reduce the CF for food production without the need to cut down on our favourite diet. The promotion of the Keto diet, which is vegetable-based and already gaining momentum, may help to improve the food CF. Studies found that people are concerned and willing to give up a little gastronome for the sake of the environment. People all over the world, in general, show a positive attitude toward food which are environmentally safe and are inclined to sustainable options. The conscience-guided self-imposed actions by citizens in many countries show a similar trend to match up the level of required sustainability practices when it comes to food or food-required materials choices [71]. A study among consumers from Italy, UK, and Germany shows that the consumers are willing to pay a reasonably higher price for food which are environmentally safe and can reduce CF. The consumers also advocated for an environmentally friendly purchasing attitude by indicating that food labelling with lower CF components draws a positive purchasing attitude [72,73], and [74]. There is a huge scope to focus on in the packaging, processing, and transportation sectors to reduce the overall CF of food products.

4.1.7. Role of circular economy

The circular economy provides ways to develop a sustainable food system. The disposal of trash and the production and consumption of food are investigated as possible answers. According to the circular economy, resources should be used first for products, then as repurposed or upcycled, and lastly as energy. It seeks to complete the loops with the fewest number of cycles while requiring the least number of auxiliary inputs, like energy. Infrastructures and technology, as well as citizen abilities, practices, and worldviews, must alter for sustainability. Nutrient recovery from manure, nutrient recovery and reuse in sewage sludge, cascading usage of materials, and support for nearby farms and de-specialized agricultural holdings are a few examples of possible solutions related to nutrient cycling. Community-run agriculture, various methods for switching to a more plant-based diet, and education on decreasing food waste are only a few examples of solutions relating to citizens and consumers that frequently serve as the focus of experiments. Furthermore, these regulations help with improved control of food surplus and waste. To reduce food waste and surplus, different institutional barriers can also be reconsidered (e.g., food quotas and standards).

Such discoveries by themselves are not particularly ground-breaking; many of the solutions are already in use, or the issues are widely understood. The circular economy offers a framework, though, within which society can develop cross-sectoral policy to support various initiatives in various “parts of the circle” with the ultimate objective of moving away from the linear and extractive model to a more sustainable mode of production and consumption.

4.2. Results and discussion for bibliometric analysis

4.2.1. Distribution and growth trend on a yearly basis

The volume of articles that are published each year is a great indicator of the direction of research in a given area of study. Assessing the volume of publications that have been published throughout time can reveal the upcoming likely research trend. The research trend on CFs of regular diet is examined using a graph of the number of publications and total publications annually from Scopus data, as shown in Fig. 13. From the trend line in Fig. 8, it can be seen that the research on this topic from 2012 to 2023 started with 69 publications annually and exponentially increased to 969 publications in 2020. A spike was observed in 2021 with 1214 publications, and in the next year, a slight surge can be seen, which was 1484 publications. This trend line indicates that in the present year, we can expect more no. of publications on this topic, which indicates that a no. of researchers are interested in this topic.

4.2.2. Classification of publications at the country level

A total of 125 countries have published articles, of which 64 have at least five publications that have been reviewed. Except for Ukraine, the Philippines, and Croatia, only 61 of these 64 countries cooperated. From Table 8, it can be seen that the highest number (287, 7.78% of total documents published) of publications were from the United States (US), followed by 227 (6.15%) documents from China. United Kingdom (UK) ranked third by publishing 170 (4.61%) documents, and India ranked fourth by publishing 136 (3.69%) documents. The fifth place was taken by Italy with 118 (3.20%) articles. The remaining countries have published an average of 45 articles. Turning to the citations, it can be seen that the US took the top position again by having 15,329 citations. Interestingly, the UK ranked third in documents, but in terms of citations, it took the second position, and China ranked third with 8214 citations. This means the UK published some quality papers after the US, no matter if they have a low number of documents published as compared to China.

Moreover, the Total Link Strength (TLS) gauges how effectively two Countries cooperate in research. According to TLS analysis, the United States is the nation that excels the most at collaborative research, with a TLS of 355. Fig. 14 shows the mapping of countries collaborating on the concerned topic. It can be observed that the US is a major country collaborating with China, the UK, Spain, Germany, Italy, Australia, France, Canada, Sweden, Switzerland, Brazil, Netherlands, Japan, Malaysia, Norway, Austria, Denmark, Ireland, Peru, Singapore, Bangladesh, Belgium, Portugal, India, Pakistan, Poland, Finland, Hong

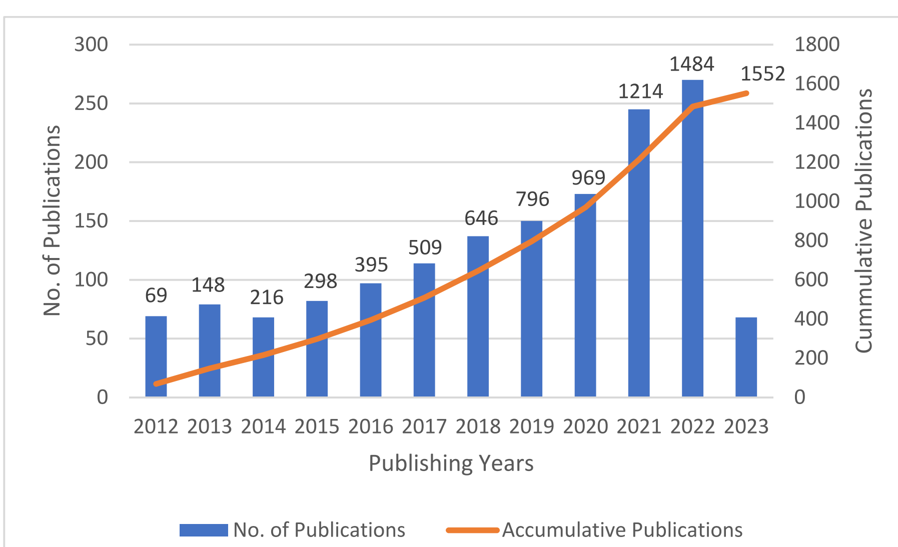

Fig. 13. Distribution and growth trend of publications on a yearly basis.

Table 8
Countries with minimum 5 publications.

No.	Country	Publications	Percentage (%)	Citations	Avg. Citations/Publication	TLS
1	United States	287	7.78	15,329	53.41	355
2	United Kingdom	170	4.61	12,110	71.24	330
3	China	227	6.15	8214	36.19	250
4	Australia	105	2.85	6171	58.77	208
5	Canada	75	2.03	5675	75.67	149
6	Switzerland	43	1.17	5268	122.51	105
7	France	92	2.49	4954	53.85	210
8	Germany	93	2.52	4758	51.16	192
9	Italy	118	3.20	3909	33.13	154
10	Netherlands	53	1.44	3869	73.00	83
11	Sweden	63	1.71	3205	50.87	146
12	Malaysia	55	1.49	2842	51.67	94
13	Spain	81	2.20	2750	33.95	126
14	Denmark	44	1.19	2599	59.07	113
15	Kenya	14	0.38	2342	167.29	60
16	India	136	3.69	2241	16.48	132
17	Austria	27	0.73	2235	82.78	97
18	Pakistan	42	1.14	1874	44.62	78
19	Norway	35	0.95	1823	52.09	72
20	South Korea	38	1.03	1733	45.61	67
21	Other 44 Countries	1892	51.27	25,153	584.95	1489

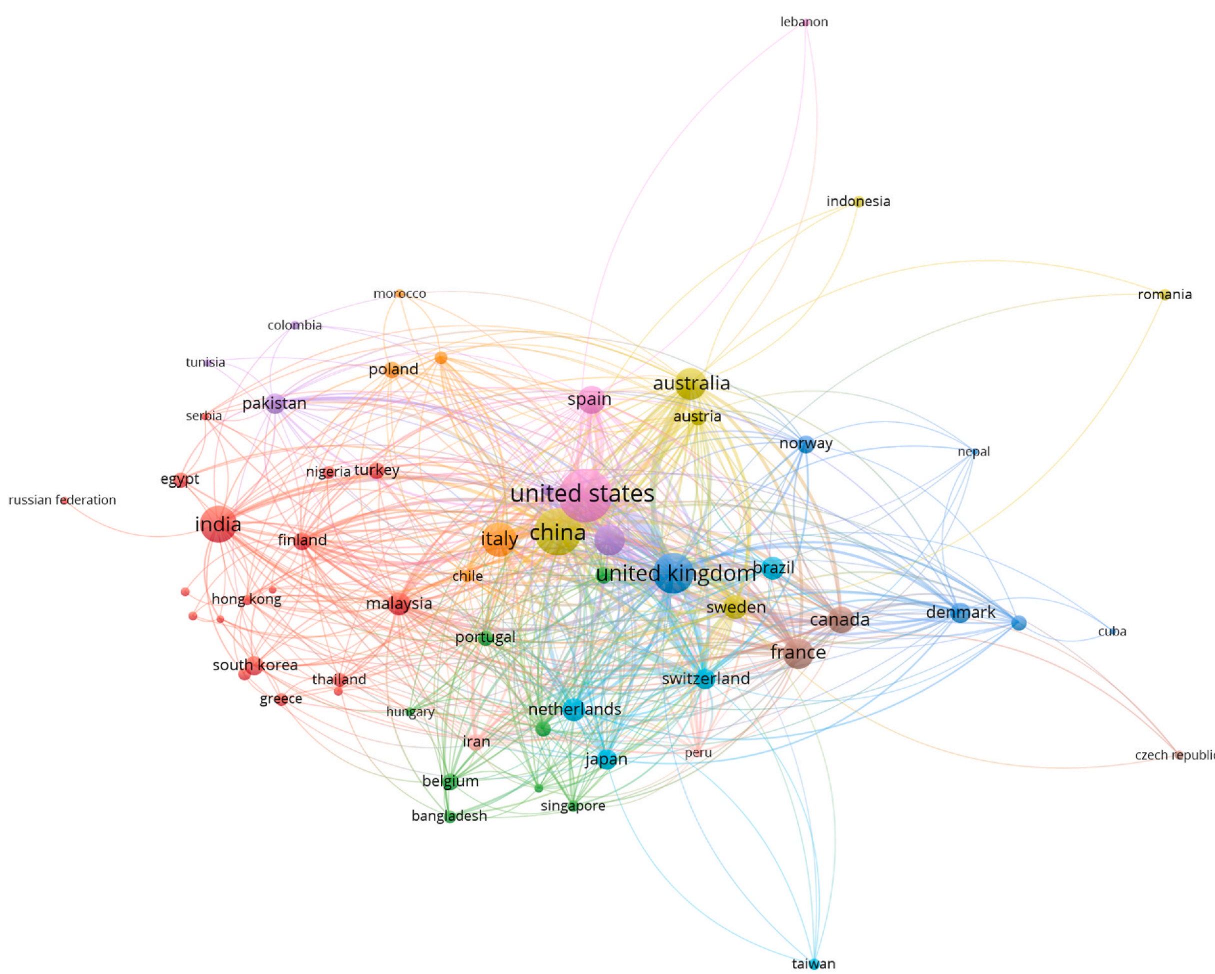

Fig. 14. Cooperation map of countries.

Kong, South Korea, Thailand, Morocco, and Taiwan. UK ranked second with TLS of 330, and it collaborated with the US, China, Italy, Pakistan, India, France, Canada, Spain, Australia, Denmark, Romania, Ireland, Norway, Peru, Japan, Brazil, Malaysia, South Korea, Nepal, Egypt, Serbia, and Morocco. China, on the other hand, ranked third with a TLS of 250, and it collaborated with US, UK, Pakistan, India, Indonesia, Italy, Sweden, Brazil, France, Canada, Japan, Netherlands, Denmark, Australia, Spain, Ireland, Switzerland, Norway, Austria, and Malaysia. From the TLS and collaboration map, it is evident that most of the countries are interested in working with US, UK, and China.

4.2.3. Distribution of publications at the university level

There have been articles published by 4805 universities in total, and 14 of the universities have been evaluated because they have at least three publications. All these 14 universities have not collaborated; they worked independently. Statistics for these universities are given in Table 9, from where only the university of the Chinese academy of sciences, Beijing, has 12 documents (22.22%) with a maximum no. of citations (209). On the other hand, the Chinese academy of sciences, Xiamen, Chinese academy of science, Nanjing, and the Chinese academy of sciences, Urumqi, has published an equal no of articles (4), but the Chinese academy of sciences, Xiamen, has 74 citations, while Chinese academy of sciences, Nanjing and Chinese academy of sciences, Urumqi have 65 and 52 citations respectively. The remaining universities have published three documents, but out of these universities Chinese academy of agricultural sciences, Beijing, received 122 citations resulting in second in the ranking. The third rank was given to the Chinese academy of sciences, Beijing, with 93 citations. Fourth and fifth ranks were taken by the university of Stirling, Stirling, and the Chinese academy of sciences, Xiamen, with 87 and 74 citations, respectively.

Cooperating map for these universities is shown in Fig. 15. It can be seen that the university of the Chinese academy of sciences, Beijing was the top university publishing quality research on CFs in a regular diet. It can also be observed that none of the universities was collaborating with each other because there was no connection with another university.

4.2.4. Distribution of publications on Author's level

The key research groups working on a particular issue around the world can be determined by looking at the connections between the authors, publications, and citations. By mapping this relationship, it may be done quickly. By creating a visual representation of the connection, the mapping technology makes it simple to look into the author's activities and their connections to other research groups. 6599 authors are examined globally for this reason. However, only 54 are chosen out of these while taking into account at least 5 articles by each author to weed out the authors that produce high-quality work. Out of these 54 authors, only 34 were collaborating with each other. Fig. 16 displays the authors' selection map, and Table 10 represents the statistics for authors. From the table, it can be seen that Nemecek T. ranked 1st with a high no. of citations (1,736) by publishing just 5 articles. Haines A. followed him by publishing the same amount of publications but received 1676 citations, and he also got the highest TLS of 22. The third position was taken by Smith P., who published the same number of articles but received only 985 citations. On the other hand, De Boer I.J.M. and Green R. shared fourth and fifth rank by receiving 851 and 532 citations, respectively, by publishing the same number of publications as the top three authors.

Moreover, by looking at the map, it can be seen that there were a total of 6 groups of researchers working on the concerned topic. Out of these groups, Yang Y. group was the big group with 8 members. They collaborated with every single group. Despite the fact that Nemecek T. and Haines A. received more citations, their group ranked second. On the other hand, it can be seen that the research groups of Zang J. and Wang X. have less interest in collaborating with other research groups, and they have only one connection with each other.

5. Conclusion

This paper has investigated the CF of a regular diet and traced its sources and impact. A comparison was drawn of CF contribution between different diets and regions, and a thematic discussion was provided to improve the CE and CF for food-related products. The sources of CF caused by food were analyzed throughout its lifecycle: extraction of raw materials, packaging and processing, transportation and distribution, acquisition and consumption, and disposal. It was found that transportation and distribution of food account for the most carbon emission (approximately 50%) in the food distribution chain. Moreover, the comparison of CF between animal-based food and plant-based food was also investigated, and it was found that animal-based food emitted more carbon for GHG than plant-based food by a huge margin. Besides, the dietary patterns of some major countries such as India, China, and Italy were also investigated. It was noticed that dietary pattern that consists more of animal-based protein emits more GHG as compared to those dietary patterns that include more plant-based food. A discussion was drawn by comparing regions based on the extraction of raw materials, distribution of food items, and the food waste produced. It was determined that the extraction of raw materials and supply chain in most countries are responsible for most of the GHG produced. This is mainly due to the production of crops and livestock. This study may provide a scope for the policymakers to implement rules to reduce the CF generated from the food products and dietary behaviours of a vast population. Since dietary behaviour involves several different energy-intensive practices which burden the CF, therefore, taking new policies for the production, transportation, and distribution of food products may help reduce the CF significantly. However, the strategies and policy may not be effective unless the end-users comply with the set of rules.

The bibliometric analysis shows that different countries, universities, and groups of researchers are working on CF. It can be seen that the US is the top country working on CF, followed by UK and China. Moreover, the analysis of universities indicates that even though the US has the top position but in terms of top universities, China is ahead. The top 3 universities working on the topic are from China, which states that it is investing a lot in this research area. Besides, the analysis of authors indicates that Nemecek T., with 1736 citations, secured 1st position in ranking while Haines A. and Smith P. took 2nd and 3rd ranks by receiving 1676 and 985 citations, respectively. Furthermore, it shows

Table 9
Universities with at least 3 Publications.

No.	University	Publications	Percentage (%)	Citations	Avg. Citations/ Publications	TLS
1	University Of Chinese Academy of Sciences, Beijing	12	22.22	209	17.42	0
2	Chinese Academy of Agricultural Sciences, Beijing	3	5.56	122	40.67	0
3	Chinese Academy of Sciences, Beijing	3	5.56	93	31.00	0
Four	the University Of Stirling, Stirling	3	5.56	87	29.00	0
5	Chinese Academy of Sciences, Xiamen	4	7.41	74	18.50	1
6	Chinese Academy of Sciences, Nanjing	4	7.41	65	16.25	0
7	Friedrich Schiller University Jena, Jena	3	5.56	52	17.33	0
8	Chinese Academy of Sciences, Urumqi	4	7.41	52	13.00	1
9	Institute Of Oceanography and Fisheries, Split, Croatia	3	5.56	44	14.67	0
10	University Of Split, Split, Croatia	3	5.56	44	14.67	0
11	China Agricultural University, Beijing	3	5.56	39	13.00	4
12	International College Beijing	3	5.56	39	13.00	4
13	Nanjing Forestry University, Nanjing	3	5.56	30	10.00	0
14	Institute Of Geographic Sciences and Natural Resources Research, Chinese Academy Of Sciences, Beijing	3	5.56	17	5.67	0

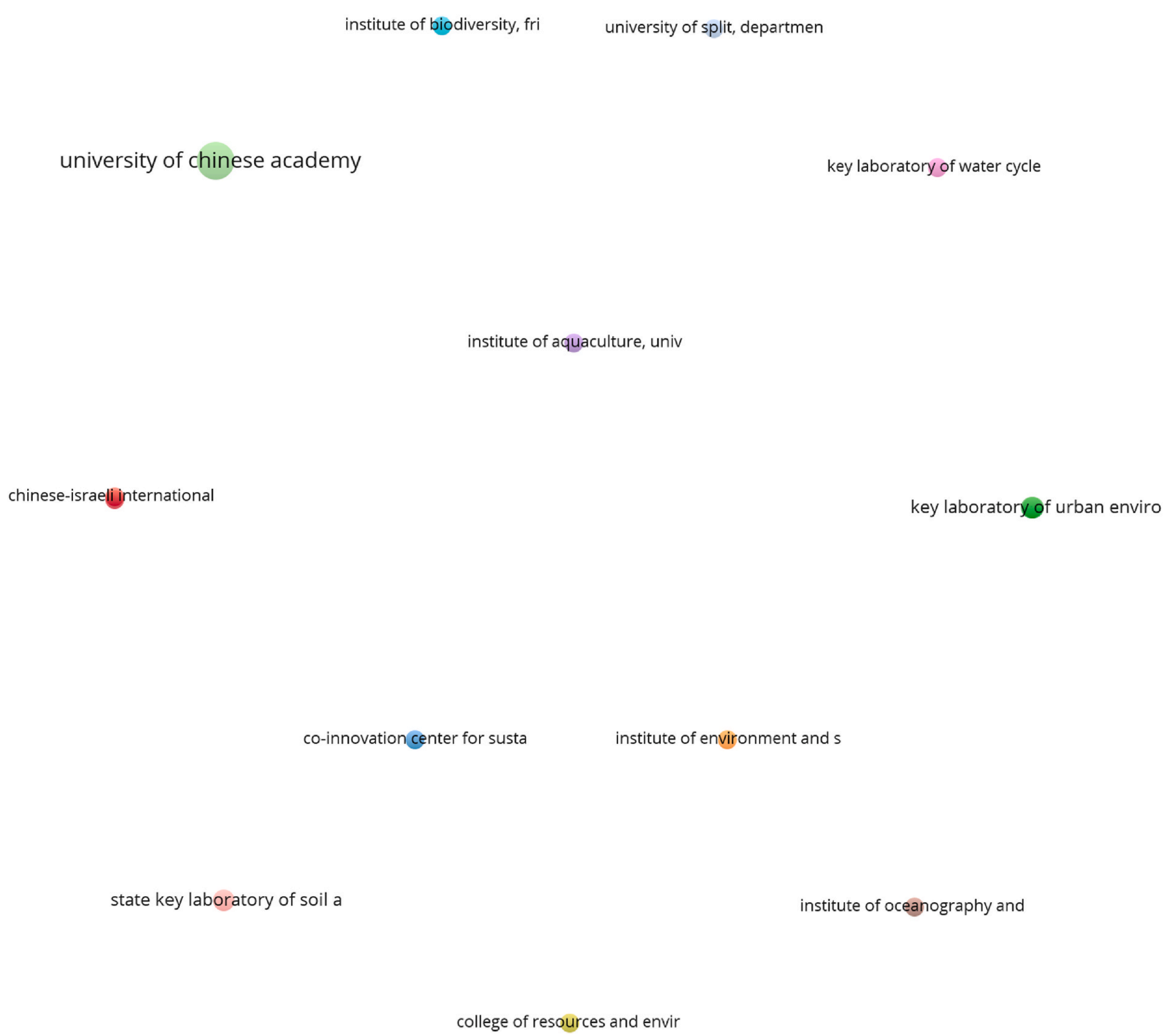

Fig. 15. Cooperation map of universities.

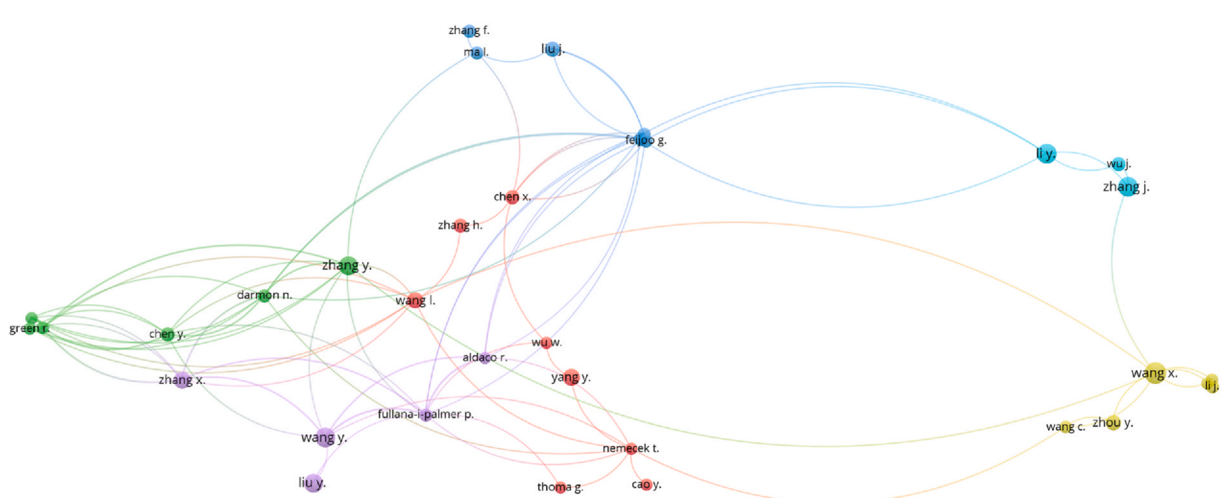

Fig. 16. Cooperation map of authors.

Table 10
Authors with a minimum of 5 articles.

No.	Author Name	Publications	Percentage (%)	Citations	Avg. Citations/Publication	TLS
1	Nemecek T.	5	1.34	1736	347.20	9
2	Haines A.	5	1.34	1676	335.20	22
3	Smith P.	5	1.34	985	197.00	16
4	De Boer I.J.M.	5	1.34	851	170.20	2
5	Green R.	5	1.34	532	106.40	16
6	Lal R.	5	1.34	369	73.80	0
7	Wang X.	16	4.29	369	23.06	8
8	Darmon N.	6	1.61	366	61.00	13
9	Zhang F.	6	1.61	339	56.50	1
10	Singh A.	7	1.88	318	45.43	0
11	Zhang H.	7	1.88	307	43.86	2
12	Li H.	8	2.14	265	33.13	0
13	Thoma G.	5	1.34	265	53.00	2
14	Wu W.	5	1.34	253	50.60	3
15	Wang Y.	14	3.75	242	17.29	11
16	Ma L.	6	1.61	233	38.83	4
17	Chen X.	7	1.88	212	30.29	6
18	Fullana-I-Palmer P.	6	1.61	211	35.17	17
19	Wang L.	9	2.41	205	22.78	9
20	Zhang J.	13	3.49	198	15.23	3
Other 34 countries		228	61.13	4181	659.63	110

that many institutions are working in solitary and much engagement is needed to establish an effective policy and management in food-related CF reduction. Therefore, the following few recommendations based on the findings in this paper may be outlined.

- Increase the usage of renewable energy sources to deliver electric power for food production and processing.
- Fund more research on inventing new crops and raw foods that can withstand adverse environmental conditions and can be cultivated for a longer crop cycle. Governments, private companies, research institutions, partnerships, crowdfunding, and international organizations can all contribute to funding research in this area.
- Raise awareness among the people about the nutritional values of local products and cut costs on exotic and energy-laden crops. Policymakers and academia to come together and work closely with different regions to create global awareness.
- Encourage people to consume more local products so that food transportation cycles can be reduced, leading to less fuel consumption and emissions of harmful gases.
- Encourage plant-based diets among the population and redesign animal farming to enjoy animal-based protein with low CF. Provide monetary incentives to farmers to encourage low CF food production.

It is essential to improve this scenario as the CF produced is highly destructive to the environment. Therefore, every individual or party must play their part in resolving this global issue – climate change, in order to provide a sustainable future through a better ecosystem for the coming generations.

Credit author statement

H. Nabipour Afrouzi: Supervision, preparing the first draft., J. Ahmed: Reviewing and Editing B. Mobin Siddique: Validation, Reviewing and Editing, N. Khairuddin: Validation, and Reviewing., Ateeb Hassan: Validation, Reviewing and Editing.

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.

Data availability

Data will be made available on request.

References

[1] Xavier Esteve-Llorens, Carmela Darriba, Maria Teresa Moreira, Gumersindo Feijoo, Sara González-García, Towards an environmentally sustainable and healthy Atlantic dietary pattern: life cycle carbon footprint and nutritional quality, Sci. Total Environ. 646 (2019) 704–715, https://doi.org/10.1016/j.scitotenv.2018.07.264.
[2] L.P. Fesenfeld, M. Wicki, Y. Sun, T. Bernauer, Policy packaging can make food system transformation feasible, Nat. Food 1 (3) (2020) 173–182, https://doi.org/10.1038/s43016-020-0047-4.
[3] J. Mulrow, K. Machaj, J. Deanes, S. Derrible, The state of carbon footprint calculators: an evaluation of calculator design and user interaction features, Sustain. Prod. Consum. 18 (2019) 33–40, https://doi.org/10.1016/j.spc.2018.12.001.
[4] I. Muniz, A. Dominguez, The impact of urban form and spatial structure on per capita carbon footprint in US larger metropolitan areas, Sustainability 12 (1) (2020) 389, https://doi.org/10.3390/su12010389.
[5] Irina Safitri Zen, Abul Quasem Al-Amin, Md Mahmudul Alam, Doberstein Brent, Magnitudes of households carbon footprint in Iskandar Malaysia: policy implications for sustainable development, J. Clean. Prod. 315 (2021), 128042, https://doi.org/10.1016/j.jclepro.2021.128042.
[6] M. Sharma, A. Kishore, D. Roy, et al., A comparison of the Indian diet with the EAT-Lancet reference diet, BMC Publ. Health 20 (812) (2020), https://doi.org/10.1186/s12889-020-08951-8.
[7] E. Röös, C. Sundberg, P.A. Hansson, Uncertainties in the carbon footprint of food products: a case study on table potatoes, Int. J. Life Cycle Assess. 10 (2010), https://doi.org/10.1007/s11367-010-0171-8, 478–48.
[8] W. Wakeland, S. Cholette, K. Venkat, Food transportation issues and reducing carbon footprint, in: J.I. Boye, Y. Arcand (Eds.), Green Technologies in Food Production and Processing, Springer US, 2012, pp. 211–236, https://doi.org/10.1007/978-1-4614-1587-9_9.
[9] E. Hallström, A. Carlsson-Kanyama, P. Börjesson, Environmental impact of dietary change: a systematic review, J. Clean. Prod. 91 (2015) 1–11.
[10] M.B. Lee, D. Clark, What Is a Carbon Footprint? The Guardian, 2010 viewed 4 May 2018, https://www.theguardian.com/environment/blog/2010/jun/04/carbon-footprint-definition.
[11] Y. Virtanen, S. Kurppa, M. Saarinen, J.M. Katajajuuri, K. Usva, I. Mäenpää, J. Mäkelä, J. Grönroos, A. Nissinen, Carbon footprint of food - approaches from national input-output statistics and a LCA of a food portion, J. Clean. Prod. 19 (16) (2011) 1849–1856.
[12] K. Schanes, S. Giljum, E. Hertwich, Low carbon lifestyles: a framework to structure consumption strategies and options to reduce carbon footprints, J. Clean. Prod. 139 (2016) 1033–1043, 2016/12/15/,.
[13] D. Pandey, M. Agrawal, Carbon footprint estimation in the agriculture sector, Assessment of Carbon Footprint in Different Industrial Sectors 1 (2014) 26–27.
[14] J.Y. Lin, Y.C. Hu, S.H. Cui, J.F. Kang, L.L. Xu, Carbon footprint of food production in China (1979-2009), J. Clean. Prod. 80 (2015) 97–103.
[15] Z.B. Wang, J. Chen, S.C. Mao, Y.C. Han, F. Chen, L.F. Zhang, Y.B. Li, C.D. Li, Comparison of greenhouse gas emissions of chemical fertilizer types in China's crop production, J. Clean. Prod. 141 (2017) 1267–1274.

[16] L. Mogensen, T.L.T. Nguyen, N.T. Madsen, O. Pontoppidan, T. Preda, J. E. Hermansen, Environmental impact of beef sourced from different production systems - focus on the slaughtering stage: input and output, J. Clean. Prod. 133 (2016) 284–293, 2016/10/01/.
[17] E.H. Bennetzen, P. Smith, J.R. Porter, Agricultural production and greenhouse gas emissions from world regions - the major trends over 40 years, Global Environ. Change 37 (2016) 43–55.
[18] G. Zervas, G. Tsiplakou, An assessment of GHG emissions from small ruminants in comparison woth GHG emissions from large ruminants and monogastric livestock, Atmos. Environ. 49 (2012) 12–23.
[19] C. Ingrao, C. Tricase, A. Cholewa-Wójcik, A. Kawecka, R. Rana, V. Siracusa, Polylactic acid trays for fresh-food packaging: a Carbon Footprint assessment, Sci. Total Environ. 537 (2015) 385–398, 2015/12//.
[20] C. Ingrao, A. Lo Giudice, J. Bacenetti, A. Mousavi Khaneghah, A.S. Sant'Ana, R. Rana, V. Siracusa, Foamy polystyrene trays for fresh-meat packaging: life-cycle inventory data collection and environmental impact assessment, Food Res. Int. 76 (2015) 418–426, 2015/10/01/.
[21] S.E. Selke, J. Shin, Food packaging, in: S. Clark, S. Jung, B. Lamsal (Eds.), Food Processing, John Wiley & Sons, Ltd, 2014.
[22] C. Saunders, A. Barber, Carbon footprints, life cycle analysis, food miles: global trade trends and market issues, Polit. Sci. 60 (1) (2008) 73–88.
[23] F. Lawrence, *Food Study Reveals Hidden £9bn Costs of Transport*, the Guardian, 2005 viewed 15/4/2018, https://www.theguardian.com/news/2005/jul/15/food.greenpolitics.
[24] K. Kemp, A. Insch, D.K. Holdsworth, J.G. Knight, Food miles: do UK consumers actually care? Food Pol. 35 (6) (2010) 504–513, 2010/12/01/.
[25] L. Sirieix, G. Grolleau, B. Schaer, Do consumers care about food miles? An empirical analysis in France, Int. J. Consum. Stud. 32 (5) (2008) 508–515.
[26] D. Coley, M. Howard, M. Winter, Food miles: time for a re-think? Br. Food J. 113 (7) (2011) 919–934.
[27] J.I. Boye, Y. Arcand, Green Technologies in Food Production and Processing, Springer Science+Business Media, 2012.
[28] A.V. Stamm, Carbon Footprint of Diets of Norwegian Households - Status and Potential Reductions, Norwegian University of Science and Technology, Norway, 2015.
[29] A. Carlsson-Kanyama, M.P. Ekström, H. Shanahan, Food and life cycle energy inputs: consequences of diet and ways to increase efficiency, Ecol. Econ. 44 (2) (2003) 293–307, 2003/03/01/.
[30] X.B. Xue, A.E. Landis, Eutrophication potential of food consumption pattern, Environ. Sci. Technol. 44 (2010) 6450–6456.
[31] J. Gustavsson, Christel Cederberg, Ulf Sonesson, Cutting Food Wste to Feed the World, Food and Agriculture Organization of the United Nations, 2018.
[32] K. Scholz, M. Eriksson, I. Strid, Carbon footprint of supermarket food waste', Resources, Conserv. Recycl. 94 (2015) 56–65, 2015/01/01/.
[33] K.M. Kibler, D. Reinhart, C. Hawkins, A.M. Motlagh, J. Wright, Food waste and the food-energy-water nexus: a review of food waste management alternatives, Waste Manag. 74 (2018) 52–62, 2018/04/01/.
[34] K.D. Hall, J. Guo, M. Dore, C.C. Chow, The progressive increase of food waste in America and its environmental impact, PLoS One 4 (11) (2009) e7940.
[35] K. Silvennoinen, L. Heikkilä, J.-M. Katajajuuri, A. Reinikainen, Food waste volume and origin: case studies in the Finnish food service sector, Waste Manag. 46 (2015) 140–145, 2015/12/01/.
[36] M.E. Edjabou, A. Boldrin, C. Scheutz, T.F. Astrup, Source segregation of food waste in office areas: factors affecting waste generation rates and quality, Waste Manag. 46 (2015) 94–102, 2015/12/01/.
[37] A.K. Choudhary, N. Kumar, Environmental impact of non-vegetarian diet: an overview, International Journal of Engieering Science & Research Technology 6 (8) (2017) 251–257.
[38] A. Bernstad, L. Malmquist, C. Truedsson, J. la Cour Jansen, Need for improvements in physical pretreatment of source-separated household food waste, Waste Manag. 33 (3) (2013) 746–754, 2013/03/01/.
[39] P. Scarborough, P.N. Appleby, A. Mizdrak, A.D.M. Briggs, R.C. Travis, K. E. Bradbury, T.J. Key, Dietary greenhouse gas emissions of meat-eaters, fish-eaters, vegetarians and vegans in the UK, Climatic Change 125 (2) (2014) 179–192, 2014/07/01.
[40] R. Vidal, E. Moliner, A. Pikula, A. Mena-Nieto, A. Ortega, Comparison of the carbon footprint of different patient diets in a Spanish hospital, J. Health Serv. Res. Policy 20 (1) (2015) 39–44.
[41] C.L. Weber, H.S. Matthews, Food-miles and the relative climate impacts of food choices in the United States, Environ. Sci. Technol. 42 (10) (2008) 3508–3513, 2008/05/15.
[42] T. Garnet, Meat and Dairy Production and Consumption, University of Surrey, UK, 2007.
[43] K. Khanna, S. Gupta, S.J. Passi, R. Seth, R. Mahna, S. Puri, Textbook of Nutrition and Dietetics, Phoenix Publishing House Ltd, New Delhi, 1997.
[44] L. Mogensen, T. Kristensen, N.I. Nielsen, P. Spleth, M. Henriksson, C. Swensson, A. Hessle, M. Vestergaard, Greenhouse gas emissions from beef production systems in Denmark and Sweden, Livest. Sci. 174 (2015) 126–143, 2015/04/01/.
[45] T. Nemecek, K. Weiler, K. Plassmann, J. Schnetzer, G. Gaillard, D. Jefferies, T. García–Suárez, H. King, L. Milà i Canals, Estimation of the variability in global warming potential of worldwide crop production using a modular extrapolation approach, J. Clean. Prod. 31 (2012) 106–117, 2012/08/01/.
[46] X. Xu, Y. Lan, A comparative study on carbon footprints between plant- and animal-based foods in China, J. Clean. Prod. 112 (2016) 2581–2592, 2016/01/20/.
[47] F.A.O. Faostat, Food and Agriculture Organization of the United Nations, Statistic Division, 2014.
[48] M. Herrero, P. Gerber, T. Vellinga, T. Garnett, A. Leip, C. Opio, H.J. Westhoek, P. K. Thornton, J. Olesen, N. Hutchings, H. Montgomery, J.F. Soussana, H. Steinfeld, T.A. McAllister, Livestock and greenhouse gas emissions: the importance of getting the numbers right, Anim. Feed Sci. Technol. 166–167 (2011) 779–782, 2011/06/23/.
[49] N.T. Francesco, S. Mirella, R. Simone, F. Alessandro, F. Nuala, S. Pete, The FAOSTAT database of greenhouse gas emissions from agriculture, Environ. Res. Lett. 8 (1) (2013), 015009.
[50] C. Buratti, F. Fantozzi, M. Barbanera, E. Lascaro, M. Chiorri, L. Cecchini, Carbon footprint of conventional and organic beef production systems: an Italian case study, Sci. Total Environ. 576 (2017) 129–137, 2017/01/15/.
[51] Consultative group on international agricultural research, in: CCAFS Info Note, 2015.
[52] K. Cheng, G. Pan, P. Smith, T. Luo, L. Li, J. Zheng, X. Zhang, Carbon footprint of China's crop production—an estimation using agro-statistics data over 1993–2007', Agriculture, Ecosystem and Environment 142 (2011) 231–237.
[53] M. Yan, K. Cheng, T. Luo, Y. Yan, G. Pan, R.M. Rees, Carbon footprint of grain crop production in China – based on farm survey data, J. Clean. Prod. 104 (2015) 130–138, 2015/10/01/.
[54] S.H. Vetter, T.B. Sapkota, J. Hillier, C.M. Stirling, J.I. Macdiarmid, L. Aleksandrowicz, R. Green, E.J.M. Joy, A.D. Dangour, P. Smith, Greenhouse gas emissions from agricultural food production to supply Indian diets: implications for climate change mitigation, Agric. Ecosyst. Environ. 237 (2017) 234–241, 2017/01/16/.
[55] FAOSTAT, Food And Agricultural Organisation of the United Nations, 2014 viewed, http://faostat.fao.org/.
[56] The American Carbon Footprint, Brighter Planet, 2010, pp. 1–17.
[57] K. Hamerschlag, K. Venkat, Meat Eater's Guide: Methodology 2011', Environmental Working Group, 2011, pp. 1–63.
[58] K. Sanders, M. Webber, A comparative analysis of the greenhouse gas emissions intensity of wheat and beef in the United States, Environ. Res. Lett. 9 (2014) 1–9.
[59] I. Acosta-Alba, E. Chia, N. Andrieu, The LCA4CSA framework: using life cycle assessment to strengthen environmental sustainability analysis of climate smart agriculture options at farm and crop system levels, Agric. Syst. 171 (2019) 155–170.
[60] A. Voglhuber-Slavinsky, A. Zicari, S. Smetana, et al., Setting life cycle assessment (LCA) in a future-oriented context: the combination of qualitative scenarios and LCA in the agri-food sector, Eur J Futures Res 10 (2022) 15, https://doi.org/10.1186/s40309-022-00203-9.
[61] W. Wakeland, S. Cholette, K. Venkat, Chapter 9: Food Transportation Issues and Reducing Carbon Footprint, 2012 (USA).
[62] Department of Environmental Quality, Food Transportation, Center for Sustainable System, 2015, pp. 1–2.
[63] Food and Agricultural Organization of the United Nations, Food Wastage Footprint & Climate Change, 2015, pp. 1–4.
[64] Food and Agricultural Organization of the United Nations, FAOSTAT, 2017 viewed 13 May 2018, http://www.fao.org/faostat/en/#data/GC.
[65] M.B.M. Siddique, N. Khairuddin, N.A. Ali, M.A. Hassan, J. Ahmed, S. Kasem, M. Tabassum, H.N. Afrouzi, A Comprehensive Review on the Application of Bioethanol/Biodiesel in Direct Injection Engines and Consequential Environmental Impact, Cleaner Engineering and Technology, 2021, 100092.
[66] A Time to Act: Climate Action and the Food and Drink Industry, Food Drink Europe, Belgium, Europe, 2015.
[67] R. Marino, A.S. Atzori, M. D'Andrea, G. Iovane, M. Trabalza-Marinucci, L. Rinaldi, Climate change: production performance, health issues, greenhouse gas emissions and mitigation strategies in sheep and goat farming, Small Rumin. Res. 135 (2016) 50–59, 2016/02/01/.
[68] H. Westhoek, J.P. Lesschen, T. Rood, S. Wagner, A. De Marco, D. Murphy-Bokern, A. Leip, H. van Grinsven, M.A. Sutton, O. Oenema, Food choices, health and environment: effects of cutting Europe's meat and dairy intake, Global Environ. Change 26 (2014) 196–205, 2014/05/01/.
[69] J.I. Macdiarmid, F. Douglas, J. Campbell, Eating like there's no tomorrow: public awareness of the environmental impact of food and reluctance to eat less meat as part of a sustainable diet, Appetite 96 (2016) 487–493, 2016/01/01/.
[70] Reducing Your Carbon Footprint, World Health Organization, Switzerland, 2008.
[71] Tiziana Laureti, Ilaria Benedetti, Exploring pro-environmental food purchasing behaviour: an empirical analysis of Italian consumers, J. Clean. Prod. 172 (2018) 3367–3378.
[72] K.G. Grunert, W.I. Sonntag, V. Glanz-Chanos, S. Forum, Consumer interest in environmental impact, safety, health and animal welfare aspects of modern pig production: results of a cross-national choice experiment, Meat Sci. 137 (2018) 123–129.
[73] Carola Grebitus, Bodo Steiner, Michele M. Veeman, Paying for sustainability: a cross-cultural analysis of consumers' valuations of food and non-food products labeled for carbon and water footprints, Journal of Behavioral and Experimental Economics 63 (2016) 50–58.
[74] Maurizio Canavari, Silvia Coderoni, Consumer stated preferences for dairy products with carbon footprint labels in Italy, Agricultural and Food Economics 8 (1) (2020) 1–16.