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Environmental impact of food products and difficulties in quantifying them

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SUMMARY

Agricultural production, the food industry and the transportation of foods all pollute our environment. Of the various aspects of the environmental impact, more and more attention is paid to the contribution of the food industry to greenhouse gas emission, and thus to climate change. There is a large number of studies in the international literature on comparing the gas emissions during the manufacture of plant and animal products, or on the measurement of greenhouse gas emissions during the manufacture of various agricultural and food products. These quantities may be given cumulatively in carbon dioxide equivalent, which is called the carbon footprint of the product, but the methods used to calculate them are not standardized. The guidance of PAS 2070 or standard ISO14067 may be used. These methods are based on product life cycle analysis (LCA), i.e., they provide the amount of greenhouse gas produced in the manufacturing process, after taking into account the resources used in manufacture of the product, the raw materials used, the production of the packaging materials, transportation and the energy use. In many cases, food reaches the consumer at the end of a long supply chain. The part of the product life cycle related to becoming waste and waste management can also be considered. In this case, a "from cradle to cradle" approach to life cycle analysis is followed. However, it is difficult to gather the appropriate data for the compilation of the raw material map and for process mapping; in our paper, this is presented through an example that may seem simple at first. It is particularly difficult if the goal is to determine the carbon footprint of not foods to be placed on the counters, but prepared foods consumed in restaurants. It is important to set boundaries during process evaluation within which the carbon footprint of a certain part of the entire chain can be calculated reliably on the basis of reliable data.

Literature review

The environmental impact of food production is indisputable. Agricultural production and the food industry, as well as the transportation of foods are all known for their environmental pollution effects. Agriculture contributes significantly to greenhouse gas emissions, while also absorbing carbon dioxide, so its role in climate change is controversial. Determination of the carbon footprint of agricultural products is an appropriate tool for measuring the efficiency and sustainability of agricultural production **[1]**. *Al-Mansour et al.* **[1]** use a model to calculate the greenhouse gas emission of a product from the start of the production process through storage up to the point where the product reaches the final consumer of the food industry. Of the various aspects of the environmental impact, more and more attention is paid to the contribution of the food industry to greenhouse gas emission, and thus to climate change. Due to the high greenhouse gas emission of the food industry, its carbon footprint has been

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the focus of researchers' attention **[41]**. Agricultural production accounts for 35% of the total greenhouse gas emission **[6]**. Ensuring the food supply of a growing population, while reducing environmental externalities, is a key issue in today's sustainability debate. Studies indicate that food consumption is a determining factor in the environmental deficit of an area, where the demand for resources and eco-services exceeds the boundaries of the ecosystem. Among the countries studied, Portugal, Malta and Greece have the highest per capita ecological footprint, while it is the lowest in the case of Slovenia, Egypt and Israel **[12]**. Sustainable consumption and production are key policy objectives of the renewed European Union Sustainable Development Strategy. These objectives are predominantly of a production rather than a consumption type, and are different for each member state of the European Union. It is important to note that according to the Global Footprint Network, the carbon footprint of consumption has now exceeded the greenhouse gas emission of production in almost all EU member states **[17]**.

Studies by *Vergé et al.* **[34]** focused on calculating the carbon footprint of the Canadian pork industry. The carbon footprint of pork production in Easter Canada ranges from 2.6 to 4.0 kg CO_2 equivalent / kg of product, depending on the technology and weighting, while in the west it is 3.2 to 5.0 kg CO_2 equivalent/kg of product. In the calculations, three weighting methods were used:

1. Calculation with no weighting: based on farm production;
2. Economic weighting: based on market research;
3. Weighting by the mass produced: best fits sustainability studies.

Buratti et al. **[5]** investigated the carbon footprint of conventional and organic beef production systems through an Italian example (where the large-scale breeding technology typical of central and southern Italy under investigation is referred to by the authors as conventional breeding technology). In the organic production process, the carbon footprint of producing one kg of live weight is 24.62 kg CO_2 equivalent (hereinafter CO_2e), while that of one kg of live weight produced by conventional technology is 18.21 kg CO_2e. When calculating the carbon footprint, 50 to 54% of the greenhouse gas emission came from the methane from the fermentation in the digestive tract. Research results of *Xu* and *Lan* **[39]** in China have led to the conclusion that the production of foods of animal origin has a higher carbon footprint than that of the production of foods of plant origin. Beef and lamb production has a higher carbon footprint than other foods, and the lowest carbon footprint was exhibited by radish production. In the case of the production of plant-based foods, most of the carbon footprint came from field production. The composition of the carbon footprint was not uniform in the case of foods of animal origin.

Organically produced foods are often considered to be more environmentally friendly compared to product manufactured the conventional way; within Europe, the market for organic products is expanding rapidly, for, example, in Germany. According to *Treu et al.* **[33]**, greenhouse gas emissions related to conventional and organic diets are essentially the same, while greenhouse gas emission from land use is roughly 40% higher in the case of the organic diet. The traditional diet contains 45% more meat than the organic diet, which contains 40% more fruits and vegetables. The dominant proportion (70-75%) of the carbon footprint came in both cases from the production of foods of animal origin and from land use. *Yue et al.* **[40]**, based on statistical data, investigated the carbon footprint of twenty-six types of cereals and six types of farm animal products in China. The following results were obtained (***Table 1***):

According to the calculations of *Yue et al.* **[40]**, of the carbon footprints of plant-based products, flooded rice cultivation and the methane emission from fertilizer use accounted for most of the footprint (36-93%). In the case of livestock production, feeding, digestive fermentation and manure treatment accounted for 96% of the emission. Also examined were the carbon footprints of home and restaurant meals: the footprint of out-of-home meals was 2.87 kg CO_2e/person/meal, while the carbon footprint of home meals was 1.57 kg CO_2e/person/meal **[40]**. In China, the evolution of the carbon footprint of fifteen types of food between 1979 and 2009 was examined by *Jianyi et al.* **[15]**. According to their results, the carbon footprint of rice cultivation increased the most, but a rapid growth was also experienced in the case of milk, beef, fruits and vegetables as well, due to the increasing yields. However, generally a decline could be seen in the factors that influence the carbon dioxide emission of these products.

In Argentina, the carbon footprint of honey was determined by *Mujica et al.* **[21]**: it is 2.5 ± 0.17 kg CO_2e/kg product, most of which comes from spinning.

The carbon footprint of whole grain bread was calculated by *Chiriaco et al.* **[7]** using the method of life cycle analysis. In the case of this product, the carbon footprints of whole grain breads made from wheat coming from organic and conventional cultivation were compared. The results showed that 1 kg of bran bread made from conventional wheat induced a 24% lower emission. The carbon footprint of bread made using wheat from conventional cultivation was 1.18 kg CO_2e/kg, while in the case of the bread made using wheat from organic cultivation the value was 1.55 kg CO_2e/kg. However, when the carbon footprint per unit area of land used for cereal production was calculated, the performance of organic cultivation was better: greenhouse gas emission per hectare was 60% lower than that of the conventional cultivation technology. Nevertheless, it is advisable to take into account the lower efficiency and greater land requirement of organic farming. *Casolani et al.* **[6]** investigated the water and carbon footprint trends in the case of durum wheat cultivation in Italy between 2011 and 2015. They examined the ratio of these indicators to each other, based on which it was revealed that this ratio is highest in the Adriatic region. The highest carbon footprint value was obtained in the case of Northern Italy (2,462 kg CO_2e/ha).

Emissions that are wasted because of waste generation were quantified by *Scholz et al.* **[26]**. Food waste is a major problem for modern societies and represents a significant social, economic and environmental expenditure. Food production generates greenhouse gas emissions throughout the entire food chain, and food becoming waste equals to the related emissions becoming unnecessary. Therefore, there is a consensus among professionals on reducing the amount of food waste. According to a survey carried out in six Swedish grocery stores, 85% of the waste generated came from the fruit and vegetable department, accounting for 46% of the wasted carbon footprint. 3.5% of the waste was produced by the meat department, accounting for 29% of the wasted emission **[26]**.

To develop strategies to reduce the amount of food waste and to develop sustainable food consumption habits, information (climate, water and land use) that quantifies the environmental impacts of consumption behavior and waste generation is needed **[29]**. Food waste generation is the biggest problem, and reducing it is essential for the development of sustainable food chains **[10]**. *Eriksson et al.* **[10]** observed thirty public catering kitchen units in Sweden and found that the amount of food waste per serving was 75 g, which was 23% of the food distributed.

The environmental effects of food consumption were quantified by *Zsófia Vetőné Mózner* **[35]** through a domestic example using the ecological and carbon footprint method. According to her results, the ecological and carbon footprints of meat and dairy products were the highest. She found that men in Hungary, based on the analysis of their eating habits, have an ecological footprint than that of women. The joint work of *Csutora* and *Vetőné* **[8]** points out that food consumption results in a significant environmental impact and the income of households and their members that can be spent on savings plays an important role in the type of food they consume. It can be said that the higher the income, the higher the food consumption. At the same time, people with higher incomes show a greater propensity to adopt healthier eating habits, resulting in lower consumption. In this context, it would be useful to identify the different social groups on the basis of income with the help of communication related to sustainable consumption. *Sommer* and *Kratena* **[28]** calculated the carbon footprint of personal consumption for the 27 member states of the European Union with the help of macroeconomic models, for five household groups classified by income. Among their results, it is important to mention that 45% of the income is held by the households in the highest income category, but they are responsible for 37% of the carbon footprint, while the lowest income households hold 6% of the income but account for 8% of the carbon footprint. In her paper, *Vetőné* **[36]** points out that environmental and health aspects must be taken into account together in environmental and economic analyses.

Food consumption has a direct effect on consumer health and the environment. According to *Benedek* **[3]**, the role of local food and the related short food supply chains is gaining increasing attention among both consumer NGOs and decision-makers at various levels. They can provide a solution to the many problems of the conventional food industry (such as food miles) for both consumers and producers. Short food supply chains have a decades long tradition in North America and Western Europe, but there are more and more commercial networks of this kind in Hungary.

Despite the large size and economic importance of the catering industry, there is a lack of scientific knowledge on its environmental impacts **[11]**. At the same time, there is a growing demand for environmentally sustainable food preparation and consumption. Generally speaking, two types of catering service methods can be distinguished. In one case, cooking and serving are done in one place, whereby the food, once it is ready, is served to the consumer immediately. In the other case, these processes are separated from each other, i.e., cooking, preparation and consumption are separated in both space and time. The environmental effects of the separated process were examined by *Fusi et al.* **[11]** through the example of a typical Italian food, pasta. They focused on two main types of systems: cooking and keeping hot, and cooking and cooling, with the different cooking procedures studied separately. According to the results, in the case of pasta cooked in a pasta cooker, energy consumption was 60% lower and water consumption was 38% lower than in the case of the traditional (stovetop) procedure. The overall environmental impact of the pasta thus prepared was 34-66% lower. The environmental impact could also be reduced by using gas-fired cooking equipment instead of the electrical one. The environmental impact of the cooking-cooling system was 17-96% higher than that of the cooking/keeping hot system, mainly due to the energy requirement of the cooling technology.

Not only the carbon footprint of foods or restaurant catering, but also that of hotels can be examined.

An example of this is the work of *Liqin* **[18]**, who examined the carbon footprint of the hospitality activities (products) of high-end hotels during their normal operation. He found that 99% of the carbon footprint of hospitality products came from direct greenhouse emission. The higher the hotel category and the more special the product range were, the higher the carbon footprint was. Certain foods have higher greenhouse gas emissions than others, and so if they are organized properly in tourism, this can contribute to reducing the effects that induce climate change. A study by *Gössling et al.* **[13]** reviews the carbon intensity of various foods and discusses how people in the catering business could change their current practices in a positive way. There are many important correlations between food production and food consumption in tourism that play a crucial role in sustainability. According to *Torres* **[32]**, one third of the money spent on tourism is spent on food. According to *Sel et al.* **[27]**, outsourcing resources, employing appropriately trained personnel and managing capacity that is growing due to the efficiency of process control can greatly contribute to the development of a sustainable hospitality chain.

Carbon footprint calculation methods

The carbon footprint is an environmental sustainability index that quantifies the amount of greenhouse gases emitted during the life cycle of a product **[21]**. Today, sustainable production includes the rational use of resources and the fulfillment of the obligation to reduce greenhouse gas emission. The carbon footprint is essentially the amount of greenhouse gas emission generated during the life cycle of products and activities **[23]**. According to *Wiedmann and Minx* **[37]**, the carbon footprint is part of the ecological footprint, measuring the total amount of CO_2 released directly or indirectly into the air by a certain activity, person area of land, etc., or the area of land necessary to neutralize this CO_2 amount **[2]**. This approach is part of the ecological footprint calculation. Organizational carbon footprint calculations, or those related to the carbon footprint of a product, are based on life cycle analysis, as well as the quantification of the emission with respect to a certain unit (for example, kg of finished product in the case of a food product).

The methods used to calculate the carbon footprint are not standardized. The guidance of PAS 2070 or standard ISO14067 may be used. The international standard defines directives, requirements and guidelines for calculating/measuring and communicating the carbon footprints of products. Standard ISO 14067 is based on standards for life cycle analysis, eco-labeling and environmental reporting (ISO 14040, 14044, 14020, 14024, 14025) **[14]**. Application of the standards of the International Organization for Standardization is voluntary. The standards provide guidance on the conditions for achieving certification under the standard. The PDCA cycle for continuous improvement serves as the theoretical basis for the ISO standards, the essence of which is described by *Kósi and Valkó* **[16]**. The above-mentioned carbon footprint calculation methods are based on the Life Cycle Assessment (LCA) of products, i.e., they give the amount of greenhouse gases produced in the production process after taking into account the resources, the raw materials and the energy used in the manufacture of the product (the process of LCA is illustrated in ***Figure 1***).

The study of *Schaltegger és Csutora* **[25]** provides a comprehensive overview of the rapidly evolving field of environmentally conscious enterprise management, i.e., the methodology for calculating carbon inventory and carbon footprint. A literature review of carbon inventory preparation and accounting methodology can be found in the studies of *Stechemesser and Guenther* **[30]**. *Vergé et al.* **[34]** point out that the choice of calculation methods for estimating the environmental impact of human activity requires careful consideration, since it may modify the results of such studies. *Vergé et al.* **[34]** uses life cycle analysis methodology to calculate the carbon footprint of the Canadian pork industry, which is a widely used method for assessing environmental performance these days. The weighting method used is also important, since it affects the results of the calculation and the conclusions that can be drawn from them. A part of the ecological footprint calculation is the carbon footprint component, which takes into account the average carbon sequestration capacity of the forests in the given area. A refinement of this part of the calculation is proposed by *Mancini et al.* **[20]**. It is important to note the fact that the calculation of the carbon component of the ecological footprint and the calculation of the carbon footprint of the product are different from a methodology point of view.

When calculating the carbon footprint, it is also possible to extend the range of observed processes. In this case, emissions are not only examined up until the manufacture of the finished product, but it is also considered in which way it is delivered to the consumer. Foodstuffs are often reach the consumer at the end of a very long supply chain. It is also necessary to take into account the part of the product life cycle concerning waste disposal and waste management. In this case, the “cradle to cradle” approach to life cycle analysis is followed. During process mapping, a great difficulty is presented by gathering the appropriate data, and if we determine the carbon footprint not of foods intended for the counter, but the carbon footprint of finished foods consumed in restaurants. Using a carbon footprint calculation method based on life cycle analysis, the carbon footprint of the cooling of cooked rice was estimated by selecting part of the process by *Zhou et al.* **[41]**. The main component of the carbon footprint is the electricity consumed for cooling **[41]**.

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According to *Xu et al.* **[39]**, energy use in cooking is a key part of the life cycle in the case of many foods. The environmentally friendly choice of the cooking method, the energy source and the cooking utensils reduces the carbon footprint of the cooked product per unit. Proper use of the cooking utensil also reduces the emission and the pollution per unit of heat used. In addition, proper pre-treatment and recycling can reduce the environmental impact of cooking waste management.

When evaluating processes, it is important to identify the boundaries within which the carbon footprint of part of the entire chain can be reliably calculated on the basis of reliable data. *Blanco et al.* **[4]** propose a method for companies to measure the carbon footprint of the supply chain. *Santeramo et al.* **[24]** summarize the increasing trends in the sectors related to the food chain in the European Union today. An important issue is the transportation of food products, which the working group of *Lopez* **[19]** drew attention to when calculating the carbon footprint, by taking into account food miles.

Methodology for carbon footprint calculation in our case study [22]

Carbon footprint calculation is a kind of chain analysis, with the help of which the amount of greenhouse gases generated during the manufacture of a product can be detected. This method tracks the amount of carbon dioxide (or other pollutants calculated in CO_2 equivalent) emitted by the product from the production of the raw material through transportation to the time of sale, but it does not take into account the emission generated at the buyer during the use of the product. Carbon footprint calculation enables businesses to treat carbon footprint as a standalone product. Indicating its numerical value on the different products would give consumers the opportunity to make an environmentally conscious choice.

The methodology consists of five main steps, where each step is closely based on the previous one and, of course, is based on several partial calculations.

Step 1: Analysis of the "inner life" of the products

This means the thorough examination of the product and the manufacturing process while paying attention to all details. It includes the knowledge of the entire process of raw material production, manufacture, storage, transportation and waste management.

Step 2: Preparation of a raw material map

This means the tracking of the path of all the raw materials that make up the given product. A raw material map can be compiled up to the point where the product is placed on the store shelf. The finished product output can be manufactured from one or several raw materials. Each of these raw materials needs to be analyzed in a complex way, from raw material production through storage to transportation.

Step 3: Creation of a manageable database

In order for the methodology to be sound, practical and easy to use, the amount of data input must be limited. If a 100% data input was achieved in the case of each product, the data would be unmanageable and the analysis would incur extreme costs. Currently, the method allows for a 90% analysis of the raw materials of the product. This can be overridden in the future by improving the methodology.

It is also vital to draw the line at which the investigation stops. This limit may be, for example, the point at which the raw material is converted into a finished product or when the finished product reaches a state where it no longer emits carbon dioxide.

Step 4: Collection of primary and secondary data

It involves the gathering of data needed to determine the material balance and to calculate the level of greenhouse gas emission. During the calculation it is advisable to give preference to primary sources, but if data on primary sources are not available, then secondary sources may be considered.

Step 5: Calculation of greenhouse gas emission on the basis of the raw material map

As a final step, it is important to calculate the material balance of the product for each element of the process. This calculation can be used to estimate the level of greenhouse gas emission. The emission shall be determined by taking into account direct and indirect energy emissions, using an emission factor converted to carbon equivalent.

The issue of carbon footprint calculation is interwoven with a complex system of cause and effect relationships, the so-called effect chain. Consideration should be given to the individual elements of the indicator system, secondary indicators, and the extent to which certain values influence the size of the carbon footprint. The calculation should be performed in a product-specific way, following general principles and steps. It is advisable to refine it to the product groups first, and within them the calculation can be done specifically for each product.

Sensitivity testing can also be performed to monitor the extent to which the index changes with the alteration of the values of the individual elements.

Further comparative studies may be warranted to determine the extent to which intervention in the investigated steps of the production process is required and possible. The socio-economic aspects of the process should also be assessed. Changes in indicators over time, improvement in cultivation technology and production processes, changes in packaging, as well as the consequences of a more efficient waste management can also be investigated. It is also not negligible to determine, when analyzing the processes, which indicators can be measured and which cannot (for example, because they are part of a "secret" manufacturing technology or patent).

Case study on a sample product (rice)

Cultivation and processing of the white long grain rice, which provided the data for our rice case study, are carried out in an area-concentrated fashion. Information regarding the details of the cultivation technology is based on the technological practice in Szarvas. In the case of the cultivation technology, the carbon footprints of arable land rice cultivation and of aquatic cultivation, which were calculated on the basis of expert estimates. The main steps of carbon footprint calculation: definition of the components, detailed analysis of the steps of the technology, preparation of the „product table", construction of the raw material map (taking into account the preparation, technological and transportation steps, the role of commerce and the end of the so-called life cycle) **[9]**. The raw material map for rice cultivation is shown in ***Figure 2***.

The evolution of the carbon footprint of rice and its distribution between the individual phases are shown in ***Figure 3*** for arable land cultivation and in ***Figure 4*** for aquatic cultivation.

In the case of aquatic cultivation, the following results were obtained: the carbon footprint for 1 ton of rice was 537.3 kg, which is significantly lower than in the case of arable land cultivation **[9]**. The carbon footprint of rice is 170.8 kg less for aquatic cultivation compared to the arable land cultivation technology. If only the cultivation part of the technology is examined, then the carbon footprint was 100.5 kg for aquatic cultivation, which is 172.5 kg lower than in the case of arable land cultivation. If we look at the percentages for aquatic cultivation, the environmental load of the cultivation is 18.89 %, compared to the 38.40% for arable land cultivation.

The distribution between the different processes of the carbon footprint of retail products coming from different cultivation technologies is shown in ***Figure 5***.

In terms of use, once again rice was chosen as a sample product, and the carbon footprint of home cooking was examined under various conditions. The rice used as the sample product was a brown rice product of a domestic manufacturer. Manufacturers often include a cooking suggestion on their products. In many cases, the recipes for the preparation of each product may differ significantly. By achieving a kind of product innovation and indicating the recipe with the lowest carbon dioxide emission, the manufacturer can reduce the carbon footprint of the product. The amount of carbon dioxide released during the preparation of 250 g of brown rice, enough for a single meal of a family of four, was determined in four cases. Results are shown in ***Figure 6***.

Brown rice is usually cooked after a few hours of soaking on an electric stove or, in other cases, on a gas stove. (Soaking before cooking can be omitted.) In the course of our investigation, rice was cooked on a gas stove and on an electric stove, with or without soaking. Soaking time was 1 hour, after which the water used for soaking was removed, so it became waste. As a result of soaking, the cooking time was shortened, so the amount of energy used during cooking was reduced.

Based on the actual results below, the carbon footprint of the given type of brown rice for 1 kg of finished product can be given:

I. On a gas stove – Average power of the gas burner was 1 kW – according to the manufacturer's data

a) With no soaking the time required for cooking was 45 minutes on average – based on the recipes, the emission was 0.6 kg CO_2e / kg cooked brown rice

b) With soaking the time required for cooking was 15 minutes on average – based on the recipes, the emission was 0.2 kg CO_2e / kg cooked brown rice

II. On an electric stove – Average power of the electric stove was 1.2 kW – according to the manufacturer's data

a) With no soaking the time required for cooking was 50 minutes on average – based on the recipes, the emission was: 2 kg CO_2e / kg cooked brown rice

b) With soaking the time required for cooking was 20 minutes on average – based on the recipes, the emission was 0.8 kg CO_2e / kg cooked brown rice

Converted to one kg of brown rice and examining the proportion of the carbon footprint components of rice, it was found that when cooked with no soaking on an electric stove, consumer use contributes far more to the carbon footprint of rice than cooking with soaking on a gas stove.

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