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# LABELLING THE CARBON FOOTPRINT AS A STRATEGIC ELEMENT OF ENVIRONMENTAL ASSESSMENT OF AGRICULTURAL SYSTEMS

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ABSTRACT

The aim of the study was to assess the potential use of the carbon footprint for the environmental evaluation of agricultural systems. Carbon footprint analysis in agriculture has a strategic dimension in terms of sustainable food production. Reducing the negative impact of agriculture on climate change is a key element of many quality management systems and is included in the legislation of many countries. One of the challenges in calculating the carbon footprint is the lack of clear methodologies for determination of the greenhouse gas (GHG) emissions at this stage. Normative documents highlight the need to consider all areas of GHG emissions, but in practice, this is exceedingly difficult due to the specific characteristics of plant production, which takes place under variable conditions related to soil type, its properties, chemical composition, climate, and production technology. Based on a review of the scientific literature, it was concluded that the carbon footprint studies of specific agricultural systems and evaluations of technology improvements (implementing actions to compensate for anthropogenic pressure) should be conducted within an individual system boundary. The system boundary should be developed based on the process map created in accordance with the guidelines of ISO 31000:2018. Most of the input data used in the calculations must be standardized due to the range of parameters dependent on the natural, geographical, and infrastructural conditions of the production location.

## Introduction

The world population in 2024 reached 8.2 billion, and it is estimated that by the mid-2080s, the Earth will be inhabited by 10.3 billion people (World Population Prospects, 2024). Due to the rapid growth of the global population, providing an adequate quantity and quality of food has become a global challenge (Alexandratos and Bruinsma, 2012). Over the last 100 years, a threefold increase in global food production has been made possible by enhanced agricultural productivity (Lanz et al., 2018a). However, the rise in agricultural efficiency and production contributes to the loss of natural ecosystems due to the land conversion for livestock grazing and crop cultivation, leading to a continuous increase in greenhouse gas (GHG) emissions (Lanz et al., 2018b; Tubiello et al., 2022).

Agri-food systems are responsible for one-third of the global anthropogenic GHG emissions (Crippa et al., 2021; Tubiello et al., 2021), with agriculture alone accounting for 20% of global emissions. Of this, 31% of GHGs are linked to livestock production, 27% to crop production, 24% to land use, and 18% to agrologistics (Gan et al., 2011). Between 1990 and 2019, global emissions from food production systems increased by 17%, driven largely by a sharp rise in emissions in developed countries. GHG emissions stem from both primary production and post-harvest processing, as well as pre- and post-production processes, such as fertilizer production and use, food processing, packaging, transportation, retail, household consumption, and food waste disposal (Moult et al., 2018). In developing countries, agricultural activities and land-use changes for food and feed production have the greatest potential for GHG emissions (Chataut, 2023). In these countries, climate change is predominantly driven by methane emissions from large and small ruminant livestock. Agriculture in the European Union (EU) is responsible for 71% of total nitrous oxide ($N_2O$) emissions and 49% of all methane emissions in 2021. GHG emissions from agriculture in the EU result primarily from livestock rearing, agricultural soil management, burning of crop residues and waste, and the operation of agricultural machinery. In 2020, agri-food systems contributed 31% of the total GHG emissions in the EU (Jensen and Scalamandrè, 2023).

The aim of this study was to assess the potential use of the carbon footprint of food products for the environmental assessment of agricultural systems.

## Literature Review

Greenhouse gas (GHG) emissions other than $CO_2$ from the agricultural sector in the EU are regulated by the Effort Sharing Regulation (ESR) which sets national targets for annual emissions across sectors covered by the collective reduction effort. The revised ESR sets a 2030 target for a 40% reduction in GHG emissions compared to 2005 for the sectors governed by this regulation (Regulation of the European Parliament and Council amending Regulation (EU) 2018/842). Although the emission reduction target has not yet been fully achieved, a slight decrease in GHG emissions was observed in 2021, indicating progress toward improving the environmental efficiency of agricultural production.

Currently, reducing the negative environmental impact of agriculture has become a primary focus of scientific research and the development of production technologies in both plant and animal sectors. Changing agricultural legislation is driven by the need to fulfil international commitments made by countries under the UN. The second context for the development of low-emission technologies in agriculture stems from the evolving needs of consumers, especially in developed countries. Economic growth and rising wealth in these countries are linked to changing consumer awareness and preferences. Today, the product quality is shaped not only by factors related to functionality, availability, and health impacts, but also by environmental impact and the use of non-renewable resources.

In response to the trends mentioned above in both legislation and market tendencies in the food sector, recent years have seen not only changes in regulations but also the rapid development of certified quality systems that emphasize sustainable agricultural practices (Braglia et al., 2024; Karaşan et al., 2024). Reducing GHG emissions is a strategic element of sustainable agricultural development and is integrated into all quality management systems in primary production, such as GLOBAL G.A.P., Integrated Production, and the SAI Platform (Niemiec et al., 2019). Many countries are also developing and implementing formalized Good Agricultural Practices (GAP) standards, which include GHG emission management as a core component (Kapoor and Pal, 2024; Habib et al., 2024). Currently, there are over 75 initiatives globally that regulate GHG emissions at the national, international, or non-governmental level. According to the data from the World Bank, global revenues from GHG emissions in 2023 reached \$104 billion, with about half allocated to environmental and climate protection projects. The total amount of GHGs subject to fees is over 12 Gt $CO_2$.

A critical aspect of GHG emission control systems is the economic quantification of emissions, typically expressed in terms of $CO_2$ equivalents. Economic factors are increasingly significant in regulating GHG emissions within the global system (Latawiec et al., 2021). It is estimated that approximately 20% of total GHG emissions are subject to these initiatives and are converted into economic values (Habib et al., 2024).

Optimizing processes within the broadly understood agri-food sector involves various areas of human activity. Scientific literature provides data on carbon footprint calculations for a wide range of crops and cultivation methods (Wu et al., 2021; Incrocci et al., 2020; Taft et al., 2015). Many studies focus on assessing the carbon footprint of specific crops to evaluate the environmental impacts of their consumption. For example, studies have shown that maize cultivation has the largest carbon footprint, followed by rice, wheat, and barley (Deng et al., 2024; Pramanick et al., 2024). Some research on optimizing agricultural systems focuses on improving fertilizer efficiency (Rashidov et al., 2021) or utilizing agricultural waste as fertilizer or production inputs (Komorowska et al., 2023). Most researchers presenting their findings focus on the amount of GHG emissions within a defined system boundary.

The environmental impact of logistics within the food supply chain is rarely included in agricultural system assessments. According to scientific literature, there is still significant potential for reducing GHG emissions in current food production and distribution processes, which would reduce the negative environmental impact of agriculture (Liu et al., 2024; Goglio et al., 2019). Global GHG emissions from fossil fuels used in agricultural fields are estimated at over 0.6 Gt $CO_2$ equivalent annually, while total GHG emissions from agriculture amount to around 5 Gt $CO_2$ equivalent per year (Shao, 2024). GHG emissions related to energy consumption in crop production are divided into primary and secondary sources. Primary emissions result from fieldwork activities such as tillage, fertilization, irrigation, pesticide use, harvesting, sowing, and logistics during cultivation, harvesting, and post-harvest processing. Secondary (indirect) sources of emissions include fertilizer and pesticide production, equipment manufacturing and maintenance, and the production and disposal of irrigation systems.

Soils used for agriculture are also a significant source of GHG emissions during both the growing season and off-season. Carbon dioxide ($CO_2$) is emitted from soil as a result of organic matter mineralization, while nitrous oxide ($N_2O$) is produced through nitrogen compound transformations, primarily from mineral fertilizers applied to the soil (Chen et al., 2024). Another critical gas in terms of agriculture's contribution to climate change is methane, which is primarily associated with ruminant livestock farming and the cultivation of certain crops like rice. The amount of nitrogen compounds emitted into the atmosphere is related not only to the intensity of fertilization but also to the efficiency of nutrient utilization from fertilizers and the farming technology used (number and type of farming operations) (Du et al., 2024).

Soil organic matter is also considered an important source of GHGs, and in all systems, it is accounted for in the calculations of agriculture's impact on climate change. This includes organic fertilizers, crop residues, and by-products left in the field after the main crop harvest (Cordeiro et al., 2024). Nitrous oxide ($N_2O$) is the key compound responsible for the greenhouse effect from agricultural sources, trapping 292 times more infrared radiation than carbon dioxide (Forster et al., 2007).

Assessing the environmental and economic efficiency of implemented quality systems in primary production is a crucial aspect of evaluating the real impact of producer requirements on product quality and the degree of environmental impact (Komorowska et al., 2024; Kapusta-Duch et al., 2019).

The size of greenhouse gas emissions, often referred to as the carbon footprint, represents the emission of greenhouse gases throughout the entire production cycle, including all sources of these emissions at every stage of production. In the case of agricultural production, however, there is a challenge associated with defining the system boundary within which the calculation of greenhouse gas emissions is made. Depending on the system boundary adopted, different results may be obtained for the same production systems (Nsabiyeze et al., 2024). The approach to calculating the greenhouse gas emissions has evolved over the years (Hu et al., 2024). Initially, carbon footprint calculations used indirect and direct sources of emissions converted to carbon dioxide equivalent within the boundary of a single growing season. As the methodology developed, additional elements were included, expanding the system boundary. This allowed for a more comprehensive approach to calculating the actual amount of greenhouse gases emitted. However, expanding the number of emission sources increased measurement errors due to the lack of clear methods for calculating partial emission levels. For example, calculating the level of emissions resulting from the depreciation of agricultural machinery used for harvesting or cultivation (Shabir et al., 2023).

Problems in unifying methodologies for assessing agricultural systems in the context of their impact on climate change are also related to determination of the product's functional unit. Typically, the functional unit is the mass of the product harvested from the field. However, some researchers point out that a food product can be considered effectively produced when it reaches the consumer in a form that can be consumed. Therefore, it is necessary to include greenhouse gas emissions from the logistics chain, not only in terms of emissions from transportation, storage, and processes such as processing, but also the mass of product wasted under specific supply chain conditions. According to FAO data, food waste levels can reach up to 10% (Bains et al., 2024).

A methodologically sound approach to calculating the carbon footprint in agricultural systems should include all elements involved not only in the main process but also in supporting processes. This approach is correct from a methodological point of view, but when assessing the environmental efficiency of specific system modifications, an approach that allows for selecting the system boundary based on the set goals is more practical. In this case, the process of establishing the system boundary and verifying it in the context of the defined qualitative and quantitative goals should be conducted according to ISO 31000:2018 (Risk Management). In such an approach, the defined risk should be the impact of experimental factors or the analysed variable on the defined goal, which could be the crop yield, the level of greenhouse gas emissions per a unit area, or a balanced combination of both parameters. The selection of emission sources for GHG calculations should result from the defined goal and the analysis of climate, soil, infrastructure, natural, and socio-economic conditions (Komorowska et al., 2023).

A methodologically correct approach to assessing agricultural systems based on a comprehensive and multi-dimensional evaluation of the quality systems involves creating a life cycle assessment (LCA) for products, including energy use, production inputs, and the consumption of renewable and non-renewable environmental resources (Li et al., 2024; Zhang et al., 2021; Šarauskis et al., 2019). These authors emphasize the need to select the system boundary to accurately assess a given agricultural production technology in terms of environmental burden. The correct selection of the system boundary is particularly important in scientific research aimed at evaluation of technology modifications. Many variables and the diverse level of impact of individual inputs on the final value of the carbon footprint make it exceedingly difficult to develop a reliable and universal method. Farms operate within a specific economic, social, and climatic reality, which significantly influences the assessment and may create ambiguities in the conducted evaluation (Devapriya et al., 2017).

For this reason, particularly in the studies on fertilization efficiency, by-product management, or techniques for increasing carbon sequestration, the evaluation of agricultural systems is often based on the selected part of the activity (Chen et al., 2024). Following global trends, more entities involved in food production are obtaining certification for compliance with ISO 14064-1:2018. Achieving certification confirming that an entity calculates its emissions in accordance with international standards increases its market potential, especially in developed countries.

## Conducting the Agricultural System Assessment

### Defining the Strategic Goal and System Boundary

The assessment of an agricultural system based on greenhouse gas emissions should be grounded in defining the strategic goal of optimization activities and mapping the processes influencing GHG emissions.

The strategic goal must be closely linked to the location where the agricultural system operates. The inventory (geographical, environmental, infrastructural, and cultural) should include:

1. **Description of the strategic goal.**
   The strategic goal should clearly state the purpose of the optimization, whether it is reducing emissions, improving sustainability, or increasing productivity while minimizing environmental impact.
2. **Description of factors modifying the agricultural system.**
   This includes any internal or external factors that affect the functioning of the system, such as technological advancements, environmental conditions, or economic pressures.
3. **Plant species in relation to natural production conditions in the area.**
   The description should include the crop being cultivated, taking into account its compatibility with the local natural conditions. This should include the level of agricultural culture and the technological advancement of the system in its current state, without optimization efforts.
4. **Description of the production location (geographical system boundary).**
   The location should be described in terms of the geographical boundary of the system. This should include an assessment of climate, soil, infrastructure, and cultural factors that influence the feasibility of cultivating the crop in the specific region.
5. **Description of applied agricultural practices (excluding the optimization factor).**
   This includes documenting current agricultural practices such as planting, fertilization, irrigation, and harvesting methods, without including the optimization factor being studied.
6. **Description of the solutions optimizing the agricultural system (both qualitatively and quantitatively).**
   It is critical to quantify the factors contributing to the optimization of the system, whether they involve technological improvements, better use of resources, or enhanced farming techniques. The qualitative and quantitative description of these solutions is crucial for evaluating the effectiveness of the agricultural system.

The process map, developed in accordance with ISO 9001:2015 guidelines, should include the main production process and the auxiliary processes that directly or indirectly influence the greenhouse gas (GHG) emissions. The substantive scope of the process map for evaluating the efficiency of the agricultural corn production system is presented in Table 1. The process map is synonymous with the system boundary and was developed to assess the efficiency of fertilization and by-product management in corn production. A properly conducted risk analysis should consider the parameters used in the system assessment and their impact on the level of emissions.

Based on the conducted risk analysis, seed production, the production and amortization of agricultural equipment used in production, and the production and amortization of infrastructure used for seed drying were excluded from the system boundary. The results of the risk analysis clearly indicated that these factors had a marginal impact on the outcome. One of the issues discussed in the scientific literature related to the methodology for calculating greenhouse gas emissions is the subjectivity in choosing the system boundary. Due to the inability to establish rigid system boundary frameworks, the approach of the person conducting the process may be shaped by their level of knowledge and experience in conducting risk analysis (Hoffmann et al., 2024, Nordahl et al., 2024).

Table 1.
*Substantive Scope of the Process Map for Evaluating the Efficiency of Fertilization and By-product Management in Corn Production*

| No. | Parameter | Context (relation to the goal) |
|---|---|---|
| 1 | Agrotechnics | The amount and type of agrotechnical treatments have a fundamental impact on the fuel consumption and rate of organic matter mineralization, both humus and dead organic matter, including crop residues. |
| 2 | Production of fertilizers and agrochemicals used for plant cultivation | The number of fertilizers used in cultivation has the greatest influence on the level of greenhouse gas emissions. Emissions are related to production, logistics, and indirect emissions from the soil after the application of fertilizers. |
| 3 | Energy consumption for fieldwork on the farm | Fuel combustion and electricity consumption are directly related to $CO_2$ emissions into the atmosphere. Increasing crop yields will positively affect the greenhouse gas emissions per functional unit of the product. |
| 4 | Emissions from the soil (direct and indirect related to fertilizer use) | Nitrogen compounds in fertilizers are transformed into nitrogen oxide. |
| 5 | Emissions from the management of crop residues and emissions from the mineralization of soil organic matter | The amount of crop residues is linked to the yield size, which affects the level of greenhouse gas emissions after harvest. Additionally, agrotechnics significantly influence the rate of organic matter mineralization. |
| 6 | Emissions related to the mineralization of by-product yields | The defined research goal is to assess the system in terms of the efficiency of fertilization and by-product management. The method of managing by-product yields will have a significant impact on the level of greenhouse gas emissions. |
| 7 | Energy consumption for harvesting and post-harvest activities | Harvesting is a key stage in plant production, and fuel consumption at this stage significantly impacts the level of greenhouse gas emissions per functional unit of the product. |

**Defining the scope of input data within the assumed boundary**

From the perspective of achieving the goal of assessing an agricultural system, one of the most important normative documents are the standards: ISO 14040: "Environmental management - Life cycle assessment - Principles and framework," ISO 14044: "Environmental management - Life cycle assessment - Requirements," and TS-EN ISO 14067, "Carbon footprint of products." According to the guidelines of these normative documents, the analysis of greenhouse gas emissions must be conducted within the established system boundary.

The scope of input data necessary for calculating the greenhouse gas emissions results from the conducted risk analysis. However, most of the input data is generalized because it is challenging to calculate actual emissions from individual sources. For example, nitrogen fertilizer production alone generates varying levels of greenhouse gas emissions, depending on the ammonia synthesis technology and energy-saving solutions in different factories (Dziuba et al., 2028). Differences in emissions between production sites can be as high as several tens of percent (Kool et al., 2012). Based on the data presented in the literature, for European conditions, the GHG emission level for nitrogen production in ammonium nitrate is assumed to be 7.99 kg $CO_2$ per kg of nitrogen. For triple superphosphate, it is 0.36 kg $CO_2$ per kg of $P_2O_5$, and for potassium chloride, it is 0.56 kg $CO_2$ per kg of $K_2O$. These values do not include fertilizer transportation. The carbon footprint for the logistical process should be calculated individually for each case, considering not only the location of fertilizer production but also the entire logistical process, including the types of transport used at different stages.

The greenhouse gas emissions from mineralization of crop residues are calculated based on the amount of biomass left after harvest and its decomposition coefficient over the timeframe of the analysed process (Zhang et al., 2023). A significant aspect of the input data for assessing agricultural systems is information on the management of by-product yields. These may be left in the field or used for energy production, such as biogas or heat energy (Liang et al., 2022; Anand et al., 2022). Obtaining reliable input data for the by-product management would require calculating the carbon footprint of energy conversion processes, including the transport of raw materials to the processing site and the transport of the energy carrier to the point of use (He et al., 2024). In many regions, burning by-products is practiced, significantly increasing the final product's carbon footprint (Deshpande et al., 2023). When by-products are left in the field, it becomes challenging to estimate what portion of the remaining biomass will undergo mineralization versus humification. The intensity and direction of these transformations are crucial for determination of the final level of greenhouse gas emissions (Thiagarajan et al., 2022). These transformations depend not only on plant species but also on soil physicochemical properties, the availability of micronutrients, particularly nitrogen, phosphorus, and calcium, as well as the type of agrotechnical treatments.

A standardized approach to greenhouse gas emissions from crop residues is outlined in the document issued by the Intergovernmental Panel on Climate Change (IPCC, 2006), which provides information on the transformation of nitrogen in biomass under soil conditions. According to this document, it is assumed that 1.25% of the nitrogen in crop residues is emitted as nitrous oxide ($N_2O$) (Novoa and Tejeda, 2006). The value of $N_2O$ emissions is usually expressed as $CO_2$ equivalents by multiplying it by the global warming potential coefficient of 298 (Forster et al., 2007). According to FAO (2017), 1% of nitrogen from mineral fertilization is emitted directly, while 0.27% of nitrogen that is dispersed in the environment is emitted as nitrous oxide. The nitrous oxide emissions from dispersed nitrogen are estimated at 0.75% of the total nitrogen not absorbed by plants during the growing season (FAO, 2017). To calculate dispersed nitrogen (not absorbed by plants), it is necessary to estimate the main and by-product yields and determine the total nitrogen content in all crop components.

The carbon in crop residues and by-products (if left in the field) is converted into carbon dioxide through oxidation. Regarding greenhouse gas emissions from the production area, the mineralization of soil organic matter should not be overlooked. The rate of mineralization depends on soil properties, climatic conditions, and the level of production intensity. Intensive production increases the rate of organic matter mineralization, which ultimately leads to higher greenhouse gas emissions from the production area. A standardized mineralization rate of 2% is often used by researchers to estimate soil organic matter mineralization (Kuboń et al., 2021).

In the assessment of the carbon footprint of agricultural systems, greenhouse gas emissions from the combustion of fossil fuels used in agrotechnical activities are essential. Based on the data provided by the EPA (2016), the emission level from diesel combustion in agricultural tractors is assumed to be 3.864 kg $CO_2$ per liter of fuel. Fuel consumption in individual agrotechnical operations depends on the machinery used, soil type, and the specifics of cultivation operations (e.g., plowing depth). Diesel engines also emit nitrogen oxides, which should be considered when calculating greenhouse gas emissions from fuel combustion and handled on a case-by-case basis (EPA, 2016).

The greenhouse gas emissions associated with pesticide use mainly result from their production and logistics. Calculating emissions for individual substances would be problematic; thus, the average value of 25.5 kg $CO_2$ per kilogram of active pesticide ingredient is often used (Audsley et al., 2009). These authors report the total greenhouse gas emissions in $CO_2$ equivalents. The $CO_2$ emission factor for irrigation is calculated based on the amount of water required, the depth of the water source, or its location relative to the cultivation area, and the technical efficiency of the pumps. For producing 1 KWh of electricity, $CO_2$ emissions are assumed to be 0.9245 kg (Wang et al., 2022).

From the perspective of managing sustainable energy production from biomass, corn cultivation is a critical area, as it is an important source of biomass for methanogenesis and the production of liquid biofuels (Zhang et al., 2024). On the other hand, corn is a crop with a very high greenhouse gas emission factor. Komorowska et al. (2024) reported greenhouse gas emissions ranging from 630.2 to 1339.8 kg $CO_2$eq per ton of yield. These authors identified the most significant factor influencing the level of greenhouse gas emissions as the yield size, with approximately half of the emissions attributed to fertilizer production. Furthermore, 10 to 15% of the total greenhouse gas emissions in corn cultivation are related to the combustion of liquid fuels, depending on the yield size. Around 25 to 30% of the total emissions are associated with the mineralization of by-product yields and crop residues (Komorowska et al., 2024; Qi et al., 2018; Costantini and Bacenetti, 2021; Cui et al., 2021).

Qi et al. (2018) found that greenhouse gas emissions from corn cultivation range from 400 to almost 800 kg $CO_2$eq per ton, depending on the level of production intensity. However, these authors excluded emissions related to the mineralization of crop residues and soil organic matter from the system boundary. In contrast, Liu et al. (2021) reported higher carbon footprint values for corn cultivation in China's Hebei Province, approximately 2000 kg $CO_2$ per ton of product. They emphasized the importance of considering soil carbon in carbon footprint assessments of agricultural systems to provide a clearer understanding of agriculture's environmental impact.

Pareja-Sánchez et al. (2019) reported $CO_2$ emissions from soil under corn cultivation ranging from about 1800 to 4500 kg $CO_2$ per hectare. The system boundary included the transformations of organic compounds and mineral nitrogen in the soil, excluding fuel combustion related to cultivation and harvesting, as well as the production and distribution of mineral fertilizers. Estimating greenhouse gas emissions from soil as a result of carbon and nitrogen transformations remains one of the most challenging aspects of quantification.

Kumar et al. (2021) found that, depending on the length of the growing season, nitrogen fertilization levels, and crop residue management, soil greenhouse gas emissions can vary by several times, independent of yield size. These factors make the quantification of greenhouse gas emissions from soil transformations highly complex and variable.

## Summary

Recently, the issues related to greenhouse gas emissions in agricultural systems have gained significant attention from researchers worldwide. Providing reliable information on agriculture's environmental impact, particularly concerning climate change, is crucial for developing and implementing measures to reduce human pressures both at the legislative level and in production technologies. Therefore, studying the carbon footprint in the broader agri-food industry provides a solid foundation for sustainable development. On one hand, agricultural production contributes to climate change, which in turn fundamentally alters the conditions for agricultural production. Climate change leads to a reduction in the productive potential of soils and worsens conditions for livestock production in many parts of the world.

Nevertheless, the issue of the carbon footprint in agriculture is still less explored compared to other areas of human activity. The main challenge in calculating the carbon footprint is the multitude of variables that influence emission levels and cannot be standardized. Factors such as soil type, its properties, chemical composition, climate, and even the cultivation of specific plant varieties significantly affect greenhouse gas emissions. Even under the same habitat conditions and using the same production technology, variations in weather patterns during different growing seasons can significantly modify the amount of greenhouse gases emitted.

However, calculating the carbon footprint is essential for assessing the environmental efficiency of agricultural systems, as it provides a quantifiable environmental value for food products. Based on a review of the scientific literature, it has been concluded that carbon footprint studies of specific agricultural systems and evaluations of production technology improvements (implementing actions to compensate for human impacts) should be conducted within an individual system boundary. The system boundary should be developed using a process map based on the guidelines of ISO 31000:2018. Therefore, it is reasonable to limit the system by excluding emission sources with significant variability, stemming from factors that are difficult or impossible to inventory. Most of the input data used in the calculations must be standardized due to the presence of numerous parameters dependent on the natural, geographical, and infrastructural conditions of the production site.

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# OZNACZANIE ŚLADU WĘGLOWEGO JAKO STRATEGICZNY ELEMENT ŚRODOWISKOWEJ OCENY SYSTEMÓW ROLNICZYCH

**Streszczenie.** Calem pracy była ocena potencjału wykorzystania śladu węglowego do środowiskowej oceny systemów rolniczych. Badanie śladu węglowego w rolnictwie ma strategiczny wymiar w zakresie zrównoważonego rozwoju produkcji żywności. Ograniczenie negatywnego wpływu rolnictwa na zmiany klimatyczne są ważnym elementem wielu systemów zarządzania jakością oraz wpisywane są w prawodawstwo wielu krajów. Problemem związanym z obliczaniem śladu węglowego jest na obecnym etapie brak jednoznacznych metodologii obliczania wielkości emisji gazów cieplarnianych (GHG). Dokumenty normatywne wskazują na konieczność uwzględnienia wszystkich obszarów emisji gazów cieplarnianych, jednakże w praktyce jest to bardzo trudne ze względu na specyfikę produkcji roślinnej, która jest prowadzona w zmiennych warunkach związanych z rodzajem gleby, jej właściwościami, składem chemicznym, klimatem czy technologią produkcji. W oparciu o przegląd literatury naukowej stwierdzono, że badania śladu węglowego określonych systemów rolniczych oraz ewaluacja doskonalenia technologii produkcji (wdrażanie działań kompensujących anropopresję) powinna być prowadzona w obrębie indywidualnej granicy systemu. Granica systemu powinna być opracowywana w oparciu o stworzoną mapę procesów zgodnie z wytycznymi normy ISO 31000:2018. Większość danych wejściowych wykorzystywanych w obliczeniach musi być unifikowana ze względu na występowanie szeregu parametrów zależnych od przyrodniczych, geograficznych i infrastrukturalnych uwarunkowań miejsca prowadzenia produkcji.

**Słowa kluczowe:** ślad węglowy, systemy rolnicze, gazy cieplarniane, ocena cyklu życia, analiza