Evaluation of Greenhouse Gas Emissions

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In the face of a changing climate, intensive efforts are needed for limiting the global temperature increase to 1.5 °C. Agricultural production has the potential to play an important role in mitigating climate change. It is necessary to optimize all of the agricultural practices that have high levels of greenhouse gas (GHG) emissions.

Keywords: plant production systems ; environmental effects ; greenhouse gas emissions

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1. Introduction

One of the tools enabling the comprehensive estimation of the ecological effects of food production is the life cycle assessment (LCA) [1][2]. Originally, this method was developed for industry [3]. Currently, studies on the environmental assessment of agricultural production and food processing using the LCA are being developed around the world [4][5][6]. The LCA allows for a broad compilation and comparison of the environmental impact of the processes and products throughout the production cycle [7].

Carrying out the LCA is crucial for obtaining the so-called Environmental Product Declaration (EPD) for the product [8]. It is a document that presents a series of data on the resource consumption and environmental impacts in relation to the product's life cycle, namely:

- Consumption of renewable sources (biomass, energy);
- Consumption of non-renewable resources (mineral resources, fossil fuels);
- Water consumption;
- Amounts of waste for recycling;
- Environmental impact category indicators (acidification potential, eutrophication potential, photooxidant formation potential);
- Environmental footprints (carbon footprint, ecological footprint, water footprint).

In response to the sensitivity to the problem of climate change, many social groups in developed countries are creating product labelling systems informing about the carbon footprint (CF) [9][10]. Placing environmental labels on products and presenting information about the LCA results, is designed to provide consumers with accurate information about the environmental effects of products, facilitating their conscious choice, as well as introducing the factor of competition between different manufacturers of similar products. Food producers, being under pressure from environmental policies and shaping the ecological criteria for food selection by consumers, are willing to modify agricultural practices that would reduce the impact of agriculture on the environment. The environmental information on the CF of a product is based on the LCA test procedures. The results of these tests must be obtained in accordance with the rules of type III EPD. Establishing an environmental declaration includes declaration preparation, verification of assessment methods, and certification. The condition for qualifying a product to be awarded this mark is the preparation of a report confirming the measurement of the CF based on the internationally recognized methods e.g., British Technical Specification PAS2050: 2011 [11]. This label is used in the USA, Canada, Australia, New Zealand, and many EU countries. A common system for labeling the CF in the Nordic countries is the Climate Declaration. It represents the climate change impact category index developed in the EPD. The declaration provides information on the total GHG emissions and, separately, for each stage of the life cycle of the product, in kg of CO_2 eq. per functional unit of the product [12].

2. Life Cycle Assessment Framework

The life cycle assessment (LCA) is a standardized method for assessing the environmental aspects and potential impacts associated with all of the stages of the life cycle of a product, process, or service [13][14]. According to the guidelines of the International Organization for Standardization (ISO), it is carried out in four phases [15][16]:

- Goal and scope definition;
- Life cycle inventory;
- Life cycle impact assessment;
- Interpretation.

In the first phase (goal and scope definition), the system boundaries and the functional unit are defined. The system boundaries define the life cycle processes that belong to the analyzed system. A functional unit is a quantitative description of the function of the system.

The life cycle inventory (LCI) is the phase of identification and quantification of all flows between the environment and the analyzed system, i.e., energy and raw materials consumption as well as emissions to air, water, soil, and waste. The stocktaking of flows is made with reference to a predetermined functional unit. Data collection and system modelling must follow the defined purpose and scope of the research.

The life cycle impact assessment (LCIA) aims to establish the links between a product or process and its potential environmental impacts. The input and output data of the flows reported in the LCI are converted into the values of the category indicators.

The impact assessment is performed in several steps:

- Selecting the impact category;
- Classification—assigning the LCI results to the impact category;
- Characterization—calculation of the category indicators;
- Normalization—calculating the value of a category indicator against the reference information;
- Grouping—the sorting or ranking of indicators;
- Weighing—assigning weights (importance) to the potential influences;
- Evaluation and reporting of the LCIA results.

The interpretation can take place at any stage of the LCA. It involves identifying, checking, and evaluating the information from the LCI and LCIA results. The interpretation aims to analyze results, to formulate conclusions, to explain limitations, and to make recommendations based on the results of previous LCA stages, and ensure an understandable and complete presentation of the results in line with the purpose and scope of the study.

3. Carbon Footprint

The carbon footprint (CF) approach is used in order to assess the greenhouse gas (GHG) emissions related to various economic processes and products [17]. It is defined as the GHG emission balance over the entire life cycle of a product or process. The characterization parameter for this environmental impact category (climate change) is the global warming potential.

The CF is expressed as the sum of the products of the greenhouse effect for a substance and the amount of emissions of the ‘i-th’ substance. It covers both direct and indirect emissions that are generated throughout the entire life cycle of a product. It is presented in the form of quantifiable indicators: As GHG emissions in kg of carbon dioxide equivalent (CO_2 eq.) per kg of product or per area unit per year. It is most often calculated for the 100-year period.

$$\mathrm{CF} = \sum_i m_i \cdot GWP_{a,i}, \quad (1)$$

where: m_i—the quantity of the substance '*i*' emitted (in kg per functional unit), $GWP_{a,i}$—the global warming potential for a substance '*i*' over a time horizon a (expressed relative to CO_2 per kg '*i*').

The analysis of the GHG emissions from plant production using the LCA methodology can be performed by examining the CF of a product or process from the extraction of raw materials and energy to the production within the system boundaries from 'cradle-to-farm-gate' and 'gate-to-gate' as shown in **Figure 1**, and by analyzing the entire life cycle of a product or process, including product disposal ('cradle-to-grave').

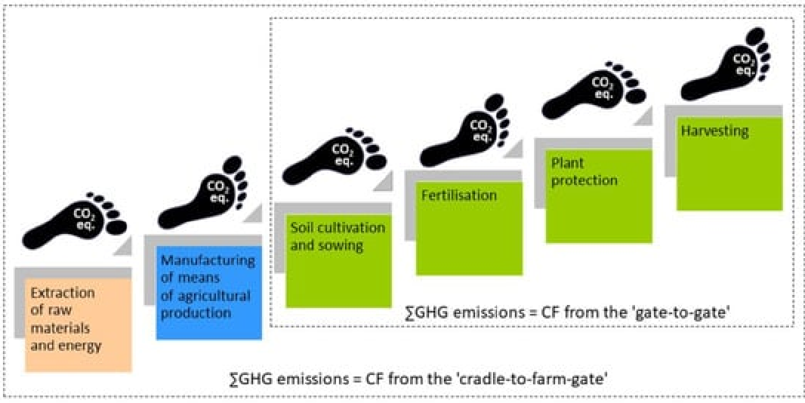

Figure 1. System boundaries of the carbon footprint (CF) estimation for the plant production systems. Source: own elaboration.

The CF of an agricultural product or process can be used to inform producers about GHG emissions related to product manufacturing, to develop and apply GHG emission management strategies at different stages of the product life cycle, to identify the potential GHG mitigation opportunities along the supply chain, to monitor the progress in reducing GHG emissions over time, and to assist consumers in choosing products with the least impact on climate change [17][18].

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