

Enhancing Agricultural Sustainability and Certification through Real-Time LCA: A Case Study on Circular Economy in Wheat Production

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Abstract Within the framework of the project “Real-time environmental assessment of agricultural and agrifood production for the support of certification schemes”, a real-time, web-based Life Cycle Assessment (LCA) tool has been developed. The tool is designed to simulate all stages of the supply chain, providing a user-friendly interface while utilizing real-world sensor data to assess the carbon footprint and environmental impacts of the agricultural sector with greater accuracy. These assessments are essential for environmental certification processes.

To demonstrate the tool’s functionality, the environmental impacts of four different wheat production routes, with or without vetch and including one or two harvests crops have been assessed. Their environmental performance has been compared in a Cradle to Gate approach, per 700 kg of produced wheat. Furthermore, to validate the tool’s accuracy against existing software on the market, the environmental impacts of these four processes have also been assessed using the OpenLCA software.

Keywords: Life Cycle Assessment; Circular Economy; Agricultural; Real-time LCA; Wheat Production;

1. Introduction

Due to the dynamic nature of product systems and services, the use of real-time data is crucial to the accuracy and reliability of the LCA results (Fnais et al., 2022). Real-time LCA engines provide advantages over the traditional LCA software, such as the dynamic fetching of data from several sensors (Koidis et al., 2023). Traditional LCA software contains a large amount of data, since it can be used for every sector. Therefore, uncertainties and differences occur in the LCA results when using different software (Herrmann and Moltesen, 2015; Iswara et al., 2020).

To reduce uncertainties related to LCA of the agricultural sector, improve the user-friendliness, a real-time and sector-specific LCA web-based engine, called FARMBENV, was developed. In a previous study (Savva

et al., 2025), the user requirements of the potential end-users of the tool were identified and used to design the functions of the LCA engine effectively, maximizing the user-friendliness of the tool and ensuring its applicability.

Once developed, the tool was utilized to assess the environmental impacts of four different wheat production scenarios, to demonstrate the tool’s functionality. To reduce the environmental impacts of the agricultural sector, the assessment of different wheat production scenarios is considered crucial, since the wheat cultivation stage represents the most impactful phase for the environment (Cappelli and Cini, 2021). Finally, the results from the FARMBENV tool were compared to the results from the OpenLCA software and the Ecoinvent database.

2. Materials and Methods

LCA was conducted according to ISO standards. The goal of the study is to assess the environmental impacts of different wheat production scenarios and to ensure the functionality of the FARMBENV tool. The system boundaries were set as “Cradle-to-Gate”, including the production of the required equipment and resources, their consumption, harvesting and storing of the needs, and the emissions that occurred due to the use of fuels and machineries. Moreover, the production of 700 kg of wheat was defined as the functional unit of the system.

The inventory was built based on the data provided by a farmer in the region of Central Macedonia. Background data were based on the Ecoinvent 3.9.1 database on the OpenLCA software and the Ecoinvent 3.11 cut-off EN15084 database on the FARMENV tool. Recipe 2016 Midpoint (H) was selected as the Life Cycle Impact Assessment (LCIA) Method for both software. Nevertheless, the EN15084 LCIA method can be used with the FARMBENV tool for the assessment of the environmental impacts, which is a method compatible with

an Environmental Product Declaration (EPD). Although the Recipe LCIA method contains 18 impact categories, which were evaluated in the project, in this study, only Global Warming Potential (GWP) was included.

In the first scenario, one harvest crop of wheat takes place, without vetch, and 300 kg of wheat are produced, while in the second scenario, one harvest crop of wheat with vetch takes place, and 400 kg of wheat are produced. The application of green manure in wheat production through the addition of vetch increases the soil fertility and reduces the demand for fertilizers (Bandh Fayaz and Malla Editors, 2023). The third scenario includes two harvest crops of wheat without vetch, and 600 kg of wheat are produced. Finally, the fourth scenario includes two harvest crops of wheat and vetch, and 700 kg of wheat are produced.

3. Results

Table 1. GWP of Each Scenario per functional unit

	1 st Sc.	2 nd Sc.	3 rd Sc.	4 th Sc.
GWP	470.9	363.3	470.9	409.4
[kg CO ₂ -eq]				

Table 1 presents the GWP of each scenario per functional unit. The addition of vetch reduces the required fertilizer, harvesting, and tillage processes, and therefore, the environmental impacts of wheat production are reduced, for both one and two-harvest crops. The achieved reduction is bigger for the case of one harvest crop. The results for the case of wheat production without the addition of vetch are identical for both one and two-harvest crops. However, with the addition of vetch, the results increase for the case of two harvest periods, due to the increased fertilizer, harvesting, and tillage processes that are required for the 2nd crop of wheat compared to the 1st.

The accuracy of the tool was ensured by comparing the results to the OpenLCA software. The FARMBENV tool presents the results with 2 decimal points, while the OpenLCA software with 5 decimal points. Hence, there was a small deviation in the 2nd decimal point, although the impact on most of the categories is insignificant. Nevertheless, the impact was significant in the Ozone Depletion Potential, where the impact of the 4th scenario was 0.00055 kg CFC-11, and due to rounding to the 2nd decimal point, the present result from the tool is equal to 0. This can be avoided by increasing the functional unit by an order of magnitude.

4. Conclusions

This study presents the functionality of the FARMBENV tool and the environmental impacts from four different wheat production scenarios. The tool's calculations and results are found to be accurate, with a minor deviation due to rounding of the results, while its user friendliness is improved compared to commercial LCA software. Furthermore, the application of green manure reduces the impact on GWP, and the best production scenario with regards to environmental impacts is the production of wheat with the addition of vetch, with one harvest crop.

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