# A Circular Approach to Wheat Residue Management: Lab-Scale Production of Biofuels

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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. To demonstrate the tool's functionality, the environmental impacts of four different wheat production routes were assessed. Emphasizing a circular economy approach in the agricultural sector can reduce waste, produce bioenergy, and reduce the overall environmental footprint. Despite this potential, there is an increased uncertainty regarding bioenergy output and electricity consumption of various small-scale technologies. Therefore, within the scope of the project, laboratory-scale experiments were conducted to evaluate the production of biofuels using wheat residues and wastes. The waste-to-energy technologies that were included are an oil press, a pellet mill, and an ethanol still. This study presents the results of the lab-scale production of biodiesel, bioethanol, and pellets. Finally, the potential reduction in Global Warming Potential (GWP) that can be achieved by the integration of waste-to-energy in wheat production was quantified.

**Keywords:** Waste-to-energy; Circular Economy; Agriculture; Biofuel production; Wheat Production

## 1. Introduction

Waste-to-Energy techniques address three key challenges: waste management, energy demand, and reducing environmental impacts, while they could aid in shifting the linear to circular model of economy (Sharma et al., 2020). Moreover, the utilization of wasted crops and crop residues can avoid conflicts between human food use and industrial use of crops (Kim and Dale, 2004). Within the scope of the project "Real-time environmental assessment of agricultural and agrifood production for the support of certification schemes", the FARMBENV tool was used to assess the environmental impacts of different wheat production routes. In this light, the production of energy using wheat residues and byproducts was evaluated in this study to assess whether environmental benefits could arise from the production of energy through three different lab-scale technologies. The waste-to-energy pathways that were evaluated are the production of bioethanol from an ethanol still, the production of biodiesel from an oil press, and the production of pellets from a pellet mill. Finally, based on the LCA results, the potential GWP reduction from each pathway was estimated.

## 2. Materials and Methods

The equipment that was used consisted of an oil press with a 1.5 kW rated power, a pellet mill with 2.2 kW rated power, a dryer with a 2 kW rated power, and the ethanol still. The ethanol still uses a 38 W pump, and an LPG cylinder with a 0.25 kg/hr flow rate. Moreover, to process the mixture into a suitable form to produce ethanol, alpha amylase, glucoamylase, yeast, and an electric heater, with a rated power of 120 W, are required. Finally, to process the produced biodiesel, methanol and sodium hydroxide are required.

In the 1st scenario, 300 g of wheat were added to the oil press, which operated for 10 minutes, and 204 g of solid residue were produced, and zero liquid was produced. The solid residue was mixed with water and entered the dryer to adjust the humidity of the mixture through trial-and-error procedures. Then, the mixture was entered into the pellet mill, which operated for 5 minutes, and 110 g of pellets were produced.

In the 2nd scenario, 600 g of wheat were germinated using water, and kept for five days to germinate, before entering the dryer for 4 hours. The final mixture, which was added to the oil press, weighed 888 g. The oil press worked for 20 minutes and produced 673 g of solid residue and 110 mL of liquid. Eventually, 355 g of pellets were produced from the pellet mill, which operated for 15 minutes. For the transesterification process, 0.9 g of sodium hydroxide and 20 mL of methanol were added to the liquid produced by the oil press. The mixture kept together for 1 week, and eventually 80 mL of biodiesel were produced.

To process the mixture required to produce ethanol, in the 3rd scenario, 2 kg of wheat were milled and mixed with 5 L of water. The mixture was heated for 2 hours by the electric heater. Then, alpha amylase, glucoamylase, and yeast were added to the mix, which was left to ferment for 1 week. LPG cylinder was used to provide the required heat for the distillation of ethanol, while a pump for the circulation of water was also used to cool the steam to condense into a liquid form. The distillation process lasted for 2.5 hours, and 1.2 L of ethanol at 30% concentration were produced.

To evaluate the potential reduction of GWP OpenLCA software, the Ecoinvent database, and Recipe 2016 Midpoint (H) were used. Moreover, it was assumed that biodiesel has an energy density equal to 30 MJ/L, ethanol at 30% concentration, 6.3 MJ/L, and pellets have an LHV of 16 MJ/kg. Pellet was assumed to provide heat with an 85% efficiency, while ethanol and biodiesel with a 40% efficiency, due to the contained water. The produced heat was assumed to substitute for heat provided by hard coal.

## 3. Results

Table 1 presents the GWP [kg $CO_2$-eq] of processing 1 kg of wheat residues with each scenario. GWP was calculated for the cases where electricity is provided by the Greek electricity mix, PVs, or Wind turbines. Moreover, the maximum GWP [kg $CO_2$-eq/kWh] of the used electricity to achieve a zero GWP was calculated. For the 3rd scenario where heat is required, for the case of PV and wind turbines, heat was assumed to be provided by an electric heater with a 90% efficiency.

In the 1st scenario, where the least amount of electricity is consumed, the maximum GWP of the electricity to achieve zero GWP is the highest. Although the 2nd scenario consumes 5 times more energy than the 3rd, the produced energy is 6.4 times higher. Therefore, the maximum electricity to achieve zero GWP in the 2nd scenario is higher than in the 3rd. When electricity is provided by the Greek mix, none of the scenarios could lead to a reduction of GWP. The impact caused on GWP is in line with the consumed energy, therefore, the 1st scenario has the lowest burden, while the 2nd has the highest burden. When electricity is provided by PV, the 1st scenario leads to the maximum reduction potential, while the 3rd scenario increases the GWP. All the evaluated scenarios could potentially lead to a reduction of the GWP if electricity is provided by wind turbines. Due to the low GWP of wind electricity, the achieved reduction is in line with the produced energy, therefore, the 2nd scenario leads to the highest potential reduction, while the 3rd scenario leads to the lowest potential reduction.

**Table 1:** GWP of each scenario for different electricity sources

| | Greek Mix | PV | Wind | Electricity Threshold |
|---|---|---|---|---|
| 1st Sc. | 0.24 | -0.58 | -0.65 | 0.5 |
| 2nd Sc. | 9.06 | -0.08 | -1.05 | 0.084 |
| 3rd Sc. | 1.17 | 0.03 | -0.15 | 0.06 |

## 4. Conclusions

In this study, the production of energy from wheat residues, based on 3 different scenarios, was evaluated in lab-scale experiments and LCA. Using electricity with a low GWP is crucial in reducing the GWP via the waste-to-energy technology, and the optimal scenario depends on the source of electricity. Specifically, when wind electricity is used, the optimal scenario regarding GWP is the 2nd, while when the Greek electricity mix or PVs are used, the optimal scenario is the 1st one.

The limitation of this study is the small amount of feedstock that was available. Due to the small amount of feedstock, further trials regarding the mixture preparation and machine settings optimization could not be performed. The improvements in preparation and machine settings could lead to higher biofuel yield, lower water content in liquid biofuels, which would increase the final energy output, or lower energy consumption during the production. Finally, the availability and use of larger amounts of feedstock could lower the energy consumption per kg of treated wheat residue, since a significant amount of energy is required for the equipment to reach the operating temperature.


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