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FEEDING OR ENERGY PURPOSES? QUANTIFYING THE ENVIRONMENTAL IMPACT OF ALTERNATIVE USES OF BIOMASS RESIDUES

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ABSTRACT: Decisions on alternative uses of biomass residues should be supported with life-cycle thinking. The present study applied the Life Cycle Assessment (LCA) methodology to compare environmental burdens and benefits associated to alternative uses of three different biomass residues in Denmark. The biomass residues were wheat straw, brewer's spent grains and sawdust. The alternative uses were mushroom production, animal feed, biorefinery, anaerobic digestion and combustion. The study evaluated the inventory of materials and substances necessary for the growth of the mushrooms, and included the avoided impacts connected to the production of meat protein and to the avoided land use change (LUC) effects. The preliminary results for the climate change impact category suggest that wheat straw could be a promising substrate for mushroom production when avoided meat production and LUC effects are included.

Keywords: Biomass residues, oyster mushroom, feed value, LCA, LUC

1. INTRODUCTION

Biomass residues, for instance food waste and agricultural residues, are renewable substrates with a large number of alternative uses, such as energy (e.g. heating and electricity generation), food, feed, and substance feedstock. Utilization of biomass residues is encouraged by the European Union's circular bioeconomy strategy (European Commission 2018). Increasing utilization of biomass in the EU can help diversify Europe's energy supply, create growth and jobs, and lower greenhouse gas emissions. In 2012, biomass and waste accounted for about two-thirds of all renewable energy consumption in the EU. However, the use of residues is particularly important to ensure carbon neutrality: cultivating biomass for uses alternative to food causes climate change impacts due to direct and indirect land use change (LUC) effects (e.g. loss of carbon stock, deforestation) (EEA, 2011). Biomass residues are therefore limited due to their multiple uses in society, and decisions regarding their use should be supported by life-cycle thinking in order to ensure optimal and sustainable utilization of the available resources.

Among their alternative uses, biomass residues can be utilized as substrates for production of oyster

mushrooms, one of the most widely produced edible mushrooms (Hultberg et al. 2018; Wobiwo et al. 2018; Pardo-Giménez et al. 2018). Oyster mushrooms represent a vegetable protein source for the human diet, which can potentially decrease the reliance on meat protein. Meat production is responsible of a large share of the climate emissions of the agricultural sector, being linked to both feed production (and its associated land use changes, as well as fertilizers and pesticides requirements) and livestock production system. Therefore, substituting meat protein with mushroom protein from biomass residue would potentially avoid impacts derived both from feedstock (land use) and livestock production. Moreover, biomass residues are considered burden-free with respect to LUC impacts connected to the production phase. However, biomass residues can also be used as animal feed and as an energy source, for example after biorefinery, anaerobic digestion and combustion processes. In the case of animal feed, the biomass residue would replace conventional feed (such as maize and soybean) and avoid direct and indirect LUC impacts. In the case of energy sources, the produced fuel, heat and electricity would in turn avoid the reliance on other energy sources.

Life Cycle Assessment (LCA; ISO, 2006) is a standardized methodology used to systematically quantify the sustainability of products and technology systems. LCA takes into account the impacts connected to the procurement materials and energy required to fulfill a specific function, as well as the avoided impacts connected to recovered materials and energy from the system. LCA allows to compare the sustainability of alternative systems based on the fulfillment of the same function, over a range of environmental impacts, and can be used to support decision-making.

The present study applied the LCA methodology in order to quantify the environmental impacts associated to the use of three different biomass residues as substrates for the growth of oyster mushrooms in Denmark. The study evaluated the inventory of materials and substances necessary for the growth of the mushrooms, and included the avoided impacts connected to the production of meat protein and to the avoided land use change effects. The use of biomass as substrate was compared to use as feed for animal and to three energy conversion pathways: biorefinery, anaerobic digestion and combustion. This paper presents preliminary LCA results obtained for the climate change impact category. The study ultimately aims to show methodological implications related to choices of system boundaries and to highlight factors influencing the choice between alternative uses of biomass residues.

2. MATERIALS AND METHODS

2.1 Case study

Three biomass residues were chosen as potential substrates for the growth of oyster mushroom. The chosen substrates were brewer's grain, wheat straw and sawdust. The potential of the substrates for mushroom growth depends on intrinsic factors, such as nitrogen content, moisture content, specific amount of inoculum required, surface area, and on extrinsic factors. Experiments on oyster mushroom growth were carried out on sterilized substrates with equal moisture content, where equal mycelium inoculum amount was added per wet weight of the substrate. Once the mushrooms were produced, the protein content and protein quality of the harvested mushrooms were analysed with the Dumas method and LC-MS (liquid chromatography and mass-spectometry), respectively.

2.2 LCA of alternative scenarios

The study investigated the environmental impacts and benefits of the use of the selected biomass residues as substrate for the growth of oyster mushroom with the LCA methodology. The functional unit was management of 1 tonne of biomass residue, which was brewer's grain, wheat straw and sawdust, respectively.

For each biomass residue type, the impacts connected the life cycle impact assessment (LCIA) results for the use as substrate for mushroom growth were compared with four alternative management

pathways: use as animal feed, use as substrate for energy purposes for biorefinery, anaerobic digestion and combustion. Additional functionalities obtained by the management scenarios were addressed by system expansion, thereby including avoided production processes. The analysed physico-chemical properties of the harvested mushroom were utilized in order to determine the animal and feed substitution ratio and the potential for different conversion pathways. The total number of scenarios was five, as shown in Figure 1. The dashed lines correspond to the processes and products avoided by the products obtained from the alternative management pathways.

- **Scenario 1**: biomass residues are used as substrate for the growth of oyster mushroom. The yield of mushroom from the biomass residue was estimated based on laboratory experiments. The scenario takes into account the materials and energy required to grow the mushroom from the biomass substrate. The avoided production of meat was based on the digestible crude protein content of the mushroom versus the digestible crude protein content of the meat. Then, the animal feed necessary for feedstock production was assumed based on Mogensen et al. (2015). The scenario takes into account avoided feed production and avoided LUC according to Tonini, Hamelin, & Astrup (2016).
- **Scenario 2**: biomass residues are used as animal feed. The avoided production of conventional animal feed (assumed maize and soybean) was calculated from the digestible energy and digestible crude protein content of the biomass residue. As in scenario 1, the avoided feedstock production and LUC are taken into account.

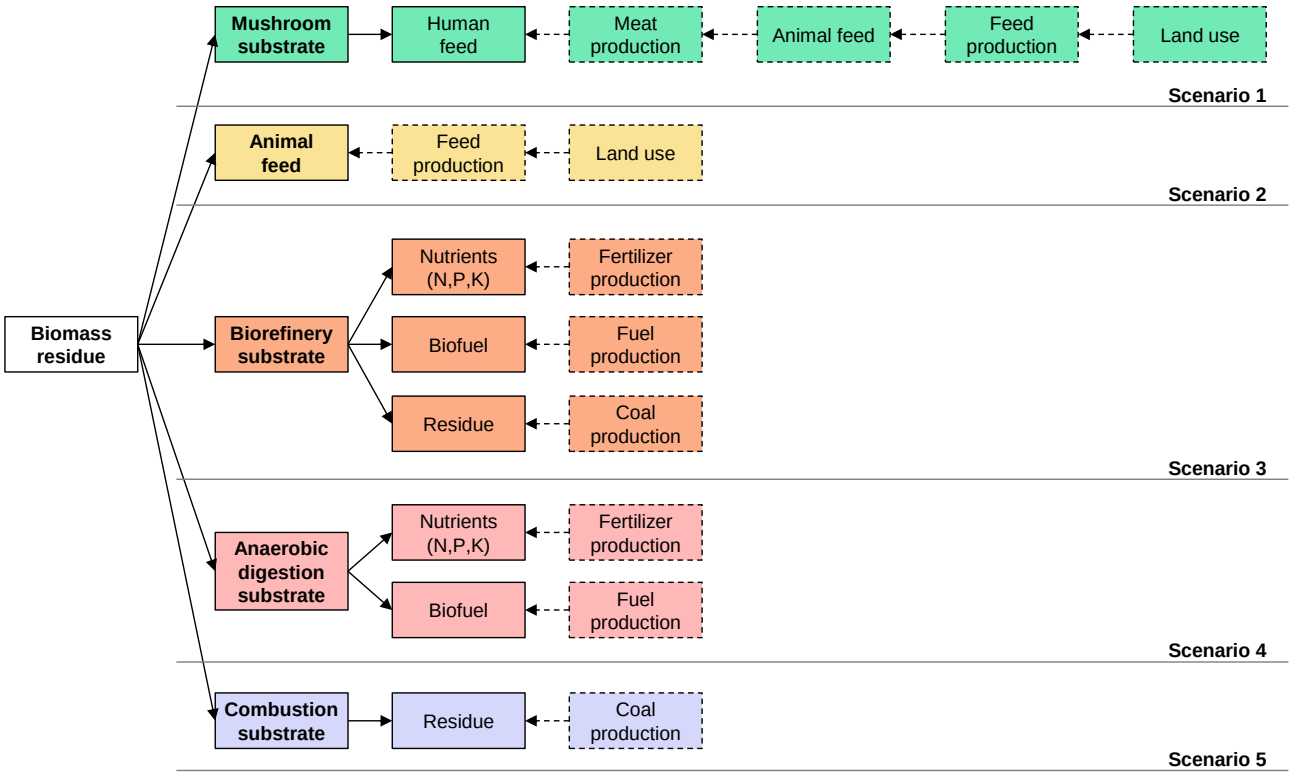

Figure 1. Biomass residue management scenarios investigated in the study. Biomass residues were brewer's grain, wheat straw and sawdust. The alternative management scenarios were five. Dashed lines indicate avoided processes by the management scenarios.

- **Scenario 3**: biomass residues are treated in a biorefinery process. The carbohydrates are used to produce biofuel (bioethanol), and then remaining biomass is anaerobically digested for biogas production. Residues from the process are combusted. Bioethanol and biomethane are assumed to substitute transport fuel (gasoline), while combusted residues substitute coal production. Nutrients recovered from the process are used on land, in turn avoiding the production of mineral fertilizers.
- **Scenario 4**: biomass residues are anaerobically digested. Biomethane is assumed to substitute transport fuel (gasoline). Nutrients recovered from the process are used on land, in turn avoiding the production of mineral fertilizers.
- **Scenario 5**: biomass residues are combusted in a combined heat and power plant, with recovery of electricity and heat. The recovered energy is assumed to displace coal.

3. RESULTS AND DISCUSSION

The results from the experimental phase showed that, with the methodology used for the present study, sawdust was less beneficial for cultivating oyster mushrooms than what was previously found in the literature. Brewer's spent grain did not give any fruiting bodies in the experiments where it was included. Wheat straw showed the best overall performance as growth media. In the cases where fruiting bodies did not appear, the protein content of the mushroom was still compliant with mushrooms grown in the other substrates.

Based on the protein content obtained from the experimental phase, potential substitution factors for feed were obtained and used in the LCA modelling. The preliminary LCA results for the climate change impact category are provided in Figure 2. Positive values correspond to burdens to the environment; negative values correspond to environmental savings.

The preliminary climate change results show that wheat straw was the most preferable biomass substrate for mushroom production. Brewer's grain presented environmental impacts due to the pressing necessary for this specific substrate, as well as plastic foil necessary for the process. Sawdust presented low environmental benefits when used as substrate for mushroom growth because of the lower protein content of the mushroom obtained from this substrate. Wheat straw was characterized by relatively higher impacts related to processing of the substrate, due to the considerably lower density with respect to the other substrates. It should be noted that, differently from the animal feed and the other conversion scenarios, climate change impacts for the mushroom growth scenarios are based on the material and energy requirements of the small-scale experimental setup. A full scale setup would probably contribute in reducing the amounts of ancillary material and energy required.

Nevertheless, decisions for these biomass resources need to take into account also environmental impacts and benefits connected to alternative conventional uses of these biomass residues. Use as animal feed presents environmental benefits both for brewer's grain and wheat straw, due to the avoided production of conventional animal feed and avoided LUC. Wheat straw presents higher environmental benefits than brewer's grain, which was also observed for the other conversion scenarios. Sawdust presented comparable environmental benefits to wheat straw for the combustion scenario due to the similar energy content. It is important to note that not all biomass types can be considered for all the scenarios: sawdust is not a viable option for animal feed, biorefinery and anaerobic digestion.

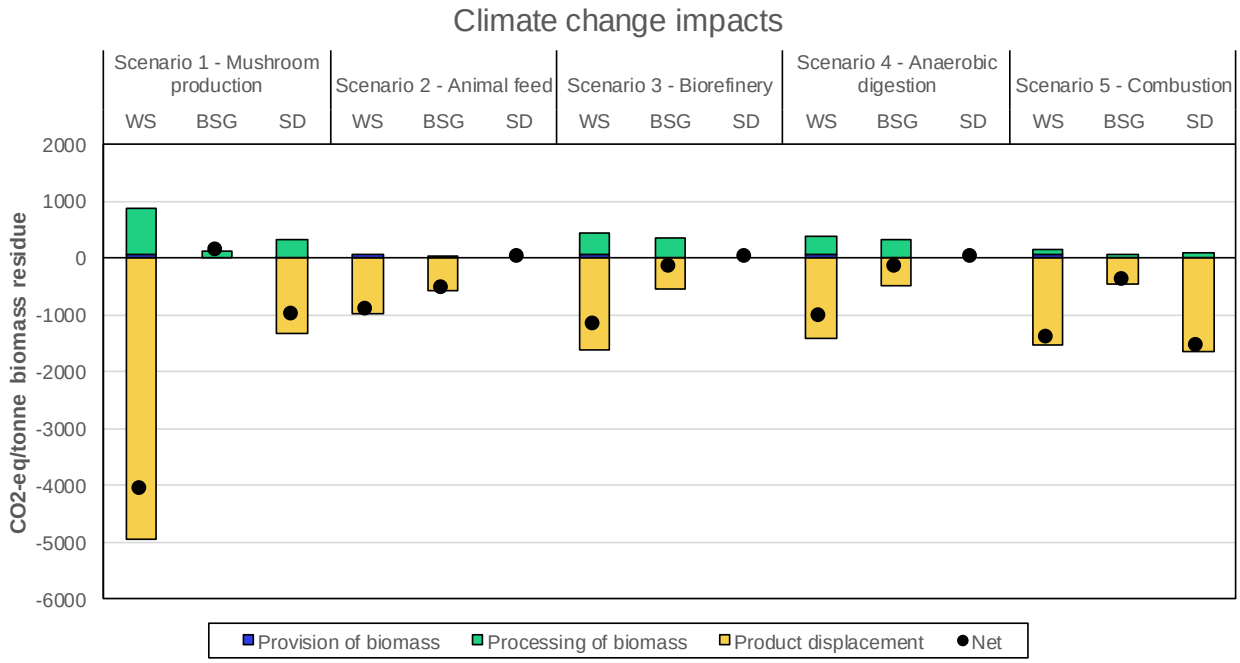

Figure 2. Preliminary climate change results for the scenarios assessed. The results show the contribution of the processes of biomass provision and processing, as well as product displacement. WS: wheat straw, BSG: brewer's spent grains, SD: sawdust.

4. CONCLUSIONS

Life cycle thinking is needed to identify the most sustainable alternative use for biomass residues. The study evaluated five management options for three different biomass residues. Sustainability of alternative management options depends on the physico-chemical characteristics of the biomass and on the aspects included by the system boundaries. For oyster mushroom production and substitution of conventional animal feed, inclusion of avoided feed production and land use change effects represents a fundamental contribution to the assessment results.

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