Environmental impact assessment of black soldier fly larvae production as a feed

Thompson, M. [1,*], Wohlfahrt, J. [2], Stadtlander, T. [2], Leiber, F. [2], Sandrock, C. [2]
[1] FiBL Projekte GmbH, Frankfurt am Main, Germany
[2] Research Institute of Organic Agriculture, Frick, Switzerland
[*] Michael.Thompson@fibl.org

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Introduction and objective

While insects are increasingly valued for their suitability as a feed in livestock and aquaculture production [1], their environmental and economic superiority to conventional feed counterparts remains largely unconfirmed. To be a viable alternative to conventional feed, insect production systems must therefore showcase equivalent nutrient outputs at competitive environmental costs. For this, black soldier fly (*Hermetia illucens*) larvae (BSFL) are recognized as a promising candidate, particularly due to their efficiency in converting a broad range of low-opportunity-cost organic material into valuable protein [1]. However, few studies exist to date which investigate the environmental performance of BSFL feed production systems using primary data [2-4]—therefore, their eco-efficiency remains poorly understood. This study addresses this deficiency by assessing the environmental impacts associated with a Swiss facility producing BSFL meal for use in fish and poultry feed.

Materials and methods

Production scenarios were defined and assessed via attributional (aLCA) and consequential life cycle assessments (cLCA). The BSFL production system was observed in four distinct stages: adult population maintenance and egg production, larvae starters, larvae grow-out and, lastly, harvesting and processing into the final product at facility-gate. Upstream processes included external production and sourcing of diet components, electricity and water. Infrastructure was excluded. For the cLCA, the BSFL system was expanded to account for avoided production of soybean meal (with and without land use change) and fish meal. This was carried out on the basis of protein equivalence. Consequences of diverting pre-consumer waste into the BSFL diet and away from anaerobic digestion (as secondary energy) and resulting digestate (as fertilizer) was also accounted for. The functional unit was 1 kg defatted, milled BSFL (dry matter: 96%, protein: 59%). Primary production data was provided by a research-pilot-scale facility in Switzerland [5]. Accompanying fish and poultry feeding trials confirmed BSFL substitutability with fish and soybean meals, respectively. Regionalized secondary data from ecoinvent 3.6 described all upstream processes. Together, these datasets established the baseline.

Scenario analysis served the purpose of exploring the influence of BSFL production scale, location, centralization and levels of direct gas emissions on environmental performance. Scenario development was guided by literature and experts and resulted in eight scenarios:

Scenario (variant)	*Description*
b	Baseline at 0,7 t a^{-1} final product
b20	Baseline production scaled to 20 t a^{-1}
b20 (M) (F)	Scaled production realized in Guadalajara, Mexico and Lyon, France
b_central (b20)	For baseline and scaled production, egg production and final BSFL processing production stages outsourced
b_ghg_min (b20)	For baseline and scaled production, minimum values from literature for BSFL direct emissions (CO_2, CH_4, NH_3 and N_2O) replaced empirical measurements of this study

To assess potential impacts, IMPACT World+ was chosen due to its updated and spatially resolved methods and inclusion of additional substances [6]. Use of all 18 midpoints was justified, though due to this poster format, only a small subset was selected. All calculations were carried out using SimaPro 9.

Results

Both aLCA and cLCA **baseline** results reveal higher impacts than protein-equivalent amounts of fish and soybean meals (Figure 1). Electricity-use and direct emissions during larvae grow-out contribute the most to global warming potential (GWP) at 51% and 45%, respectively. Since pre-consumer waste was assumed to be unavoidable and carried no direct environmental burdens, the overall contribution of external feed, which included transportation of all components and burdens of non-pre-consumer waste components, was lower than in other studies, here 4%.

The increased production level in **b20** made more efficient use of production equipment and thus absorbed a portion of impacts—yet not enough to deem BSFL meal superior. When first-hand measurements of direct emissions were replaced with the lowest values found in literature (**b_ghg_min**) [7, 8], results were still higher than in other BSFL LCA studies which either excluded several direct emissions or used values from a non-*H. illucens* insect species [2-4]. If not for the dominating contribution of direct emissions, GWP impacts would have approached competitive levels in **b20M** and **b20F** due to lowered use of climate control and lighting in Guadalajara and the nuclear-based energy mix in France. Lastly, although outsourcing production stages (**b_central**) might reduce the knowledge intensity for producers, it only resulted in a minor increase in energy-use efficiency.

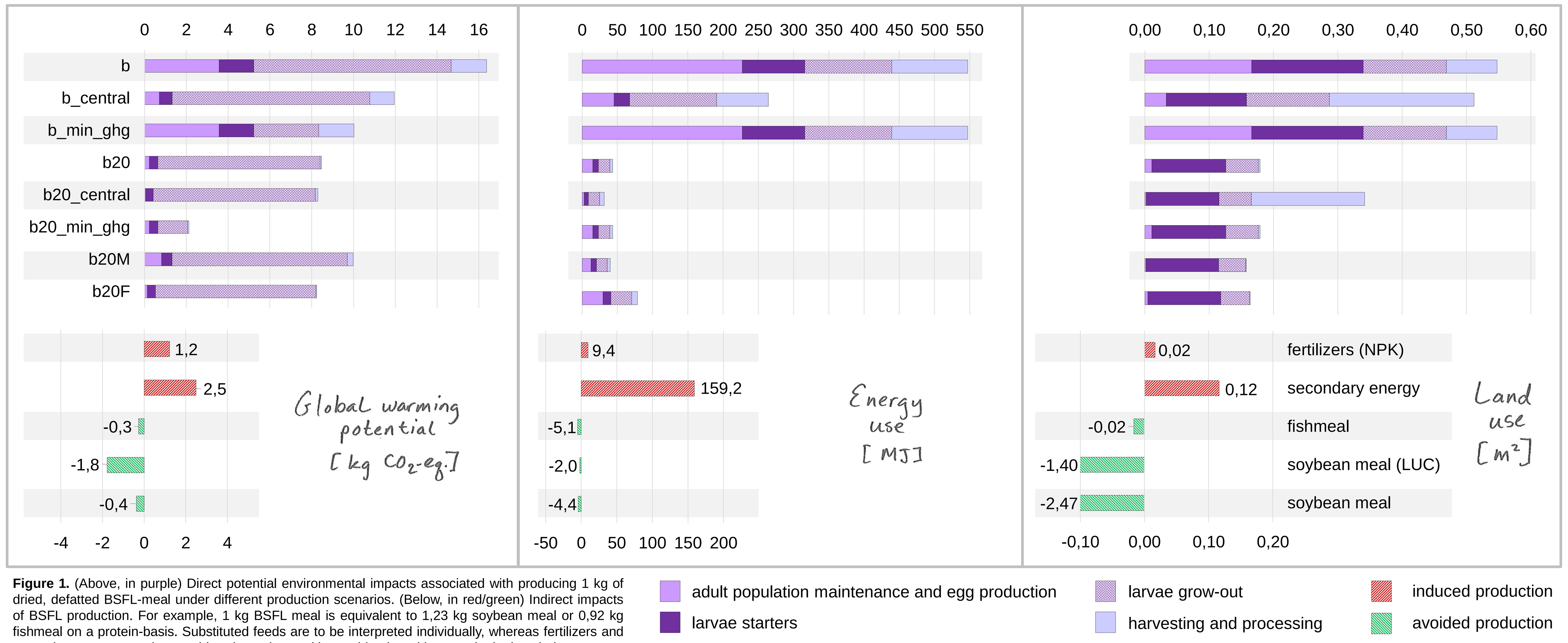

Figure 1. (Above, in purple) Direct potential environmental impacts associated with producing 1 kg of dried, defatted BSFL-meal under different production scenarios. (Below, in red/green) Indirect impacts of BSFL production. For example, 1 kg BSFL meal is equivalent to 1,23 kg soybean meal or 0,92 kg fishmeal on a protein-basis. Substituted feeds are to be interpreted individually, whereas fertilizers and secondary energy may be considered together and in combination with any substitution choice.

Conclusion

As the insects-as-feed sector continues to mature, related technologies and production systems will incrementally approach optimal designs. This will likely be paralleled by a scaling up and diffusion of overall activity. LCA studies can serve as a feedback mechanism for this maturation process via guiding developments away from burden-shifting traps and towards increased food system eco-efficiency. This study showcased this potential by revealing the sizable contribution of direct emissions, as well as estimated impacts associated with scaling up, diffusion and division of production. In future LCA studies, use of primary direct emissions associated with larvae grow-out must be emphasized.

References

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