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FROM FOOD-WASTE TO COMPOST AND FEED: LIFE CYCLE ASSESSMENT OF A PILOT PLANT OF INSECT MASS-REARING

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ABSTRACT

Food waste is a problem that urgently requires strategies for facing it. In this context, the potential environmental impacts of food-waste bioconversion by the action of Hermetia illucens into compost and dried larvae, are assessed, through the application of Life Cycle Assessment. Two different functional units, used for carrying out the analysis, are selected: 1) the input of production process (1 tonne of food-waste); 2) the output composed by dried larvae, considering the protein content (1 kg). Results, in terms of Global Warming Potential (GWP), show a value of 30.2 kg CO_2 eq, mainly due to the electricity consumption and direct GHG emissions. Instead, comparing the utilisation of H. illucens for protein production, instead of soy meal (considering 1 kg of protein) caused an increase in GWP and Energy Use (EU) of 0.4 kg CO_2 eq and 15.1 MJ, respectively, and a decrease in Land Use (LU) of 8.65 m^2.

Keywords: Food-waste, LCA, *Hermetia illucens*, black soldier fly, bioconversion, compost, dried larvae, feed.

INTRODUCTION

The problem of food waste (FW) production is nowadays largely discussed by European Commission (EC), that estimates, in the EU-28, an amounts of FW to about 100 million tonnes per annum (EC 2015), confirming that the projection for 2020 is 126 million tonnes (EC 2010). Due to this, is very important finding new solutions and strategies for prevention and valorisation of FW. An interesting strategy for the valorisation can be represented by the utilisation of FW as substrate for mass-rearing of edible insects, to be used as a protein resource for the livestock sector. This solution can contribute positively both to the increasing amount of FW and the rising global demand for feed, which is about one billion tonnes per annum (IFIF 2013) and is expected to increase.

To evaluate the environmental profile of insect-based products and their role as a valuable alternative for FW valorisation, quantification of environmental impacts associated with the whole life cycle of these processes should be carried out.

The aim of this study is to apply the LCA methodology to a system of mass-rearing of *Hermetia illucens* (an insect of the order of Diptera: Stratiomyidae, also known as Black Soldier Fly – BSF), in which from FW bioconversion, compost and dried larvae (used as feed in aquaculture) are produced.

BACKGROUND

In the international scientific literature there are many studies concerning the utilization of insects for food-waste bioconversion, but very few articles relate to the application of Life Cycle Assessment (LCA) in this sector (van Zanten et al. 2015, 362-369; de Boer et al. 2014; Oonincx and de Boer 2012) and none of these refers to *H. illucens*. Furthermore, only two studies on the quantification of Green House Gas (GHG) emissions from insects were carried out (Oonincx et al. 2010 and Hackstein and Stumm 1994, 5441-5445).

METHOD

The Life Cycle Assessment (LCA) methodology was applied to evaluate the potential environmental impacts of FW bioconversion by *H. illucens*. LCA is a methodology, standardized by ISO 14040-44 (ISO 2006a; ISO 2006b), to assess the potential environmental impact associated with a product/process/service throughout its entire life cycle. As proposed by ISO, an LCA study consists of four phases: goal and scope definition, inventory analysis, impact assessment, and interpretation.

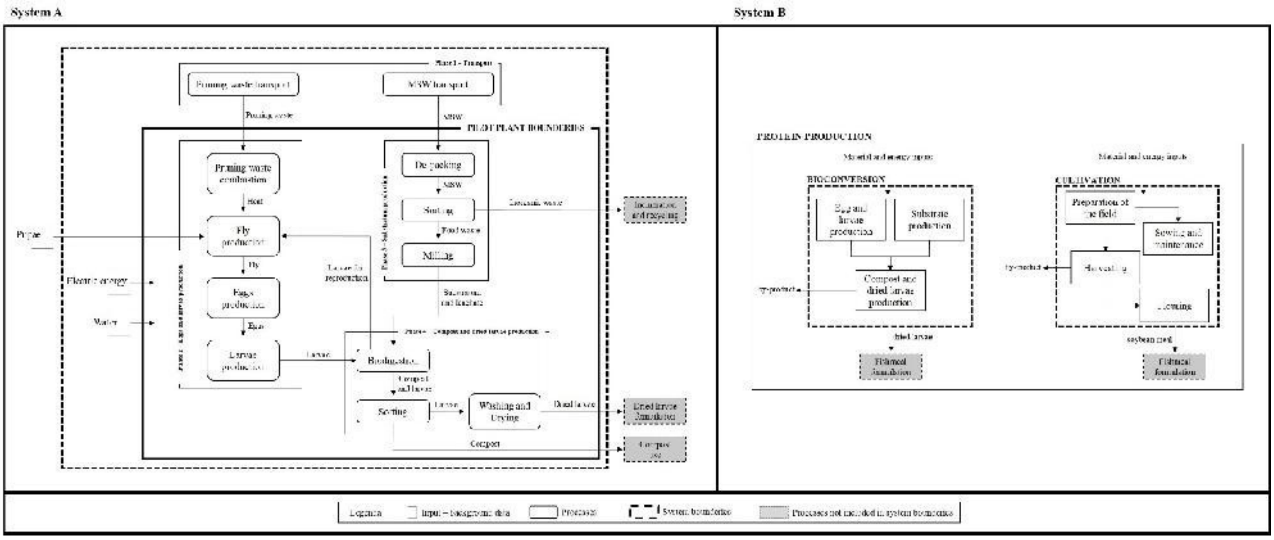
Goal and scope definition

The goal of the study is to quantify the potential environmental impacts attributed to the production of insect-based products from mass-rearing of *H. illucens* fed with FW from different sources. The analysis refers to a pilot plant located in Southern Italy in which *H. illucens* is employed for FW bioconversion.
Two different functional units (FU) were chosen in this study:

- *1 tonne of FW biodigested* - in order to present a first general assessment of the bioconversion process;
- *1 kg of proteins* - to compare the bioconversion system with a conventional production system. In this case, considering that the system includes multifunctional processes due to the production of compost and dried larvae, economic allocation was applied; due to the big difference in terms of economic values between the two outputs, all impact of bioconversion process was allocated to dried larvae.

System boundaries were defined following a cradle to gate approach, including four different phases: 1) transport of inputs, 2) egg and larvae production, 3) substratum production, and 4) compost and dried larvae production. In addition to the processes in dotted boxes, other processes were excluded from system boundaries: electricity and water consumption in the offices; disposal of inorganic waste (paper, plastics, etc.); machinery; the initial input of pupae to start the process; the big bags used for packing dried larvae; the methane emissions from organic waste during substrate production phase; and the methane emissions during biodigestion activity of *H. illucens*.
The two systems are represented in figure 1.

Figure 1. System boundaries



Life cycle inventory analysis (LCI)

Primary data was collected from the pilot plant and includes: pupae used for reproduction; water and electricity consumption; transport activities; pruning waste used in the boiler; FW biodigested; larvae manure produced; dried larvae produced; chemical composition of larvae and compost. The main input and output data per FU of *1 tonne of FW biodigested* is shown in table 1. Secondary data include both data from international literature and data from international databases, as summarized in table 1.

Due to the lack in literature of specific data of GHG emissions for *Hermetia illucens*, we assumed that it does not emit methane – according to Hackstein and Stumm 1994, 5441-5445, Diptera does not seem to be a methane-emitting insect species – and for the other GHGs, available data referred to other species were included. In detail, we referred to the study of Oonincx et al. (2010) who estimated GHGs for five insect species but, considering that none of the insects studied by Oonincx et al. is *Hermetia illucens* or is an insect belonging to Diptera order, data expressed in terms of body mass per day referred to *Pachnoda marginata* were assumed as similar to *Hermetia illucens* considering that it has a larval stage and a complete metamorphosis and feeds on decaying material, similarly to *Hermetia*.

Table 1. Main inventory data

Description	Unit	Amount	Description	Unit	Amount
Input			*Output*		
Food Waste	t	1	Compost	kg	334.6
Transport	tkm	24.3	Dried larvae	kg	29.6
Pruning waste	kg	5.5	CO_2	kg	16
Water	kg	61.1	CH_4	g	51.2
Electric energy	kWh	12.9			

Source: Primary and Calculated data; Ecoinvent, 2007 (Transport, lorry 7.5-16 t; Transport, lorry 3.5-7.5 t; Electricity, medium voltage, IT); Salomone and Ioppolo, 2012; Oonincx et al., 2010

In the system considering as FU *1 kg of proteins* the content of protein in dried larvae was compared with the content of protein in soy meal because, according to different authors (e.g. Iribarren et al. 2012, 837-848; Nguyen 2008) soy meal is used as fishmeal and larvae meal can be used in the diet of different fishes (Kroeckel et al, 2012, 345-352). In this context, considering the protein content of larvae meal and soy meal, the production of 1 kg of protein requests respectively 2.08 kg of dried larvae and 2.17 kg of soybean flour.

Life cycle impact assessment (LCIA)

SimaPro 8 software (Prè Consultant 2010) was used to assess the environmental impact of the systems investigated. For the system using *1 tonne of FW biodigested* as FU, LCIA was conducted using CML 2 baseline 2000 method (CML 2000), except for Global Warming Potential (GWP) for which the IPCC 2007 GWP 100a v. 1.02 method (IPPC 2007) was used. For the systems using *1 kg of proteins* comparative LCIA was conducted using three main impact categories (the same used in Oonincx & De Boer 2012 and in van Zanten et al. 2015): Global Warming Potential (GWP - IPPC 2007), Energy Use (EU - VDI 1997; Frischknecht et al. 2004), and Land Use (LU - Guinèe et al. 2001).

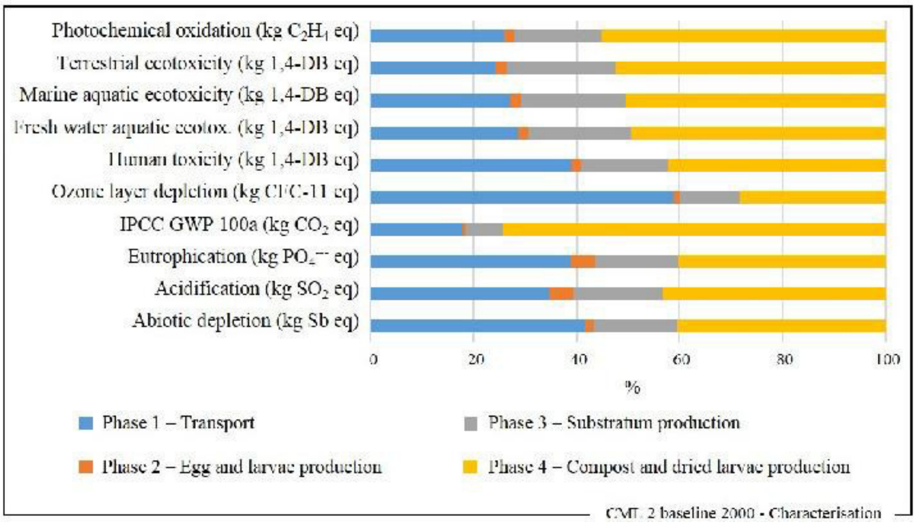
Life cycle interpretation

Due to the higher uncertainties related to direct GHG emissions and the main impacts associated to energy consumption in drying process, a sensitivity analysis was carried out considering: 1) no emissions of GHGs and GHG emissions calculated in terms of mass gain, and 2) use of alternative sources of energy in drying process (natural gas and photovoltaic).

RESULTS AND IMPLICATIONS

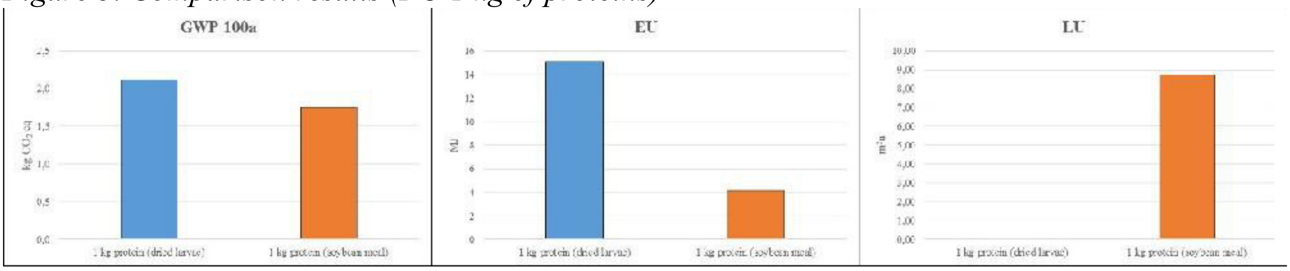
The results referred to the FU of *1 tonne of FW biodigested* (Figure 2) highlight that higher impacts for each category are caused by compost and dried larvae production (phase 4), followed by the transport phase (phase 1), except for ozone layer depletion for which the higher impacts are associated principally to the transport phase. Analysing the GWP category, results show that the total impacts related to this category are 30.2 kg CO_2 eq; the contribution of phase 1 and 4 are, respectively, 5.4 kg CO_2 eq and 22.5 kg CO_2 eq, while the phases 2 and 3 contribute, respectively, 2.1 kg CO_2 eq and 0.2 kg CO_2 eq. An examination in depth underscores that in the transport phase the higher impacts are referred to transport of municipal solid waste, while in compost and dried larvae production the main impact are related to GHG emissions during the bioconversion process and to consumption of electricity in the drying process. Observing the other impact categories, in particular for water aquatic ecotoxicity, marine aquatic ecotoxicity, terrestrial ecotoxicity and photochemical oxidation, the main impacts are related to electricity consumption in drying process.

Figure 2. Characterisation results (FU 1 tonne of FW biodigested)



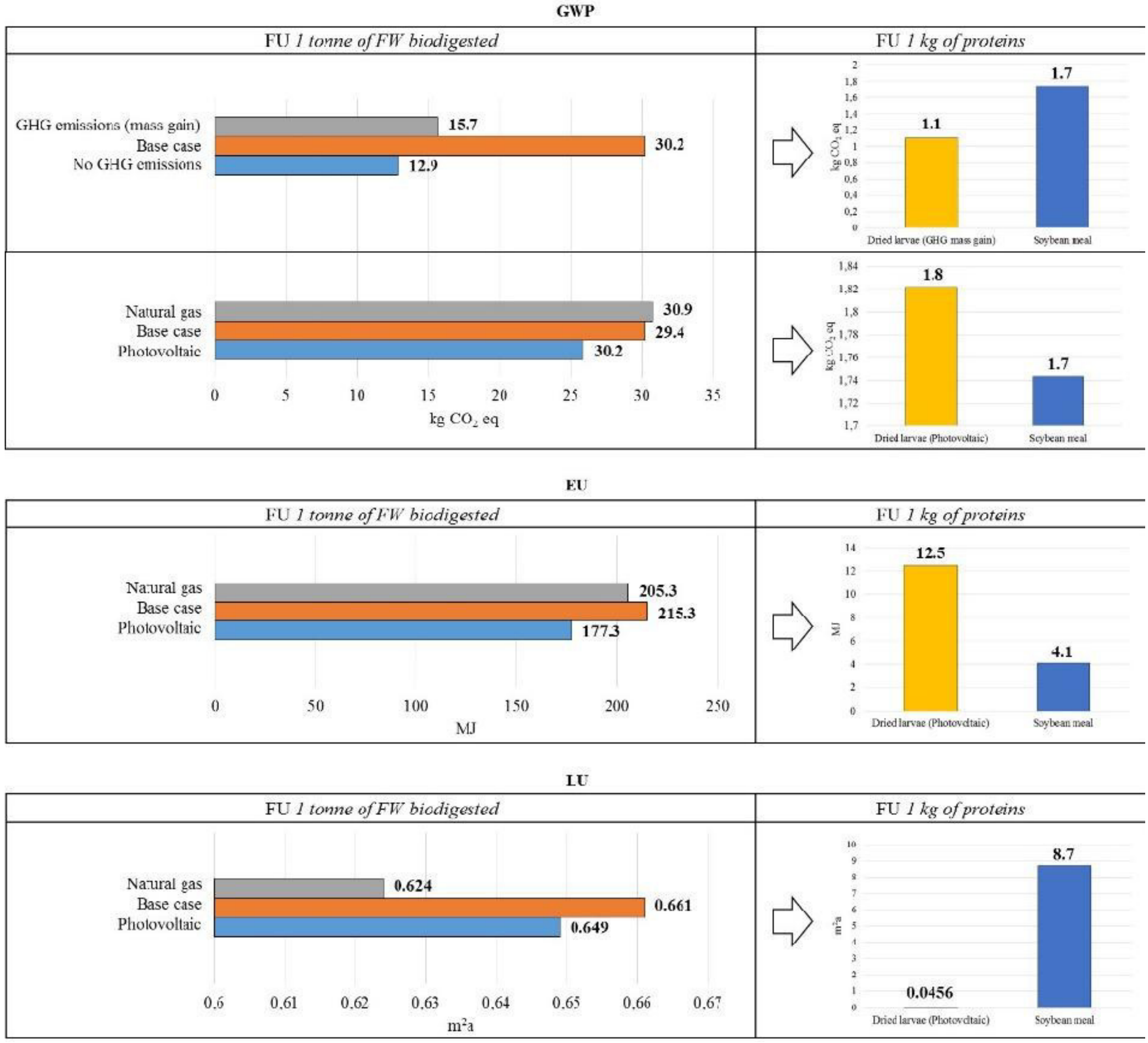
To analyse the environmental benefits of the production of dried larvae to be used as a source of protein for fishmeal formulation, the system was compared with the production of soybean meal, considering the FU of *1 kg of proteins*. The comparison results (Figure 3) show that the *H. illucens* system presents higher impacts in GWP (mainly due to the direct GHG emissions) and EU (mainly due to the transport of FW and the drying process) categories, while in terms of LU there is a significant environmental benefit when dried larvae substitute soy meal production. Indeed, using larvae instead of soy meal caused an increase in GWP and EU of 0.4 kg CO_2 eq and 15.1 MJ, respectively, and a decrease in LU of 8.65 m^2.

Figure 3. Comparison results (FU 1 kg of proteins)



The results of the sensitivity analysis (Figure 4) underscore that changing the effect of GHG emissions there is a variation of 57% between highest and lowest GWP impacts. This highlights the significant role of direct GHG estimation, that is confirmed by the fact that comparing the *H. illucens* system (including an estimation of direct GHGs based on mass gain) with soy meal (using as FU *1 kg of proteins*), the bioconversion process shows a lower GWP compared with soy meal. Furthermore, considering the utilisation of alternative energy sources in the drying process, there is an improvement of 14-25% (GWP), 19.2% (EU) and 1.8% (LU) if a photovoltaic system is adopted. This means that just changing a conventional energy system with photovoltaic in this process may cause a higher reduction in GWP and EU (10% improvement of total energy efficiency of the whole bioconversion system). Instead, if a natural gas system in the drying process is used, it could cause lower impacts in EU (-6.4%) and LU (-5.6%), while GWP would be higher about +1.9%. The comparison between *H. illucens* (adopting photovoltaic in drying process) and soy meal, considering the FU of *1 kg of proteins*, shows that despite a reduction of the impacts, proteins production in bioconversion system still presents higher GWP and EU values than the system in which proteins are produced by soy meal, while lower impacts in LU are confirmed.

Fig. 4. Results of the sensitivity analysis



CONCLUSION

The main results of this study highlight that higher impacts are connected to the consumption of electricity mainly in drying process (compost and dried larvae production phase), followed by the transport phase in which the highest contributes are related to the transport of FW. The comparison with an alternative source of protein such as soy meal underscores that *H. illucens* system entails higher impacts in GWP and EU, while, on the contrary, significant benefits are connected to LU. The sensitivity analysis highlights that variation in direct GHG emissions may have significant influence on the results; furthermore, the change from a conventional electricity source to photovoltaic, only in the drying process, makes possible a higher reduction of GWP and EU, with a 10% improvement of the total energy efficiency. Nevertheless, when photovoltaic is used for the drying process, the bioconversion process still shows higher EU values compared to proteins produced by soy meal. Under these conditions, insect-based products can be a very attractive option for both FW valorisation and production of alternative sources for feed. Thus, it would not be surprising that the intensive *H. illucens* production could be implemented on an industrial scale in the next future. However, due to the many uncertainties and data lack, there is a need for more LCA studies on insects, in particular, specific inventory on GHG data for *H. illucens* and other insect species, as well as a protein qualitative analysis of dried larvae and their effect on fish diet.

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