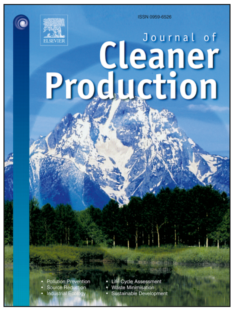

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Investigating on the environmental sustainability of organic animal products? The case of organic eggs

Michele Costantini[1], Daniela Lovarelli[1], Luigi Orsi[1], Andrea Ganzaroli[1], Valentina Ferrante[1], Pierluigi Febo[2], Marcella Guarino[1], Jacopo Bacenetti[1]*

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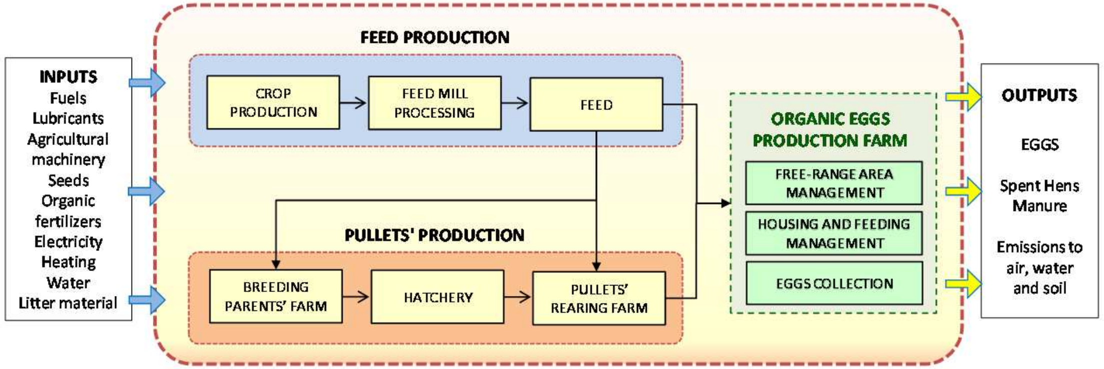
AIM

- → quantify the environmental impact related to the production of eggs according to the organic method in Northern Italy
- → identify some potential mitigation solutions that could be implemented for impact reduction



INPUTS
Fuels
Lubricants
Agricultural machinery
Seeds
Organic fertilizers
Electricity
Heating
Water
Litter material

FEED PRODUCTION
CROP PRODUCTION → FEED MILL PROCESSING → FEED

PULLETS' PRODUCTION
BREEDING PARENTS' FARM → HATCHERY → PULLETS' REARING FARM

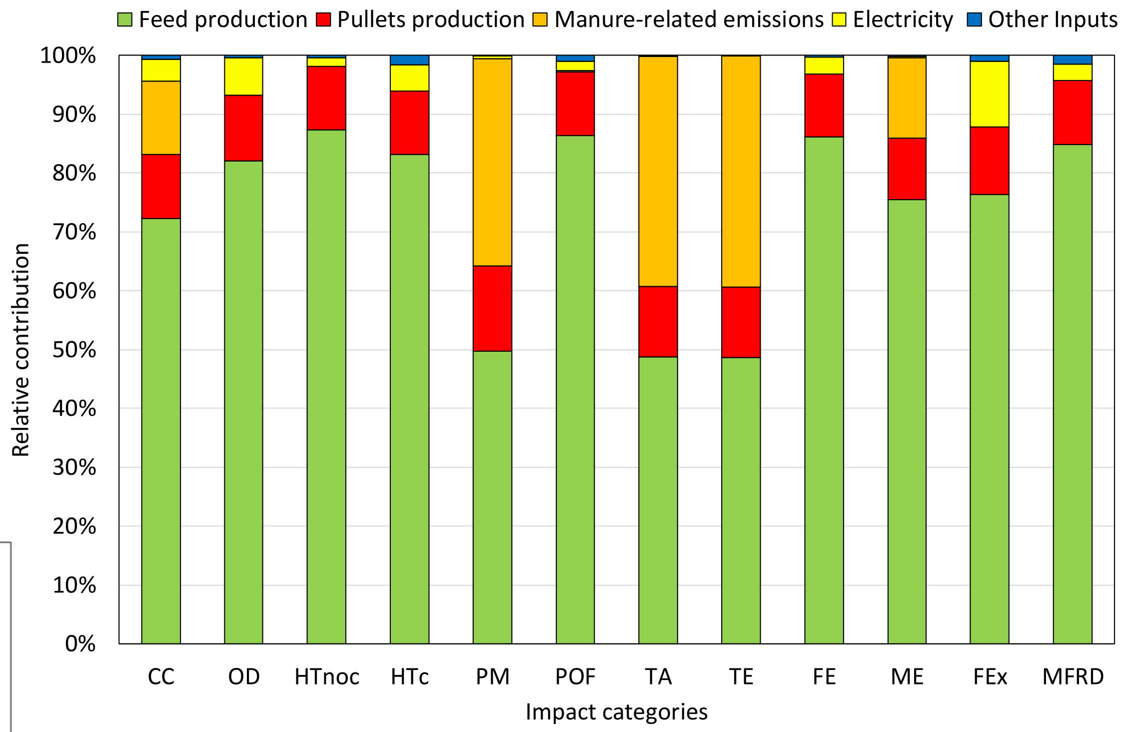
ORGANIC EGGS PRODUCTION FARM
FREE-RANGE AREA MANAGEMENT
HOUSING AND FEEDING MANAGEMENT
EGGS COLLECTION

OUTPUTS
EGGS
Spent Hens
Manure
Emissions to air, water and soil

FUNCTIONAL UNIT

1 kg of fresh shelled eggs produced with organic method

RESULTS



Climate change (CC), Ozone depletion (OD), Particulate matter formation (PM), Human toxicity-no cancer effect (HTnoc), Human toxicity- cancer effect (HTc), Photochemical ozone formation (POF), Terrestrial acidification (TA), Terrestrial eutrophication (TE), Freshwater eutrophication (FE), Marine eutrophication (ME), Freshwater ecotoxicity (FEx), Mineral and fossil resource depletion (MFRD)

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Abstract

The organic farming of laying hens is experiencing a growing trend in Italy, following an increase in consumer demand for organic eggs. The present study aimed to investigate the environmental performance of organic egg production for the first time in the Italian context. To this end, the Life Cycle Assessment (LCA) of organic egg production in a farm rearing laying hens located in Northern Italy was performed. The analysis was carried out in a cradle to farm gate perspective, with 1 kg of eggs selected as functional unit. Primary data relating to animal performances and resources consumed was collected on site, and subsequently integrated with secondary data, including estimates of manure-related emissions. In order to model in a representative way the organic feed consumed, data relating to typical cropping systems of the country has been used for the various ingredients, keeping the organic production method specifications into account. Inventory data was then converted on an annual basis and characterized using the ILCD method, and twelve impact categories were assessed. Moreover, the influence on impact results of different allocation choices and efficiency in terms of hen-day egg production were explored with a sensitivity analysis.

The main environmental burden for organic egg production showed to be feed production and supply, with a share ranging from 49% to 87% over all the evaluated impact categories. Other hotspots are pullets rearing, responsible for a share between 10 and 14% over all categories, and manure-related emissions, which weighed significantly for PM (35%), TA (39%) and TE (39%). A value for CC of 1.56 kg CO_2 eq/kg shelled eggs was obtained, thanks to good production performances together with some benefits given by organic feed use, particularly the avoidance of mineral fertilizer consumption and of land use change related emission. At the same time, the results show clearly that environmental improvements should be sought primarily in the same feed area. This must be done both on-farm, which was highlighted also by the sensitivity analysis on hen-day egg production, and at the supply chain level, acting on the impact related to crop production and pullets rearing phases. Starting from the results, some environmental weaknesses and strengths of organic farming have been discussed. Future studies must further investigate the impact of this rearing system in a wider perspective and explore possible scenarios of mitigation practices.

Keywords

Life Cycle Assessment, Organic production, Animal Product, Poultry, Environmental impact

List of acronyms

CC – Climate Change
CP – Crude Protein
FCR – Feed Conversion Ratio
FE – Freshwater Eutrophication
FEx – Freshwater Ecotoxicity
FU – Functional Unit
HTc – Human toxicity, cancer effects
HTnoc – Human toxicity, non-cancer effects
LCA – Life Cycle Assessment
LUC – Land Use Change
LW – Live Weight
ME – Marine Eutrophication
MFRD – Mineral, Fossil and renewable Resource Depletion
OD – Ozone Depletion
PM – Particulate Matter formation
POF – Photochemical Oxidant Formation
TA – Terrestrial Acidification
TE – Terrestrial Eutrophication

1. Introduction

The global demand for products of animal origin has been steadily increasing over the past 50 years driven by rapid population and income growth and it is expected to grow further in the near future (FAO, 2018). At the same time, animal food products are key drivers of adverse environmental effects such as climate change, water and air pollution, land degradation and biodiversity loss, to name a few (Poore & Nemecek, 2018; Crenna et al., 2019). The poultry industry is strongly linked to these phenomena since today it appears the most developed among the supply chains of animal products and is experiencing continuous growth that shows no signs of stopping. Although the poultry supply chain has been identified by several authors as the most environmentally efficient among those of animal products (Roma et al., 2015), raising concerns about the environmental sustainability of livestock productions have put even this sector under investigation.

As regards in particular the chicken egg production, in 2017 it accounted globally for 80.0 Mt, the maximum production ever reached. The European Union (EU-28), with 7.1 Mt produced in the same year, contributes significantly to the market for this product (FAOSTAT, 2020). Italy ranks among the most important European egg producers: in 2018, it hosted a population of about 39 million laying hens and the national production reached about 12.6 billion eggs, which made the country self-sufficient for eggs demand (ISMEA, 2019).

With regard to the rearing systems, in the EU countries, until the early 2000s the majority of egg farms practiced rearing of laying hens in cages, while recently alternative housing methods are spreading, mainly due to a growing public concern for animal welfare. A survey conducted by the European Union, in fact, indicates that an absolute majority of citizens (94%) are of the view it is important to protect the welfare of farmed animals (Eurobarometer, 2016). Moreover, most respondents (59%) indicate a higher willingness-to-pay for improved animal welfare. Referring specifically to laying hens, some recent studies (Leenstra et al., 2014; Zakowska-Biemans & Tekien, 2017; Rahmani et al., 2019) have shown that European consumers may consider free-range farming systems positively influencing animal welfare, which explains the increase in consumer demand for eggs deriving from cage-free facilities. Furthermore, the European Union ban on conventional cage rearing (Council Directive, 1999/74/EC), which came into force on January 1, 2012, has forced many farmers to shift towards different housing techniques. Still in accordance with EU Council Directive 1999/74/EC, the currently accepted rearing systems of laying hens are *furnished cages*, more commonly known as enriched, and three forms of *alternative systems* (cage-free), namely barn, free-range and organic.

In 2018, Italian egg production was divided as follows: 45% came from barn systems, 42% from enriched cages, 9% from organic and 3% from free-range systems. However, market trends in recent years show that sales of eggs from caged hens are continuously decreasing at the expense of those from alternative systems (ISMEA, 2019).

Generally, organic farming claims to lighten the environmental burden of agricultural production while generating ecological benefits. However, organic agriculture is accused of being less productive than traditional agriculture, and this efficiency gap is often identified negatively from an environmental point of view (Clark & Tilman, 2017). As concerns egg production, the organic system generally appears to be less efficient of the other rearing systems, particularly of cages. According to *Röös et al.* (2018), organic hens usually show a higher feed conversion ratio (FCR) between +2% and +20% compared to hens housed in cages or aviaries, and commonly present even an increased mortality due to injuries and diseases. Considering the important role of feed on the overall impact (Clune et al., 2017), many authors agree that organic eggs perform worse than non-organic in environmental terms, while on the other side there is who claims that the production gap is compensated by low input of resources to the system (Leinonen & Kyriazakys, 2016). However, both sides show a degree of variability in literature and there is not one that performs better than the other with consistency, nor for all impact categories in the same way (Leinonen et al., 2012; Pelletier, 2017). For all these reasons, the issue is still hotly debated.

Up to now, authors have conducted studies on this topic mainly in order to track a representative egg environmental performance for a regional or a country production, namely for Sweden (Cederberg et al., 2009), Australia (Wiedemann & McGahan, 2010), Netherlands (Dekker et al., 2011), United Kingdom (Leinonen et al., 2012), Iowa (USA) (Pelletier et al., 2013), Alborz (Iran) (Ghasempour & Ahmadi, 2016) and Canada (Pelletier, 2017). Some of these studies additionally aimed to compare different rearing systems and verify their influence on environmental performance. In particular, the organic system was included in the analysis by *Dekker et al.* (2011), *Leinonen et al.* (2012) and *Pelletier* (2017). *Abín et al.* (2018) instead, investigated the impacts of a single rearing system (i.e. enriched cages) in Spain. *Van Hal et al.* (2019) performed an LCA study on the impact of egg production by exploring an innovative allocation method that rewards low-opportunity-cost-feedstuffs as they avoid feed-food competition. Compared to other livestock sectors, however, studies on the environmental impact of egg production are limited.

All the previously quoted studies adopted the environmental Life Cycle Assessment (LCA) approach. LCA, whose normative reference is represented by ISO 14040 (ISO, 2006) and 14044 (ISO, 2018), is a method originally developed for industrial processes but recently has also been commonly employed in the agri-food sector (Lovarelli & Bacenetti, 2017a; Bernardi et al., 2018; Tedesco et al., 2019). LCA allows to quantify the potential environmental impact of a product (or process) during its whole life cycle, or a part of it, and to identify hotspots within the examined systems, thus to generate targeted mitigation strategies (Notarnicola et al., 2017). In the Italian context, although several livestock systems have already been analysed with the environmental LCA approach, there is a lack of studies related to egg production. This is the first study focused on the environmental performance of organic egg production in Italy and therefore aims to: quantify its impact in order to provide a national reference; highlight the main contributors to this impact, also referred to as *environmental hotspots*; starting from these, discuss possible mitigation strategies, highlighting any environmental critical issues of the system and rooms for improvement.

2. Materials and methods

2.1. Goal and Scope definition

Based on the gaps identified in the introduction, this LCA study was performed with the following aims:

- quantify the environmental impact related to the production of eggs according with the organic method in Northern Italy;

identify the processes mainly responsible for this impact and, consequently, discuss some potential mitigation solutions that could be implemented for impact reduction;

- strike up a debate on the influence of the rearing system on the environmental impact of egg production, with a keen eye on main parameters that determine differences between them.

The analysis is based on data collected from a farm specialized in organic egg production located in the North-Eastern Italian region of Friuli-Venezia Giulia, which, given its characteristics, can be considered representative of this egg production system in the Po valley.

The outcomes of this study could be useful for the stakeholders involved in the poultry industry (e.g. feed producers, farmers and processors) to have a better understanding of the environmental performance of the supply chain they work in. At the same time, the results could support actions and/or policies to raise environmental awareness and sustainability by farmers, as well as by individuals, organizations, associations and policymakers.

2.2. System description

The analysed farm rears laying hens in an organic farming system, following the indications of Council Regulations (EC) n. 834/2007 and 889/2008 on organic production.

The production cycle begins with the purchase of a 3000 pullets flock, raised with organic method in another specialized farm that is located in the neighboring region. This flock corresponds to the maximum number of animals that can be raised simultaneously in a poultry house for laying hens, according to the aforementioned European regulations on organic production. Pullets are imported at 16 weeks of age and a live weight (LW) of 1.55 kg, ready to start the laying cycle. In fact, the analysed farm manages only the egg-laying phase, which lasts up to 72 weeks. During this period, animals spend part of the time inside the barn, and they also have free daily access to a free-range area, normally allowed by the farmer during daylight hours. The barn has an area of 500 m^2, which is partly covered with sand as litter material, and is also equipped with a raised tier with a slatted floor, on which automatic feeders, perches and special nests are placed. Eggs are collected from nests with automatic belts. The free-range is 1.25 ha and is cultivated with alfalfa, which is renewed every 3 years. In detail, the mechanized operations carried out are plowing and harrowing, seed bed preparation, and subsequently sowing and rolling. No other intervention is carried out during the 3 years. Since the farm does not own any land other than that destined for the free-range area, the entire feed supply is purchased externally by a specialized feed mill authorized in organic feed production. During the laying cycle, two different feeds are provided: the first with a crude protein (CP) content of 18.5% for a period of 24 weeks, and the second with 17% CP until the end of the cycle, for a total of 48 weeks. These two commercial feeds are produced locally, as required by the organic method legislation, and are mainly composed by maize and wheat grains, wheat bran and soybean meal.

At the end of the productive cycle, at a LW of 1.95 kg, spent hens are sent to the slaughterhouse. Then, following the all-in/all-out principle, a depopulation period of 21 days is carried out before a new batch of pullets is brought in. In this time frame, the barn is completely cleansed with steam and the whole amount of manure (40 tons) produced during the cycle is collected. The manure is entirely exported to a nearby cereal farm producing maize grain, which forms part of the maize used as feed ingredient.

2.3. Functional unit and system boundary

The Functional Unit (FU) is the unit to which refer all the inventory data and the environmental results. In this study, 1 kg of fresh shelled eggs produced with organic method was selected as FU, in accordance with Livestock Environmental Assessment and Performance Partnership (LEAP) guidelines (LEAP, 2016).

The study was carried out in a *cradle-to-farm gate* perspective, thus including in the system boundary the eggs life cycle until the end of the agricultural phase (**Figure 1**). Therefore, all inputs related to the rearing cycle, such as the production, purchase and on-farm transportation of feed and pullets, as well as the supply of other inputs such as electricity, water and litter material, were considered. On the contrary, packaging, from-farm transport, possible processing, market distribution and consumption phases, and all related waste disposal were excluded.

Figure 1 around here

As crop intended for feed production is concerned, this assessment considered raw material extraction (e.g., fossil fuels and minerals); manufacture (seeds, fertilizers and agricultural machines); use (diesel fuel consumption and engines exhaust gas emissions, tire abrasion emissions and fertilizer related emissions); maintenance and final disposal of agricultural machines.

Emissions due to feces deposition during animal housing have been included in the assessment, while the impact related to manure export and its field spreading was not, since considered as falling outside the system boundaries.

Due to the lack of information, similarly to previous LCA studies on poultry productions (Roma et al., 2015), impacts related to drug use were excluded, and the same was done for production and maintenance of farm's facilities and devices.

As concerns agricultural land directly and indirectly involved in the analysis, no changes in the soil organic carbon were taken into account because considered to be in a steady state. In fact, according to the legislation on organic agricultural products, all feed ingredients are produced locally, thus on agricultural land of the Po Valley destined for arable crops where no land use change (LUC) has occurred recently. This assumption agrees with previous studies on the soil carbon stock topic (Huang et al., 2012; Han et al., 2016) and with previous LCA analyses focused on agricultural production in Northern Italy (Noya et al., 2018; Bacenetti, 2019).

2.4. Inventory data collection

Primary data refer to a farm located in North-Eastern Italy, whose production system is described in detail in section 2.2, and were gathered through a survey at the farm and a questionnaire completed by the farmer.

Table 1 reports the main data about the animals' productive parameters, as well as quantity and type of inputs consumed and outputs generated, relating to a production cycle that took place between 2018 and 2019.

Table 1 – around here

The inventory data for the three-year renewal of alfalfa cultivation in the free-range area were obtained directly from the farmer, and subsequently integrated with information from *Bacenetti et al.* (2018), who explored the environmental impact of alfalfa cultivation in the Northern Italian context.

Feed composition (**Table 2**) was modeled starting from commercial ingredients lists and main nutritional values, provided by the farmer. Ingredients below 1% w/w (i.e. feed additives) were excluded from the study. In calculating the farm feed consumption, an additional 2.5% was considered compared to the average animals' intake, due to wastes declared by the farmer that occur during animal feeding. This share of spilled feed falls to the ground and mixes with litter material and animal excreta, contributing to manure formation.

As regards the inventory data relating to crop production of feeds, detailed information on field operations and related inputs and outputs were recovered by *Bacenetti et al.* (2016), *Bacenetti et al.* (2017a), *Dal Ferro et al., (*2017) as regards maize, wheat and soybean; *Bacenetti et al.* (2017b) as for flax and *Forleo et al.* (2018) for sunflower. These studies reflect peculiarities of the Italian agricultural context for the different feed ingredients production. However, to ensure the consistency with the system under study, i.e. to comply with organic production specifications, mineral fertilizers inputs and relative distribution operations were not included in the inventory. The same was done with pesticides, which were replaced with mechanical weeding interventions, for which data were taken from *Lovarelli & Bacenetti* (2017b) and *Lovarelli et al.* (2017). Finally, to take into account the significant drop in yields normally observed in organic farming (de Ponti et al., 2012), a yield ratio of 70% was assumed for all the cultures with respect to the conventional farming references, similarly to the average value observed by *Dal Ferro et al. (*2017) in Northern Italy.

Table 2 – around here

Background data relating to feed processing, production of pullets, electricity, water, litter and on-farm transports were obtained from the established life cycle inventories data sources Ecoinvent V3.5 (Weidema et al., 2013, Moreno Ruiz et al., 2018) and Agrifootprint (Blonk Consultants, 2014). All electricity consumptions, both direct on the farm and those related to upstream processes, were modeled using the medium voltage Italian energy mix at grid. Impact due to the on-farm transport of pullets, litter material and feed inputs was computed through the ton-per-kilometer method, knowing the distance from the suppliers.

Emissions related to animal housing and manure management were estimated by following the IPCC guidelines (IPCC, 2006; 2019); in particular, Tier 2 was used to quantify methane (CH_4) emissions and Tier 1 for nitrous oxide (N_2O) and ammonia (NH_3). Methane emissions from enteric fermentations were assumed to be zero, in consistence with previous LCA studies on poultry systems, both when intended for the production of eggs (Leinonen et al., 2012; Pelletier, 2017) and broiler meat (Cesari et al., 2017; Da Silva et al., 2019).

In order to estimate CH_4 emissions from manure, volatile solids excretion was predicted using the equation n. 5 provided by LEAP (2016). Due to the lack of specific data, the diet digestibility was considered to be fixed at 80% and manure ash content at 10% (LEAP, 2016). Subsequently, a methane producing capacity factor (B_0) of 0.39 m^3 CH_4/kg of volatile solids and a methane conversion factor of 1.5% were used for computing manure CH_4 emissions (IPCC, 2006; 2019).

The excreted nitrogen, required to estimate nitrogen compounds emissions, was calculated by deducting nitrogen retention from nitrogen intake. The latter was derived from the dry matter intake of the animals and the diet CP content, both provided by the farmer. The retention instead was predicted using the equation n. 10.33D provided by IPCC (2006; 2019), thus considering egg mass production, average nitrogen content in eggs (1.85% on mass), daily weight gain and average nitrogen content in LW (2.8% on mass).

Subsequently, nitrous oxide and ammonia emission were calculated using the Tier 1 conversion factors of IPCC (2006; 2019). For both nitrogen compounds, specific conversion factors were used for the interior of the barn and the free-range area. In this regard, considering the average time spent by the hens in the different areas of the farm, it has been assumed that the animals deposit 70% of the feces inside and 30% outside. For the share deposited externally, nitrate (NO_3^-) leaching was calculated according with *Brentrup et al.* (2000) considering as if it were spread manure.

As in the majority of LCA studies focused on livestock systems (Roma et al., 2015), CO_2 emitted by the animals was not accounted because considered balanced by that fixed by means of photosynthesis by the plants involved in the system, i.e. crops (IPCC, 2006).

Further information on crop production elaboration (Tables S1, S2, S3, S4, S5) and emissions estimation (Table S6) can be found in the supplementary materials.

2.5. Allocation

When multifunctional processes are studied, allocation should be introduced in order to assign impact shares to the different co-products. As the function of the system under analysis in this study is to supply eggs, the environmental impacts were not allocated but attributed entirely to eggs, by far the most relevant product of the system both in economic, mass and nutritional value terms. However, to check if this methodological choice had a significant effect on the results, a sensitivity analysis was carried out which explored the influence of other possible allocation methods, as suggested in LEAP guidelines (2016). The setting of this analysis is discussed in section 2.7.

2.6. Impact assessment

In the life cycle impact assessment phase, emissions and resource data identified during the inventory are translated into indicators that reflect environment pressures as well as resource scarcity. The impact assessment was performed using the ILCD (International Reference Life Cycle Data System) 2011 Midpoint + method (V1.03), which is the impact assessment method endorsed by the European Commission, and processed with the SimaPro® 8.0.5 software. The evaluated impact categories are the following: climate change (CC), ozone depletion (OD), particulate matter formation (PM), photochemical oxidant formation (POF), terrestrial acidification (TA), terrestrial eutrophication (TE), freshwater eutrophication (FE), marine eutrophication (ME), freshwater ecotoxicity (FEx), mineral and fossil resources depletion (MFRD).

2.7 Sensitivity analysis

A sensitivity analysis was carried out with the variation of some methodological choices and key parameters to investigate their effect on the environmental impact. The following aspects were taken in consideration:

- Allocation method. Results variation was evaluated when considering the meat of spent hens as a relevant co-product. In this regard, LEAP guidelines (2016) suggest that it would be preferable to handle this co-production using biophysical allocation. This was made by portioning metabolizable energy requirements between growth and egg production. As a reference for these requirements, 5.5 kcal/g of LW gain (starting from the hatchling weight) and 2.07 kcal/g of egg were considered (NRC, 1994).
  In addition, economic allocation was evaluated, taking reference prices from the wholesale poultry exchange of Forlì, one of the most important for the sector in Northern Italy. The prices used were € 14.68/100 units for organic eggs and € 0.27/kg of LW for

medium-sized spent hens (averages for January 2020, ISMEA, 2020). It should be noted that the value of spent hens' meat is much lower than that of broiler meat. Moreover, the rearing system from which spent hens come does not influence the meat price, as it is however considered low quality poultry meat.

- Hen-day egg production. Indeed, it is a key production parameter, directly connected to the FCR, and which may possibly undergo variations due to environmental (temperature, humidity, etc.) and health (dysmetabolic diseases, leg injuries, etc.) conditions, and possibly due to the presence of other stressors, such as sporadic attacks by predators in the free-range area. The environmental performance was therefore explored for hen-day egg production of 85% (LOW scenario) and 93% (HIGH scenario). As a consequence to daily egg-laying changes, variations in animals' nitrogen retention and excretion rates were taken into account, thus estimates of manure-related emissions were adapted.

When cross-referencing both aspects, changes due to different total productions on the total value of eggs produced and energy requirements were also taken into consideration.

3. Results

3.1. Environmental results for organic egg production

The absolute results for 1 kg of organic eggs are reported in **Table 3**, while **Figure 2** shows the contribution analysis.

Table 3 – Around here

In more detail, for each evaluated impact category, **Figure 2** shows the relative contribution of the different inputs. Each column of the graph can be read as a pie chart, facilitating the identification of environmental hotspots. The input and output flows considered to make the analysis run are grouped for the results presentation into five classes: feed production (referring to consumption that takes place during the egg-laying cycle), pullets production, manure-related emissions, electricity (referring to on-farm consumption for lighting, automatic feeder and egg collection belts) and other inputs (referring to the sum of impacts due to on-farm transport of pullets, feed and litter; litter material production; water supply; free-range area management operations).

Figure 2 around here

The impact of each class is discussed below:

- Feed production is the main environmental hotspot, being the major driver of the impact for all the evaluated categories with a share ranging from 49% for TA and TE to 87% for HTnoc. This impact is related to energy requirements and machinery use for agricultural production and feed mill processing, as well as to emissions occurring during crop cultivation. Breaking the feed impact down between the two different feeds used, it emerges that the feed with 17% CP impacts for approximately two thirds (from 64% to 68% over all the evaluated impact categories) of the total, while the feed with 18.4% CP for the remainder. This is due to the fact that they have a similar composition but the first is used for a period of twice the duration of the other within the laying cycle therefore about twice the mass is consumed.
- Manure-related emissions affect significantly CC (12%), PM (35%), TA (39%), TE (39%) and ME (14%). Among these, the manure-related impact is entirely due to NH_3 volatilization for PM, TA and TE. NH_3 is also responsible for 83% of the manure-related share for ME that, even if to a lesser extent (17%), is also influenced by NO_3^- leaching in the free-range area. Regarding the CC, the contribution of manure-related emissions is mainly due to N_2O, which represents 77% of the manure-related greenhouse gases emissions, while CH_4 contributed the remaining 23%.
- Pullets production is responsible for a share ranging from 10% to 14% for all the evaluated impact categories. This impact, in turn, is due especially to the feed consumption necessary for feeding the growing pullets in the specialized farm (Figure S1). Other contributing factors are emissions related to manure and housing management, electricity and heat consumptions and the supply of one-day-old chickens to the pullets farm.

- Electricity consumption on-farm has a limited contribution on the total impact for all the evaluated impact categories, resulting in less than 4% for all categories except for OD and FEx, for which it makes up respectively 6% and 11%.
- Other inputs were grouped due to their small overall impact. Indeed, their share is below 2% for all the evaluated impact categories.

Given the growing global concern on the climate change issue and its strong connection with the livestock sector (McClelland et al., 2018), specific attention is hereby paid to this aspect. Feed production affects the total CC impact (1.56 kg CO_2 eq/kg eggs) for 72%, representing by far the major contributor, followed by manure-related emissions (12%), pullets production (11%), electricity (4%) and other inputs (1%). **Figure 3** shows the results of a contribution analysis conducted on greenhouse gases.

Figure 3 – around here

The overall CC impact, expressed in kg CO_2 eq., is caused mainly by CO_2 emissions (58%), followed by N_2O (34%) and, lastly, CH_4 (8%) (Table S8). The effect of other substances is negligible (about 0.1%), thus not reported in the graph. Feed production is the main emitter for all the three gases (Table S9): huge amounts of CO_2 are emitted during mechanized field operations and feed processing, while N_2O and CH_4 are emitted from organic fertilizers storage, handling and spreading on fields. Pullets production is the second contributor for CO_2; manure-related emissions, on the other hand, represent a significant share of N_2O and CH_4.

3.2. Sensitivity analysis results

Results of the sensitivity analysis are reported in **Table 4**.

As regards the allocation choice, the results show that if the biophysical allocation is adopted, the environmental impacts associated with egg production significantly decrease. This result, despite being the method recommended primarily by ISO standards and LEAP guidelines (2016) when allocating this type of product, raises doubts regarding the distribution of impacts among the co-products of the system, considering that the primary function of the examined system is to supply eggs, while spent hens’ meat is a low-value and low-quantity co-product. Indeed, in previous LCA studies on egg production no author has applied this allocation method.

The economic allocation, instead, shows to be almost irrelevant, resulting in a reduction of the impact always <1% compared to the baseline scenario with no allocation, and regardless of the hen-day egg production considered. This is due to the abovementioned large gap existing between the two co-products both in terms of mass produced and price, even assuming different hens' productivity. However, it should be underlined that this result could undergo fluctuations depending on the prices variability.

Table 4 – around here

As regards the influence of the hen-day egg production, the variation is uniform among categories within the two alternative scenarios when considering same allocation methods, with the categories influenced by manure-related emissions that undergo slightly more marked variations than the others. More specifically, the impact categories highly influenced by NH_3 emissions (PM, TE and ME) are those most affected both in terms of impact reduction in the HIGH scenario and of impact increase in the LOW scenario. In general, these results highlight the influence of system efficiency on environmental performance while keeping unaltered the system inputs. When considering the absolute values, the impact ratio between the HIGH and LOW scenarios vary overall in a range of 87.1-92.1%.

3.3. Uncertainty analysis results

An uncertainty analysis was carried out with the Monte Carlo technique (5,000 iterations and a confidence interval of 95%) to test the robustness of the achieved results. The results, reported in **Figure 4**, show that the uncertainty due to selection of the data source, model imprecision and variability of background data does not significantly affect the results for CC, PM, POF, TA, TE, FE (coefficient of variation < 3%) and ME (coefficient of variation < 8%) while it has great influence on OD, the toxicity related impact categories and MFRD.

Figure 4 – around here

4. Discussion

The results clearly revealed feed production as the main hotspot for any impact category for the system under analysis. The primary role of feed in determining impacts and its relative contribution appears in line with previous LCA studies on egg production (Dekker et al., 2011, Leinonen et al., 2012, Pelletier, 2017, Abín et al., 2018), and without particular differences attributable to geographic location or adopted rearing system. Also, pullets production and emissions related to manure contributed significantly. As concerns the substances contribution analysis of CC, the results obtained in this study are in accordance with *Dekker et al. (2011)* and *Wiedemann and McGahan (2010)*, while other authors (e.g. Abín et al., 2018) identified N_2O instead of CO_2 as the main greenhouse gas emitted in terms of CO_2 eq from the egg production system.

The absolute value for CC observed in this study for the selected FU (1.56 kg of CO_2 eq/kg eggs) falls within the lower quartileof the values range identified in a recent literature review (1.3-6.0 kg of CO_2 eq/kg eggs, Clune et al., 2017). With the awareness that some of the variability observed between different LCA studies is due to methodological choices, the result still shows the analysed farm to have a good environmental performance in terms of carbon footprint. The farm's productivity and the avoidance of some inputs that normally weigh heavily from an environmental point of view in conventional systems, such as mineral fertilizers and imported feed ingredients, have contributed to achieving this result. An important role in determining the impact was certainly played by the replacement of South American soybeans with Italian-produced one, thus excluding impacts related to long distances transportation and LUC at the expense of forest areas. The result also confirms that eggs, represent together with milk the most sustainable product of animal origin with regard to CC (De Vries & De Boer, 2010), beyond the production system adopted.

For the other impact categories it is difficult to make comparisons because different assumptions were made on the model used for emissions estimation and/or on the characterization factors used (De Vries & De Boer, 2010), as well as because of the use of a different functional unit or system boundary. At the same time, it is important to consider a full set of impact categories to avoid impact shifting among them as well as a misrepresentation of trade-offs between impacts. This calls for comprehensive studies that cover a large spectrum of environmental impacts to avoid the previously mentioned burden-shifting in order to assess the environmental trade-offs between conventional and organic egg production systems.

The results show that mitigation interventions on feed production would be the most incisive option to reduce the overall impact, leading to an environmental improvement for all impact categories. What can be done at the farm level in this regard is to seek continuous improvement in FCR in order to lower feed consumption. The goal must be to optimize this consumption without sacrificing productivity. However, the environmental mitigation on feed production must also take place beyond the farm boundaries: it is essential that sustainable production starts from crops, adopting strategies to obtain an increase in yields and/or a reduction in resource consumption, thus amortizing the impact per kg of consumed feed. This mitigation strategy is limited by the fact that the farmer cannot intervene directly in this field, since the analysed farm depends entirely on the external purchase of feed. What would therefore be needed is a joint action between stakeholders of the supply chain, which should be undertaken at a collective level from farmers since the scarce availability of land for self-production of feed is a common feature to most of the poultry holdings in Italy (Eurostat, 2020). The same should be done for the mitigation of the impact due to pullets rearing.

Concerning the impact categories strongly affected by manure-related emissions, namely PM, TA and TE, a considerable mitigation could be obtained by deploying abatement technologies in farm facilities, such as ventilation systems that allow rapid drying of the excreta after deposition or air scrubbers, which have been proven to be a good solution in particular for ammonia (Van der Heyden et al., 2015). However, this latter implementation is unlikely to be applied in organic farms' barns since they normally use natural ventilation systems. A careful fulfilment of protein requirements has also been identified as a potential mitigation strategy (Vesela et al., 2016), so that it can simultaneously avoid protein overdoses in the ration, reducing inputs of protein ingredients, and limiting the nitrogen excretion of animals. A weakness of organic farming in this sense is that restrictions exist on the use of some ingredients, such as synthetic amino acids, making it more difficult to accurately meet nutritional requirements of the animals.

Another mitigation opportunity could be the partial replacement of traditional protein sources with alternative ones (insects and worms). Recently, many studies have explored this topic in the poultry sector, highlighting promising results both in production and environmental sustainability terms (Khan, 2018). Further research efforts are needed to better investigate the impacts that alternative protein meals can have if implemented regularly and in large quantities in laying hens' diets.

Finally, even if manure is collected only once at the end of the cycle, its energetic valorisation through anaerobic digestion and biogas production would be a viable option for further mitigation. By providing renewable energy, biogas production from manure could contribute to the “eco-functional intensification” of organic farming (Siegmer et al., 2015) and also foster the circular economy concept in agriculture (Toop et al., 2017). Several LCA studies (Uusitalo et al., 2014; Bacenetti & Fiala, 2015; Ingrao et al., 2019) have shown how a biogas plant fed with animal manure can reach a negative value (i.e., environmental benefits) for the Climate Change impact category when are considered the credits for the avoided traditional storage of manure. Anaerobic digestion of poultry manure would also be positive from an agronomic point of view since the anaerobic digestion increases the proportion of ammoniacal nitrogen on total nitrogen in digestate (Röös et al., 2018) and, consequently, its effectiveness in the substitution of mineral fertilizers. Moreover, poultry manure, if digested together with other biomasses (to avoid/reduce the risk of high ammonia concentration into the digesters) has an excellent energy potential both because it normally has a higher volatile solids content than other livestock effluents and it presents also a higher CH_4 yield per kg of volatile solids (Garcia et al., 2019).

Due to the lack of information, this study did not include the effect of the system on land use, water use, biodiversity and carbon sequestration, therefore the discussion may present restrictions. Future analyses should deepen the relationships between organic laying hens farming and these topics in a wider environmental perspective. Also, a challenge for future studies is to encompass the environmental dimension of sustainability, creating a connection with animal welfare aspects: several studies have investigated and compared the influence that different rearing systems, feeding management and housing conditions can have on animal welfare (EFSA, 2005; Nicol et al., 2017). Nevertheless, these aspects are not taken into consideration when carrying out an LCA analysis. Recently, a preliminary approach to include animal welfare in a social-LCA model for chicken production was proposed (Tallentire et al., 2019). Next step could be to combine this approach together with the LCA in a broader life cycle framework.

5. Conclusions

The environmental impact of organic egg production was evaluated by the LCA approach. The results show that feed production is the major impact contributor for all the evaluated categories. Consequently, a greater effort in reducing the environmental burden of egg production should be made first of all in the optimization of feed consumption on farm and in the crop production phase.

The outcomes of the sensitivity analysis point out the importance of allocation choice in defining the environmental load of eggs when considering co-products of the system, as it happens for other products of animal origin, and also highlight that the production efficiency of the rearing system plays an important role in determining positive environmental performance.

Each rearing system (conventional or organic) has peculiar positive and negative characteristics from an environmental point of view, and some variability can be observed across and within the different systems. Despite some criticisms that organic farming receives in literature, the farm analysed in this study has a good productivity, which was decisive for determining the environmental impact. The impact largely depends on farmers' management choices, rather than on the adopted rearing system and, a priori, there is not a best farming system for all circumstances. In any case, opportunities for further mitigation exist at the farm level in terms of feeding strategies, manure management and measures related to the housing system. Efforts at the supply chain level are instead needed to mitigate the impact of feed production and supply.

As this represents, to the authors' knowledge, the first LCA analysis on eggs in Italy, a starting point for future studies is to expand the sample to other farms and explore with comparative LCA different rearing systems, in order to directly compare the performance of organic and conventional production in the same context. Even some alternative scenarios with the mitigation solutions proposed in this study could be explored, evaluating their feasibility and social (animal welfare in particular), environmental and economic performance.

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Table 1 – Productive parameters of the analysed farm

Purchased pullets	n. · cycle^{-1}	3000
Laying cycle duration	weeks	72
Production cycles	n. · year^{-1}	0.64
Live weight, at pullets purchase	kg	1.55
Live weight, end of the cycle	kg	1.95
Feed intake, as fed	g · day^{-1} · head^{-1}	130
Egg weight	g	58
Hen-day egg production	%	90
Feed Conversion Ratio (FCR)	kg feed intake (as dry matter) · kg eggs produced^{-1}	2.19
Mortality	% · cycle^{-1}	4
Broken eggs	%	1.5
Indoor stocking density	n. hens/m^{2}	6
Electricity consumption	kWh · year $^{-1}$	7200
Water consumption	l · day^{-1}	700
Sand, as litter material	kg · cycle^{-1}	3200

Table 2 – Feed ingredients composition , expressed in dag · kg^{-1}, as fed. Both feeds have 88 % dry matter on fresh mass.

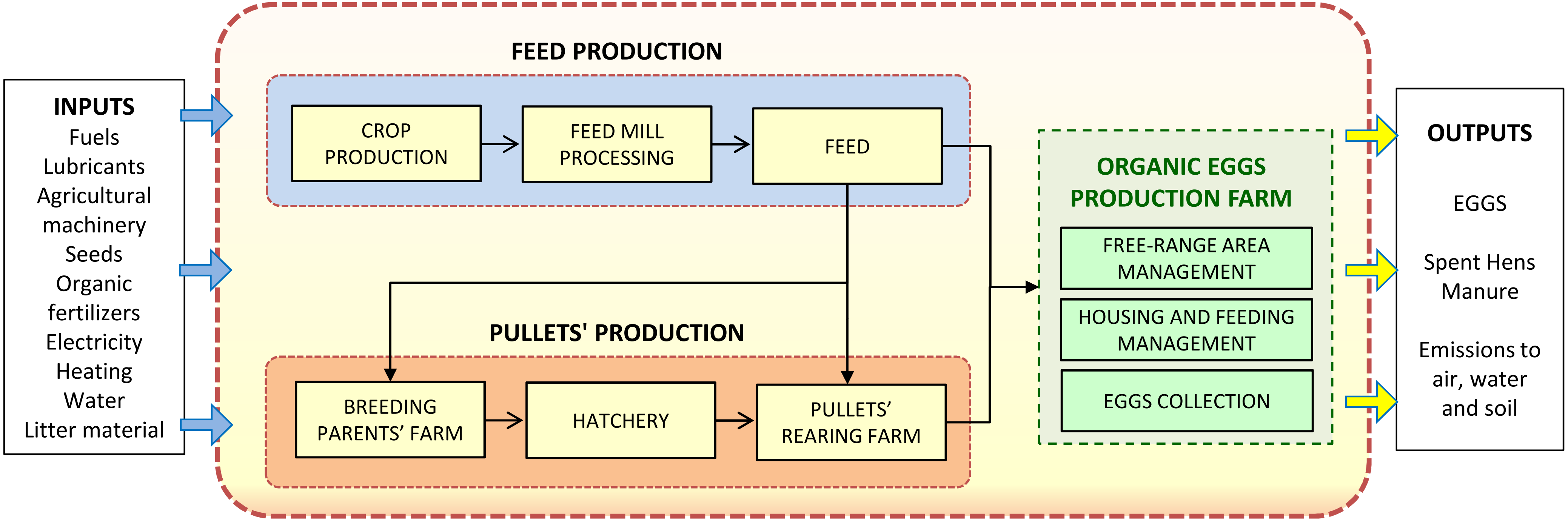
Feed component	**Feed 1st phase** (18.4 % CP on dry matter basis)	**Feed 2nd phase** (17.0 % CP on dry matter basis)
Maize grain	50	56
Soybean meal, extracted	15	12
Wheat bran	10	8
Wheat grain	10	8
Sunflower meal	8	8
Calcium carbonate	4	5
Maize germ	2	2
Linseed meal	1	1

Table 3 - Absolute results for the selected FU (1 kg of organic shelled eggs)

Impact category	**Unit of measure**	**Score**
CC	kg CO_2 eq	1.56
OD	mg CFC-11 eq	0.10^{4}
HTnoc	CTUh	$5.13 \cdot 10^{-7}$
HTc	CTUh	$4.02 \cdot 10^{-8}$
PM	g PM2.5 eq	4.12
POF	g NMVOC eq	7.63
TA	molc H^{+} eq	0.17
TE	molc N eq	0.75
FE	g P eq	0.55
ME	g N eq	17.8
FEx	CTUe	3.17
MFRD	g Sb eq	0.03

Table 4 - Results of the sensitivity analysis: impact variations with respect to the baseline scenario (BS) (i.e. no allocation and 90% hen-day egg production).

Impact category	Allocation method	Hen-day egg production		
		93% (HIGH)	90% (BS)	85% (LOW)
CC	No allocation (BS)	-3.3 %	—	6.1 %
	Biophysical	-18.9 %	-16.0 %	-10.7 %
	Economic	-4.1 %	-0.8 %	5.3 %
OD	No allocation (BS)	-3.2 %	—	5.9 %
	Biophysical	-18.8 %	-16.0 %	-10.9 %
	Economic	-4.0 %	-0.8 %	5.0 %
HTnoc	No allocation (BS)	-3.2 %	—	5.9 %
	Biophysical	-18.8 %	-16.0 %	-10.9 %
	Economic	-4.0 %	-0.8 %	5.0 %
HTc	No allocation (BS)	-3.2 %	—	5.9 %
	Biophysical	-18.8 %	-16.0 %	-10.9 %
	Economic	-4.0 %	-0.8 %	5.0 %
PM	No allocation (BS)	-3.6 %	—	6.6 %
	Biophysical	-19.2 %	-16.0 %	-10.2 %
	Economic	-4.4 %	-0.8 %	5.8 %
POF	No allocation (BS)	-3.2 %	—	5.9 %
	Biophysical	-18.8 %	-16.0 %	-10.9 %
	Economic	-4.0 %	-0.8 %	5.0 %
TA	No allocation (BS)	-3.7 %	—	6.7 %
	Biophysical	-19.3 %	-16.0 %	-10.1 %
	Economic	-4.5 %	-0.8 %	5.9 %
TE	No allocation (BS)	-3.7 %	—	6.7 %
	Biophysical	-19.3 %	-16.0 %	-10.1 %
	Economic	-4.5 %	-0.8 %	5.9 %
FE	No allocation (BS)	-3.2 %	—	5.9 %
	Biophysical	-18.8 %	-16.0 %	-10.9 %
	Economic	-4.0 %	-0.8 %	5.0 %
ME	No allocation (BS)	-3.3 %	—	6.0 %
	Biophysical	-18.9 %	-16.0 %	-10.8 %
	Economic	-4.1 %	-0.8 %	5.2 %
FEx	No allocation (BS)	-3.2 %	—	5.9 %
	Biophysical	-18.8 %	-16.0 %	-10.9 %
	Economic	-4.0 %	-0.8 %	5.0 %
MFRD	No allocation (BS)	-3.2 %	—	5.9 %
	Biophysical	-18.8 %	-16.0 %	-10.9 %
	Economic	-4.0 %	-0.8 %	5.0 %


INPUTS
Fuels
Lubricants
Agricultural machinery
Seeds
Organic fertilizers
Electricity
Heating
Water
Litter material
FEED PRODUCTION
CROP PRODUCTION
FEED MILL PROCESSING
FEED
PULLETS' PRODUCTION
BREEDING PARENTS' FARM
HATCHERY
PULLETS' REARING FARM
ORGANIC EGGS PRODUCTION FARM
FREE-RANGE AREA MANAGEMENT
HOUSING AND FEEDING MANAGEMENT
EGGS COLLECTION
OUTPUTS
EGGS
Spent Hens
Manure
Emissions to air, water and soil

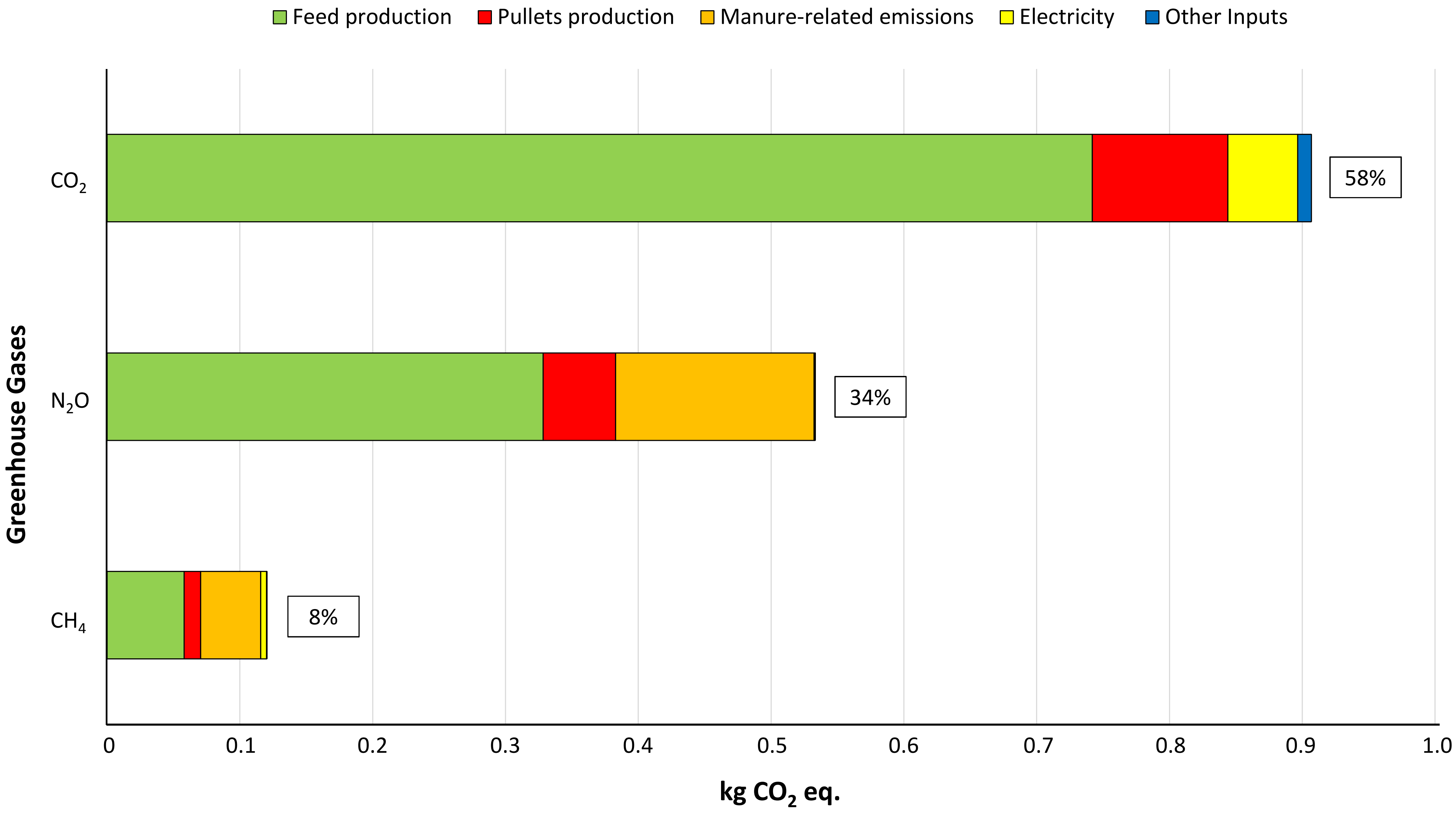
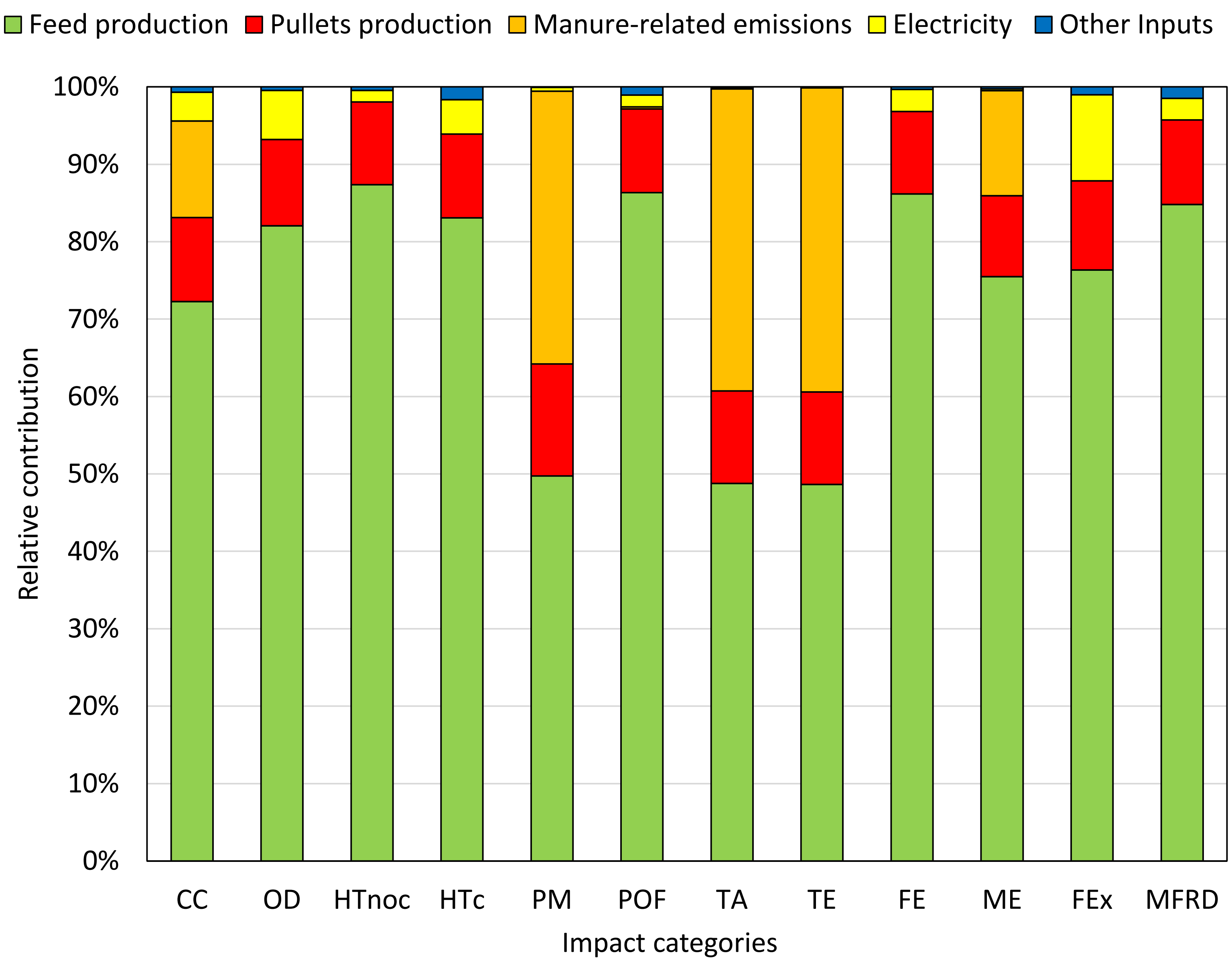

Feed production
Pullets production
Manure-related emissions
Electricity
Other Inputs
Greenhouse Gases
CO_2
N_2O
CH_4
58%
34%
8%
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
kg CO_2 eq.

Figure 1 – System boundaries.

Figure 2 – Contribution analysis of organic egg production.

Figure 3 – Contribution analysis of greenhouse gases emission for 1 kg of organic eggs.


Feed production
Pullets production
Manure-related emissions
Electricity
Other Inputs
Relative contribution
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
CC
OD
HTnoc
HTc
PM
POF
TA
TE
FE
ME
FEx
MFRD
Impact categories

SimaPro 8.5.2.0	Valutazion Data:	########	Periodo:	23:11
Progetto	_Pilmo			

Calculation:	Analizza
Results:	Valutazione dell'impatto
Product:	1 kg Organic eggs production {ITA} (of project _Pilmo)
Metodo:	ILCD 2011 Midpoint+ V1.10 / EC-JRC Global, equal weighting
Indicatore:	Caratterizzazione
Skip categories:	Mai
Esclude processi di infrastrutture:	No
Esclude le emissioni di lungo termine:	No
Sorted on item:	Categoria d'impatto
Sort order:	Ascendente

Etichetta	Unità	Totale	Organic eg	Transport,	Transport,	Transport,	BIO Laying	Mangime	Mangime	Tap water,	Erba medi	Sand {GLO	NO3- leac	NH3 emiss	CH4 Manu	N2O manu	Electricity, medium voltage {IT}|
Riscaldamento globale	kg CO2 eq	1.561819	0	0.00192	2.44E-05	0.00534	0.16933	0.75418	0.374685	0.001577	0.001551	0.000429	0	0	0.045274	0.149384	0.058127
Assotigliamento strato ozono	kg CFC-11	1.02E-07	0	3.93E-12	4.99E-14	1.09E-11	1.13E-08	5.52E-08	2.83E-08	1.18E-10	2.76E-10	6.06E-11	0	0	0	0	6.44E-09
Tossicità umana - Effetti non canc.	CTUh	5.13E-07	0	3.21E-11	4.07E-13	8.91E-11	5.49E-08	2.98E-07	1.5E-07	7.29E-10	1.37E-09	1.17E-10	0	0	0	0	7.6E-09
Tossicità umana - Effetti canc.	CTUh	4.02E-08	0	1.44E-12	1.83E-14	4.01E-12	4.35E-09	2.23E-08	1.12E-08	4.44E-10	1.81E-10	2.8E-11	0	0	0	0	1.8E-09
Formazione polveri sottili	kg PM2.5	0.004107	0	1.85E-07	2.17E-09	5.16E-07	0.000593	0.001314	0.000729	7.43E-07	1.22E-06	3.45E-07	0	0.001448	0	0	2.02E-05
Formazione smog	kg NMVOC	0.007625	0	1.5E-05	1.65E-07	4.17E-05	0.000826	0.004358	0.002225	3.98E-06	1.68E-05	2.88E-06	0	0	1.83E-05	0	0.000117
Acidificazione	molc H+ e	0.16786	0	1.18E-05	1.31E-07	3.28E-05	0.020034	0.052465	0.029415	8.26E-06	1.55E-05	3.34E-06	0	0.06554	0	0	0.000335
Eutrofizzazione terrestre	molc N eq	0.745549	0	6.08E-05	6.64E-07	0.000169	0.089006	0.232169	0.130468	1.45E-05	6.05E-05	1.05E-05	0	0.292975	0	0	0.000616
Eutrofizzazione acque dolci	kg P eq	0.000548	0	6.19E-09	7.86E-11	1.72E-08	5.82E-05	0.000318	0.000154	9.9E-07	5.91E-07	9.35E-08	0	0	0	0	1.58E-05
Eutrofizzazione marina	kg N eq	0.01776	0	5.55E-06	6.06E-08	1.54E-05	0.001857	0.009049	0.004357	1.42E-06	2.07E-05	9.53E-07	0.000414	0.001997	0	0	4.22E-05
Ecotossicità acque dolci	CTUe	3.173034	0	0.000818	1.04E-05	0.002275	0.366018	1.600739	0.821336	0.014505	0.011343	0.003025	0	0	0	0	0.352964
Consumo di ris. minerali e fossili	kg Sb eq	2.7E-05	0	4.51E-10	5.73E-12	1.26E-09	2.95E-06	1.5E-05	7.86E-06	1E-07	2.6E-07	3.59E-08	0	0	0	0	7.53E-07

Etichetta	Unità	Totale	
Riscaldamento globale	kg CO2 eq	1.562	1
Assotigliamento strato ozono	kg CFC-11	0.102	1000000
Tossicità umana - Effetti non canc.	CTUh	5.13E-07	1
Tossicità umana - Effetti canc.	CTUh	4.02E-08	1
Formazione polveri sottili	kg PM2.5	4.107	1000
Formazione smog	kg NMVOC	7.625	1000
Acidificazione	molc H+ e	0.168	1
Eutrofizzazione terrestre	molc N eq	0.746	1
Eutrofizzazione acque dolci	kg P eq	0.548	1000
Eutrofizzazione marina	kg N eq	17.760	1000
Ecotossicità acque dolci	CTUe	3.173	1
Consumo di ris. minerali e fossili	g Sb eq	26.979	1000000

market for | APOS, U

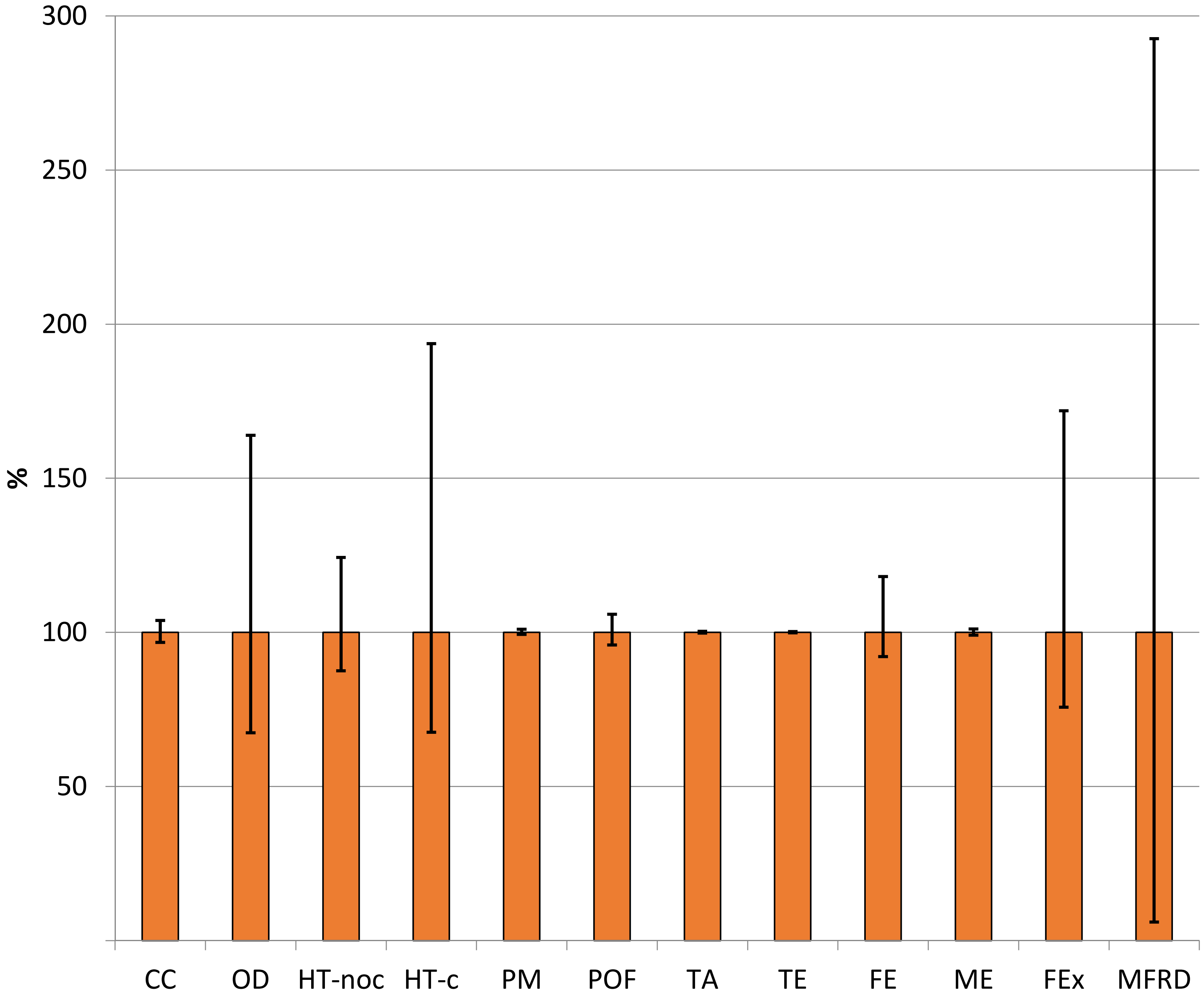
Esportato da SimaPro 8.5.2.0
Esportato il: 24/01/2020 a23:11:42
Analizzando 1 kg 'Organic eggs production {ITA}';
Metodo: ILCD 2011 Midpoint+ V1.10 / EC-JRC Global, equal weighting / Caratterizzazione
Unità usata %

Etichetta	**Transport, truck >20t, EUI**	**Transport, truck >20t, EL**	**Transport, truck >20t, EURO4**	**BIO Laying hens <17 wee**	**Mangime 2 Bio pg 17%**	**Mangime 1 Bio pg 18.5%**	**Tap water, at user {Euro**	**Erba medica per parchet**	**Sand {GLO}| market for**	**NO3- leaching - uova bio**	**NH3 emissions - uova bi**	**CH4 Manure manageme**	**N2O manure manageme**	**Electricity, medium volta**
Riscaldamento globale	0.1229	0.0016	0.3419	10.8418	48.2885	23.9903	0.1009	0.0993	0.0274	0	0	2.8988	9.5647	3.7217
Assotigliamento strato ozono	0.0039	4.9E-05	0.0107	11.152	54.248	27.8053	0.1163	0.2712	0.0596	0	0	0	0	6.3328
Tossicità umana - Effetti non canc.	0.0062	7.93E-05	0.0174	10.6937	58.1021	29.2657	0.1421	0.2677	0.0227	0	0	0	0	1.4823
Tossicità umana - Effetti canc.	0.0036	4.56E-05	0.01	10.8146	55.3692	27.7153	1.1037	0.45	0.0695	0	0	0	0	4.464
Formazione polveri sottili	0.0045	5.3E-05	0.0126	14.4358	32.001	17.7518	0.018	0.0297	0.0084	0	35.2459	0	0	0.4922
Formazione smog	0.1965	0.0022	0.5464	10.836	57.1515	29.1798	0.0522	0.221	0.0378	0	0	0.2399	0	1.5368
Acidificazione	0.007	7.82E-05	0.0196	11.935	31.255	17.5236	0.0049	0.0093	0.002	0	39.044	0	0	0.1995
Eutrofizzazione terrestre	0.0081	8.91E-05	0.0227	11.9383	31.1406	17.4995	0.0019	0.0081	0.0014	0	39.2965	0	0	0.0827
Eutrofizzazione acque dolci	0.0011	1.43E-05	0.0031	10.6226	58.0245	28.1592	0.1807	0.1079	0.017	0	0	0	0	2.8838
Eutrofizzazione marina	0.0312	0.0003	0.0869	10.4537	50.9541	24.5333	0.008	0.1163	0.0054	2.3313	11.242	0	0	0.2374
Ecotossicità acque dolci	0.0258	0.0003	0.0717	11.5353	50.4482	25.8849	0.4571	0.3575	0.0953	0	0	0	0	11.1239
Consumo di ris. minerali e fossili	0.0017	2.12E-05	0.0047	10.9403	55.6614	29.1329	0.3707	0.9648	0.1332	0	0	0	0	2.7903

Etichetta	**Trasporti**	**Altri Fattori Produttivi**	**Mangime 18,5% pg**	**Mangime 17% pg**	**Pollastre**	**Emissioni gestione pollina**
Riscaldamento globale	0.4664	3.9494	23.9903	48.2885	10.8418	12.4635
Assotigliamento strato ozono	0.0147	6.7799	27.8053	54.2481	11.1521	0.
Tossicità umana - Effetti non canc.	0.0237	1.9148	29.2657	58.1021	10.6937	0.
Tossicità umana - Effetti canc.	0.0136	6.0873	27.7153	55.3692	10.8146	0.
Formazione polveri sottili	0.0171	0.5484	17.7518	32.0011	14.4358	35.2459
Formazione smog	0.745	1.8478	29.1798	57.1515	10.836	0.2399
Acidificazione	0.0267	0.2156	17.5236	31.255	11.935	39.0441
Eutrofizzazione terrestre	0.0309	0.0941	17.4995	31.1406	11.9383	39.2965
Eutrofizzazione acque dolci	0.0043	3.1895	28.1592	58.0245	10.6226	0.
Eutrofizzazione marina	0.1185	0.3671	24.5333	50.9541	10.4537	13.5733
Ecotossicità acque dolci	0.0978	12.0338	25.8849	50.4482	11.5353	0.
Consumo di ris. minerali e fossili	0.0063	4.259	29.1329	55.6614	10.9403	0.

								Contributo dei due mangimi sul totale del feed	
	Feed production	**Pullets production**	**Manure-related emissions**	**Electricity**	**Other Inputs**			**Mangime 18,5% pg**	**Mangime 17% pg**
CC	72.2788	10.8418	12.4635	3.7217	0.6941			33	67
OD	82.0534	11.1521	0.	6.3328	0.4618			34	66
HTnoc	87.3678	10.6937	0.	1.4823	0.4562			33	67
HTc	83.0845	10.8146	0.	4.464	1.6368			33	67
PM	49.7529	14.4358	35.2459	0.4922	0.0733			36	64
POF	86.3312	10.836	0.2399	1.5368	1.0561			34	66
TA	48.7786	11.935	39.0441	0.1995	0.0428			36	64
TE	48.6401	11.9383	39.2965	0.0827	0.0424			36	64
FE	86.1836	10.6226	0.	2.8838	0.3100			33	67
ME	75.4875	10.4537	13.5733	0.2374	0.2481			32	68
FEx	76.3331	11.5353	0.	11.1239	1.0078			34	66
MFRD	84.7943	10.9403	0.	2.7903	1.4751			34	66

ge {IT}| market for | APOS, U


300
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TA
TE
FE
ME
FEx
MFRD

SimaPro 8.5.2.0 Valutazion Data: ######## Periodo: 19:49
Progetto _Pilmo

Titolo: Analisi di incertezza di 1 kg 'Organic eggs production {ITA}', metodo: ILCD 2011 Midpoint+ V1.10 / EC-JRC Global, equal weighting, interva
Indicatore: Caratterizzazione

Categoria d'impatto	Unità	Mean	Median	Standard deviation	CV	2.5%	97.5%	SEM	
CC	kg CO2 eq	1.562617	1.561087	0.028441	1.820093	1.510303	1.622086	0.000402	
OD	kg CFC-11 e	1.01E-07	9.71E-08	2.44E-08	24.18038	6.55E-08	1.59E-07	3.46E-10	
HT-noc	CTUh	5.14E-07	5.05E-07	1.12E-07	21.82982	4.42E-07	6.28E-07	1.59E-09	
HT-c	CTUh	4.03E-08	3.73E-08	1.74E-08	43.15835	2.52E-08	7.22E-08	2.46E-10	
PM	kg PM2.5 e	0.004108	0.004106	1.82E-05	0.443124	0.004079	0.004148	2.57E-07	
POF	kg NMVOC	0.007632	0.007612	0.000201	2.628044	0.007303	0.008062	2.84E-06	
TA	molc H+ eq	0.167881	0.167851	0.000272	0.162208	0.167469	0.168468	3.85E-06	0.0335
TE	molc N eq	0.745615	0.745558	0.00081	0.108678	0.744202	0.747346	1.15E-05	
FE	kg P eq	0.000549	0.000541	4.1E-05	7.477261	0.000498	0.000638	5.8E-07	
ME	kg N eq	0.017763	0.017757	9.36E-05	0.52688	0.017598	0.017956	1.32E-06	
FEx	CTUe	3.171724	2.994263	0.807895	25.47178	2.266677	5.147021	0.011425	
MFRD	kg Sb eq	2.73E-05	2.49E-05	1.92E-05	70.32954	-3.7E-06	7.3E-05	2.71E-07	

Intervallo di Confidenza: 95

llo di confidenza: 95 %

Esportato da SimaPro 8.5.2.0
Esportato il: 26/04/2020 a19:48:48
Analisi di incertezza di 1 kg 'Organic eggs production {ITA}',metodo: ILCD 2011 Midpoint+ V1.10 / EC-JRC Global, equal weightin

Unità usata %

Etichetta	**Organic eggs production**	**Basso**	**Alto**
CC	100	3.253	3.9074
OD	100	32.558	63.9114
HT-noc	100	12.4889	24.3194
HT-c	100	32.402	93.6918
PM	100	0.6629	1.0304
POF	100	4.0641	5.9017
TA	100	0.2276	0.3674
TE	100	0.182	0.2398
FE	100	7.8803	18.0898
ME	100	0.8985	1.1183
FEx	100	24.2993	71.896
MFRD	100	94.	192.6774

, intervallo di confidenza: 95 %

- Organic egg production was evaluated using the Life Cycle Assessment approach
- The environmental impact for 1 kg of organic eggs was evaluated
- A “from cradle to farm gate” approach was considered
- Feed supply is the main hotspot (from 49% to 87%) for all the impact categories
- For Climate Change (1.56 kgCO_2 eq/kg) the impact is lower than for conventional eggs

Declaration of interests

☒ The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

☐The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

On behalf of all the Authors