Measuring circularity: an application of modified Material Circularity Indicator to agricultural systems

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Abstract

The transition from a linear to a circular economy is a research trend topic, as well as the possibility to measure the degree of circularity of products and systems. In a linear economy, raw materials are taken from nature and transformed into final products, which are subsequently used and become waste. On the contrary, a circular economy is an economic model that is restorative by intent and design. To measure the degree of circularity is fundamental for understanding processes and improving them. Moreover, this kind of measure could be useful for driving policies on the topic and achieving a higher level of sustainability. Until now, only few studies have been focusing on how to effectively measure the circularity level of a product, a supply chain, or a service. Moreover, in the circular economy paradigm, there are two types of cycles: the technical and biological ones. Biological cycles are mainly connected to the agricultural sector, and for this kind of cycle, the lack of measurement is even bigger. However, some agricultural productions, such as intensive meat production processes, have basically a linear structure. Intensive broiler production, for instance, uses a quite high rate of inputs, which is not entirely converted into edible products but instead results in a percentage of wasteful outputs. The aim of this work is to propose a modification of one of the few available tools for measuring the circularity, the Material Circularity Indicator (MCI), for adapting it to biological cycles. The modified MCI was applied to the poultry sector, integrating the results with the Life Cycle Assessment methodology.

Keywords: Circular economy, Broiler production system, Indicators, Modified Material Circularity Indicator, Life Cycle Assessment

Introduction

The transition from a linear to a circular economy (CE) is currently considered a trend topic, both by the academic community and governments, in particular in Europe. The European Union has launched its Circular Economy Action Plan in 2016 and adopted a new set of measures in January 2018. The great interest about CE is due to its ability to operationalize the concept of sustainable development for business activities (Sauvé et al. 2016; Kirchherr et al. 2017). Moreover, Europe has the highest net import of

resources for person in the world (Di Maio et al. 2017); therefore, going towards circularity means being less dependent on raw materials.

In a linear economy, raw materials are taken from nature and transformed into final products, which are subsequently used and become waste. In a world that deals with a finite amount of resources, a linear economy cannot be considered a long-run strategy. On the contrary, a circular economy is a model that is restorative by intent and design (EM Foundation 2015). The features of CE include low pollutant emission, low energy consumption, waste elimination, and increased efficiency (Murray et al. 2017).

According to the circular economy approach, there are two types of cycles: technical and biological ones. In the former, materials, products, and components remain in the market, as long as possible, through repair, reuse, re-manufacture, and recycling. In the biological cycles, non-toxic materials can be directly restored into the biosphere. The issue of restoration is crucial in such approach, as it allows CE to be not only preventative but also active to repair previous damage (Murray et al. 2017).

The development of circular metrics is essential for business and public stakeholders, because "only what gets measured gets management" (Linder et al. 2017). Usually, CE indicators are grouped into micro-level (e.g., organizations, products, consumers), meso-level (e.g., eco-industrial parks), and macro-level indicators (e.g., city, province, region, country) (Pauliuk 2018). While indicators for environmental performance or resource efficiency are numerous (Pauliuk 2018), few studies focused on how to effectively measure the circularity level of a product, a supply chain, or a service (Elia et al. 2017; Linder et al. 2017). This lack is particularly evident at the micro-level, with negative effects both for producers who want to provide circular products and services and for consumers who want to know how to compare and chose products (Kristensen and Mosgaard 2020).

There is no single, commonly accepted approach for measuring the circular economy at the micro-level (Kristensen and Mosgaard 2020). Some attempts have been done in the years. However, the analysis of the literature shows that most of the considered indicators focused on metrics based on a single aspect, usually on inputs and outputs in the production systems, or took into consideration just some of the aspects of circularity (Moraga et al. 2019). In their review, Kristensen and Mosgaard (2020) identified recycling, end-of-life management, and regeneration as trend topics for circularity indicators, while fewer works considered dismantling, extending of useful life, efficiency of resources, or reuse. Scheepens et al. (2016) proposed an LCA-based metric for products as an indicator for circularity; however, the proposed method deals with the reduction of externalities and not with measuring the degree of circularity. Genovese et al. (2017) used a lifecycle perspective for comparing supply chain performance in chemical and food sectors, integrating the circular economy within sustainable principles. Di Maio and Rem (2015) developed the Circular Economy Index (CEI), including also environmental and economic aspects, which focuses on the recycling process, excluding the recovery materials. Cayzer et al. (2017) designed an indicator for measuring the CE performance of industrial products. Approaches not based on mass units are also present. Franklin-Johnson et al. (2016) developed a performance indicator based on longevity, i.e., the amount of time that a resource is kept in use. Di Maio et al. (2017) expressed the degree of circularity in terms of value in chemical and food sectors, highlighting the difference between the resource efficiency of a process and of a

product within supply chains, in a lifecycle perspective. Zhijun and Nailing (2007) proposed a system of indicators for evaluating the degree of circularity in China and monitoring national policies to improve it.

In this scenario, one of the newest attempts made is the Material Circularity Indicator (*MCI*), proposed by the Ellen MacArthur Foundation (EM Foundation 2015. *MCI* provides indication on the "degree of circularity" of materials composing products. It has some similarities with Life Cycle Assessment (LCA), but it is more focused on the flow of materials; therefore, it can be considered as complementary to LCA. The methodology of *MCI* is designed for technical cycles and materials from non-renewable sources only.

The aim of this paper is to propose a modification of the *MCI*, for adapting it to biological cycles, specifically to zootechnical production.

The reasons for this choice lean on the fact that some agricultural productions can greatly affect the environment Notarnicola et al. 2017; in particular, meat production consumes the majority of the global agricultural land and almost half of the global croplands, causing also a competition between feed and food Mottet et al. 2017. However, there is no general consensus on how to address the reduction of animal-based food Van Zanten et al. 2019. Some studies proved the relevance for mankind to continue the animal rearing, but with the need of shifting under a circular paradigm Van Zanten et al. 2019. This is particularly important in the case of intensive rearing systems (i.e., poultry and pig production), which are built according to a linear "extract-produce-consume-discard" model. The livestock industry, and in particular that of poultry, is recognized as being responsible for the greatest share of ammonia emissions in the environment, and for this reason, various strategies have been considered recently to reduce emission levels in this sector Boggia et al. 2019.

EU data on poultry meat show a significant increase in its consumption (EEA 2018. In emerging economies, especially in China and India, the demand for food is rapidly increasing and the composition of the diet is shifting in the direction of a greater consumption of proteins of animal origin Mariani and Viganò 2013. Therefore, we suggest that a circular economy in agriculture could mean to catch up the production of goods using the minimal amount of external inputs, closing the nutrient loops and reducing the negative outputs (i.e., reducing waste and emissions). The goal of the work is to present a specific indicator for comparing circularity among zootechnical products, with a special emphasis on poultry production at the farm level.

Materials and methods
Material Circularity Indicator (MCI)
MCI of a product measures how much the linear flow has been minimized and the restorative flow maximized for its components, and, at the same time, how long and intensively. It is based on four principles guides (EM Foundation 2015: (i) using feedstock from reused or recycled sources, (ii) reusing components or recycling materials after the use, (iii) keeping the products longer, and (iv) making more intensive use of products. Points i and ii are linked to the restorative part of the production; points iii and iv are connected to the linear one. Secondary products are not considered.

In comparison to other indicators, *MCI* is one of the few that includes retention in its metric, as it considers how much an element is used in the process in terms of intensity and duration. As Parchomenko et al. (2019) highlighted, despite this was a core principle in CE, very few CE metrics include it.

MCI is constructed by means of several steps, as it is shown in Fig. 1 and described in the following. The first step is the computation of the virgin feedstock (V), followed by the calculation of the unrecoverable waste (W_0) and of the utility conversion factor X. Calculating the Linear Flow Index is the last step before the computation of MCI.

Virgin feedstock is the virgin raw material used in the production and it is calculated as follows:

$$V = M(1 - F_R - F_U) \tag{1}$$

where M is the mass of the finished product and F_R is the recycled fraction of the feedstock while F_U is the reused one. Also, the unrecoverable waste is calculated as a residual part, and it is given by:

$$W_0 = M(1 - C_R - C_U) \tag{2}$$

where C_R is the fraction of the product collected for recycling, which will produce the recycled waste (W_C) and depends on a certain efficiency rate (E_C); C_U is the fraction of the product collected for reusing.

Another component needed for *MCI* calculation is the utility X, which is related to the length and intensity of the use. The length component (L/L_{av}) accounts for any change (both positive and negative) in the waste stream, which makes the lifetime (L) of the product longer or shorter than the industry average(L_{av}). The intensity of the use (U/U_{av}) is a measure of how much a product is used to its full capacity, putting in relation the average number of functional units achieved usually for industry product use (U_{av}) and the actual one use (U). The two components are combined as follows:
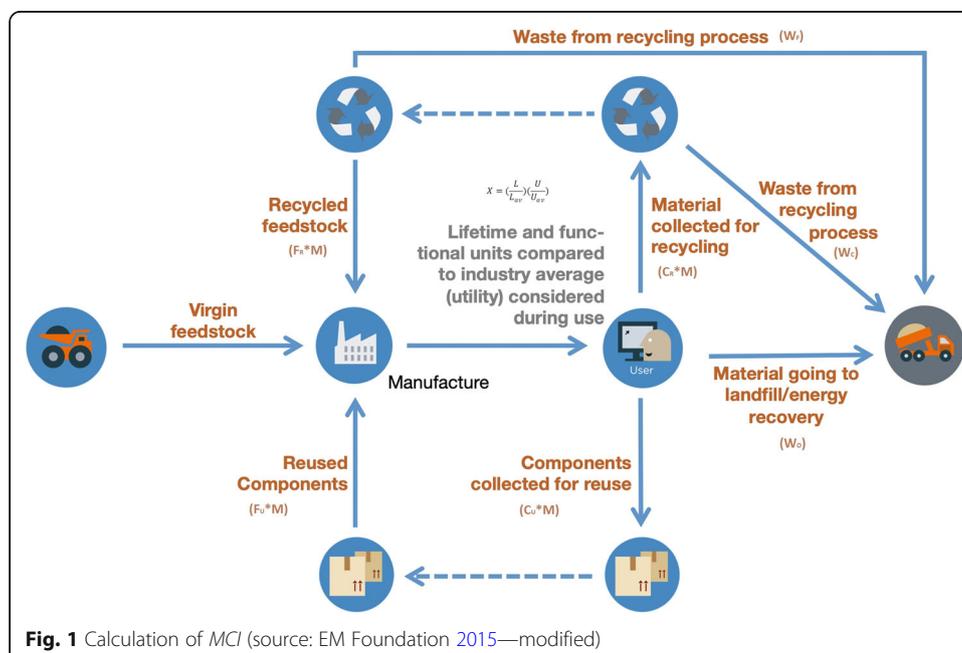

Fig. 1 Calculation of *MCI* (source: EM Foundation 2015—modified)

$$X = \left(\frac{L}{L}\right)\left(\frac{U}{U_{av}}\right) \tag{3}$$

Figure 1 does not report the Linear Flow Index (LFI), which represents the proportion of material flowing in a linear chain. However, it can be calculated based on WC, which is the amount of waste generated by the recycling phase of the product, and WF, which is the amount of waste generated for producing recycled feedstock. It represents the part of the production that cannot circulate. When the recycling process is 100% efficient (easiest scenario), both at upstream and downstream levels, the LFI can be calculated using Eq. 4

$$LFI = \frac{V + W_0}{2M} \tag{4}$$

Finally, the *MCI* can be defined by considering the *LFI* and the factor *F(X)*, using the following equation:

$$MCI_P^* = 1 - LFI \cdot F(X) \tag{5}$$

MCI assigns a score between 0 and 1 to the product analyzed, assessing how restorative or linear are the flows of the materials for the product itself. For products highly linear (LFI = 1) and with a utility worse than the average, *MCI* could be negative. So, the definition is derived by:

$$MCI_P = max(0, MCI^*) \tag{6}$$

Limitations and missing points

As noted by Figge et al. (2018), most of the circularity metrics aim to capture the circularity of resource flows, while fail to simultaneously consider the length of time for which a resource is in use. However, the circular economy is about to create value through material retention; therefore, we cannot avoid considering duration Franklin-Johnson et al. 2016. According to Lonca et al. (2018), *MCI* is the only available circular metric that attempts to take product durability into account, thanks to the calculation of the Utility Flow Index. However, due to the complexity of the overall metric, only a part of the utility factor would be used (EM Foundation 2015; Figge et al. 2018). Moreover, some limitations are directly connected to the measurement of each component (Linear Flow Index and Utility Flow Index) and it could be difficult to accommodate the variety of reuse and recovery rates for each resource (EM Foundation 2015; Linder et al. 2017; Figge et al. 2018).

Additionally, *MCI* focuses only on the technical cycles and especially on non-renewable resources. Therefore, it covers just partially the circularity concept (Åkerman 2016; Lonca et al. 2018) and excludes all the biological-based production with a high impact on the environment, as the intensive livestock (Gerber et al. 2005). Directive 2010/75/EU included intensive poultry (with more than 40,000 places) and pig systems (with more than 2000 places for pigs over 30 kg and 750 places for sows) among the industrial activities under the integrated pollution prevention and control framework, because of their impact in terms of emissions. However, although intensive livestock productions are considered industrial activities and their impact is proved, it is not

possible to apply directly the *MCI* to them. Thus, the development of a new index for biological cycles and specifically tailored for zootechnical products is required.

Modified MCI

The modification of the *MCI* presented in this paper can be considered a first attempt for the creation of an index devoted to biological cycles, including their main characteristics and peculiarities. Figure 2 reports the modified *MCI*, adapted for being closer to a biological scenario, an animal-based production in particular. In such a scenario, the virgin feed is used for rearing animals and obtaining the final product "meat" for consumers. Remains partially go to energy recovery producing residual waste to be treated (represented by the way-out arrow on the right side of Fig. 2) and gas released into the biosphere. Manure that is produced can be used in other processes or in the same. However, in the proposed methodology, the focus is on the single product; therefore, the degree of circularity is assessed within it. Crossed circularity along the supply chain or generation of value through the cascade cycles have not been considered.

According to the characteristics of biological cycles, in particular within poultry animal production systems (i.e., where feeding and growing have to be considered), some simplifications have been applied. The biological product is not built by single components as a technical one. In the standard *MCI*, the focus is on the assembly of the materials (virgin, recycled, or reused) in a final product: this is not possible in a biological cycle where transformation of the materials happens. In a zootechnical system, the mass V of virgin raw material is related to the animals and their feed. The capacity to transform feed into meat has to be considered. Therefore, we modified the (1) as follows:

$$V = \frac{Mf}{FCR} + Ma \qquad (7)$$

FCR represents the feed conversion rate, which is the ratio between the input (feed) and the output (meat) involved in a production. *FCR* is more used in poultry and pig production, while for cattle the feed efficiency is usually used, which is calculated as the output on the input (Cottle and Pitchford 2014). M_a and M_f represent the initial mass of the animal (M_a) and the feed mass (M_f). In this way, V is expressed in the same way, as animal mass. The ratio between M_f and *FCR* represents the final produced mass (M).

Fig. 2 Modified MCI, a scheme (source: our elaboration)
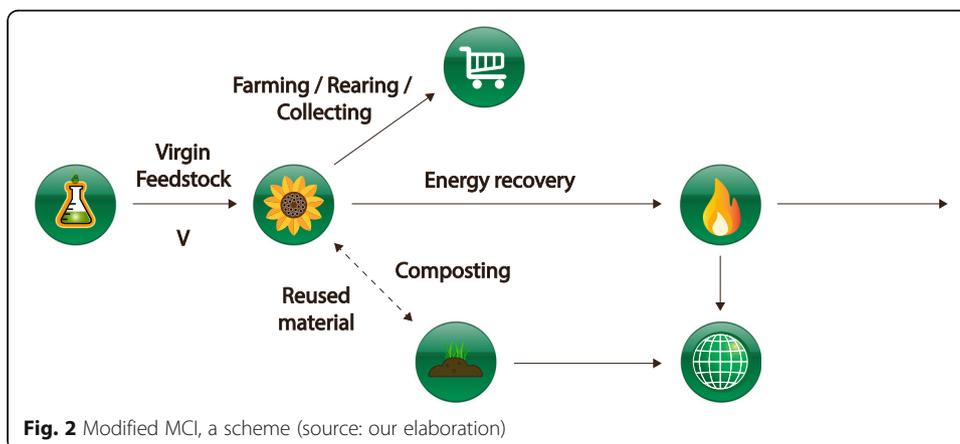
The mass of unrecoverable waste (W_0) attributed to the product is calculated by sub-tracting the fractions used for composting (reused materials) or the biogas recovery (recycled materials) from the total waste (W). Differently from an industrial product, where the recycling and reuse processes are calculated on the mass of the product, for cycles involving animals, manure production has to be considered. Equation (2) for the rearing system has been changed as follows:

$$W_0 = W(1 - C_R - C_U) + M_A(1 - C_{RA} - C_{UA}) \tag{8}$$

where W is calculated as the quota (α) of the mass (M) that is discharged (W = M · a); M_A is the mass of the manure and C_{RA} and C_{UA} are the fractions of manure collected for recycling and reusing. As suggested by EM Foundation (2012), the production of biogas has to be considered as a recycling process; the use of manure for composting is instead a reusing, since it enters as input, after a modification, in a new process. Be-cause the focus of the modified *MCI* is the production of meat at the farm level, we did not consider the product after it enters the human food chain.

Another simplification has to be done for the utility (X), which is related to the length and intensity of the use of industrial products in the technical cycles (see Eq. (5)). For biological cycles, we considered the utility conversion factor (X_C), calculated as the complementary of the mortality rate. Mortality rate expresses the number of dead ani-mals at the end of each cycle, divided by their initial number and multiplied by 100. The complementary of mortality rate represents the percentage of animals which stay for the whole cycle. Equations from (4) to (6) do not need any other modifications, ex-cept for the substitution of X with X_C. The modified *MCI* ranges between 0 and 1, as the *MCI*. As for the original one, highly linear processes or processes with a very low utility can show negative value but, in this case, *MCI* should be round to 0.

Case study: the poultry industry

Poultry industrial production can generate not only local disturbances (e.g., odor, flies, and rodents), and landscape degradation (Gerber et al. 2005), but also a significant amount of waste (Seidavi et al. 2019). Poor manure management may cause also pollu-tion of soil and water, with the presence of nutrients, pathogens, and heavy metals where manure is stored. Environmental concerns are related to the geographical con-centration of production units and to the complete decoupling of crops from poultry production.

However, poultry performs better from an environmental perspective compared to other livestock species. A substantial comparative advantage of poultry over other ani-mal sectors relates to efficiency in feed conversion. Poultry's feed conversion ratio (called "feed index") represents a major contribution not only to the profitability of the industry in terms of reduced feed inputs, but also in terms of waste reduction (Gerber et al. 2007). Another comparative advantage lies in the low water content and high nu-trient content of poultry manure. Manure is often handled with more care than manure from other species—especially pigs—as its recycling is generally economically profitable (Gerber et al. 2007). Also, the waste resulted from poultry processing steps can be recycled for raw materials or converted into new products of higher value. All these as-pects are important from economic and environmental perspectives (Alidadi et al.

2017) and suggest the broiler system may be a feasible case study for a first application of the modified MCI.

Intensive broiler farming is typically characterized by high stocking densities, fast growth rates leading to a young slaughtering age, very large holdings, and indoor rearing. A typical broiler breeding cycle involves the following phases: cleaning and disinfection of animal housing, bird arrival, growth management, loading, and transportation of birds at the end of the cycle. Animal rearing follows the indication of European Directive 2007/43/EC, specifying the guidelines for the protection of chickens reared for meat production and providing minimal standards required. Breeding takes place in a controlled environment both in terms of temperature and humidity. The animals have free access to water and commercial pelleted diets, formulated to meet nutritional requirements for all animal categories. The broiler chicks are grown according to appropriate market standards of age and weight. In particular, broilers are slaughtered at 32 days (1.6 kg—light broilers), at 40 days (2.5 kg—medium broilers), and at 53 days (3.8 kg—roasters, i.e. heavy broilers). The carcasses of birds that die on the farm require disposal; faster growing breeds tend to have higher weekly mortality rates.

The case study considered a breeding of 6.4 cycles per year, with a density of 12.69 birds per m^2. The cycle length was of 57 days. The feed index of the poultry is equal to 1.9 and a final live weight of 2.6 kg was considered. The data used were based on Castellini et al. (2012) for a comparison and integration with Life Cycle Assessment (LCA), as suggested for the *MCI* (EM Foundation 2015, and they are representative of the standard central Italy rearing. Data on the production and management of waste, necessary for the calculation of the modified *MCI*, come from field data in the same area of the study.

Results

Calculation of *MCI* starts from the assessment of the inputs involved and their transformation in virgin material (*V*). Table 1 reports the reference data for the calculation of *V* according to (7). The *FCR* for intensive broilers is 1.9.

Using the data in Table 1, we can calculate *V* (in tonnes):

$$V = \frac{Mf}{FCR} + Ma = \frac{31.62}{1.9} + 0.27 = 16.91$$

For calculating the unrecoverable waste, we first estimated the total amount of discharge (*W*) as equal to the 7% (*a*) of the final produced mass (*M*). Then, we considered the fraction of them collected for recycling (C_R) and the one collected for reusing (C_U). Production discharges are not used in the composting process; therefore, C_U is equal to 0. The fraction used for biogas is also very little: C_R is equal to 0.25 for discards. In relation to manure, it is collected both for biogas ($C_{RA}=0.5$) and for composting ($C_{UA}=0.5$); therefore, it is not part of the unrecoverable waste. Equation (8) gives an amount of unrecoverable waste equal to 0.87 t.

Table 1 Materials and related mass

Input	Material	Mass (t)
Input 1	Chicks	0.27
Input 2	Feed	31.62

Subsequently, we calculated the *LFI*, following Eq. (4):

$$LFI = \frac{V + W_0}{2M} = \frac{16.91 + 0.87}{2 \times 16.64} = 0.53$$

The last input needed is the $F(X)$, which is complementary to the mortality rate (expressed on a 0/1 scale). According to Castellini et al. (2012), the mortality rate is equal to 4%; therefore

$$F(X_C) = (1 - 0.04) = 0.96$$

We can now calculate the modified MCI, following Eq. (5):

$$MCI = 1 - LFI \times F(X_c) = 0.4812$$

Discussion

The results of our case study show a modified *MCI* value of 0.4897. As the modified *MCI* ranges between 0 and 1, values lower than 0.5 could be considered more linear than circular. The data itself confirm the assumption connected to the application of *MCI* to the broiler system: poultry meat product is comparable to industrial products. It has to be noted as this result was obtained in a quite "optimal" situation, where manure is completely reused and recycled within the farm; therefore, it had no impact on the modified *MCI*. As in the modified index at the moment we did not consider crossed circularity, reuse of the manure externally would worsen the value. The result seems also to support what some authors stated: the food system is still far to be completely circular, due to its openness and complexity, which generate material and nutrient losses, partly impossible to recover (Van Zanten et al. 2019).

To have an idea of how much the obtained value can be considered good or bad, it is possible to try a comparison with other examples reporting a *MCI* standard value. EM Foundation (2015) reported different values of *MCI* for industrial products, ranging between 0.10 and 0.60. However, due to the problem of data sensitivity, the report did not divulge the calculation behind results for many of these products, causing a direct comparison difficult. Therefore, we can just affirm that the obtained value is in line with general industrial items whose data are available. In our case, the linearity of the process (*LFI*) is the crucial factor for the global results, while in the industrial products proposed by EM foundation, there is also a great impact of the utility factor (*X*), which severely affects the final result.

Comparing our results with literature about CE and agriculture, we found some convergence. In their work, Van Hal et al. (2019) found that extensive livestock systems are more circular than intensive ones, due to their ability to valorize feed from upcycling processes. Although the approach used in the work is quite different, the results go in the same direction: intensive rearing systems do not improve circularity.

Although the *MCI* is a good indicator for understanding the degree of circularity of a product, it is not enough to understand the whole context. As suggested by EM Foundation (2015), complementary indicators are required. They are additional indicators that can be used alongside the *MCI* to offer further business management insight into the product. Moreover, it is assumed that the increase of circularity reduces the use of resources. Thus, another complementary analysis suggested is the Life Cycle

Assessment (LCA) (ISO, 2006). The application of the LCA allows considering other impacts not included in the *MCI*, as energy consumption in the process or the water used for cleaning operations, which are not taken into account also by the modified *MCI*. We performed an LCA study, based on the same *MCI* database, but we did not integrate *MCI* with any indicators for business or risk model, as the case study is not based on a specific firm. Moreover, since the LCA has been carried out for integrating the analysis based on modified *MCI*, methodological details are not reported here.

Figure 3, reporting the LCA results, shows the most part of the impacts of poultry production is devoted to the feed, which involves in particular the impact categories respiratory inorganics, land use, and fossil fuels. The rearing phase is the second one for importance and impacts, in particular for the categories: respiratory inorganics, acidification, and climate change.

Putting the information coming from the modified *MCI* and LCA together, the intensive broiler production confirms to be a production that is mainly linear, with high consumption of resources. The LCA analysis showed the impact on land consumption and fossil fuels, which are among the scarcer resources in the world. Feed production is a key aspect in both the analysis. The high LFI, which derives from the feed process mainly, has a great impact on the results of the MCI. On the other side, the LCA showed the great impact of the feed in almost all the impact categories. Different rearing systems may change the results, but in both the approaches, modified *MCI* and LCA, the feed index greatly affects the results. This means that in case of organic production we may have even worst results, due to the longer cycles and the lower efficiency in meat production. However, this result can help in understanding how to improve the circularity of the system. Shifting to a more circular rearing paradigm means limiting the use of food as feed and increasing the use of by-products from the food system and grass resources. This could positively affect the level of circularity, although the modified *MCI* cannot completely capture it, in this current version. Differently, LCA can capture partially the aspect of by-product management, as the by-products from the food system can be computed as avoided impact. The use of grass resources, in particular in the case of marginal areas, is not captured and valorized neither by the *MCI* nor by the LCA approach. Another key aspect affecting the circularity

Fig. 3 Normalized results of intensive poultry system (1 tonne of living weight)
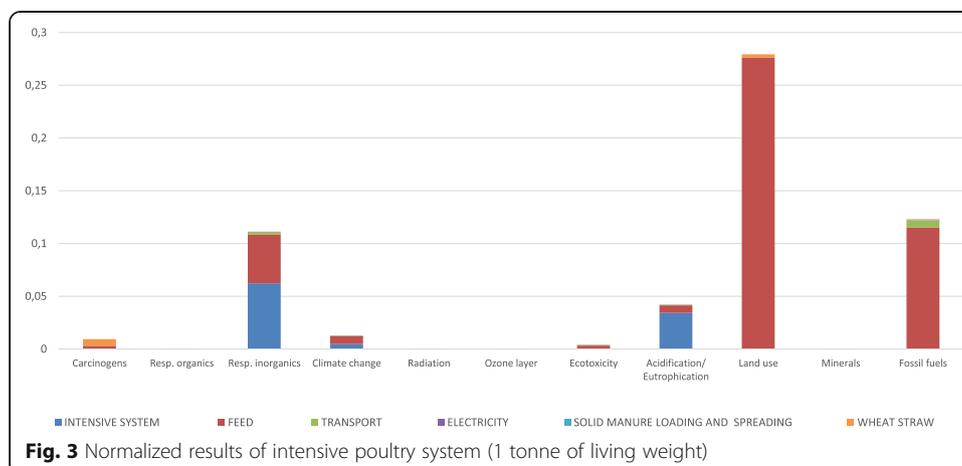
and influencing the *MCI* value is the use of manure. In our application, all the manure is reused or recycled. If we suppose to not use just a quarter of the total manure produced, the LFI would increase from 0.53 to 1.37, which means totally linear production. Therefore, the use of manure within the farm is considered by the modified *MCI*, although the manure contribution to close the loop of the nutrient is not fully valorized, because aspects like fertility or structure of soil are not taken into account, in this approach.

Moreover, integrating the results with other indicators based on scarcity of resources and toxicity or risk of the production could be useful for a global evaluation of the system. Also, a comparative valuation between different rearing systems could be useful, applying multicriteria analysis, as it has been done using other types of indicators (Rocchi et al. 2019).

Conclusions

The strategic importance of agriculture for mankind and its intense use of resources, associated with the population growth path and climate change challenge, require to re-think agriculture itself, and animal-based food production in particular. A circular economy may lead the sector to a better strategic management than today.

In order to move the food system towards a more circular animal farming system, we need circular economy metrics, suitable for the biological cycles. Such kind of metrics is not yet developed; the method proposed in this article, which we called "modified *MCI*," tries to fill the gap in this direction, although some weak points are present. The modified *MCI* applied to livestock production could be a useful indicator for giving a first evaluation of the degree of circularity of rearing systems, and comparing different types of rearing species.

Some aspects need a further development. The approach proposed here does not consider the possibility of crossed circularity, as circularity is considered just within the single rearing system. This choice was connected to the type of indicators at the moment available (micro-level indicators). However, for agricultural systems, meso-level could be an interesting focus.

In the modified *MCI*, manure management generated a great advantage, due to its re-using or recycling. However, its contribution in closing the loop of the nutrient was not calculated. As closing the loop of nutrient is one of the key points of CE in agricultural systems, this point should be improved in the future. Another aspect to be improved should be the type of feed used by the animals. The modified *MCI* included the global amount of feed expressed as quantity, without any consideration about the origin of it. The use of by-products of the food system in the diet, in particular the no-edible ones, is not valorized in any way in the *MCI*, although this would help in the global circularity of the system.

The complexity of the agricultural system requires a complex set of metrics, for better understanding the right direction for making production of food more circular. We live in a planet with finite resources, including some strategic ones for the food production: land, water, and nutrient. Complex assessments at micro, meso, and macro levels will not lead to a solution, but they may guide us in re-thinking our way to approach to food production.

Abbreviations
CE: Circular economy; CEI: Circular Economy Index; C_R: Fraction of the product collected for recycling; C_U: Fraction of the product collected for reusing; C_{RA}: Fractions of manure collected for recycling; C_{UA}: Fractions of manure collected for reusing; E_C: Efficiency rate of recycling; F_R: Recycled fraction of the feedstock; F_U: Reused fraction of the feedstock; FCR: Feed conversion rate; L/L_{av}: Length component; L: Lifetime of the product; L_{av}: Industry average lifetime; LCA: Life Cycle Assessment; LFI: Linear Flow Index; M: Final produced mass; M_a: initial mass; M_A: Manure mass; MCI: Material Circularity Indicator; U/U_{av}: Intensity of the use; U_{av}: Industry functional units; U: Functional units; V: Virgin feedstock; W: Waste; W_0: Unrecoverable waste; W_C: Recycled waste; W_F: Reused waste; X: Utility conversion factor MCI; X_C: Utility conversion factor modified MCI

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