Assessing the Sustainability of the Italian Beef Supply Chain

Abstract

The objective of this paper is to develop an effective quantitative method to assess the sustainability of Italian beef cattle rearing while avoiding the complexities connected to greenhouse gases estimation. A methodology based on Principal Component Analysis is utilized to calculate a set of environmental pressure indices using data taken from the FADN database. Results are presented for the single stages of production and methodologies utilized, highlighting significant differences among them that are also confirmed by the available literature in the field. Finally, a ranking of different supply chains casts some doubts on the sustainability of the typical Italian production scheme.

Keywords: Sustainability indicator; Environmental pressure; beef supply chain; Sustainable livestock rearing; Principal Component Analysis

1 Introduction

1.1 The Italian beef cattle supply chain

What makes the Italian beef supply chain particularly interesting to study is the uniqueness of its structure with respect to other European countries. The first stage commonly identified as the cow-calf phase is the one that produces calves and raises them from the birth to nearly 350 kg of weight. The second stage is represented by the fattening of the animals. More in detail farms can specialize in the fattening of suckling calves coming mainly from Italian dairy farms (97%) and appreciated by consumers for the tender white meat (13% of beef production in 2013), or in the fattening of steers that represents the core of the beef supply chain accounting nearly for the 70% of the beef meat supply (Rama et al., 2015; Macrì et al., 2015; ISMEA, 2016). If in other European countries it is more likely to find firms integrating all the stages of the beef supply chain inside the farm, the opposite is true for the Italian context in which farms tend to focus on a single step only. This is also connected to the strong dependency of Italian farms on animals for fattening imported from other countries, mainly France. According to ISMEA (2016), in year 2015 about 47% of Italian beef fattening farms bred weanlings imported from other countries, while the 53% relied on cattle raised in Italy.

Independently from the stage of production performed, we can also identify two different methods of production. Absolutely predominant in the Italian production system are the intensive farms located mainly in the Po valley. The size of these farms changes from region to region, ranging from a mean farm size around 1000 heads in Veneto to a mean of 400 heads in Piedmont. In general terms, it is noticeable a high-density of Livestock Units (LU) over the Utilized Agricultural Area (UAA), commonly called stocking rate. This method of production in the Italian context is usually associated to the second stage of production: these farms specialize in fattening young weanlings bought in Italy or imported (mainly from France), reared in indoor feedlots, and fed with ensiled maize and concentrate to promote maximum daily gain. The second methodology that is possible to identify is the extensive farming prevalent in Piedmont, south-central Apennine, and islands. These farms usually rear Italian beef breeds (Maremmana, Chianina, Marchigiana, …) and are often based on a cow-calf system where the animals associate feed meals to pasture. During the fattening period, the animals are housed in pens on permanent bedding or tied in small closed barns. The mean size of these farms is often very small, around 20-25 heads per farm, for this reason it is common to find a low stocking rate. (Cozzi, 2010; Rama et al., 2015; Macrì et al., 2015; ISMEA, 2016).

1.2 Environmental sustainability of the Italian beef cattle supply chain

Particularly significant when dealing with bovine rearing, is its contribution to greenhouse gas (GHG) emissions. The principal gases involved in beef production are methane (CH_4), carbon dioxide (CO_2), and nitrous oxide (N_2O). Considering cattle, a significant share of emissions comes from enteric CH_4, which is produced as a by-product of microbial fermentation during rumination. The amount of methane produced by each animal depends on several parameters, such as feed intake, nutrient composition, and genotype (Cederberg et al., 2013). Animal manure is also an important contributor for what concerns methane and nitrous oxide emissions. In particular, it depends on the way it is stored (solid, liquid) and managed (collection, storage, spreading). Manure contributes not only to the release of GHGs but also to eutrophication and acidification of water and soils due to its nitrogen content. Similar effects are provoked by the excessive use of chemical nitrogen fertilizers for the on-farm cultivation of feed crops (Cederberg et al., 2013; Steinfeld et al., 2006). Carbon dioxide emissions are generated mainly from fossil fuels used in the production process, feed production, and transformation and transport of the products. The carbon balance is also altered by the conversion of land into pasture or in feed crops (Steinfeld et al., 2006).

1.3 Measuring the environmental impact of beef cattle

The diversified nature of the agricultural sector, and its variety of production and management practices makes the assessment of its environmental impacts particularly complex and requires a comprehensive methodology. The life cycle assessment (LCA) has been widely used in the last decades to assess the contribution to global warming of a product based on the sum of its life-cycle GHG emissions, usually defined as the Carbon Footprint (CF). CF estimation takes into consideration the main greenhouse gases deriving from the agricultural activity: N_2O, CH_4, and $CO_{2,}$ expressing their estimates in “carbon dioxide equivalents” (CO2-eq.) (Cederberg, 2013; Coderoni, 2014). The LCA encloses the whole supply chain in the analysis, from the production of inputs at the manufacturers’ plants (e.g. feed, fertilizers, pesticides, seeds, purchased animals, …), to emissions occurring at farm level (e.g. enteric emissions of ruminants, waste management, fodder production, energy and water consumption, …), and to emissions related to the transformation and commercialization of the product. (Crosson, 2011; Cederberg, 2013). For what concerns livestock rearing, the typical system boundaries are the “cradle to farm gate”, given the fact that the farmer cannot influence operations downstream the chain, more related to consumption (Coderoni, 2014).

Among existing reviews of published papers on livestock GHG emissions, the one conducted by Crosson et al. in 2011 seems the one providing the greatest amount of detail on the matter. For the beef system, they reviewed 15 different whole farm modelling studies on GHG emissions conducted across the five continents. The studies analysed take in consideration several models for pasture, confinement, or feedlot systems using data collected on-farm or through national or regional statistics. What emerges from this literature review is a wide range in results, fluctuating between a minimum of 3,28 recorded by Stewart et al. (2009) in South Alberta, to a maximum of 37,5 in the cow-calf system studied by Phetteplace et al. (2001). Much of the variation in results reflects differences in modelling methodologies used, and in emission factors applied. However, these differences can also be partly explained by inherent differences among the production systems investigated.

Despite the differences in scales of the estimates, it is possible to notice that some variables seem to have a more relevant impact on GHG emissions. This is the case of: enteric emissions (more relevant for the cow-calf system given the presence of suckler cows and the restock of the herd); off-farm feed production; on farm crops (also connected to the use of nitrogen fertilizers); differences in waste management (permanent litter or slatted floors); energy and water consumption; dietary composition; intensity of production (also related to the stocking rate) and length of the fattening cycle.

This finding may be used to obtain a simplified measure of the environmental impact of beef production without incurring in the methodological and informational needs coming from the measurement of GHG emissions. For this purpose, the construction of multidimensional indicators might be very useful in order to communicate a set of information briefly and in a straight-forward way. An appropriate index would allow taking into consideration environmental impacts in an easier way for end users, in this context mainly for farm management and policy decisions. Otherwise, it is necessary to account for the drawbacks that descend from synthesizing information. The excessive simplification of the context's complexity and the appropriate aggregation method are issues that must be considered to obtain valid measures.

2 Data and Methodology

2.1 The dataset construction

The data used in this analysis are taken from the Italian section of the Farm Accountancy Data Network (FADN) database. The extraction of data has been filtered according to several parameters. First, we decided to focus on one year only, since the evaluation of the results in different years was not the scope of the research. Year 2014 was chosen, since it was the latest year available in the FADN database, and because there were not significant events that could have influenced fattening beef production. In order to provide a wider analysis, we decided to extract data referring to all the Italian regions. The first filter applied to our data was related to the Type of Farming. We decided to focus our analysis on farms specialized in the production of fattening beef (Bovine specializzate – orientamento allevamento e ingrasso). A further refining of the data allowed to consider only bovines as animal species, and only meat as production trait. The result was a dataset containing technical and economic characteristics of 294 firms specialized in fattening beef for meat production in year 2014. When data on characteristics of the cattle and fertilizers was added, the sample was reduced because of missing data in some observations. The final dataset includes 202 firms.

2.2 The methodology: Principal Component Analysis

The principal component analysis (PCA) is a multivariate statistical technique widely used in many scientific disciplines. The functioning of the procedure stands on the analysis of a data table representing observations described by a set of dependent variables, which are generally inter-correlated. The principal idea in PCA is that much of the data variation in the sample can be explained by a small number of uncorrelated variables called principal components. This is achieved through linear combinations of the original variables that allow to extract important information from the data table used to compute the principal components (Abdi and Williams, 2010). There are as many PCs as the number of variables included in the analysis, each one accounting for a smaller share of variance until the last component absorbs all the residual variance. The PCA can be a useful and objective tool in the process of constructing an index since it allows to select the variables that show greater variability within the available data, and to set the weights as a function of the explained variance (Soler and Soler, 2008).

In order to obtain a pressure index, the methodology proposed by Li et al. (2012) has been followed. Three environmental pressure indicators have been computed using three PCA correlation matrices of m variables x n farms. The selection of m variables for each pressure category has been defined based on the literature review on a set of 17 Lifecycle Assessments on the beef supply chain and is provided in Table 1. These variables represent potential sources of environmental pressure produced during beef rearing activity, and they can be grouped according to the macro category they belong to in order to build three environmental pressure indices. This would allow to create different indices for each category and be more precise in the attribution of environmental pressure to the different groups. The categories identified are External inputs, Animals, and Crops.

Given the fact that variables included tend to be expressed in different units of measure, data are then standardized to zero mean and unit variance. The output provides the eigenanalysis of the correlation matrix which includes values for: the eigenvalues, which represent the proportion of variance explained by each component, and the cumulative variance. Moreover, the analysis lists the eigenvectors, providing the value of each component for each variable included in the analysis, and the factor scores, which are the values of each principal component for each observation in the dataset. The number of components retained in the analysis is determined by the individual contribution of variance that should exceed 10%, and by the cumulative contribution that should be greater than 60%. Eigenvalues and eigenvectors are used to compute the loadings of the correlated indicators for each included variables, and the squared loadings. These loadings provide a value that represents the correlation coefficients between each variable and each component. Finally pressure values are computed for each firm in the dataset according to the formula:

$$PV_i = \frac{\sum_{k=1}^{j} F_{ki}\sqrt{\lambda_k}}{\sum_{k=1}^{j}\sqrt{\lambda_k}}\ , i = 1,2 \dots n$$

Where F_{ki} is the factor score of each observation i for the component k, and the λ_k represent the eigenvalue for the principal component k. In order to obtain a pressure index falling into the range 0-1, pressure values are then normalized.

The indices provided by the principal component analysis are encompassed between the range 0-1, where the former value indicates the lowest level of environmental pressure, while the opposite is true for the latter. In order to provide a better comprehension of the indices, a ranking of farms based on their performance with the environmental pressure indices has been created for each index. For the purpose of coherency between the index and the ranking, the farm with the highest level of environmental pressure has been given the rank of 1, while the farm with the lowest level of environmental pressure takes the value of 202 since it is the total number of farms in our sample.

3 Results and discussion

3.1 Indices results for the dataset

In general terms, we can see from Table 2 that compares the three indices for the total number of firms in the dataset, that the animal pressure index plays the major role in environmental pressure. The median[1] of its distribution is greater than 0,63, while the crops pressure index is much lower

---

[1] For the interpretation of the indices' results, the use of the median rather than the mean can give a more precise idea of the distribution of data. In facts, the median provides the value positioned in the middle of the distribution and is less influenced by outliers in the numbers.

with a median of 0,38. The external inputs pressure index provides, on the one hand, the lowest median value among the three indices (0,03), but on the other hand, it has the greatest variation in its observations compared to the other indices (Coefficient of variation: 1,87). According to these results we could infer that for the Italian beef supply chain the most relevant impact category is represented by the animal composition and density of the herd which assumes values closer to the maximum level of the environmental pressure index range. Crops and external inputs median values are concentrating in the lower boundary of the index range which suggests an overall positive result for these two figures. These results tend to be consistent with the literature in the field which attributes a greater share of emissions to the animal component in measuring GHG emissions for the beef supply chain. As an example we can quote the results provided by Berton et al. (2016), which assigned the 47% of total farm emissions to the herd management, or Coderoni et al. (2016) which estimated for the cow-calf phase that the 37% of emissions derived from enteric fermentation and the 19,5% to waste management. Concerning the other two indices, there is not a likewise evidence of the consistency of the results with the available literature since the majority of the studies does not provide the attribution of the impacts to each pressure category considered.

3.2 Indices results for different stages of the supply chain

In order to investigate the existence of significant differences in the indices results related to different stages of beef production, firms have been classified according to their specialization in the supply chain based on the number of heads for each animal category present on-farm. The categories identified are:

- Cow-calf production: farms specializing in the first stage, producing weanlings which are sold to other facilities for fattening. The presence of fattening beef in the sample of farms analyzed is below 17%.
- Intensive calves fattening: in order to select farms pertaining to this category, we selected those farms which have a presence of suckler cows lower than 10% and whose composition of animals for fattening shows a majority of calves with respect to fattening beef.
- Fattening beef production: we selected those farms which have less than 10% of suckler cows and prevalence of fattening beef with respect of calves.
- Integrated supply chain: these are farms with a high presence of suckler cows, which suggests the performance of the first stage of production (cow-calf phase), but also a high presence of animals for fattening, which implies also the performance of the second stage of beef production (fattening) inside the farm. For this reason, a fourth category has been defined for the farms in the sample which have an integrated supply chain.

The results of the indices for the different stages of beef production show interesting differences among them[2]. As expected, the animals pressure index shows the highest median value for farms specializing in the cow-calf system (0,65), ranking 59. On the contrary, the lowest median value pertains to the fattening beef category (0,61) that ranks 169. This result is coherent with existing literature which attributes higher emissions to the cow-calf phase with respect to the others. This difference is attributed mainly to the prevalence in those farms of mature suckler cows and other bovines, which emit greater shares of CH_4 and N_2O compared to animals in the fattening phase. This is also due to a greater life duration with respect to fattening animals. This finding is confirmed for example by Coderoni et al. (2016), Phetteplace et al. (2001), and Beauchemin et al. (2010). Just to provide some numbers taken from the literature review, Beauchemin et al. (2010) found that

---

[2] Here are presented, in Table 3 and Table 4, the results for the cow-calf system and the fattening beef that show the most relevant results. The indices' scores for the integrated supply chain and the intensive calves present similar figures to the cow-calf and fattening phase respectively, but with a smaller magnitude.

enteric CH_4 was the largest contributing source of GHG accounting for 63% of total emissions and, about 84% of enteric CH_4 was produced by the cow–calf herd, mainly from mature cows.

For what concerns the other two indices, opposite results are found. Farms specializing in the fattening show rankings above the half of the distribution for both the external inputs pressure and the crops pressure indices. The scores for these two indices for the cow-calf system give rankings below the half of the distribution, and consequently indicate a better performance of this farm category in these two dimensions. Also this finding is consistent with the literature review, particularly regarding the external inputs pressure index. As found by Phetteplace et al. (2001), CO_2 emissions (which are closely linked to the usage of fossil fuels for feeding, agricultural machinery, energy production, etc.) were greatest for the feedlot scenarios and the least for the cow-calf system.

3.3 Indices results for different methodology of beef production

A further classification might be useful to obtain a greater level of information over the environmental pressure imposed by different stages and methods of beef production. For this reason, a new variable has been constructed to obtain information over the intensity of production. This variable is the ratio between Livestock Units (LU) and Utilized Agricultural Area (UAA) for forage production (computed summing data on the utilized surface of the crop varieties considered in the indices). Each farm showing a LU/UAA for forage lower than 2 has been classified as Extensive, given the high availability of on-farm fodder that is typical of extensive farms, which are less relying on the purchase of forage from the market. Conversely, farms with a LU/UAA for forage greater than 2 have been classified as intensive. This distinction has been applied to all farms in the sample except the fattening calf production since it is assumed to be implemented only in an intensive way.

In general, regarding the cow-calf line we can say that the intensive type of production shows the best performances in the animals' pressure index and the crops pressure index. On the contrary, the extensive type of rearing is performing better in the off-farm inputs pressure index. It is very interesting to notice that the analysis conducted for the fattening beef farms follows the same patterns of the intensive/extensive cow-calf line in the results. Even if the scale is different (since they tend to reflect the scales of the reference step of production), we can see better figures for the environmental performance of the intensive fattening beef farms for what concerns the animals pressure index and the crops pressure index. Conversely, the extensive fattening farms show better results in the external inputs pressure index.

Unfortunately, the literature available does not provide greenhouse gas emission assessments tailored on single stages of production for different methods of production. However, the findings are consistent with the logic behind the estimation of these indices and the characteristics of the two methods of production. In fact, we expect that the farms rearing in a more extensive way hold a greater number of animals not devoted to the fattening, which are consequently a relevant source of environmental pressure due to their longer lifespan. Besides, a negative result associated to the crops pressure index for extensive farms may reflect a stronger exploitation of natural resources, particularly pastures and maize cultivations. Finally, concerning the off-farm inputs pressure index, it is coherent with the intensive method of production to make a greater use of external inputs like feed, forage, and energy. Consequently, we can assume greater emissions in terms of CO_2. This lead to an expected negative outcome for the intensive farms which is captured by the index.

An average of the median values for the indices has been also computed in order to identify the method of production that should be preferred from a sustainable perspective. Coherently with the results provided for the cow-calf phase, as shown in table 5, the intensive method of production has a lower average value in the median of the indices and its ranked far below the extensive one. For this reason the intensive cow-calf system, considering all the necessary assumptions, should be chosen. If the prevalence of one method of production with respect to the other is more evident for the cow-calf phase, the opposite is true for the fattening phase. In this case the two methods are rather comparable due to strong differences in results for the crop pressure index and the external inputs pressure index. This is confirmed by the calculation of averages for the median figures, presented in Table 5, where the results are pretty close in particular for what concerns the rankings. Otherwise from this assessment seems that a slightly better performance can be assigned to the extensive method of production.

Concerning the firms implementing an integrated production, results tend to differ with respect to firms focusing on a single stage of production. In this case, the firms producing beef in an extensive way show a better performance in all the three indices computed with respect to intensive farms (even if differences in ranking are relatively small, except for the crop pressure index). The results for the external inputs pressure index are pretty close, both in terms of ranking and range in results covered by the index. The same happens for the animal pressure index. In both cases, differences in data values of the two samples are not particularly relevant and this could lead to similar results for the two methods of production. Otherwise, the crops pressure index shows a more consistent difference in the results for the two methods, that is also in contrast with the trend recorded in the previous analysis. The main difference in this extensive sample, with respect to the others, is the presence of alfalfa and other legumes herbages (10 firms over 17) which are also the firms with the lowest scores for the crops pressure index. This can be seen as a driver of good performance for the crops pressure both for the index and in reality, due to the benefits of nitrogen fixation to the soil. In this case, the comparison between the two methods of production is much clearer. The extensive farms reach a much better performance than the intensive ones, as reported also by the average indices and rankings in Table 5.

In this context comparisons with literature are made possible since there are studies carried out on integrated beef supply chains differing for the method of production. The most relevant case is the analysis performed by Casey and Holden (2006) which confirm the findings of these indices. In facts, the overall GHG emissions for the extensive Irish beef farms was equal to 21,8 CO_2-eq./kg, while greater results (23,2 CO_2-eq./kg) were computed for the conventional type of rearing.

3.4 Comparisons between different combinations of cow-calf and fattening farms and the integrated supply chain

In order to draw some conclusions about the goodness of one supply chain with respect to another, we rearranged the samples of farms identified in the previous section to obtain a set of different combinations of cow-calf and fattening firms. Specifically, we created four sets of firms: the first including cow-calf and fattening firms with an intensive production method; the second refers to a supply chain where the cow-calf phase is carried out in an intensive way and the fattening in an extensive way; the third set describes a supply chain with extensive cow-calf line combined with intensive fattening; and the forth includes cow-calf and fattening firms operating in an extensive way. This approach would allow to compare these different supply chains with respect to firms following an integrated approach in production and allow to suggest a preferable supply chain structure when taking in consideration environmental pressure. Following what presented in the previous paragraph, average values for the different median indices are computed and provided in Table 6. A final ranking of the preferable methods of production for environmental performance is also provided. What emerges from the final scores for the supply chains analyzed is that the extensive integrated supply chain shows the best environmental performance. It is also interesting to notice that the three supply chains in the top positions include a fattening activity practiced in a more extensive way, while the firms including intensive fattening are all placed in the lowest half of the final ranking. This can be due of course to the slightly better general performance of extensive fattening farms already underlined in the previous section. Otherwise, given that this difference was really small, this outcome was not clearly predictable. The result could suggest that the positive effect of an extensive fattening activity could be more significant when considered in the framework of a complete supply chain.

According to the structure of the Italian beef supply chain, the majority of firms focuses just on one step of the supply chain rather than on a closed cycle. Because of this, it is also interesting to identify the best choice among the different methodology combinations of supply chains. Among the combinations computed we can see that the top performance is recorded by the intensive cow-calf line associated to an extensive fattening beef activity. This is in line with the findings of the previous paragraph that attributed a better performance to these two methodologies in the analysis of the single steps of the supply chain. Also from a logic standpoint the result is credible since, as demonstrated by the literature, the greatest share of emissions is attributed to the cow-calf line. Adopting a more intensive method of production for this stage could significantly reduce the environmental impact due to animals and crops pressure. Besides, given the small impact of the fattening phase on the overall environmental impact, a more extensive method of production could still guarantee a good animal performance while reducing the impact due to excessive external input usage.

It is particularly interesting to notice that the best alternative identified in this analysis in terms of composite supply chain is the exact opposite of the typical Italian productive scheme. In facts, Italian cow-calf farms commonly adopt methods that are rather extensive while fattening farms are known for their intensive livestock rearing. The result of this analysis identifies this supply chain structure as the one with the worst environmental impact among the samples analyzed. This finding, taken with all the necessary assumptions, might call into question the environmental sustainability of the classical Italian beef supply chain and open research questions that might not have been addressed yet in the available literature.

4 Conclusions

The aim of this paper was to explore an alternative approach to the assessment of sustainability in beef cattle farms. Given the significant impact of beef cattle rearing in impacting greenhouse gas emissions, the study focused on an alternative approach that could obviate to the technical complexity and data requirements in the estimation of emissions. Consequently, the most significant variables affecting greenhouse gas emissions in the beef cattle production have been selected with the objective of constructing an index accounting for this environmental impact. Data were taken from the Farm Accountancy Data Network, which provided economic and stock information about Italian beef farms. This allowed on the one hand to use a database that is easily accessible from researchers (also in the perspective of the application of this method to other livestock sectors) but, on the other hand, the lack of some significant information must be taken into consideration when evaluating the results. In particular, the FADN database lacks structural information on the types of bedding, and more in general on how waste is managed, which might highlight interesting differences in the indices too, due to the different emissions regimes of manure and slurry. Moreover, even if the database provides information about duration in years of the cattle and average weight, a more precise indication of these value could make possible to include the finishing time into the analysis.

For what concerns the creation of the index, the main difficulty has been finding the appropriate weighting method to account for differences in importance between the variables, without falling into subjective judgments. The availability of existing literature in the construction of a sustainability index using Principal Components Analysis, even if applied to other contexts, allowed to follow a robust statistical approach for relating the variables included in the analysis. The explanation of the variance of data by the principal components is good, and overall we can see that the most important variables contributing to greenhouse gas emissions are taken into account by the analysis. The only significant exception is the stocking rate which, according to the literature is an important factor to take into account in the estimation of emissions, and is explained only by the 26% of its variance in the index.

Looking at the relationship between the pressure index results and the assessments found in the literature, we can see that they tend to reflect some general conclusions widely verified from researchers. In particular, the importance of the animal category in placing pressure into the environment is well measured, and the different impacts of this category in the different stages of production are well depicted too. The crops and external inputs indices show reasonable results associated both to the different stages of production and methodology utilized. Finally, the integrated supply chain, other than confirming the existing literature on the difference in emissions between intensive and extensive systems, highlight a strong driver of the goodness of crop performance being the cultivation of alfalfa and other legumes.

Regarding the ranking of different supply chains it is interesting to notice the dominance of the extensive integrated supply chain in the goodness of environmental performance. Otherwise, given the particular structure of the Italian beef supply chain, identifying the best combination of cow-calf phase and fattening phase seems particularly interesting both for farm management and environmental policy interventions. The result of the analysis is that combing an intensive cow-calf phase with an extensive fattening phase could provide the least environmental pressure among the combinations identified. It is curious to observe that this result is in contrast with the typical structure of the Italian beef supply chain, which usually pairs extensive cow-calf farms with the intensive beef fattening, which occupies also the last position in the ranking.

Drawing conclusions, even if the analysis lacks some useful information due to the dataset composition or for reasons inherent the statistical methodology, the overall results tend to be in line with much more complex sustainability assessments. A further development and improvement in the data and statistical construction can for sure make this methodology a useful tool for simple and fast measurements of animal production supply chains' environmental pressure, both for policy development and farm management use.

5 References

Abdi, H. and Williams, L. J. (2010). Principal component analysis. *WIREs Comp Stat*, 2: 433–459.

Beauchemin, K.A., Henry Janzen, H., Little, S.M., Mcallister, T.A., and Mcginn, S.M. (2010). Life cycle assessment of greenhouse gas emissions from beef production in western Canada: A case study. *Agricultural systems*, 103(6): 371-379.

Berton, M., Cesaro, G., Gallo, L., Pirlo, G., Ramanzin, M., Tagliapietra, F., and Sturaro, E. (2016). Environmental impact of a cereal-based intensive beef fattening system according to a partial Life Cycle Assessment approach. *Livestock Science,* 190: 81-88.

Casey, J.W., and Holden, N.M. (2006). Greenhouse gas emissions from conventional, agri-environmental scheme, and organic Irish suckler-beef units. *J. Environ. Qual.*, 35: 231–239.

Cederberg, C., Henriksson, M., and Berglund, M. (2013). An LCA researcher's wishlist – data and emission models needed to improve LCA studies of animal production. *Animal*, 7:212–219.

Coderoni, S., Pontrandoni A. (2016). Zootecnia italiana e mitigazione dei cambiamenti climatici. Analisi delle potenzialità e delle prospettive. https://www.researchgate.net/publication/304535403. Accessed 5 October 2016.

Coderoni, S., Valli, L., Pignedoli, S., Tozzi, L., Pantano, A., Vinci, A., and Sonaglia, L. (2014). Emissioni di gas serra degli allevamenti italiani: quali scenari? http://dspace.inea.it/handle/inea/988. Accessed 20 August 2016.

Cozzi, G. (2010). Present situation and future challenges of beef cattle production in Italy and the role of the research. *Italian Journal of Animal Science,* 6(1s): 389-396.

Crosson, P., Shalloo, L., O'brien, D., Lanigan, G.J., Foley, P.A., Boland, T.M., and Kenny, D.A. (2011). A review of whole farm systems models of greenhouse gas emissions from beef and dairy cattle production systems. *Animal Feed Science and Technology,* 166-167: 29-45.

ISMEA (2016). *Allevamento bovino da carne: scheda di settore*. Osservatorio economico sulla zootecnia. ISMEA, Roma: ISMEA.

Li, T., Zhang, H., Yuan, C., Liu, Z. and Fan, C. (2012). A PCA-based method for construction of composite sustainability indicators. *The International Journal of Life Cycle Assessment*, 17(5): 593-603.

Macrì, M.C., Pierri, F., De Leo, S., Doria, P., Monda, M., and Battistini, A. (2015). La filiera della carne bovina: un'analisi preliminare per il rilancio del settore. http://dspace.inea.it/handle/inea/1170. Accessed 12 August 2016.

OECD. (2008). Handbook on constructing composite indicators. Methodology and user guide. http://www.oecd.org/els/soc/handbookonconstructingcompositeindicatorsmethodologyanduserguide.htm. Accessed 23 October 2016.

Phetteplace, H., Johnson, D., and Seidl, A. (2001). Greenhouse gas emissions from simulated beef and dairy livestock systems in the United States. *Nutr. Cycl. Agroecosyst.*, 60: 99–102.

Rama, D. (ed.) (2014). *Il mercato della carne bovina. Rapporto 2014*. Milano: Franco Angeli.

Soler, R.J. and Soler, R.P. (2008). *Assessment of aggregated indicators of sustainability using PCA: the case of apple trade in Spain*. Proceedings of the 6th Int. Conf. on LCA in the Agri-Food Sector. Zurich November 12–14, 133–414.

Steinfeld, H., Gerber, P., Wassenaar, T., Castel, V., Rosales, M., and de Haan, C. (2006). *Livestock's Long Shadow*. The Livestock, Environment and Development Initiative (LEAD). Rome: FAO.

Stewart, A.A., Little, S.M., Ominski, K.H., Wittenburg, K.M., and Janzen, H.H. (2009). Evaluating greenhouse gas mitigation practices in livestock systems: an illustration of a whole-farm approach. *J. Agric. Sci,*. 147: 367–382.

6 Appendix

Table 1: Indices variables per macro category

Variables per category	Unit of Measure	Influence on GHG according to literature
CROPS:		
- Hectares of Maize	Ha	+
- Hectares of Soy	Ha	+
- Hectares of Pasture	Ha	-
- Hectares of alfalfa-legumes	Ha	-
- Hectares of other herbages	Ha	+
- Nitrogen fertilizer/Hectares	100kg	++

ANIMALS: - Number of calves - Number of fattening beef - Number of suckler cows - Number of other bovines - Stocking rate	 n n n n n	 + ++ +++ +++ +++
EXTERNAL INPUTS: - Extra forage expenditure - Extra feed expenditure - Extra bedding expenditure - Energy expenditure - Water expenditure	 € € € € €	 ++ ++ + +++ +

Table 2: Indices results for the whole dataset

	External Inputs PI	*Rank 1*	*Animals PI*	*Rank 2*	*Crops PI*	*Rank 3*
Mean	0,0769	101,465	0,6421	101,5	0,3875	101,5
Median	0,0299	101,5	0,6386	101,5	0,3839	101,5
St. Dev	0,1439	58,40	0,083	58,46	0,0974	58,46
Coeff. Var.	1,87	0,58	0,13	0,58	0,25	0,58
Nr. Obs.	202	202	202	202	202	202

Table 3: Indices results for farms specializing in cow calf production

	External Inputs PI	*Rank 1*	*Animals PI*	*Rank 2*	*Crops PI*	*Rank 3*
Mean	0,0451	117,63	0,6748	60,10	0,3833	105,16
Median	0,0233	119	0,6568	59	0,3808	108
St. Dev.	0,1130	55,19	0,0505	35,51	0,0722	55,08
Coeff. Var.	2,5087	0,47	0,0749	0,59	0,1884	0,52
Range	0,9998	200	0,2771	123	0,5280	195
Nr. Obs.	79	79	79	79	79	79

Table 4: Indices results for farms specializing in fattening beef production

	External Inputs PI	*Rank 1*	*Animals PI*	*Rank 2*	*Crops PI*	*Rank 3*
Mean	0,1460	81,36	0,6076	149,17	0,4151	87,94

Median	0,0484	70	0,6171	169	0,3886	79
St. Dev.	0,2028	65,09	0,1014	53,92	0,1291	63,23
Coeff. Var.	1,3888	0,80	0,1669	0,36	0,3111	0,72
Range	0,8468	200	0,7520	200	0,6900	193
Nr. Obs.	47	47	47	47	47	47

Table 5: Average indices for the intensive and extensive methods of production for farms specializing in the cow calf production, fattening beef production, and integrated supply chain

	Average of the median of the indices	**Average of the indices rankings**
Intensive cow-calf	0,3526	97,33
Extensive cow-calf	0,3584	81,33
Intensive fattening	0,3544	103,66
Extensive fattening	0,3488	104,16
Intensive integrated	0,3541	92
Extensive integrated	0,3435	115

Table 6: Average indices for different combinations of stages and methodologies of production for the Italian beef supply chain

	Average indices	***Average rankings***	***Goodness of environmental performance***
Intensive cow-calf + Intensive fattening	0,3520	96,16	4
Intensive cow-calf + Extensive fattening	0,3509	99,33	2
Extensive cow-calf + Intensive fattening	0,3556	89,33	6
Extensive cow-calf + Extensive fattening	0,3514	94,5	3
Intensive integrated supply chain	0,3541	92,0	5
Extensive integrated supply chain	0,3435	115,0	1