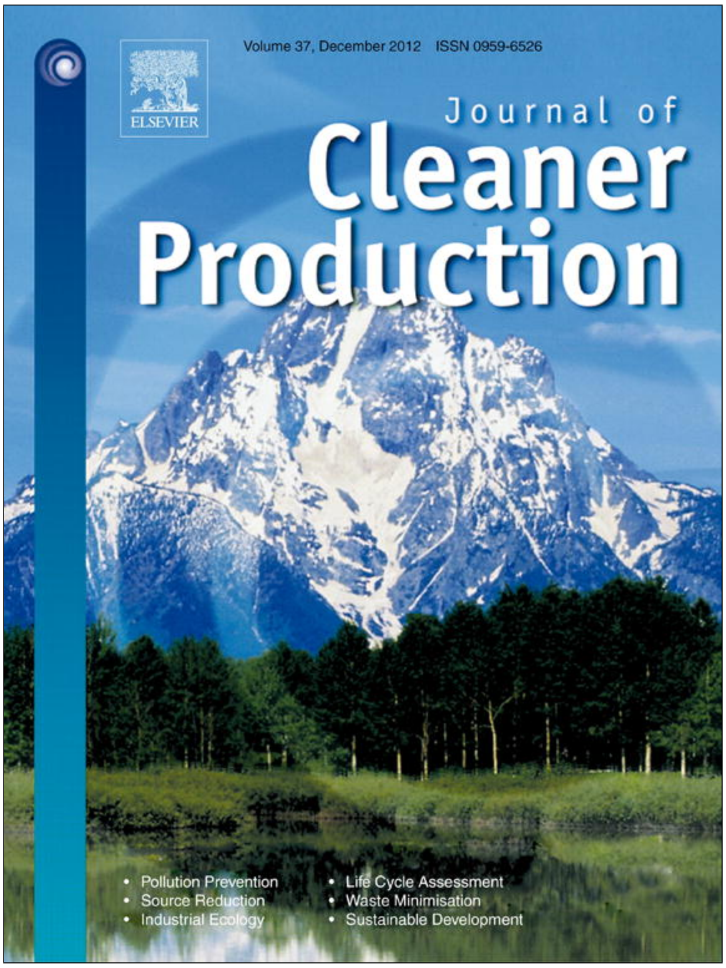
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A multicriteria approach for measuring the sustainability of different poultry production systems

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ABSTRACT

This study aimed to analyze the sustainability of different poultry production systems and was intended as an integrated systems approach to address human food needs, environmental preservation, economic feasibility and quality of life. The sustainability of the following three poultry production systems was compared: conventional, organic and organic-plus (this category is comprised of more restrictive requirements to improve animal welfare and meat quality). A bio-economic model combining on-farm data recording with a multicriteria decision analysis (MCDA) was assessed. To make a general sustainability evaluation, the following four dimensions were considered: economic, social, environmental and quality. The majority of the data was collected directly on the farms, and the environmental indicators were estimated with life cycle assessment (LCA), ecological footprints and emergy analysis. To develop the MCDA, six indicators for each dimension (economic, social, qualitative and environmental) were selected. The analyzed farming systems showed different results based on the stakeholder being considered (scientists, consumers and producers). The OP system showed the best performance when economic, social and environmental dimensions were integrated following the scientist and consumer stakeholders criteria.

1. Introduction

Livestock production is considered to be one of the major causes of environmental problems, including global warming, air pollution and water pollution (FAO, 2006). In recent decades, large and intensive livestock units have emerged in response to a rapidly growing demand for livestock products, and this trend is particularly true for intensive pig and poultry farms. However, there are serious concerns regarding the long-term sustainability of intensive farming systems (Veleva et al., 2001; Tilman et al., 2002; Cerutti et al., 2011; Acosta-Alba et al., 2012; Lindsey, 2012; Zhang et al., 2012).

Achieving sustainable animal production requires production systems where the management and conservation of resources in addition to the technological and institutional components ensure the attainment and continued satisfaction of human needs (eco-social health) for present and future generations (FAO, 1990). Thus, a production system that is economically profitable, ecologically sound, and socially acceptable should be pursued.

Organic agriculture has been established to optimize an ecological production management that promotes and enhances biodiversity, animal welfare, environmental sustainability, food safety and food quality. In poultry, such expected improvements depend mainly on the genetic strain used. The EC Regulation 834/2007 and the final recommendation of Network for Animal Health and Welfare in Organic Agriculture (Hovi et al., 2003) suggest the use of autochthonous breeds because of their higher rusticity and their capacity to utilize outdoor pens and pastures. These breeds, which have a slow-growing rate, show a higher vitality, resistance to diseases and adaptability to outdoor conditions (Castellini et al., 2009). However, due to strain availability and economic reasons, fast-growing birds are also often used for organic production. These commercial hybrids are genetically designed to be slaughtered at a younger age (40–55 days), and they do not have a growth profile suited for 81-day production, which is the minimum slaughtering age for organic chickens. Furthermore, their biodiversity is almost nonexistent, and analysis of the entire chicken genome has shown

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that commercial chickens have lost more than 90% of their alleles relative to native and non-commercial hybrids (Francham et al., 2004).

Some studies have analyzed the effect of an organic system on particular aspects of production (e.g., performance, quality, welfare, and environment), but only a few studies have compared the global performance of this farming system (Bokkers and De Boer, 2009).

A suitable method for summarizing and comparing global performance of a production system can be solved with many different approaches. Multicriteria decision analysis (MCDA) can be used to specify the criteria involved in the decision and to suggest a priority of choices among the alternatives (Morais and Almeida, 2006). The methodology of MCDA (Zeleny, 1982) is based on the outranking relation concept established by Bernard Roy through the development of the Electre method (Roy, 1996; Roy and Bertier, 1971), which can be employed to facilitate decision-making activities (Huang and Chen, 2005).

To our knowledge, this is the first study that evaluates the effect of farming system (FS) by developing a method that summarizes different aspects of the production chain. This approach is particularly sound because there is no homology of FS in terms of animal welfare (Castellini et al., 2009; Meluzzi et al., 2009), product characteristics (Chartrin et al., 2005; Fanatico et al., 2005a,b; Lewis et al., 1997; Branciari et al., 2009; Sirri et al., 2010), landscape aesthetics and biodiversity (Mugnai et al., 2009).

For this study, a model was developed that directly acquired on-farm data and compared the economic, ecological, social and qualitative performance of three poultry production systems (conventional, organic, and organic-plus) through MCDA.

2. Material and methods

The methodology of this study was partly based on the study by Bokkers and De Boer (2009). Thus, the novelty of the current study resided in an on-farm evaluation of different traits (economic, ecological, social and quality; EESQ) and in the assessment of a final rank.

Briefly, the main steps were as follows: a description of productive systems; the selection of relevant economic, ecological, social, and quality issues in addition to data recording; and the development of a final rank by means of MCDA with a weighting procedure assessed by a panel of stakeholders.

2.1. Animals and housing systems

The data were collected directly from 6 farms located in central Italy (2 organic, 2 conventional and 2 organic-plus farms) (Table 1).

The conventional (C) poultry production system was represented by traditional broiler farms, which used meat-type birds, concentrated feed and controlled housing (artificial light and climate control). Water and feed were furnished automatically, and the floor was covered with wood shavings.

In the organic (O) poultry production system, the birds were raised according to the Council Regulation (EC) 889/2008 and other specific national rules. Organic broilers were kept in houses with natural ventilation and natural daylight, and the daylight was supplemented with artificial light. External pens were available (4 m^2/bird). Water and feed were furnished automatically. Feed was GMO-free, and 95% of the feed dry matter was of organic origin. Synthetic amino acids, vitamins, antibiotics and coccidiostats were not allowed.

The organic-plus (OP) system had more restrictive requirements for improving animal welfare and meat quality than the O system. Slow-growing strains and wider outdoor spaces (10 m^2/bird) were used. The slow-growing strains better utilized the natural environment due to their high foraging behavior, kinetic activity and higher adaptability to a free-range system (Castellini et al., 2008).

All the systems used an ‘all-in all-out’ procedure, which means that all birds within a production cycle arrive and leave the farm on the same day.

2.2. Indicators

To develop the MCDA, six indicators for each different dimension (economic, social, meat quality and environmental) were selected.

2.2.1. Economic indicators

Three indicators are typically economic indicators. Three other indicators are linked to animal performance and, therefore, are connected with economic performance.

2.2.2. Classic economic indicators

To evaluate the purely economic indicators, all of the production costs were calculated. Variable costs (chicks, feed, labor, energy, medication, chicken capture and other costs) and fixed costs (depreciation of buildings, depreciation of equipment, and interest) were considered.

The following economic indicators were used to compare the three poultry production systems: 1) net income, which was the difference between the gross production and all the production costs (€/kg); 2) revenue, which was the price per production unit showing how active the poultry market is (€/kg); and 3) labor per production unit, which indicated the more labor intensive poultry production method (h/head).

2.2.3. Animal performance indicators

The following animal performance indicators were used to compare the three poultry production systems: 1) final weight of animals (kg), which was recorded immediately before slaughtering

Table 1
Mean characteristics of the three poultry farming systems.

	C	O	OP
Genetic strain used	Fast-growing (Ross 308 − M + F)	Fast-growing (Ross 308 − only F)	Slow-growing (Gaina −M + F)
Total birds per cycle (*N*)	53,781	9600	65,800
Buildings area (m^2)	2955	2000	3,000[a]
Density indoor (birds/m^2)	18.2	9.6	16.6[b]
Pasture area (ha)	–	8.0	57.0
Density outdoor (birds/m^2)	–	0.25	0.10
Age at slaughter (d)	48 (mean for M + F)	81	100 (mean for M + F)
Cycles of production (*n*/year)	6.1	3.7	3.3

M = Male; F = Female.
[a] Buildings are used mainly in case of bad weather and during the night.
[b] For conventional and organic-plus systems, the values are means of the performance considering a female/male ratio = 1. Source: Direct surveys of the three systems.

($n = 50$ birds/farming system/cycle); 2) feed consumption, which was recorded for the determination of feed conversion (kg feed/kg meat produced); and 3) mortality rate, which was considered at the end of the cycle and expressed as dead birth/number of initial birds (%).

2.3. Social indicators

Labor safety was assessed according to the "Environmental, Health, and Safety Guidelines of poultry processing" of the World Bank (2007). The occupational health and safety risks included chemical hazards that may pose a threat to the health of workers. In conventional poultry buildings, air usually contains significant levels of dust, toxic gases (NH_3 and H_2S) and chemicals (for disinfection). Alternatively, birds raised with access to the outdoors and with organic methods reduce the health risks of the workers. Therefore, we included an arbitrary index of labor safety for conventional and organic poultry production (0, 1, and 1 for C, O and OP systems, respectively).

2.3.1. Biodiversity

An arbitrary index of genetic diversity of birds reared in the farms was assessed. The value of this index was the same for organic and conventional systems (0) because fast-growing hybrids were used. The use of a slow-growing genotype in the OP system sustained a superior degree of genetic diversity (1).

2.3.2. Animal welfare and health

Bird behavior was recorded each morning and afternoon during the last week of each bird's life (C system from 38 to 45 days; O system from 72 to 80 days and OP system from 92 to 99 days). Observations were taken for periods of 3 h using the focal animal sampling method (Martin and Bateson, 1986). Twenty birds per FS/cycle were chosen at random, and the behavioral observations taken included the following behaviors: moving (running, walking, foraging, and stretching), rest (lying and standing), eating (food and water), ground pecking, comfort and others (socials behaviors). Among all of the behaviors recorded, only moving activity was considered in the MCDA because this was the most characterizing behavior.

On the last day of behavioral investigation, blood samples were collected from the brachial vein. Leucocytes, including heterophils, lymphocytes, monocytes and eosinophils, were counted in each sample. The heterofil/lynphocyte (H/L) ratio of the birds was calculated ($n = 20$/FS/cycle) as a stress indicator (Singh et al., 2009).

At slaughtering age, the breast blister and foot pad lesions of the carcasses were recorded in 50 animals/FS/cycle according to the methodology of Kjaer et al. (2006).

2.4. Meat quality indicators

Food safety refers to substances or organisms that contaminate food and are health risks to the consumer. Poultry meat mainly holds the risk of being contaminated with residues of antibiotics and bacteria. Because the tests for antibiotic residues and bacterial contamination (*Campylobacter* spp. and *Salmonella* spp.) were negative in all of the systems, these data were omitted from the analysis.

2.4.1. Chemical-physical characteristics of breast meat

Twenty birds per FS/cycle were chosen at random. Several characteristics of the refrigerated carcasses (after 24 h at 4 °C) were collected. The percentage of breast meat was estimated using the following equation: breast weight/carcass weight × 100. The breast tenderness was estimated by means of shear force, which was evaluated on cores (1.25 cm × 2 cm) obtained from the cooked breast (roasted for 15 min with a core temperature of 80 °C). The breast meat was cut perpendicular to the direction of the fibers using an Instron (model 1011) equipped with a Warner–Blatzler shear apparatus. The sampled breasts were analyzed for antioxidants (sum of tocopherol and carotenoids). Tocopherols were extracted and evaluated by means of HPLC according to Zaspel and Csallany (1983). Total carotenoids were assessed according to AOAC (1995). The extent of lipid oxidation was evaluated as TBARS using the modified method of Ke et al. (1977). Oxidation products were quantified as malondialdehyde equivalents (mg MDA kg^{-1} muscle). The fatty acid profile was determined for lipids extracted from breast meat samples using the method of Folch et al. (1957). Fatty acids were determined as methyl esters with a Mega 2 Carlo Erba Gas Chromatograph (model HRGC, Milano, Italy) using a D-B wax capillary column (0.25 mm × 30 m). The fatty acid percentages were calculated by the Chrom-Card software.

2.5. Environmental indicators

A recognized and unique method for measuring environmental impacts is difficult to define.

Thus, according to Bastianoni et al. (2010), the main results of the LCA, emergy, and ecological footprint were combined to measure environmental impacts.

Although these methods present some overlapping areas (because they are functional to the analysis of the same dimension - the environmental one), we chose to use all the three methods because each of them shows both positive and negative aspects, but all of them are effective in representing the environmental features of a given activity (Bastianoni et al., 2010); therefore, the results can be used as input in a sustainability assessment process. The choice to use Emergy Evaluation, Ecological Footprint Analysis, or LCA depends upon the main objective of the assessment process. If we are dealing with a problem of environmental impacts, LCA is a reliable tool to analyze the situation from a multidimensional perspective. On the contrary, if we are dealing with a problem of resources availability, Ecological Footprint or Emergy Analysis are better ways to evaluate the exploitation level of the analyzed resources. However, in many cases it is not necessary a choice, because the three methods can be used together, and the results can be integrated to build combined indicators, capable to ensure a wide and complete analysis.

Life cycle assessment (LCA) indicators analyze the environmental impacts that a product creates by considering its whole life cycle and by quantifying the resources involved and emissions produced. The inputs and outputs were quantified for the life cycle phases of the system from the extraction of raw materials to the production, assembly, use, maintenance and disposal of the products. The main LCA steps were as follows:

a) Definition of the goal and scope consists of the methodological choices, assumptions and limitations of the study in addition to the functional unit (Goedkoop et al., 2008; Guinée et al., 2002). In this case study, an LCA for each of the three production systems was performed, and 1 kg of poultry meat was considered to be the functional unit. The choice of such a functional unit was due to the following reasons:
   - the major simplicity in calculating it, and the higher comparability among the three systems, and with available literature (kg is the most reference unit used in these studies);
   - the invariability of mass unit during the time; prices of poultry could be very variable in the course of the time, and the variability can depend by several different factors (social, economic, etc.).

b) Life cycle inventory consists of data collection and quantification of the input and output flows involved in the system. The system under study was modeled as a sequence of single operations that communicate among themselves and with the environment by means of inputs and outputs (Pizzigallo et al., 2008). The majority of the data was collected through direct surveys on the poultry farms, and the remaining data was collected from the literature and Ecoinvent database (Nemecek et al., 2004). Additional details have been reported in a previous study (Boggia et al., 2010).
c) The life cycle assessment consists of the evaluation of the environmental impacts derived from the data collected in the inventory. The impact categories used for the LCAs (Eco-indicator 99; Goedkoop and Spriensma, 2001) were divided according to the following three broad areas: human health, ecosystem quality and resource consumption. For each category, higher values indicate worse environmental performance.
d) A life cycle interpretation was performed by compiling the conclusions resulting from the study, which describe the environmental impacts, in addition to the recommendations for the improvement of the environmental performances of the system.

Emergy analysis indicator (*Em*) corresponds to the available energy of a certain kind of energy that has been directly or indirectly used to make a product, and the unit for this indicator is the emjoule (Odum, 1996). *Em* stands for "embedded" energy, which indicates the memory energy contained in the production process (Nelson et al., 2001). Emergy analysis makes it possible to count all of the natural resources depleted to create a product with a single unit of measure. Odum (1996) suggested that there are different energy qualities and that there is a hierarchy of energy transformations. The position in the energy hierarchy is measured with transformity (Tr_i), which corresponds to the emergy of one type of energy required to make a unit of energy of another type. Therefore, through transformities, it is possible to convert matter and different energy levels into solar energy. The emergy of a product i is calculated as follows: $Em = \Sigma Tr_i, E_i$; where Em is the emergy; E_i is the available energy of one kind embodied by the product i; and Tr_i corresponds to the amount of solar energy necessary to have one unit of E_i.

The unit of measure for emergy is the solar joule or sej. The unit of measure, E_i, can be joule, kcal or g depending on the method used to calculate the energy of the product i. Transformity expresses the amount of sej necessary to create 1 J, kcal or g of product i. The transformity of a production process (Tr_o) is calculated as follows (Odum et al., 2000):

$Tr_o = Em/E_o$; where Em is the emergy necessary for the production of the output; and E_o is the energy that the output can generate. The circularity between (1) and (2) is avoided because, by definition, the transformity of solar energy is 1 sej J^{-1}. An in-depth discussion of the emergy principles and accounting method has been previously published by Odum (1996) and Brown and Herendeen (1996).

A production process (poultry meat/year) that requires lower emergy uses less solar energy. Although there are many criticisms of the utility of the emergy concept in assessing the sustainability of a production method (Bastianoni et al., 2010), an indicator of emergy analysis can be useful for expressing how far a production system is from the full use of renewable resources. This useful indicator is the environmental loading ratio (ELR). ELR is defined as follows: $ELR = (N + F)/R$; where R is the renewable emergy of the system; N is the non-renewable emergy; and F is the external emergy. Farming systems based on more renewable resources are considered more sustainable. Therefore, when the ratio in equation (4) is lower than one, the system is energetically balanced. When the ratio is higher than one, the system is energetically unbalanced. In this study, the majority of the necessary data was collected through direct surveys on the farms.

Ecological footprint (EF) is a measure of how much land and water are required by an activity to produce all the resources it consumes and to absorb all of the wastes it generates. The EF is usually measured in global hectares (Global Footprint Network, 2009b), i.e., hectares with global average productivity (Kitzes et al., 2007; Galli et al., 2007). The EF was calculated as follows (Wackernagel and Rees, 1996): $EF = \Sigma aa_i$ with $i = 1$ to n and $aai = ci/pi$; where aa_i is the per capita land area (aa) necessary for the production of each consumption item i; c_i is the average annual consumption of item i expressed in kg/capita; and p_i is the average annual productivity or yield of item i expressed in kg/ha. Moreover, the c_i/p_i ratio is the final measure unit, ha/capita (Global Footprint Network, 2009a,b).

In the footprint methodology, a product is considered a one-time expense that embodies the biological services of a certain number of global hectares for a specific period of time. The EF of a product is defined as the sum of the footprint of all the activities required to create that product. In this study, the product corresponded to 1 kg of poultry meat/year. Thus, aa_i corresponded to the land area assigned to produce 1 kg of meat. Because the dimensions of the rearing systems were relatively small, the measured unit area used in this analysis was m^2. Another essential indicator of an ecological footprint is the biocapacity (BC), which corresponds to the capacity of ecosystems to produce biological resources and to absorb generated waste materials. The BC was calculated by multiplying the actual physical area with a yield factor and the appropriate equivalence factor (Global Footprint Network, 2009c). The EF/BC ratio states the consumption of natural resources intended as ecosystem services and natural resource availability. We assumed BC as the rearing area of the farming systems. Thus, the EF/BC ratio represents the ecological debt or credit of the rearing systems. When the value of this ratio is higher than 1, the farming system depletes more natural resources than the area has (ecological debt). Alternatively, when the ratio is lower than 1, the system sustains the production by its BC.

The data were collected directly on farms. The conversion of materials and energy consumed by the farms into productive land was based on the Ecoinvent database (Nemecek et al., 2004), which made it possible to obtain carob dioxide emissions. Moreover, the conversion was based on cropland and developed land related to many of the inputs of the production process.

2.6. Multicriteria decision analysis (MCDA)

All the data recorded were processed by MCDA. MCDA is based on pair-wise comparisons of alternatives, and its final aim is to find a ranking. As with related methods, the scores of the effects are standardized and weighted prior to analysis. Using the Electre I method (Huang and Chen, 2005), a dominance relationship for each pair of alternatives was derived using both an index of concordance and discordance. The concordance index represents the degree by which alternative i is better than alternative i', and the discordance index represents the degree by which alternative i is worse than alternative i'. This latter index reflects the idea that a bad performance on one effect beyond a certain level cannot be compensated by a good performance on the other effect. Two sets of effects, a concordance set ($C_{II'}$) and a discordance set ($D_{ii'}$), are constructed to obtain these indexes.

Four different thresholds (strong and weak thresholds for the concordance and discordance tables) supplied by the decision maker are used to establish a weak and strong outranking relationship between each pair of alternatives. A step-by-step procedure of elimination is used to transform the weak and strong graphs representing these outranking relationships into an overall ranking of alternatives.

In the comparison between two alternatives, one alternative is ranked above the other if the concordance index is higher and the discordance index is lower than the set threshold. First, the ranking of the alternatives are determined by taking strong threshold values into account. Alternatives that are placed in the same position are then ranked according to their weak threshold values.

The final result is a ranking of alternatives. In the intermediate term, the procedure provides a set of intermediate results (concordance and discordance tables).

Briefly, the MCDA in this study consisted of the following steps: construction of the effects table; standardization of the scores and setting of the weights; construction of concordance and discordance tables (strong and weak graphs); and final ranking.

2.6.1. Effects table

The effect table was constructed by putting together all the indicators chosen for the MCDA, including the economic, social, quality, and environmental indicators.

2.6.2. Standardization of the scores and setting of the weights

The standardization of the scores was carried out by the maximum standardization method, which standardizes the score with a linear function that varies between 0 and the highest absolute score. For the benefit effects, the absolute highest score was indicated as one. For the cost effects, the absolute highest score was indicated as zero.

The weighting step was carried out by ranking the effects in order from the most to the least important. In this case, three different groups of stakeholders assigned three levels of priority to the different proposed indicators (the first position was the most important, 1; and the third position was the least important, 3). The stakeholders were composed of different categories of people involved in the poultry production chain as follows: scientists, consumers and producers ($n = 10$ per subgroup). Stakeholders were asked to indicate their priorities under the abovementioned traits (Table 2). These different stakeholders were asked to assign a priority level to the different indicators according to their own perspectives. Thus, the subgroups of stakeholders assigned different weights to the indicators (uncertainty analysis).

Consumers and producers were informed with a sheet of paper containing information on the significance and implication of the different variables.

The scientific view was the priority level assigned to different indicators, and it was considered as the reference value.

2.7. Statistical procedures and software used

SimaPro 8.0 and Definite software were used to perform the LCA (Product Ecology Consultants, 1990) and MCDA study, respectively.

All the data collected were preliminarily analyzed with a linear model comprised of a fixed effect of farming system, and mean values were reported (proc ANOVA: STATA, 2009).

Table 2
Priority levels assigned by different stakeholders.

	Scientists	Consumers	Producers
Indicators			
Live weight at slaughtering	2	3	1
Feed conversion	2	3	1
Mortality rate	2	3	1
Net income	3	3	1
Revenue	3	3	1
Labor per production unit	3	3	1
Index of labor safety	1	2	2
Biodiversity birds	1	2	3
Moving (% of budget time)	1	1	3
Foot pad lesions	1	1	3
Breast blister	1	1	2
H/L	1	2	3
Percentage of breast	2	2	1
Shear force	2	1	2
Fat content	1	1	2
Antioxidants	1	1	3
$n-3$ fatty acids	1	2	3
Oxidative stability	1	2	3
Climate change	1	1	3
Land use	1	1	3
Ecotoxicity	1	1	3
Fossil fuels	1	1	3
EF/BC	1	1	3
ELR	1	1	3

3. Results

3.1. Economic performance

The economic analysis showed (Table 3) that poultry feed was the major component of input costs and that it accounted for up to 70% of the total cost for O production and approximately 60% of the total cost for C and OP production. The total cost per production unit of the O system was almost 20% higher than that of the C system, and the total cost per production unit of the OP system was almost 91% higher than that of the O system.

The final weight, feed conversion and mortality rate were best in the C system followed by O system (Table 4). Chickens in the OP system, except at higher ages ($d = 100$), had a lower performance due to the slow-growing strain used. The O system had a higher net income and high revenue per unit compared to the other FS. The OP system had a higher revenue performance but required more labor per production unit compared to the other FS, which was largely due to the outdoor access and low mechanization (e.g., no automatic feeding).

3.2. Social performance

Table 5 shows all of the data for social performance and welfare indicators. Labor safety and biodiversity indices were calculated according to the considerations described above (Materials and methods).

The kinetic activity of birds in the C system was low, and the birds in the O and OP systems had high kinetic activity. Moreover, severe lesions on the footpad and breast were higher in the O system followed by the C system, and body lesions were not observed on the birds in the OP system. The H/L ratio of birds in the C system was the highest followed by the O and OP systems.

3.3. Quality performance

Table 6 shows the main qualitative characteristics of carcass and breast muscle in the different farming systems. The amount of breast muscle was high in the C and O systems, and it was low in the OP system. The fat content of the breast was the same in the C and OP systems, and it was the highest in the O system. The meat from the birds in the C system had the highest tenderness.

The meat produced in the OP system was healthier than the meat produced in the C and O systems due to the higher amount of

Table 3
Economic analysis of the three poultry farming systems.

FS	C			O			OP		
Cost	€/head	€/kg	%	€/head	€/kg	%	€/head	€/kg	%
Chicks	0.45	0.21	17.58	0.49	0.13	9.37	0.82	0.40	14.60
Feed	1.54	0.72	60.32	3.73	1.01	71.38	3.22	1.55	57.41
Labor	0.18	0.09	7.18	0.13	0.03	2.43	1.00	0.48	17.89
Energy	0.10	0.05	3.84	0.06	0.02	2.84	0.16	0.08	2.92
Medication	0.05	0.02	1.95	0.13	0.05	2.39	0.10	0.04	1.78
Other costs	0.10	0.05	3.95	0.22	0.06	4.25	0.08	0.04	1.49
Chicken capture	0.05	0.02	1.95	0.16	0.04	3.06	0.08	0.04	1.48
Direct cost	**2.48**	**1.14**	**96.77**	**4.91**	**1.35**	**95.72**	**5.48**	**2.63**	**97.58**
Depreciation	0.07	0.03	2.67	0.19	0.05	3.72	0.10	0.05	1.85
Interests	0.01	0.01	0.56	0.03	0.01	0.56	0.03	0.02	0.57
Total cost	**2.56**	**1.18**	**100.00**	**5.14**	**1.41**	**100.00**	**5.62**	**2.70**	**100.00**

Source: Data directly collected in 6 farms in central Italy, 2010

$n-3$ fatty acids and antioxidants and a lower extent of lipid oxidation.

3.4. Environmental performance

Table 7 shows the environmental performance of the three FS. The C system impacted the climate change and environmental loading ratio more than any other FS. The OP system had the highest impact on land use, ecotoxicity, fossil fuels and ecological footprint. In general, the O system had the best values, except for land use and ecological footprint values, which were between the values found in the C and OP systems.

3.5. Standardization of all indicators scores

Fig. 1 shows the values of the most representative indicators after standardization.

The traits showed that the OP system had better results for social (Fig. 1c and d) and quality (Fig. 1e and f) performance. The C and O systems had better economic performance (Fig. 1a and b) and environmental parameters (Fig. 1g and h).

3.6. Final ranking

The final rank of MCDA permitted the global comparison of FS. Such final ranking changed according to the weight assigned by the different stakeholders to the different traits.

Considering the scientific view (Fig. 2) as the reference point of view, the OP system had the best overall result taking into consideration the environmental, economic, social and quality aspects. The C and O systems had the same final rank.

The superior quality and social issue results (welfare and biodiversity) of the OP system represented approximately 75% of the weights assessed by stakeholders who were scientists.

The O and C systems had the same rank but for different reasons. The O system had greater environmental performance, and the C system had higher economic and animal welfare performance. Moreover, the O system unexpectedly yielded low animal welfare results relative to the C system due to the use of non-adapted genetic strains.

For consumers focused on quality and social issues (welfare) (approximately 66% of total weight) with a low weight assigned to economic performance (approximately 8%), the OP system was the best, and the O system was the worst (Fig. 3).

For producers (Fig. 4) focused on economic performance (60% of total weight), the ranking was inverted with the O system ranked first followed by the C and OP systems. The weights of social, welfare, quality and environmental issues were relatively small.

4. Discussion

The higher efficiency of fast-growing birds is primarily responsible for the different productive and economic performance of poultry FS. The higher kinetic activity of slow-growing birds (OP system) reduces the body energy available for body growth despite its positive influence on animal welfare and meat quality (Fanatico et al., 2007; Castellini et al., 2009).

Part of the lower feeding efficiency of these producer systems is also due to the older slaughtering age of the O (81 d) and OP (100 d) systems relative to the C (48 d) system.

Regarding animal welfare, the results from the present study confirmed previous results (Castellini et al., 2006a; Branciari et al., 2009). Fast-growing birds are not tailored for the O system, and their welfare is even worse than in the C system. Good pasture management is essential when applying this type of poultry production to maintain adequate bird health and welfare (Dal Bosco et al., 2010; Castellini et al., 2006a; Mugnai et al., 2009). The attainment of positive expectations of organic agriculture in terms of animal welfare and biodiversity is not necessarily guaranteed. Instead, the extensive systems require a fine-tuning of the

Table 4
Economic indicators of the three poultry farming systems.

FS	C	O	OP
Indicators			
Final weight at slaughtering (kg)	2.65	3.48	2.45
Feed conversion ratio	1.9	2.9	3.6
Mortality rate (%)	3.8	5.1	6.0
Net income (€/kg)	0.01	0.13	0.05
Revenue (€/kg)	1.20	1.56	2.76
Labor per production unit (h/animal)	0.02	0.02	0.10

Source: Data directly collected in 6 farms in central Italy, 2010

Table 5
Social and animal welfare indicators of the three poultry farming systems.

FS		C	O	OP
Indicators				
Labor safety	Index	0	1	1
Biodiversity	Index	0	0	1
Kinetic activity	% budget time	10.8	28.5	85.4
Foot pad lesions	%	4.5	20.5	0.0
Breast blister	"	2.0	10.7	0.0
H/L		0.94	0.75	0.45

Table 6
Carcass and meat quality performance of the three poultry farming systems.

FS		C	O	OP
Indicators				
Breast	% refrigerated carcass	20.7	18.2	11.0
Shear force	kg/kg breast	3.2	4.1	5.2
Fat content	% f.m.	0.9	1.2	0.9
$n-3$ fatty acids	% total f.a.	4.3	5.6	7.7
Total antioxidants	μg/g breast	1.2	1.0	1.6
Oxidation	ηg MDA/g breast	158	165	109

Table 7
Environmental performance of the three poultry farming systems.

FS	C	O	OP
Indicators			
Climate change (Daly × 10^3)	0.25	0.18	0.22
Land use (PDF*m^2*yr)	1.94	3.68	4.59
Ecotoxicity (PAF*m^2*yr)	0.24	0.76	0.91
Fossil fuels (MJ surplus)	1.68	1.45	1.74
Ecological footprint (gm^2*yr)	12.81	20.37	26.13
Environmental loading ratio	3.80	1.75	2.01

DALY: disability adjusted life years, PAF*m^2*yr: potentially affected species per m^2 per year, PDF*m^2*yr: potentially disappeared species per m^2 for year, MJ surplus: additional energy requirement to compensate lower future ore grade.

main productive factors (namely genetic strains and pasture availability).

Commercial hybrids are selected for intensive production systems where animals are slaughtered at 35–50 d of age. When animals are older than this, extremely high body weight and unbalance (high weight of breast muscle) increase lameness and animals lying on the excrement-filled litter (Dal Bosco et al., 2010) close to the feeder, thus, resulting in body lesions (Berg, 2001). Moreover, synthetic amino acids and additives are banned in O systems, so it is more difficult to satisfy the higher dietary requirements of such productive strains (Lampkin, 1997). As indicated by Schütz and Jensen (2001), selection for high production rates results in modified behavior. Weeks et al. (1994) compared the behavior of Ross broilers reared free-range or kept inside, and they showed that free-range birds made little use of pastures because they stayed indoors and/or near the house. The authors attributed this behavior to weak legs of this strain, which prevented the birds from pasturing and behaving naturally. Accordingly, the areas near (within 5 m) the buildings in the O system were completely compacted and bare, whereas the entire area of the OP farm was perfectly weed-free, which implied greater environmental damage resulting from soil compaction and concentration of feces and nitrogen.

Kinetic and foraging behaviors of birds are linked to animal health and qualitative characteristics of meat. Slow-growing birds are able to consume grass, worms and insects (Sossidou et al., 2010), which in turn increases the intake of $n-3$ fatty acids and antioxidants (Castellini et al., 2002, 2006a). Such different foraging behaviors contribute to the explanation of different qualitative characteristics of O and OP systems (less fat, more antioxidants and more $n-3$). On the contrary, the tenderness of such birds was reduced as a likely result of their older age (Bokkers and Koene, 2003) and higher motor activity (Sirri et al., 2010).

On the surface, the OP system is more balanced in terms of social and quality attributes, which should improve its productive and environmental performance. However, the low growth performance (feed conversion, live weight) of this system caused animals in this system to have a larger impact on the environment (higher land use, ecotoxicity, fossil fuels and ecological footprint) due to their longer rearing period and higher pasture availability (10 m^2/bird). Thus, this system is of little interest for the producers. Some author found that the organic animal production reduces primary energy use by 15–40%, but when the productive performance of animals are significantly reduced the benefits of the lower energy needs for the production of organic feeds are sometimes overridden because more feed is needed per kilogram of meat produced (Foster et al., 2006).

However, there are few comparisons of the environmental impacts of poultry production systems. Boggia et al. (2010) compared the environmental impacts of three similar poultry production systems by LCA, and they confirmed that the O system had the best environmental performance. The same ranking (O system > C system) was found by Castellini et al. (2006b) using the emergy approach.

Although examining single traits of the different production systems is useful, the more interesting comparison is that of the MCDA final rank.

Taking into consideration the environmental, economic, social and quality dimensions, the OP system had the best overall

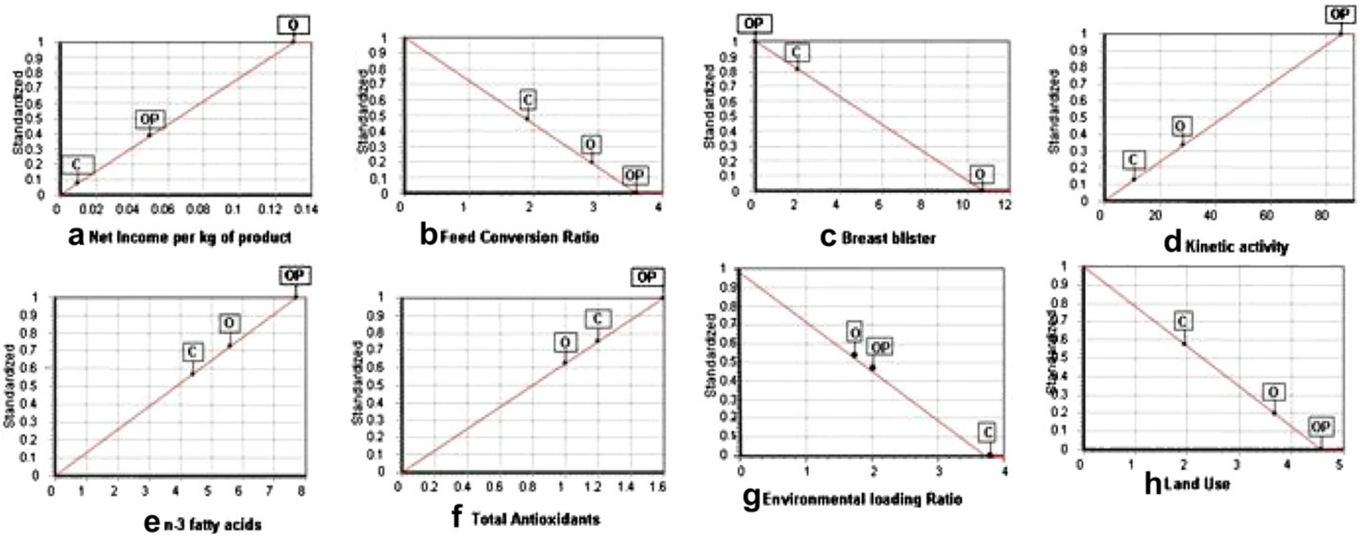

Fig. 1. Standardization curves of economic (a and b), social (c and d), quality (e and f) and environmental (g and h) performance.

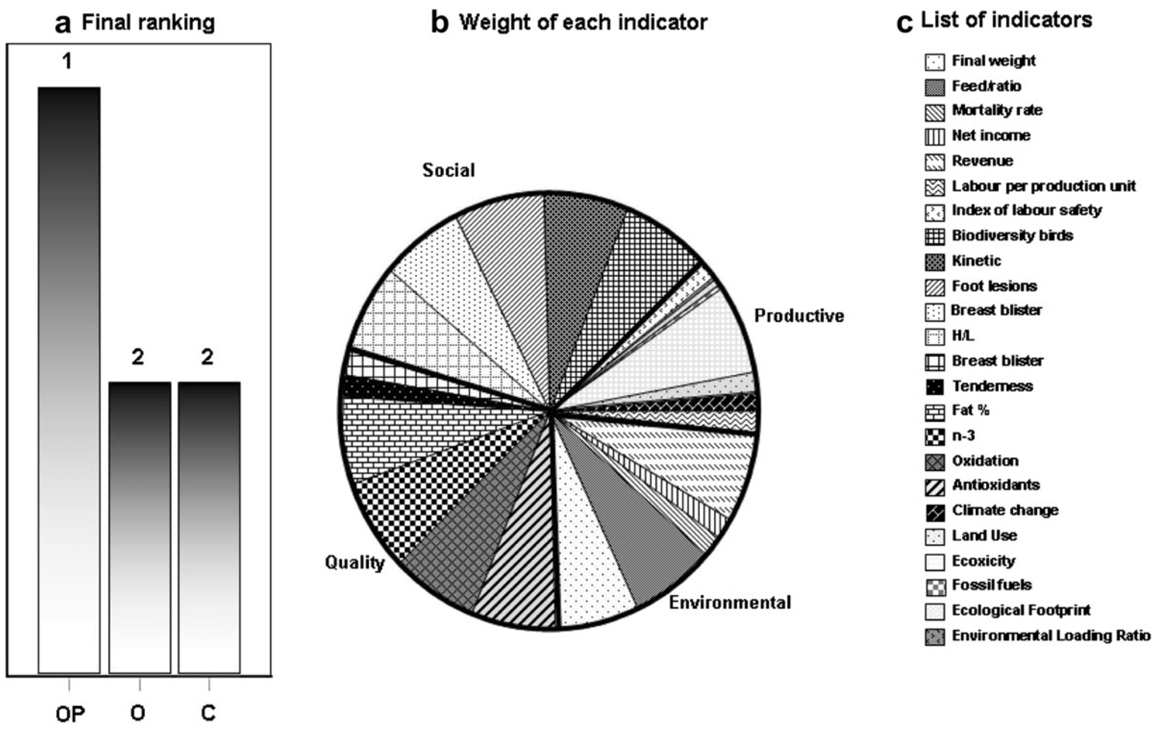

Fig. 2. Final ranking and weight of indicators in the three production systems (subgroup of scientists).

performance, and the C and O systems had the same final rank. The OP system had the highest results in terms of quality and social issues (welfare and biodiversity), which represented approximately 75% of the weights assessed by scientists. The O and C systems had the same rank due to the greater environmental performance of the O system and the higher economic and animal welfare of the C system. Moreover, the O system yielded lower animal welfare results than the C system due to the use of non-adapted genetic strains.

By changing the weights assigned by different stakeholders to the various traits, the final ranking changed. For consumers focused on quality and social issues (welfare) with a low weight on economic performance, the OP system ranked first and the O system ranked last.

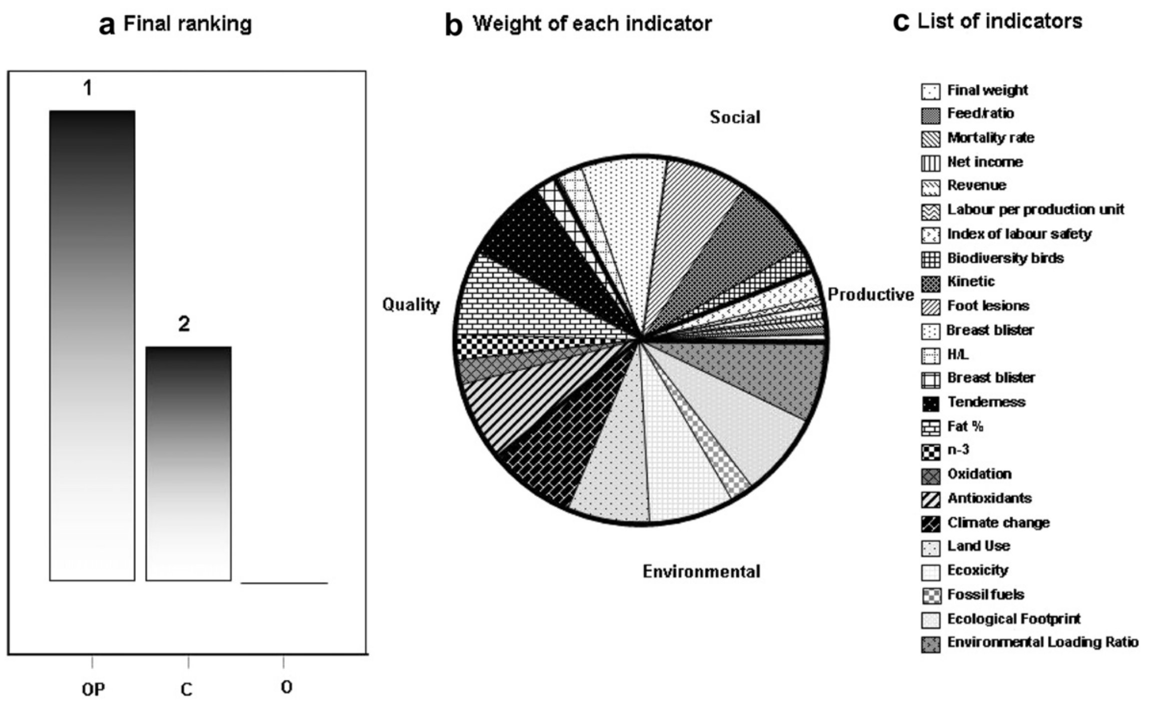

Fig. 3. Final ranking and weight of indicators in the three production systems (subgroup of consumers).

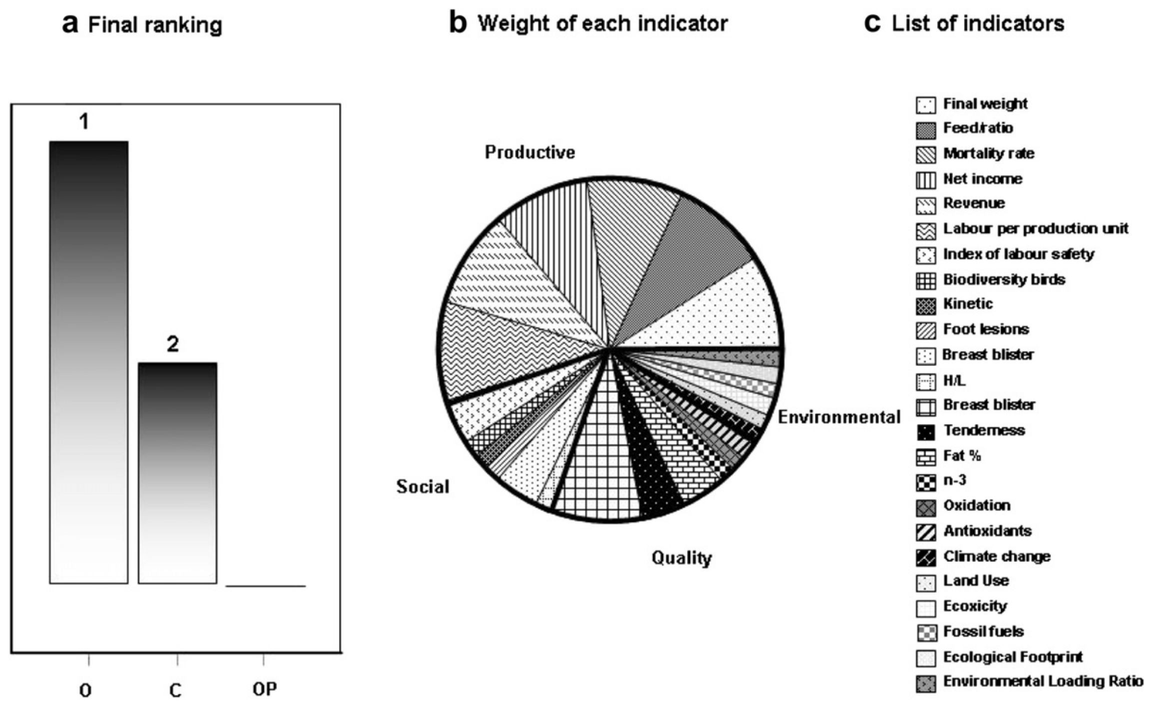

Fig. 4. Final ranking and weight of indicators in the three production systems (subgroup of producers).

In contrast, for producers focused on economic performance, the ranking was reversed with the O system being the highest followed by the C and OP systems because the weight of social/welfare (12%), quality (20%) and environmental issues (8%) were relatively small.

The divergence rankings obtained from scientists, consumers and producers were in agreement with the current situation in organic poultry production systems, which verified the compulsory rules (e.g., drug-free, GMO-free, and age at slaughtering) with little consideration for animal welfare, environment and quality of product.

The most important issue to reach an equilibrium between economic, social, qualitative and environmental performance is the genetic strain (i.e., causing the primary difference between the O and OP systems). From this point of view, it is essential to start with a different genetic strategy specifically designed for the extensive system by selecting strains starting from old poultry breeds (high biodiversity and kinetic activity), which maintains adaptability to the natural environment while simultaneously having higher productive efficiency and better environmental performance.

For this reason, genetic selection will set new goals by not only considering aspects of production but also parameters related to the reduction of environmental impacts.

5. Conclusion

The use of a multicriteria approach that combined economic, social, qualitative and environmental indicators into the many dimensions of sustainability allowed a more complete evaluation of different poultry FS. Sustainability in FS rests on the principle to meet the needs of the present without compromising the ability of future generations to meet their own needs.

In addition, the uncertainty analysis allowed the verification of differences in the obtained ranking based on different stakeholder's points of view. Examining this sensitivity analysis, in particular the priority levels assigned by producers, it is important to note that even if it is recommended by EC Regulation to not use birds selected for fast-growing and to provide outdoor access as much as possible, these suggestions are not always considered by producers.

Solutions to poultry welfare problems will not be easy if the EU Council does not establish these managing practices that allow improved animal welfare and meat quality as mandatory rules. Therefore, to reach equilibrium among all of the dimensions considered, namely performance, environment protection, animal welfare and meat quality, it is necessary to find a production system that conciliates them into one coherent scheme. Moreover, further studies are necessary to more thoroughly investigate the effect of different bird densities on the environmental impact of pasture and soil fertility. More emphasis should be paid to the contribution of vegetation, soil fauna, vitamins, minerals and fatty acids to the poultry rations, and more focus should be given to the potential of management practices to enhance soil fauna populations (e.g., earthworms in mulched vegetation). The results of this trial can be used as a support for public decision makers, to address new investment programs or to manage environmental evaluation and authorization processes. Furthermore, the results of this study can support decision makers at the farm level, for example, when they have to plan new livestock plants and need to consider costs and benefits of different production systems.

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