Chapter 10
Measuring Environmental Sustainability of Intensive Poultry-Rearing System

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Abstract Sustainability of human activities is one of the most important concerns of the European Union. Consequently, the need to assess the level of sustainability achieved both at local and at government level is increasing. This process involves all economic sectors, including agriculture and, in particular, livestock. Until several years ago livestock production systems were mainly focused on production efficiency and qualitative characteristics of meat. However, nowadays rules regarding animal welfare and environmental impact are becoming more and more compulsory and require attention by all the poultry chain. European subsidies are in many cases linked to an environmentally sound behaviour of farms. However, there is still an ongoing discussion regarding the definition of sustainable-agriculture strategic objectives, the criteria to take into account, the actions to develop, and the methodological tools to use for the evaluation. This chapter provides suggestions for improving the environmental evaluation part of a process of sustainability assessment specific for intensive poultry production. The environmental sustainability of an intensive poultry-rearing system is evaluated through the use of three different methods: Emergy Evaluation, Ecological Footprint Analysis and Life Cycle Assessment (LCA). For each of the three methods a review of its application in agriculture, and specifically in poultry breeding, is presented. Through Emergy Evaluation we found that diet is the most important impact factor for the analysed system, accounting for more than 82% of the total emergy flow. Our results obtained from Ecological Footprint Analysis point out that cropland, which is connected

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with chicken diet, is the main land component in the indicator, accounting for 73% of the total. Particularly, the high quantity of maize and soya needed for feed requires much cropland. Finally, using LCA, we found that feed production is the element which contributes the most to the environmental impacts of the system, influencing the impact category ‘land use’. As Ecological Footprint, LCA regards the cultivation and the transformation of maize and soya as the processes with the strongest impact. Therefore, although the three methods use specific indicators and methodology, they come to the same conclusions for the system investigated. After applying each method to the poultry system, we propose a comparative analysis between the three methods, based on four different criteria: representativeness, verifiability, reproducibility, comprehensibility. By comparing the methods according to these criteria, we found that each of them shows both positive and negative aspects, strengths and weaknesses, but all of them are effective in representing the environmental features of a given activity, and the results can be used as input in the sustainability assessment process. The choice to use Emergy Evaluation, Ecological Footprint Analysis, or LCA can depend upon the main objective of the assessment process. 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.

Keywords Emergy • ecological footprint • life-cycle assessment • poultry • sustainability

10.1 Introduction

Poultry is one of the major and fastest growing sources of meat, representing over 25% of European meat production in 2007. Because of their nutrient content and relatively low caloric value, egg and poultry products are natural candidates to meet consumer demands of Western countries. Until several years ago, the livestock production systems were mainly focused on production efficiency and qualitative characteristics of meat; however, nowadays rules regarding animal welfare and environmental impact are becoming more and more compulsory and require attention by all the poultry chain. It is widely known that the production of food requires resources such as land, water, materials, and energy, and causes emissions such as greenhouse gases, pesticides, heavy metals, and various other wastes. This is particularly evident for intensive animal production that uses a large amount of world grain (36%) which could be directly used for human nutrition.

However, the rapid evolution of the poultry industry toward intensive production systems has strongly enhanced the efficiency, the growth and the feed conversion of birds, but has reduced the resource use per kilogram produced.

Indeed, a recent UK study on the impact of several animal species showed that poultry resulted as the most environmentally efficient meat comparing resources used in the production of beef, sheep meat, poultry meat, eggs and milk

(Williams et al. 2006). Next comes pork, followed by sheep meat and beef. The efficiency of chicken in converting its feed into meat plays a big part. This efficiency had been achieved through a strong selection of traditional breeding and through better matching of feed to the birds' dietary needs at each stage of their development. The poultry industry of the future needs to meet increasing consumer demand while addressing issues of health, safety, animal welfare and environmental impact. At the same time the increasing relevance of sustainability has initiated a debate on appropriate frameworks and tools that will provide guidance for a measure of sustainability which should capture, address and suggest solutions for a series of issues that affect different stakeholders. However, sustainability assessment is still not a mature framework and several indexes have been developed with different responses.

The agricultural and rural policy of EU has increased the attention to the environment in the last 10 years; however, there is still an ongoing discussion regarding the definition of sustainable-agriculture strategic objectives, the criteria to take into account, the actions to develop, and the methodological tools to use for the evaluation of the same. Sustainability is a multi-dimensional concept: economic, social and environmental aspects must be considered simultaneously. 'Sustainable economic development involves maximizing the net benefits of economic development, subject to maintaining the services and quality of natural resources over time' (Pearce et al. 1988). The Renewed EU Sustainable Development Strategy, published in 2006, encourages development of sustainable indicators to ensure proper assessment of the situation in each challenge, and not only for an overall monitoring of the strategy. In this way, the development of indicators and a proper assessment of sustainability are key issues.

This chapter aims to provide suggestions for improving the environmental evaluation part of a process of sustainability assessment specific for intensive poultry production. In this study environmental sustainability of an intensive poultry-rearing system is evaluated, through the use of three different methods: Emergy Evaluation, Ecological Footprint Analysis and Life Cycle Assessment (LCA). For each of the three methods a review of its application in agriculture, and specifically in poultry breeding, is presented.

After applying each method to the poultry system, we propose a comparative analysis among the three methods, based on four different criteria: representativeness, verifiability, reproducibility, comprehensibility.

10.2 The Intensive Poultry-Rearing System

The farm surface area is 1.5 ha. Part of this area belongs to the animals' buildings (2,585 m^2 of covered surface), and the remaining surface to firm's road network. The construction materials are mainly steel tubes, bricks, polyvinyl chloride, polyurethane and concrete for the foundations. The shelters are air conditioned to maintain a constant humidity level (65–85%) and the right temperature (17–28°C) in order to maximize the chickens' performances. Feed and drinking systems are completely automatic. Table 10.1 shows the main characteristics of the farm. The

Table 10.1 Main characteristics of poultry-rearing system

Buildings and space allowance	
Total birds per cycle (*n*)	45.334
Surface area covered (m^2)	2.585
Density (birds/m^2 covered surface)	17.5
Productive performance[a]	
Final weight (kg)	2.6
Age at slaughtering (days)	50
Daily weight gain (g/day)	51.2
Cycles of production/year (*n*)	6
Feed index	2.02
Mortality rate (%)	4
Output after slaughtering (%)	83

[a] Mean performance considering a female/male ratio = 1

Table 10.2 Diet composition for poultry rearing, from the Ross Breeders–Broiler management manual (Aviagen Technical Team 1999)

Total ingredients	100%
Maize	40.00%
Wheat bran	8.00%
Sorghum	12.00%
Soybean oil	1.00%
Soybean meal	34.00%
Salt	2.00%
Bicalcium phosphate	1.00%
Calcium bicarbonate	1.00%
Additives	0.80%
Coccidiostatic	0.03%
DL-methionine	0.01%

analysis concerns the poultry production of a whole year. Energy and material requirements for poultry were assessed at the end of the growing period without taking into account transport to the slaughtering house, slaughtering, processing of carcasses and distribution.

The accounted animals in a year are 261,120, depurated of mortality rate. The duration of each cycle is 50 days which implies six cycles of production in a year. The genetic strain of birds is ROSS 308. When animals arrive at the farm they are about 40 g, while their mean weight when they leave is 2.6 kg; therefore feed index is 2.02. After the end of every production cycle the rearing buildings are cleaned and sanitised and there is an all-in all-out period of 10 days. All the indicators containing a reference to weight measure units took into account the carcass weight, calculated as 83% of the live weight.

The diet is formulated with common ingredients according to the standard recommendations of Ross Breeders-Broiler management manual (Aviagen Technical Team 1999). Table 10.2 illustrates the diet composition. For each productive cycle several vaccines and antibiotic treatments are administered. Coccidiostatic molecules are also administered until 10 days before slaughtering age.

10.3 The Methods

10.3.1 Life Cycle Assessment

Life Cycle Assessment (LCA) has been defined by International Standardization Organization (ISO) 14040 of 2006 as a 'compilation and evaluation of the inputs and outputs and the potential environmental impacts of a product system throughout its life cycle'. It is a method to evaluate the environmental impacts of products, activities and services, based on a 'cradle-to-grave' approach. This means that it is based on the identification and quantification of the flows of substances, materials and energy, to and from the techno sphere (which is the set of all human activities) and the environment, during the entire life cycle of the product or activity. The life cycle consists of the following phases: extraction of raw materials, production and assembly of the materials, use, and disposal of the product. Figure 10.1 shows a scheme of the overall structure of an LCA and of the considered elements.

LCA is an iterative method. This means that initial choices and initial requirements can be adapted later when more information becomes available (Goedkoop et al. 2008). Also old data can be replaced with new ones or with more precise data, re-evaluating in this way the earlier actions.

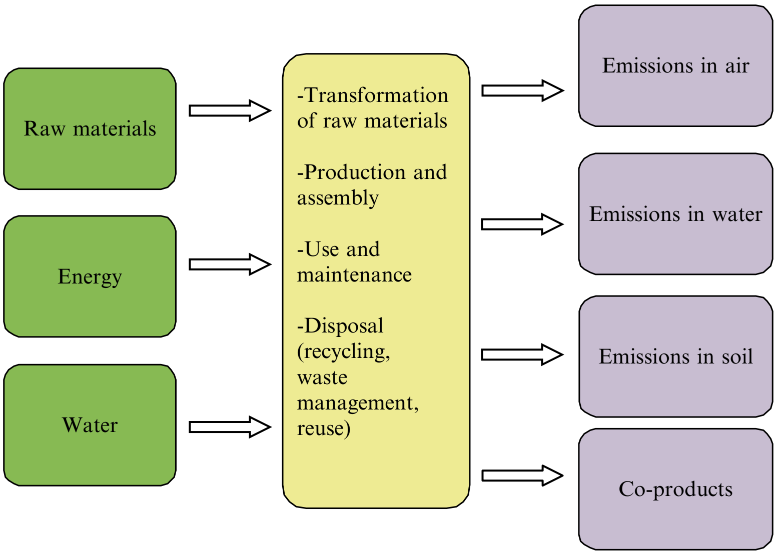

Fig. 10.1 Structure of a Life Cycle Assessment (ISO 14040)

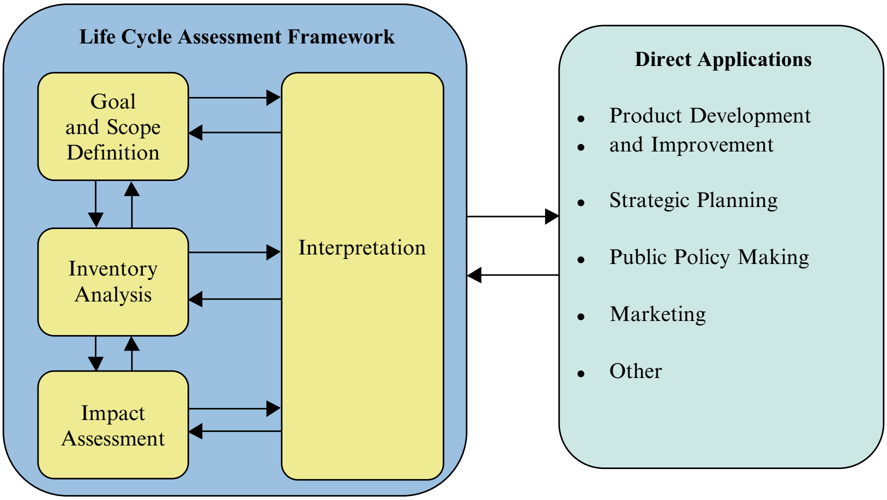

Fig. 10.2 The general methodological framework for Life Cycle Assessment (ISO 14044)

The implementation of LCA products, services, or production processes is developing quickly in all the sectors of economic system. In agriculture, and particularly in animal husbandry, the LCA approach is fundamental to have a complete view of environmental impacts, emissions and resources consumptions which are involved in every step of the productive chain, from the cultivation of crops and their transformation for making feed, to the phase of breeding.

Figure 10.2 shows the main methodological framework of LCA, established by ISO. ISO 14044 sets the requirements for every phase of the LCA. ISO standards contain the elements that should be considered when conducting an LCA, and when communicating the results. They are very important guidelines that provide an international reference on principles, framework and terminology for conducting and reporting LCA studies. The LCA methodology, according to ISO requirements, consists of four main phases enumerated below.

10.3.1.1 Goal and Scope Definition

Defining the goal of the study means determining clearly the reasons for carrying out the study and determining the application, and the intended audiences (Goedkoop et al. 2008). Some LCA studies could serve more than one purpose and the results may be used both internally and externally to the subject conducting the study.

The scope definition describes instead the most important methodological choices, assumptions and limitations made in the study. Initially the Functional Unit or comparison basis must be defined. It describes the primary function(s) fulfilled by a product system, and indicates how much of this function is to be considered in the intended LCA study. It will be used as a basis for selecting one or more alternative product systems that might provide these function(s) (Guinée et al. 2002). Therefore all the process inputs and outputs will refer to the Functional Unit.

After the Functional Unit, it is necessary to determine the system boundaries intended as the level of tracing of the system; the spatial, temporal, geographical and technological characteristics of the used data; the criteria for the inputs and outputs inclusion; and the level of sophistication of the study.

10.3.1.2 Life Cycle Inventory

This phase consists in collecting all the necessary data, and quantifying the inputs and outputs of the considered production system. Its main result is an inventory table listing the quantified inputs and outputs associated with the Functional Unit. The system under study must be modelled as a complex sequence of unitary operations that communicate among themselves and with the environment through inputs and outputs (Pizzigallo et al. 2008). Two main types of data can be distinguished: the foreground data, which are typically specific data describing a particular production system, and the background data, which relate to general materials, energy, transport, waste management. The first should be determined, if possible, by communicating with data providers and developing questionnaires, while background data can be easily found in databases or the literature.

10.3.1.3 Life Cycle Assessment

This third phase consists in the evaluation of environmental impacts deriving from the data collected in the Inventory. Life cycle impact assessment is defined by ISO as the phase in the LCA aimed at understanding and evaluating the magnitude and significance of the potential environmental impacts of a product system (Goedkoop et al. 2008). Different impact categories and assessment methods can be selected, depending on the goal and the scope of the study. Initially, the results of the Inventory analysis are assigned to relevant impact categories. For example CO_2 and CH_4 emissions are both assigned to the impact category 'global warming', while SO_2 and NH_3 emissions are both assigned to the impact category 'acidification'. The 'baseline' impact categories are: depletion of abiotic resources, impacts of land use, climate change, stratospheric ozone depletion, human toxicity, ecotoxicity (aquatic and terrestrial), photo-oxidant formation, acidification and eutrophication. Moreover, there are 'study-specific' impact categories, which could be included in the LCA study, depending on its goal and scope (Goedkoop et al. 2008).

Once the impact categories are selected and the Inventory results are assigned to them, it is necessary to define the characterisation factors. These factors should reflect the relative contribution of an inventory result to the impact category indicator result. For example, on a time scale of 100 years the contribution of 1 kg CH_4 to global warming is 42 times higher than the emission of 1 kg CO_2. This means that if the characterisation factor of CO_2 is 1, the characterisation factor of CH_4 is 42. Thus, the impact category indicator result for global warming can be calculated by multiplying the LCI result by the characterisation factor.

After characterisation, the normalisation step can be carried out, as optional step. Normalisation is a procedure needed to show to what extent an impact category contributes to the overall environmental problem. This is done by dividing the impact category indicators by a 'Normal' value. There are different ways to determine the 'Normal' value. The most common procedure is to calculate the impact category indicators for a region during a year, and divide this result by the number of inhabitants in that area. Finally, it will be necessary to determine which phases of the production system contribute the most to the identified impacts.

10.3.1.4 Life Cycle Interpretation

This last phase consists in interpreting the results, and compiling conclusions and recommendations to improve the environmental performances of the studied system.

In the field of animal husbandry several LCA researches have been conducted, especially for cattle and pig production systems. An interesting article of Halberg et al. (2005) compares different environmental assessment tools for the evaluation and improvement of European livestock production systems. Among them, Life Cycle Assessment and Ecological Footprint Analysis are considered.

Another study evaluates the effectiveness of environmental indicators derived from three methods that are widely used in animal production: Input–Output Accounting, Ecological Footprint Analysis and LCA (Thomassen and de Boer 2005). The data used to evaluate the environmental indicators effectiveness were collected from eight organic dairy farms in the Netherlands.

During the past years several LCA studies comparing different milk production systems have been conducted. In a Swedish study an LCA is performed on organic and conventional milk production at farm level in Sweden, focusing especially on concentrate feed production (Cederberg and Mattsson 2000). Other studies on similar topics consider different aspects of the livestock productions systems, i.e. the differences in terms of energy flows, in the production of conventional and organic milk (Grönroos et al. 2006). The study of Haas et al. (2001) applies the LCA methodology to evaluate the impacts caused by three different typologies of pasture: intensive, extensive and organic.

There are also several LCA studies performed in the sector of pig breeding: for example, the research by Basset-Mens and van der Werf (2005) compares three different production systems, while Eriksson et al. (2005) focus on the impact of feed choice in three pig production scenarios. Other studies consider the environmental impacts of different pig production potential scenarios to illustrate environmental benefits and disadvantages integrated in the production systems (Cederberg and Flysjö 2004), or to analyse the implications of uncertainty and variability in the LCA of pig production systems (Basset-Mens et al. 2006).

Only few researches have been conducted in reference to LCA studies in the poultry sector. Bennett et al. (2006) present the results of an LCA applied to an Argentinean conventional production of maize grain, compared with a similar production from a genetically modified variety, showing its impact when fed to broiler chickens. Another study (Ellingsen and Aanondsen 2006) aims to assess the environmental impacts of Norwegian cod fishing and salmon farming, compared with chicken farming.

The study of Pelletier (2008) about the environmental performance in the US broiler poultry sector aims to analyse, through LCA, the macro scale environmental impacts of material and energy inputs and emissions along the US broiler supply chain, as opposed to the most published research regarding the potential environmental impacts of broiler production, which is focused principally only on farm-specific emissions.

10.3.2 Ecological Footprint Analysis

The Ecological Footprint Analysis is a biophysical resources accounting method able to measure the load that a population or a production activity imposes on the ecosphere. The Ecological Footprint is an area-based indicator as it expresses the impact in terms of area (real and virtual) that is effectively required to sustain that population or activity (Rees 1992; Wackernagel and Rees 1996). Formally, the Ecological Footprint of a certain population or a production activity is defined as the area of productive land and water ecosystems required, on a continuous basis, to produce the resources consumed and to assimilate the waste produced, wherever on the earth the relevant land/water may be located and with the prevailing technology (Wackernagel and Rees 1996; Monfreda et al. 2004, Wackernagel and Kitzes 2008, Kitzes et al. 2007). The methodology also proposes a second indicator called Bio-capacity that measures the annual production of biologically provided resources (Wackernagel and Rees 1996).

Both Bio-capacity and Ecological Footprint are expressed in terms of global hectares (*g*ha), or hectares with global average productivity (Kitzes et al. 2007; Galli et al. 2007). It is a normalised unit useful to make a comparison among lands with different productivity (Monfreda et al. 2004).

Six categories of productive areas are usually included in the calculation: crop land, grazing land, fishing grounds, forest area, built-up land and energy land (or carbon footprint, that is the amount of forest land required to capture those carbon dioxide emissions not sequestered by the oceans) (Wackernagel and Rees 1996). Yield factor and Equivalence factor are used to translate these six land types into global hectares (Monfreda et al. 2004). Equivalence factor represents the relative productivity of the six categories of land and water area, while yield factor represents local to global average productivity of the same land category.

The difference between Bio-capacity and Ecological Footprint defines a sort of ecological balance. When Ecological Footprint exceeds the Bio-capacity, the region runs an ecological deficit, which means that a population uses more resources than annually available. The opposite of ecological deficit is ecological reserve or surplus. The Footprint method is widely used to give a measure of the (un)sustainability of consumption patterns at different scales: regional (see for example Folke et al. 1997; Bagliani et al. 2008), national (see for example Erb 2004; Medved 2006; Moran et al. 2008) and global (Van Vuuren and Bouwman 2005; WWF 2006).

Ecological Footprint has also been analysed as temporal series together with economic indicators such as Gross Domestic Product – GDP (Jorgenson and Burns 2007) and Index of Sustainable Economic Welfare - ISEW (Niccolucci et al. 2007), or incorporated in thermodynamic-based methods (Zhao et al. 2005, Chen and Chen 2006; Nguyen and Yamamoto 2007).

Up-to-date industrial and agricultural Footprint applications are still rare. Studies on cultivation of tomatoes (Wada 1993), conventional versus organic wine farming (Niccolucci et al. 2008), shrimp and tilapia aquaculture (Kautsky et al. 1997) have been carried out to highlight the appropriation of natural capital, the efficiency of natural resource use, and the environmental pressure. Evaluations of the environmental impact of farms (van der Werf et al. 2007) and dairy production (Thomassen and de Boer 2005) as well as assessment of economic and ecological carrying capacity of crops (Cuandra and Björklund 2007) proposed the Footprint jointly with other methods, such as Life Cycle Assessment, Emergy Analysis and Economic Cost and Return Estimation.

10.3.3 Emergy Evaluation

Solar Emergy (from now Emergy) represents the total amount of available solar energy (i.e. exergy), directly or indirectly required to make a product or to support a process; the Emergy of a product is therefore related to the way it is produced. It is expressed in solar emergy joule (sej). All process inputs (i), including energy of different types and energy inherent in materials and services, are converted into Emergy by means of a conversion factor called transformity (Tr, Emergy per unit energy, sej J^{-1}) and the Emergy flow to a product (Em, sej) is calculated as

$$Em = \sum_i Tr_i E_i \tag{10.1}$$

where E_i is the available energy. A higher transformity means that more Emergy is needed to produce a unit amount of output. (See Equation 10.2, where E_o is the energy of the output (measured), while Tr_o is the transformity of the output (calculated).

$$Tr_0 = \frac{Em}{E_0} \tag{10.2}$$

The circularity of Equations 10.1 and 10.2 is avoided since, by definition, transformity of solar energy is 1 sej J^{-1}. In this way all inputs are converted into the solar equivalent energy needed to create those energy flows; each flow is multiplied by its transformity and summed, and the result is the amount of total resources (renewable and non-renewable) that have been necessary in order to obtain a product or a process (Equation 10.1). When an input is available in mass unit, instead of Joules, a specific emergy is used, measured in sej g^{-1}.

Emergy analysis obeys a logic of memorization (i.e. emergy is 'accumulated' over time and not simply 'conserved') and therefore needs its own algebra that was summarised in four main rules by Brown and Herendeen (1996):

1. All emergy sources of a process are assigned to the processes output.
2. By-products from a process have the total emergy assigned to each pathway.
3. When a pathway splits, the emergy is assigned to each 'leg' of the split based on its percentage of the total energy flow on the pathway.
4. Emergy cannot be counted twice within a system: (a) emergy in feedbacks cannot be double counted; (b) by-products, when reunited, cannot be added to equal a sum greater than the source emergy from which they were derived.

For an in-depth discussion of this issue and the differences between energy and emergy analyses, see Brown and Herendeen (1996) and Odum (1996). For our purpose it is important to note that in our calculations among solar energy, rain and wind, only the highest of the three contributions to the total emergy flow will be considered, since they are co-products of the same phenomenon, i.e. the sunlight reaching the biosphere (Odum 1996). The baseline of global emergy flow used in this paper is 9.44×10^{24} sej $year^{-1}$. Emergy analysis separates renewable from non-renewable inputs and local from external inputs. These distinctions allow to define several emergy-based indicators that can provide decision support tools, especially when there are several alternatives (Bastianoni and Marchettini 1996; Brown and McClanahan 1996; Odum 1996; Ulgiati et al. 1995).

Emergy evaluation classifies inputs into different categories (i.e. local renewable, R, local non-renewable, N; and purchased, F). On the basis of these classes, some indicators can be computed in order to assess the sustainability of the use of resources.

The environmental loading ratio (ELR) is the ratio of purchased (F) and non-renewable local emergy (N) to renewable environmental emergy (R). A high value of this ratio indicates a low proportion between the use of non-renewable resources and that of renewable resources, so that environmental cycles are overloaded. The emergy investment ratio (EIR) is the emergy of purchased inputs (F) divided by local emergy, both renewable and non-renewable (N + R). A high level of this index represents a certain fragility of the system because of its dependence on inputs from other economic systems. The emergy flow density (ED) is given by the total emergy flow (R + N + F) supporting a system divided by its area. If this ratio is high, a large quantity of emergy is used in a certain area: this can mean a high stress on the environment and regards the land surface as a limiting factor for future development.

Emergy evaluation is particularly suitable for studies in agriculture, as it is a system in which natural and man-made contributions interact in order to obtain the final product, emphasising the role of ecological inputs that constitute the basic life support for living beings, for instance, in primary production (Lagerberg and Brown 1999; Brandt-Williams 2002).

In the past, emergy was already applied to several agricultural systems, both for comparative evaluations and simple agricultural systems (see for example Cavalett et al. 2006; Lefroy and Rydberg 2003; Liu and Chen 2007; La Rosa et al. 2008), and in particular to grape or wine productions together with exergy and Life Cycle Assessment (Bastianoni et al. 2003; Pizzigallo et al. 2008). Castellini et al. (2006) have already emphasised the importance of poultry farming production for Italian agriculture.

10.4 Results

10.4.1 Life Cycle Assessment

An LCA of an intensive poultry-rearing system has been carried out, considering data related to the farm for what concerns the breeding phase. The data have been collected through a direct survey of the farm reality. The goal of the LCA was to evaluate the environmental impacts associated to the system. The LCA results are then involved in the comparison with the results of the other two methods, the Emergy Analysis and the Ecological Footprint. The Functional Unit considered in the LCA is 1 kg of poultry meat.

For what concerns the scope definition, in this LCA only the phases of production of raw materials and production of the product ‘poultry meat’ have been taken into account, leaving out the phases related to the product use and disposal. This choice has been made to obtain the same basis of comparison of the methods, as the other two methods do not consider the use and disposal phases, but they only take into account the production phase. In reference to spatial and temporal boundaries, European and Italian production systems, during the most recent years, have been considered as boundaries for the analysis.

With regard to the implementation of the inventory, local data (related to Umbrian reality) have been used where possible, in particular for the processes ‘maize cultivation’, ‘sorghum cultivation’, and ‘soya cultivation’, which represent some of the components of the poultry feed, and also for the processes ‘transformation of maize in feed’, ‘transformation of soya in feed’, and for the overall phase of poultry rearing. The database Ecoinvent from SimaPro 7 software has been used for the other data (Nemecek et al. 2004).

The impact assessment phase has been developed using the method ‘Eco-Indicator 99’ (Goedkoop and Spriensma 2001). It is a method to measure various environmental impacts, and it is based on a damage function approach. The damage function presents the relation between the impact and the damage to human health or to the ecosystem. Impacts can be computed according to 11 different impact categories, or they can also be aggregated into three wider categories (Human Health, Ecosystem Quality, Resources). In our study we present the impact assessment for the 11 impact categories.

Results of impact assessment are already presented in the normalised version. Normalisation consists in dividing the impact category indicators by a 'normal' value. As said above, the most common procedure is to determine the impact category indicators for a region during a year and divide this result by the number of inhabitants in that area. Therefore, final results are expressed in Points: the higher the score, the more important is the impact.

The LCA carried out consists of three main phases: cultivation, feed production and breeding. Every phase includes different sub-processes. The cultivation phase involves the cultivation processes of maize, sorghum, soya and grain, which constitute the raw materials of the feed. Every single process includes all the necessary inputs to obtain the cultivated product (seed, fertilizers, pesticides, use of machinery, transport inside and outside of the farm), and the related emissions. Regarding emissions derived from the use of fertilizers, a national manual of emissions has been considered (Bini and Magistro 2002). The second phase investigated consists in the feed production. It includes, for each crop, the transformation process from crop to feed, involving mainly water, energy and fuel consumption. In this case emissions have been evaluated through direct surveys of the firms' realities. The final product is then obtained by assembling the transformed crops together with other minor components (calcium carbonate, sodium chloride, bi-calcium phosphate, and other chemical organic additives). Finally, in the poultry-breeding phase the main input is the feed, and the other inputs considered are water, fuel and energy consumption, and all the infrastructures materials (steel, aluminum, synthetic rubber, glass, plastic, copper, zinc). The principal emissions related to breeding are also taken into account (ammonia, methane, dinitrogen monoxide) (European Commission 2003). Table 10.3 reports the main emissions for each phase.

Figure 10.3 shows the principal components belonging to the system life cycle. Feed production is the element which contributes the most to the environmental

Table 10.3 Principal emissions in the Life Cycle Assessment study (database Ecoinvent; method of impact assessment Ecoindicator 99)

Substance	Unit	Value	Process mainly contributing	Value in the process
NO_x	(g/FU[a])	3.8	Feed production	3.0
CO_2 biogenic	(g/FU)	10.2	Feed production	10.0
CO_2 fossil	(g/FU)	677.0	Feed production	567.4
CO biogenic	(mg/FU)	95.1	Feed production	88.6
CO fossil	(g/FU)	1.3	Feed production	1.0
Particulates, <2 μm[b]	(mg/FU)	382.0	Feed production	335.6
Particulates, >10 μm	(mg/FU)	387.0	Feed production	328.5
Particulates, 2–10 μm	(mg/FU)	197.0	Feed production	174.7
SO_2	(g/FU)	2.5	Feed production	2.1
Methane	(mg/FU)	463.0	Breeding phase	463.0
Methane biogenic	(mg/FU)	18.4	Feed production	18.1
Nitrates	(g/FU)	4.3	Feed production	4.1

[a] FU = Functional unit

[b] μm= Micrometers

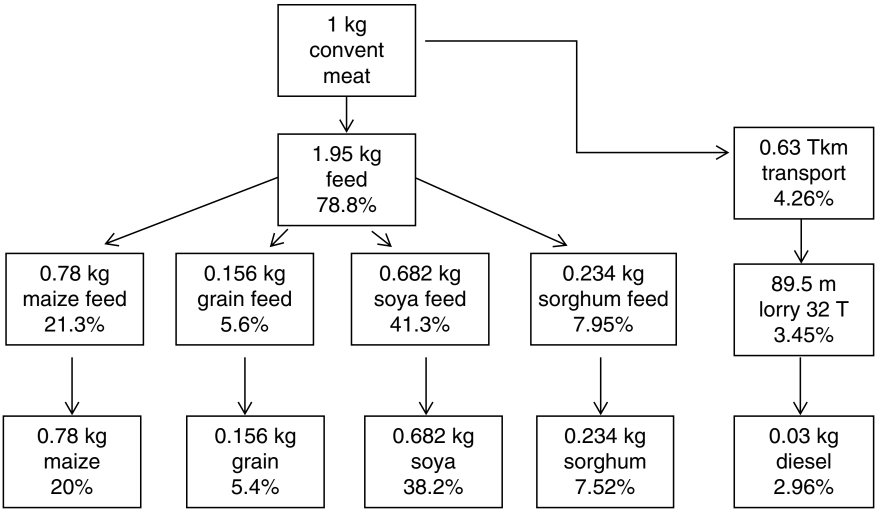

Fig. 10.3 Conventional poultry system life cycle. This figure shows the principal processes involved in the conventional poultry system. For each process the relative quantity (in kg) necessary to produce 1 kg of poultry meat (Functional Unit) and the process contribution to the environmental impact of the system, in percentage, are presented

impacts in the system. In particular the cultivation and then the transformation of maize and soya are the processes with the strongest impact.

With regard to the impacts assessment, Fig. 10.4 reports the analysis conducted with Eco-Indicator 99. The figure shows the normalised impact categories. The category showing the greatest impact is ‘land use’, followed by ‘fossil fuels’ and ‘respiratory inorganics’ categories. The impact assessment carried out for each phase shows that feed production weighs the most on these three impact categories, while the breeding phase influences especially the two categories, ‘acidification and eutrophication’ and ‘respiratory inorganics’ and, to a minor extent, the ‘climate change’ category.

10.4.2 Ecological Footprint

The Ecological Footprint of a product is defined as the sum of the Footprint of all the activities required to create, use, and/or dispose of that product (Global Footprint Network 2009). As suggested by the document ‘Ecological Footprint Standard 2009’ (Global Footprint Network 2009) there are two widely used approaches for calculating the Footprint of a complex finished product: process-based life-cycle assessment and extended input–output life cycle assessment.

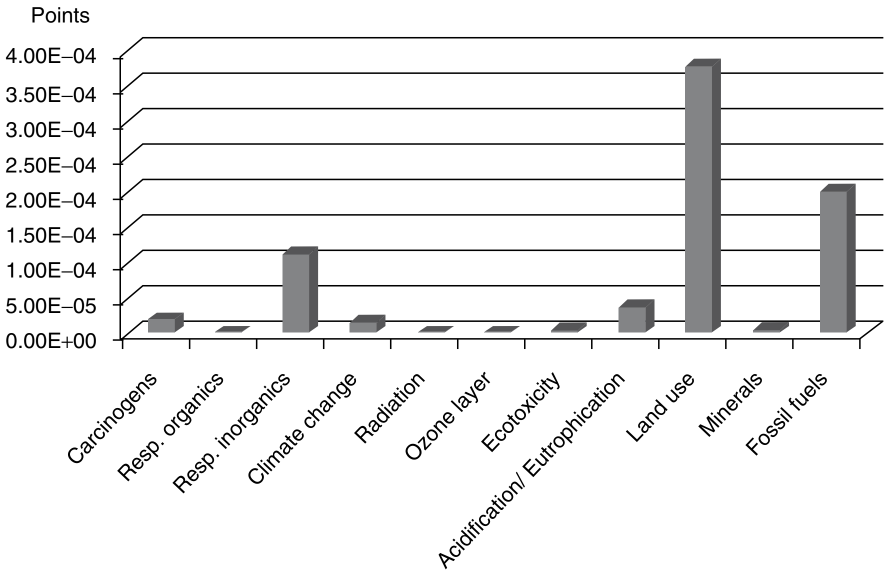

Fig. 10.4 Conventional poultry system impact assessment. The figure shows the environmental impact of the conventional poultry system relative to the 11 different impact categories by the method Eco-Indicator 99. Results are expressed in normalised Points. The higher the score, the more important is the impact. 4.00E-04 refers to 0.0004

In this study a 'life cycle approach' is used. All relevant inputs, from cradle to gate (until the animals leave the farm, without taking into account slaughtering processes and retailing), are accounted to give an estimation of environmental impacts. Information is provided directly by the farm and refer to 2008. Table 10.4 reports the inventory of energy and material data (considered on the basis of their lifetime) required to sustain this conventional poultry production.

As first step each input is converted into relative bio-productive areas by means of specific conversion factors as indicated in the footnotes of Table 10.4. When opportune conversion factors are not directly available, energy intensity coefficients are adopted to convert data into energy units. A conversion into emission of CO_2 and then into the area of forest needed for sequestration is then performed. A world-average carbon absorption factor of 0.2071 ha tCO_2^{-1} is used to translate the emissions into forest land necessary to absorb them (Global Footprint Network 2006).

Furthermore, due to the lack of detailed information on the feed, data for 1–12 input are extracted from ECOINVENT® database (Nemecek et al. 2004). In this way it is possible to know how much carbon dioxide is emitted and how wide are cropland and built-up land necessary to support the production of one functional unit of a given input by considering similar production processes. For example, it was found that the production of 1 kg of maize emits 0.31 kg of CO_2 and requires 0.28 m^2 of built-up and 1.28 m^2 of cropland.

Table 10.4 Energy and material data, with relative conversion factor, for conventional poultry production

		Unit	Quantity	Conversion factors		
				Energy land	Built-up land	Crop land
				(kg CO_2/unit)	(m^2/unit)	(m^2/unit)
Input						
1	Maize	kg	5.48E+05	0.31[a]	0.28[a]	1.28[a]
2	Wheat bran	kg	1.10E+05	0.20[a]	0.01[a]	1.26[a]
3	Sorghum	kg	1.64E+05	0.20[a]	0.01[a]	1.34[b]
4	Soya meal	kg	4.66E+05	0.50[a]	0.05[a]	2.80[a]
5	Sodium chloride	kg	2.74E+04	0.20[a]	0.002[a]	0.00002[a]
6	Bicalcium phosphate	kg	1.37E+04	0.04[a]	0.003[a]	0.0001[a]
7	Calcium bicarbonate	kg	1.37E+04	0.04[a]	0.001[a]	0.0001[a]
8	Additives	kg	1.10E+04	1.60[a]	0.003[a]	0.00003[a]
9	Coccidiostatic	kg	4.52E+02	1.60[a]	0.003[a]	0.00003[a]
10	DL-Methionine	kg	1.37E+02	1.60[a]	0.003[a]	0.00003[a]
11	Drugs and antibiotics	kg	2.67E+02	1.60[a]	0.003[a]	0.00003[a]
12	Disinfectants	kg	2.75E+02	0.40[a]	0.004[a]	0.00005[a]
13	Buildings and shelter[e]					
14	Machinery	t	3.20E-01	2,770[a]		
15	Steel	t	2.20E-01	2,770[a]		
16	Plastic	t	2.41E-02	1,700[a]		
17	Human labour	Work-days	597.50	–	–	–
18	Electricity	kWh	3.08E+04	0.48[c]		
19	Diesel	l	6.00E+02	2.65[d]		
20	Liquid petroleum gas	l	2.50E+04	1.69[d]		
21	Copper	kg	1.81E+00	1.53[a]	0.72[a]	0.00076[a]
22	Water	l	1.94E+06	0.00037[f]		
23	Buildings and roads	m^2	1.50E+03	–	–	–
Output						
1	Poultry	kg	5.63E+05			

5.48E+05 is for 5.48×10^5.
[a] From Ecoinvent database.
[b] Our estimation.
[c] Our evaluation on Italian electricity system in 2006.
[d] IPCC 2006.
[e] This input is the sum of several inputs of different kind. It is not possible to provide a single value for this input or a single conversion factor. All these data are available upon request.
[f] Chambers et al. 2000.

Human labour contribution is also included by allocating the Footprint of an average Italian citizen (WWF 2006) on the basis of the number of work hours per year. Each kind of land (energy, cropland and built-up) is then normalised into global hectares by means of its equivalence factor obtained from the WWF Living Planet Report (WWF 2006). Finally, the Ecological Footprint for poultry production is given as the sum of all croplands, energy lands and built-up areas.

Results show that the total amount of bio-productive land, or Ecological Footprint, required for the conventional poultry production is 721.60 gha year that means 12.81 gm^2 year kg^{-1} of chicken. Comparison with other kind of meat production is not possible due to the lack of specific Footprint literature. However, Gerbens-Leenes and Nonhebel (2005) estimated the land requirement (values are expressed in m^2 year kg^{-1}) for producing three different types of meat: beef (20.9), pork (8.9) and chicken (7.3).

The ratio of the total Footprint value with respect to Bio-capacity (item 23 in Table 10.4, expressed in gm^2) measures how much the overall demand exceeds the local supply of resources. The value calculated for this production is 172. This means a very high dependence on resources imported from outside of the system that generally are not renewable. The lower this ratio, the lower the request of natural capital from outside (or greater is the virtual land-component).

Figures 10.5 and 10.6 show the Footprint results by land and consumption categories, respectively. The main Footprint land component is cropland (73%). This can be related to chickens' diet that requires high quantities of feed, especially

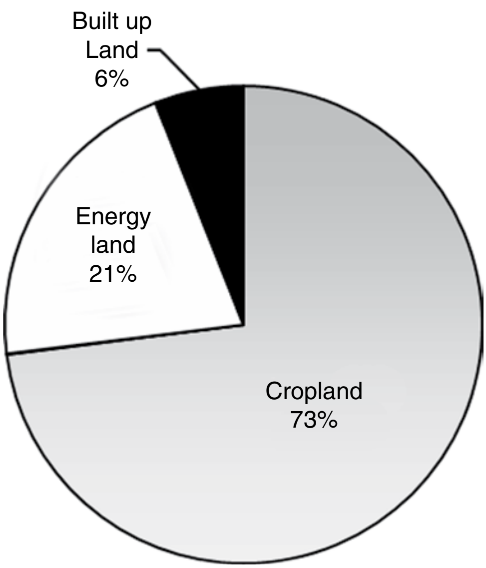

Fig. 10.5 Ecological Footprint for conventional poultry production disaggregated by land categories. The main contribution is due to cropland which is highly needed to cultivate maize and soya meal

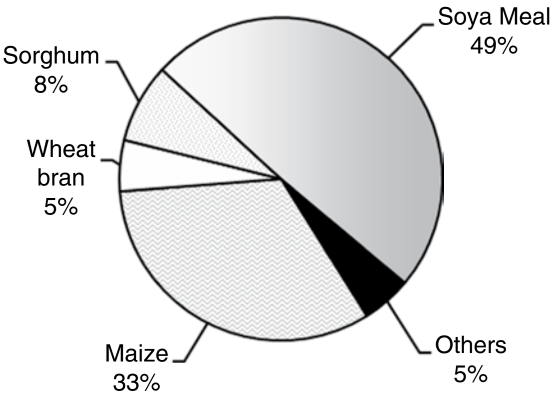

Fig. 10.6 Ecological Footprint for conventional poultry production disaggregated by consumption categories. Main contributions are related to chickens' diet

maize and soya meal, which, in turn, requires wide cropland. Energy land (or the land needed to absorb the carbon dioxide emissions) accounts for 21%, while built-up is just 6%. The other land components are not relevant. These values are quite typical for this kind of product.

When Footprint is considered according to consumption categories, it is possible to detect the contribution of each input. Results show that the 95% of the total Footprint is given by the diet component. In particular, soya meal and maize are Footprint-intensive cultivation. Footprint results agree with those derived from Emergy evaluation.

10.4.3 Emergy Analysis

All the results are related to the whole system under analysis. Table 10.5 shows the emergy evaluation of the system considered. Moreover, all the inputs to the system are differentiated by their categories, as described in the methods paragraph. Some of the emergy flows listed in the tables are considered only partially renewable, according to the percentage of renewable inputs required for their production.

For all the inputs that determine the diet we have considered their characteristics of renewability/non-renewability. Human labour is also considered partially renewable in emergy evaluation, according to Ulgiati et al. (1994). The diet is the most important factor in the whole emergy evaluation, accounting for more than 82% of the total emergy flow. The percentage of renewability of these inputs is not very high since they come from industrialised agriculture. Conventional poultry production uses techniques that utilise various additives, growth hormones and other chemicals to help produce their chickens faster and larger in size, aiming to be

Table 10.5 Raw inputs and emergy evaluation of the poultry production analysed in this study

#	Inputs	Unit	Flow (unit year^{-1})	Transformity (sej unit^{-1})	Reference[a]	Emergy flow (sej year^{-1})	Type of resources[b]
1	Solar energy	J	5.83E+13 [c]	1.00E+00	a	5.83E+13	R
2	Rain	g	1.03E+10	8.99E+04	a	9.28E+14	R
3	Wind	J	1.32E+11	1.50E+03	a	1.98E+14	R
4	Geothermal heat	J	4.73E+10	2.55E+04	a	1.20E+15	R
5	Erosion of soil	J	5.01E+11	7.38E+04	b	3.70E+16	N
6	Water	g	2.67E+07	4.74E+07	f	1.27E+15	N
7	Liquefied petroleum gas (LPG)	J	5.84E+11	5.54E+04	d	3.24E+16	F
8	Concrete	g	1.38E+07	1.09E+09	d	1.50E+16	F
9	Bricks	g	3.29E+06	2.21E+09	e	7.26E+15	F
10	Straw for litter	J	4.41E+04	4.30E+03	f	1.90E+08	42 % R 58 % F
11	Steel	g	1.38E+06	4.18E+09	d	5.78E+15	F
12	Copper	g	1.81E+03	6.24E+10	d	1.13E+14	F
13	Plastics	g	4.06E+05	9.86E+09	f	4.01E+15	F
14	Maize	g	5.48E+08	7.82E+08	f	4.28E+17	22% R 78% F
15	Wheat bran	g	1.10E+08	5.41E+09	f	5.93E+17	42% R 58 % F
16	Sorghum	g	1.64E+08	6.92E+08	f	1.14E+17	37 % R 63 % F
17	Soybean oil	g	1.08E+07	1.66E+05	f	1.79E+12	10 % R 90 % F
18	Soy flour	g	4.66E+08	1.82E+09	f	8.47E+17	10 % R 90 % F
19	Salt	g	2.74E+07	1.00E+09	f	2.74E+16	F
20	Bicalcium phosphate	g	1.37E+07	3.90E+09	f	5.34E+16	F
21	Calcium bicarbonate	g	1.37E+07	1.00E+09	f	1.37E+16	F
22	Additives	g	1.10E+07	1.48E+10	b	1.62E+17	F

(continued)

Table 10.5 (continued)

#	Inputs	Unit	Flow	Transformity	Reference[a]	Emergy flow	Type of resources[b]
			(unit year^{-1})	(sej unit^{-1})		(sej year^{-1})	
23	Coccidiostatic	g	4.52E+05	1.48E+10	b	6.69E+15	F
24	DL-Methionine	g	1.37E+05	1.48E+10	b	2.03E+15	F
25	Drugs	g	2.67E+05	1.48E+10	b	3.95E+15	F
26	Disinfectants	g	2.75E+05	1.48E+10	b	4.07E+15	F
27	Human labour	J	4.40E+09	7.38E+06	f	3.25E+16	10% R 90% F
28	Electricity	J	1.11E+11	1.24E+05	d	1.38E+16	F
29	Diesel	J	2.06E+10	6.60E+04	d	1.36E+15	F
30	Total emergy flow	g	5.63E+08	4.27E+09		2.41E+18	Y

[a] References for transformity and specific emergy: (a) Odum et al. 2000; (b) Brandt-Williams 2002; (c) Odum 1996; (d) Brown and Arding 1991; (e) Brown and Buranakarn 2003; (f) Castellini et al. 2006.

[b] Local renewable input (R), local non-renewable input (N), purchased input (F).

[c] 5.83E+13 is for 5.83×10^{13}

Table 10.6 Summary of the main emergy-based indexes for the conventional poultry production analysed

Emergy index	Expression[a]	Value	Unit
Investment ratio (EIR)	F/(N + R)	3.69	–
Environmental loading ratio (ELR)	(N + F)/R	4.07	–
Empower density (ED)	(R + N+ F)/area	1.61E+14[b]	sej $ha^{-1}\cdot year^{-1}$

[a] Local renewable input (R), local non-renewable input (N), purchased input (F).
[b] 1.61E+14 is for 1.61×10^{14}.

competitive in the current market. These inputs reach 10% of the total emergy flow supporting the system and are considered as non-renewable.

Energetic resources, such as fuels, electricity and liquid petroleum gas, human labour and buildings materials make up the rest of the inputs since the other natural renewable inputs, such as sun, rain and wind, represent less than 1% of the total.

Table 10.6 shows how the characteristics of renewability and the location of the inputs are reflected in the emergy indicators. The investment ratio is quite high, indicating that the emergy acquired from outside the system is 3.69 times higher than the local emergy. The environmental loading ratio (ELR) indicates that the non-renewable resources are more than four times higher than the renewable ones, demonstrating a high concentration of non-renewable inputs in the area, confirmed by the empower density (ED), that can highly impact the environmental characteristics of the area. The impact suggested by this ratio can be located anywhere, since the exploitation of non-renewable resources has an impact per se, while their use implies another impact, the empower density, which is around two orders of magnitude higher that in the case of agricultural or extensive breeding systems; it suggests that the main impact is local. This explains the need of further inputs for the cleaning up and the additional energy, material (and economic!) expenses for the environmental and health safety of the system.

10.5 Discussion

In order to assess the quality of the information that each method provides on sustainability, we adopted the following judgement criteria:

1. *Representativeness*: ability to describe all the features of the observed phenomenon
2. *Verifiability*: possibility to check the information of the model
3. *Reproducibility*: ability to achieve the same results in future time
4. *Comprehensibility*: ability to be easily understandable for people who do not deal with the specific research argument

10.5.1 Representativeness

Representativeness is the most important feature of the four above-mentioned criteria because it corresponds to the link between the object to judge and the way it is represented in the analysis. The objective of the analysis, as stated in the introductory part of the chapter, is to assess the environmental sustainability of a poultry-rearing system by means of three different methods. Generally, sustainability is connected with three main dimensions: economic, environmental and social. In the specific case of the poultry-rearing system we focus particularly on the environmental one.

Two aspects must be analysed to evaluate the state of environmental sustainability of a system: the impact or exploitation of a resource, and the availability of that resource (Bell and Morse 1999). In our specific case the resource corresponds to the environment as a whole. In assessing the ability of the three methods to bring out information on environmental sustainability, we analyse how they reflect the two aspects just mentioned.

In the three assessment methods the impact on the environment is evaluated in different ways. This can be easily noticed by the measure unit employed in each analysis (Table 10.7). LCA has several categories of impact. For each category there are several indicators. Depending on the aspect observed by the indicators (damage to human health, damage to ecosystem or damage to mineral and fossil resources) the measure unit can be Disability Adjusted Life Years (DALY), Potentially Disappeared Fraction of plant species (PDF m^2 year) or additional energy requirement to compensate lower future ore grade (MJ surplus energy). LCA provides information about direct and indirect effects on human being caused by environmental changes. The direct effects are captured by the categories concerning the impact on human health while the indirect effects by the categories concerning the ecosystem and the mineral and fossil resources. Our results for LCA (Fig. 10.4) show that the main impact categories affected are in ascending order: respiratory inorganics, fossil fuels, land use.

In the Ecological Footprint Analysis the indicator used to describe the impact on the environment is one, the Ecological Footprint. The measure unit is the global hectare (gha). The Ecological Footprint allows understanding which type of land category is mainly used or impacted: crop land, land to absorb greenhouse gas emissions, or built-up land (Fig. 10.5). Thanks to the Ecological Footprint, we found that 9.35 gha of the 12.81 gha of impacted land used to produce 1 kg of poultry in a year belong to the category crop land. Therefore the main human pressure on the ecosystem for the production of poultry meat derives from crop cultivation.

Among the indicators developed by Emergy Analysis, the Environmental Loading Ratio is the one focusing more on environmental sustainability. The measure unit is the Solar joule. Our Emergy Analysis shows that four trillion solar joule are employed to produce 1 kg of meat. This indicator represents the ratio between resources provided by the economic system (external to the analysed production system and not renewable) and renewable resources, describing in this way how much the system relies on resources exploited in a not-sustainable manner.

Table 10.7 Denomination of indicators and measure units used in the analysis (Goedkoop and Spriensma 2001)

Life Cycle Assessment		Ecological Footprint Analysis		Emergy Analysis	
Categories of the indicators employed for the analysis	Measure unit	Indicators employed for the analysis	Measure unit	Indicators employed for the analysis	Measure unit
Carcinogens	DALY	Ecological Footprint	gha	Free renewable emergy (R)	sej
Resp. organics	DALY	Bio-capacity	gha	Free non-renewable emergy (N)	sej
Resp. inorganics	DALY			Purchased emergy brought by the economic system (F)	sej
Climate change	DALY				
Radiation	DALY				
Ozone layer	DALY				
Ecotoxicity	PDF m^2 year				
Acidif./Eutrop.	PDF m^2 year				
Land use	PDF m^2 year				
Minerals	MJ surplus energy				
Fossil fuels	MJ surplus energy				

DALY: Disability Adjusted Life Years PDF m^2 year: Potentially Disappeared Fraction of plant species
MJ surplus energy: Additional energy requirement to compensate lower future ore grade
gha: Global hectare
sej: Solar joule
R: local renewable input, N: local non-renewable input, F: purchased input

However, without classifying the type of emergy used, Emergy Analysis is not able to provide significant information about human counteractions to the impact produced.

Therefore, considering these differences in terms of measure unit and type and quantity of indicators used, we can state that the multi-dimensionality of LCA brings out much more information on the impacts than Ecological Footprint or Emergy Analysis, also because it considers the indirect effects on human being caused by environmental changes. The information on the environmental impacts is broader than in the other methods. A common information that all the three methods convey (Figs. 10.3, 10.6 and Table 10.5) is that the major source of the impacts is the feed for animals.

On the other hand, Ecological Footprint and Emergy Analysis have other advantages which LCA does not offer. LCA allows giving judgements on the impacts generated by the poultry production, in relation to a previous state of the environment taken as reference point (Goedkoop and Spriensma 2001). However, a trend from a previous state does not provide any information about the resources availability and LCA analysis is not able to evaluate how much of the consumed resources are still available. Although it is not possible to define precisely a sustainable state (Bell and Morse 1999) we cannot affirm that a production system is environmentally sustainable only considering the dynamism of its impacts.

Instead Ecological Footprint Analysis uses the bio-productive land effectively owned by the breeding system (Bio-capacity) as an indicator of resources availability. The measure unit of this indicator is the global square meter. The mono-dimensionality of the method allows comparing the value of impact with the value of available resource, thus to define if the production system, concerning only the category of the ecosystem exploitation, is sustainable. In our study the ratio between Ecological Footprint and Bio-capacity shows that the production system is not sustainable (Fig. 10.7) because the bio-productivity used by the system is 172 times higher than the bio-productivity really owned.

For what concerns Emergy Analysis, as stated above it is possible to classify the type of Emergy source used in the system (Fig. 10.8). In our study, 79% of the total amount of emergy necessary to produce 1 kg of poultry derives from external and non-renewable factors provided by the economy (F), 1.5% derives from non-renewable factors available in the spatial boundary of the breeding system, and 19.5% derives from renewable factors. Through the Environmental Loading Ratio, we can see that the non-renewable emergy is four times higher than the renewable one. As in the Ecological Footprint Analysis, the mono-dimensionality of the method allows to compare resources depletion with resources availability (which in this case can be identified with the rate of renewable factors). Finally the results show that the breeding is not sustainable.

We can conclude that every method gives useful but different information for the representativeness of environmental sustainability in the analysed rearing system. LCA has a micro-focus approach; through its multi-dimensionality it describes in detail how the human well-being is affected, allowing a real intervention on concrete problems and indicating the direction to follow with respect to a previous system state. On the other hand, Ecological Footprint and Emergy Analysis consider the availability of natural resources and not only the impact produced. This allows to state if a production system is sustainable from the environmental point of view. However, only one measure unit and dimension is used, leading to a reduced amount of information.

Since LCA is composed of multiple indicators it is possible, as some software allow, to integrate also the indicators concerning Ecological Footprint and Emergy Analysis. In this way the information on environmental sustainability could be complete, thanks to the fusion of the three different methods perspectives.

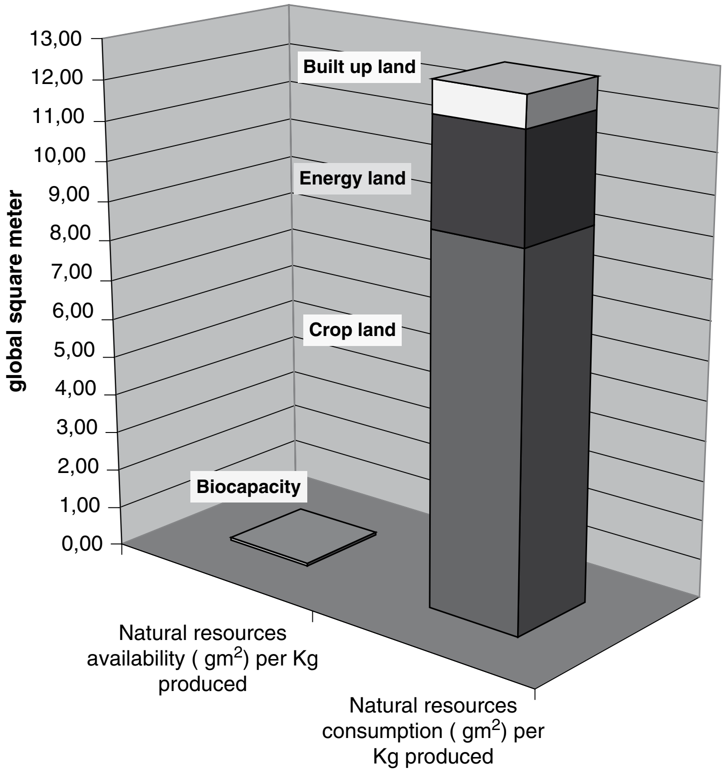

Fig. 10.7 Resources exploitation and resources availability in Ecological Footprint Analysis

The analysis refers to a single case study. Nevertheless, the three methods turn out to be more useful in the environmental sustainability decision-making process when considering the same production system over time, or comparing two production systems that provide the same output.

There are other important information to take into account about representativeness. The three methods can be considered systemic because the researcher has the possibility to set the boundaries (spatial and time limits) of the analysed system (Bell and Morse 1999). A negative aspect concerning Ecological Footprint is the absence of computation of matter and water depletion, unlike Emergy Analysis and LCA, in which these two aspects are taken into account for the final values of their indicators.

A general weakness of LCA method is that often available databases offer data coming from realities which are very different from the one represented in the study. In this case the results are not properly representative of the situation investigated.

The resilience effect can be regarded as the strength of Ecological Footprint. In fact the sub-category of required productive land to absorb carbon dioxide (energy land) includes the environment mitigation of human greenhouse gases production.

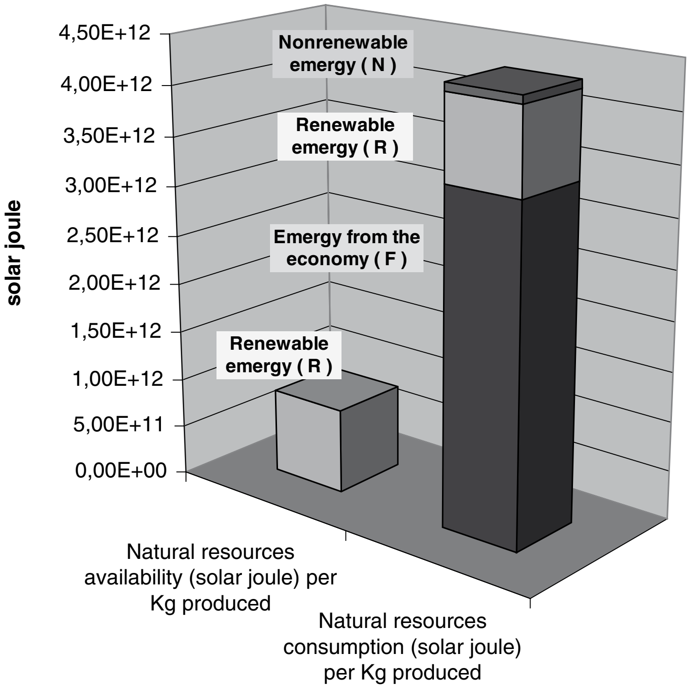

Fig. 10.8 Resources exploitation and resources availability in Emergy Analysis

Negative and more relevant aspects of Emergy Analysis about representativeness are strictly related to the general validity of the theory. Ayres (in Hau and Bakshi 2004) argues that it is hard to connect a defined value of solar joule to the matter (rocks and minerals) and its several specific states. Also Hammond (2007) raises doubts on the physical validity of Emergy.

10.5.2 Verifiability

In LCA the verifiability of the model is possible but not for the overall set of the data. In fact foreground data derive from the communication with data providers. As a consequence they are generally obtained from real measurements or surveys. On the contrary, background data derive from databases or literature; hence they could be also assessed values.

Although Ecological Footprint and Bio-capacity are composite indicators based on a mono-dimensional value they can be considered quite verifiable. In fact both are a sum of many productive land categories; hence the values of the latter are measurable with real and existent tools.

The verifiability of Emergy Analysis information is a major problem. The measure unit of the model is mono-dimensional and the solar joule values are necessarily assessed since, at the moment, there are no available tools that can directly measure them.

10.5.3 Reproducibility

Reproducibility of results is one of the advantages of LCA. In fact this assessment method has a consistent set of specific databases which contain a huge amount of information. However, the results of the LCA study are strictly dependent upon the initial assumptions and upon the type of data used, and they can significantly change if using different information from the databases or starting from different assumptions. Moreover, if the complexity and the scope of the LCA study increase, processing time and costs will grow considerably.

Despite the easy computation in Ecological Footprint, the information reproducibility on sustainability pays the consequences of the lack of a specific database. This problem is highlighted by the calculation of the productive land required to absorb CO_2. There is no matter-specific direct conversion factor to assess this value. When considering each evaluated item, first of all it is indispensable to find the amount of greenhouse gas emissions and secondly to get the corresponding productive land to absorb them.

Emergy computation corresponds to a simple product of two factors. The reproducibility of the information raises problems only in reference to the conversion-factor (transformity). In fact, the same transformity was used for many assessed factors of the breeding system because of the lack of appropriate and specific conversion factors.

10.5.4 Comprehensibility

Regarding comprehensibility, unfortunately LCA language is not easily understandable by a ‘not expert public’. This is because one of the main outputs of the method is the inventory table, which represents a long series of data; that is, all the set of emissions deriving from the system.

On the contrary, comprehensibility is probably the strongest feature of Ecological Footprint. The indicators language is easily understandable even though specific. Explaining the concept to farmers from whom data have been collected did not seem difficult as happened in the case of other models. This was twice as effective on the survey: first of all because farmers were able to provide more appropriate data to build the indicator, secondly because this reinforced in themselves the awareness of being an active part of the survey team. Therefore, the quantity of available information was higher than usual.

Unlike Ecological Footprint, the language of Emergy Analysis is not quickly comprehensible. People who are not used to deale with this specific subject have difficulties in understanding what a solar joule corresponds to.

Table 10.8 reports the main characteristics of the three different methods and allows to appreciate the differences for each of the above mentioned criteria. Each method presents both positive and negative aspects.

10.6 Conclusion

The appropriate instrument for a multi-dimensional representation of sustainability is a suitable set of indicators that must be an integral part of an assessment methodology. The three methods that we compared in this study provide a solution, since they are able to cover most of the information needs for the environmental dimension of sustainability in agriculture. We have detected several analogies when comparing the methods in terms of results related to the analysed system, that is, the intensive poultry-rearing farm.

Thanks to the Emergy Evaluation we found that for the analysed system the diet is the most important factor in the whole analysis, accounting for more than 82% of the total emergy flow. Our results obtained from Ecological Footprint Analysis point out that crop land, which is connected with chickens' diet, is the main land component, accounting for 73% of the total. The high quantities of maize and soya needed for feed require much crop land. Finally, thanks to the use of LCA, we found that feed production is what contributes the most to the environmental impacts of the system, influencing the impact category 'land use'. Our LCA analysis comes to the same conclusion as Ecological Footprint: the cultivation and the transformation of maize and soya are the processes with the strongest impact.

Finally, in our study both Emergy and LCA pointed out that the percentage of non-renewability of the inputs is high, with respect to the renewable ones. Emergy leads to this conclusion thanks to the Environmental Loading Ratio, while LCA thanks to the use of 'fossil fuels' impact category. Therefore, although the three methods use specific indicators and methodology, they come to the same conclusions for the system investigated.

By comparing the methods according to the four criteria of representativeness, verifiability, reproducibility and comprehensibility, we conclude that each of the three methods shows both positive and negative aspects, strengths and weaknesses, but all of them are effective in representing the environmental features of a given activity; 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 analyse the situation from a multi-dimensional perspective. On the contrary, if we are dealing with a problem of resources availability, Ecological Footprint or Emergy Analyses are

Table 10.8 The three methods positive and negative aspects

	Life Cycle Assessment		Ecological Footprint Analysis		Emergy Analysis	
	Positive aspects	Negative aspects	Positive aspects	Negative aspects	Positive aspects	Negative aspects
	Systemic	No carrying capacity	Systemic.	No matter and water depletion computation	Systemic	No resilience
Representativeness	Many impact categories considered	Data from realities different from the one investigated	Carrying capacity		Carrying capacity	Uncertainty of basic theory assumptions
		No resilience	Resilience		Matter and water computation	
Verifiability	Measurable values	Some values necessarily assessed	Measurable sub-categories	Mono-dimensional		Mono-dimensional. Values necessarily assessed.
Reproducibility	Presence of specific databases	Results strictly dependent from the type of data. Complexity of the study implies more costs and time	Easy computation	Absence of specific database	Easy computation	Absence of specific database
Comprehensibility		No easy access language	Easy access language			No easy access language

better ways to evaluate the exploitation level of the analysed 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.

Therefore, all environmental impact indicators used in our study, resulting from the application of the three methods to the case study, constitute a proper set of environmental indicators, to be used for sustainability assessment. So far, there are too few applications of the three methods in agriculture. In particular, in the livestock sector they are really rare, and the situation in poultry breeding is even worse. On the other hand, the need to conduct studies on the relationships between livestock and the environment is widespread throughout the world.

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