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The joint use of LCA and emergy evaluation for the analysis of two Italian wine farms

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Abstract

The aim of this paper is to evaluate two agroindustrial productive processes in their entirety (one organic and one semi-industrial), focusing on the comparison of impacts derived from the inputs and outputs of the system (life cycle assessment, LCA), integrated with a physical evaluation of the resources and natural services, on a common basis (emergy).

Methods based on the joint use of LCA and emergy evaluation are useful, as they measure the contribution of environmental services and products to the productive process thus focusing primarily on the environmental impact of emissions and non-renewable energy inputs.

The complementarity of the methods used in this paper contributes important elements and information useful for the comprehension of the organization of agriculture within Siena's territory.

The results show important elements and useful information: (1) for the comprehension of the two agroecosystems' organization; (2) for the use of the energy flows that determine their development. Moreover, the combined use of emergy and LCA gives a comparative thermodynamic performance evaluation between organic and semi-industrial farming.

Keywords: Life cycle assessment (LCA); Emergy; Wine; Siena

1. Introduction

In an age in which agriculture has assisted in the decline of energy sources, and in the pollution of soils and water tables, it has become urgent to manage natural resources in an effective and efficient way in order to sustain agricultural activity (Kang and Park, 2002). In general, agricultural economies represent a meeting point between human essential needs and nature's primary production. Since environmental issues affect so many disciplines, cross-disciplinary interaction is essential for the development of ‘‘eco-centric’’ methods (Bakshi and Fiksel, 2003).

Methods based on the laws of thermodynamics are useful, because they measure the contribution of environmental services and products to the productive process. Therefore their use, and the fact that they allow for a representation of all the energetic flows that feed a system, makes possible an evaluation of the sustainability of agricultural productive processes.

Life cycle assessment (LCA) in agriculture focuses primarily on the environmental impact of emissions and non-renewable energy inputs. In other words, it considers the impact of all agricultural processes in a product's life cycle, from the extraction of the natural resource to the use and disposal of the product. LCA ignores ecosystem services and products, and the final results of this analysis depend on subjective evaluation (Ulgiati et al., 2005). For this reason, it has become necessary to promote integration among methods that may be potentially complementary. Therefore, the usefulness of the emergy methodology for the ecological and economic analysis of agricultural systems and natural resources will be emphasized (Odum, 1996). 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., 2005; Lefroy and Rydberg, 2003; Liu and Chen, 2005), and

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in particular to grape or wine productions together with exergy (Bastianoni et al., 2003).

Emergy evaluation is a method that is able to evaluate environmental and economic products and services on a common basis, that of the equivalent solar energy, called "solar emergy", or "solar memory energy" (Scienceman, 1987). All systems and their inputs and outputs are organized hierarchically, considering their importance within a web of relationships, introducing the concept of "energy quality". Emergy evaluation is a powerful tool, for it is one of the very few methods that accounts for the contribution of ecological products and services. The main potential of this method is normalizing forcing factors, state variables, and other system attributes to one metric unit, namely solar emergy (Tilley and Swank, 2003).

The importance of this paper derives from the combined use of emergy and the LCA for the comparative thermodynamic evaluation of two wine producing farms—one using organic and one conventional farming methods—both situated in the Province of Siena, Italy. The aim of this paper is to evaluate the agroindustrial productive processes as a whole, focusing on the comparison of impacts derived from the inputs and outputs of the system (LCA), integrated with a physical evaluation of the resources and natural services, on a common basis (emergy). The complementarity of the methods used in this paper contributes important elements and information useful for the comprehension of the organization of the two agroecosystems and the use of the energy flows that determine their development, in relation to the importance that agriculture holds for the territory of Siena.

2. Methods

2.1. LCA

LCA's main objective is to assess needs and emissions of a production process. The data are classified in specific impact categories representing known environmental effects. The LCA procedure is an iterative methodology; every successive phase of the study focuses on aspects to be investigated in more detail: the old data will be replaced with new ones leading to a more realistic evaluation. Sometimes the complete analysis of the product life cycle from "cradle to grave" can be replaced by a shorter one called from "cradle to gate". This is normally allowed if there is a lack of data about a part of the production cycle and especially when the responsibility of the producer cannot be tracked outside the system.

The most up-to-date structure of the LCA is proposed by the ISO 14040 standard.

The LCA methodology can be synthesized in four main phases:

Phase 1: *Goal definition and scoping* (ISO 14040, 1997): During this phase, the objective of the study, the Functional Unit, and the limits of the system under study must be defined. The Functional Unit may be defined as the measure of the performance of the functional outputs of the production system. The main goal of the Functional Unit is to provide a reference to which the process inputs and outputs may be correlated.

Phase 2: *Life Cycle Inventory* (ISO 14041, 1998): This phase consists of the gathering of data and the calculation procedures aimed at quantifying the relevant inputs and outputs of a production system. This is an iterative process, which may be repeated if a need for further information emerges during its implementation. 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. The construction of an analogical model of reality is necessary, that will be able to represent, as accurately as possible, all exchanges among the individual operations belonging to the actual productive chain.

Phase 3: *Life cycle assessment* (ISO 14042, 2000): This phase consists of the evaluation of the significance of potential environmental impacts, associated with data deriving from the inventory phase. The level of detail, the choice of the impacts to evaluate, and the methods of evaluation depend upon the objectives and scope of the study. Initially, environmental impacts are classified; in other words, initial collected data are allocated to categories of impact that are relatively homogeneous. Afterwards, levels of importance are assigned to the various categories. This last procedure is performed at the end, in order to allow for the comparison of the potential impacts of various products. The main categories of environmental impact to be considered regard the use of resources, human health and ecological consequences. The first evaluation approach is general, and will simply quantitatively link a productive process with specific categories of impact; for a precise evaluation, it will then be necessary to proceed to the identification of the parts of the system that contribute most to the impacts that have been identified, as well as to the widening of the study with the assistance of more sophisticated investigative techniques.

Phase 4: *Life cycle interpretation* (ISO 14043, 2000): This phase consists of the interpretation of the results of the inventory phase and of the evaluation of impacts, as well as the eventual compiling of conclusions and recommendations for the improvement of the environmental performance of the system under study.

2.2. Emergy

Emergy is defined as the quantity of solar energy directly or indirectly necessary to support a given system and its level of organization (Odum, 1996). The emergy of all inputs to a system is calculated in terms of solar emjoules (sej) by means of suitable conversion factors called transformities (expressed in sej/J), or specific emergy (expressed in sej/g-or other units). Emergy accounts for both the free environmental and the purchased inputs that constitute the direct and indirect support of human activities. Solar energy is the primary source that feeds all processes and cycles that are found on Earth. Travelling backwards in the history of the thermodynamic transformations of energy, it is possible to perform an analytic calculation of the content of solar energy "stored" in every natural resource. Therefore, emergy is a sort of memory of the solar energy (Scienceman, 1987) that has been used in order to obtain a given product or flow through a series of transformations. This memory is associated with the effort that Nature executed in order to make a given resource available.

It should be pointed out that, in the emergy evaluation, rain and wind are considered to be co-products of sunlight; to avoid double counting among the three possible inputs, only the item with the highest value is added to the total amount of emergy (Odum, 1996).

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, emphasizing 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).

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 the ELR 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 EIR 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 to the environment and points to the land surface as a limiting factor for future development.

In this paper, we have assumed a global emergy flow base of 15.83×10^{24} sej/yr; therefore, all calculated transformities, starting from the previously used 9.44×10^{24} sej/yr standard, have been multiplied by 1.68 (Odum et al., 2000).

3. The systems

The systems under study are two farms located in Tuscany (Italy): an organic farm in the Chianti area (Tuscany) and a semi-industrial farm in the Montepulciano area. Both produce wine and belong to the Province of Siena, but apply two very different production systems. The first produces wine utilizing an organic farming method, the other does it in a semi-industrial manner.

The organic farm, of approximately 63 ha, reserves 10 ha for the production of organic wine; the rest is divided among olive groves and grass.

The species of vine planted is *Sangiovese*, with a planting density of 4200 plants per hectare. Each vineyard has an expected average lifespan of 30 yr. Full production is reached at the fourth year. The average yield per hectare is approximately 5 t of grapes per year. The placing of the rooted vine cuttings is done by hand, as are most of the operations performed on the farm. The machinery owned by the farm is relative to the ordinary operations of the vineyard (ploughing, plant protection products distribution, manure spreading, etc.), while the planting phase is entrusted to external businesses given the specificity of the machinery used. Machinery maintenance is performed in internal garages. The farm does not regularly employ farmhands, and only hires workers during the heaviest phases of production (for example, the grape harvest). Production practices are based on the laws established by organic farming regulation and utilize natural fertilizers (manure, compost, etc.) and "traditional" antiparasitic systems that integrate the use of simple natural chemical products with agricultural practices aimed to comply with their production planning.

The semi-industrial farm, of approximately 200 ha, is subdivided among various crops: next to the 120 ha reserved for the production of grapes lie 50 ha of sowing terrain and approximately 30 ha of forests and olive groves.

The species of vines cultivated are mostly *Sangiovese*, which are bordered by smaller numbers of *Prugnolo Gentile*, *Canaiolo*, *Mammolo* and *Cabernet* grapes. The planting density is approximately 6000 vine stumps per hectare, normally divided into 24 rows of 250 rooted vine cuttings each. Every year approximately 4 ha of vineyards are replanted, each of which has an expected average lifespan of 30 yr. Full productivity is only reached at the fourth year. The average yield per hectare is approximately 6.25 t of grapes per year. Only 50% of the grapes produced are suitable for wine production; the rest are either removed or harvested for other purposes.

Almost all the machinery necessary for production is owned by the farm; work is only entrusted to third parties for that which concerns certain planting operations, such as the trenching of the terrain, the planting of the rooted vine cuttings and the hanging of the wires necessary for the support of the vines themselves. These are operations that require machinery that is very technologically advanced with high cost and need for skilled manpower. The maintenance of all machinery is entrusted to external garages. Farm labour is performed by 40 workers, 15 permanent and 25 temporary, who are assisted by 40 more temporary workers during the period of the grape harvest. The farm utilizes usual standard practices of defence against pathogenic agents and fertilization for semi-industrial production systems.

It is important to highlight how both strategies utilized by the farms are very dependent upon climatic factors, that may often have a very clear influence upon both the productive practices adopted and the results obtained, in terms of yield and resources invested. The organic farm is particularly sensitive to these variations, as it more closely follows the development of natural events, and therefore suffers from levels of production that are more irregular when compared to the semi-industrial process, in which the use of more technological input creates a sort of ‘‘buffer-effect’’.

All the inputs to the systems of wine production and their emergy content are shown in Tables 2 and 3. This analysis has been conducted for 1 mt of final product and over 1 yr, to avoid the seasonal oscillations of parameters. As a final product we have considered the wine bottled. The comparison is between two wines, both of which are at the same market level and, from expert reviews, are considered to be more or less of the same quality.

4. Results and discussion

4.1. LCA

In Fig. 1a and b, the productive cycles of the semi-industrial and organic farms are illustrated. A basic common model has been devised for both productive processes that consists of five phases: the planting phase, the production phase, the wine cellar phase, the wine bottling phase and the glass recycling phase.

The planting phase is the first to be executed. In this phase, the uncultivated land is prepared for the undertaking of the vineyard. Work includes improvements to the structure and the chemical–physical characteristics of the soil, preparation of the supports for the vines (poles and wires) and the planting of the rooted vine cuttings.

This phase may include a ‘‘deep’’ fertilization (Fig. 1a).

The second phase investigated is that of production. The work undertaken in the vineyard, which is by now at a productive level, follows a routine that must be adapted to environmental conditions, but that constantly follows basic set steps. This phase includes all the steps necessary for grape production in a productive vineyard.

The third phase is that of the wine cellar, where the grapes from the vines are left to ferment and are processed until their transformation into wine, ready to be bottled and sold.

In the fourth phase the wine is bottled ready to be delivered to the market. The bottles' glass recycling scenario has been taken into consideration too.

The necessary inputs and relative emissions are reported for each phase (Fig. 1a and b).

The estimate of the emissions was executed using databases specifically for LCA analyses, and considers the possible recycling of some inputs that are not consumed in the productive process (SimaPro 6 software). The national Italian energetic mix was taken into consideration for the emissions relative to the consumption of electricity.

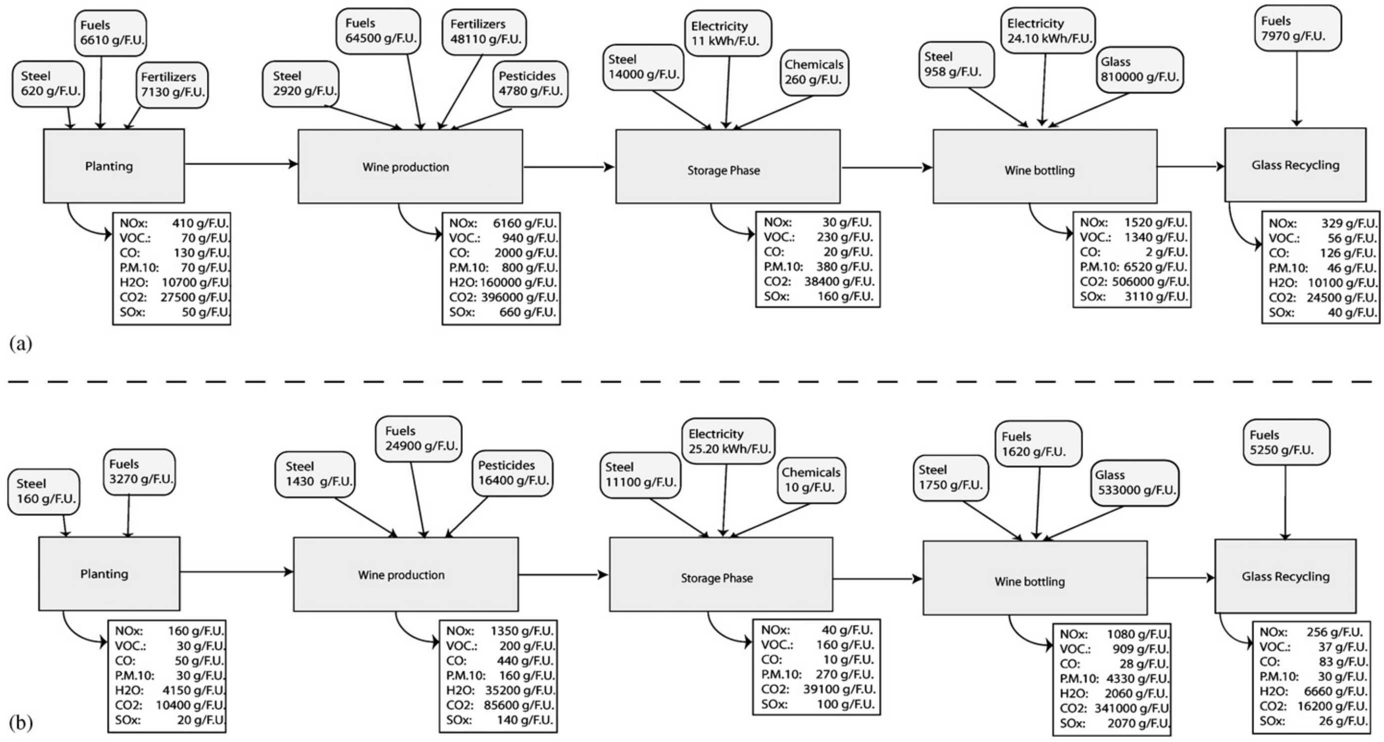

Fig. 1. The productive cycles of the semi-industrial and organic farms.

The organic farm does not implement any deep fertilization, as compared to the semi-industrial farm, and only attempts to enrich soil nutrients through its agronomic practices. The use of these practices allows for great energy savings, which reflects in a positive way on the outgoing emissions. The planting phase demonstrates how the material requirements are greater in the farm that utilizes semi-industrial procedures than in the organic farm.

In spite of the fact that both farms entrust the planting phase to external businesses, in the semi-industrial farm the levels of consumption are found to be doubled with regards to fuels, and actually are six times greater regarding the consumption of steel.

The use of materials in this particular phase depends strictly upon the mode of breeding of the chosen vines and on soil and terrain characteristics. The organic farm stretches across a portion of land that is looser (with a bare and sandy fraction that is higher), and this requires the use of machinery that is less intrusive and at a lower level of power; nevertheless, the semi-industrial farm may take more care of its vineyard, because it invests much more capital than the organic one.

In regards to the production phase of the vineyard, the first clear difference is the use of chemical fertilizers by the semi-industrial farm. The organic farm only utilizes manure originating from local breeding, and therefore we considered only the consumptions relative to the transportation and distribution of the soil organic amendments, as opposed to the semi-industrial farm that, in addition to these costs, we considered also the pollutants related to the production of the chemical fertilizer. The semi-industrial farm's increased consumption of steel depends on its much higher quantity of processing, such that the organic farm's consumption of fuel is 2.5 times lower, in spite of the fact that the organic farm's machinery is much older, and therefore much less fuel-efficient. The organic farm only utilizes traditional pesticides (copper sulphate, sulfur, etc.) which, given their less effective and invasive action, must be distributed in the vineyard in greater quantities. The semi-industrial farm utilizes chemical fertilizers with active synthesis principles, which are effective at lower doses, but that require much greater quantities of energy for their production, due to their very complex molecules.

Steel consumption relative to the wine-cellar phase, and relative to their annual production, is comparable, given that both farms use similar machinery.

A great difference is noted, though, for the consumption of electricity. The semi-industrial farm makes use of new structures with modern energy-efficient installations. The organic farm uses structures based on old buildings, which, though they have been restructured and modernized, do not reach the same levels of efficiency of the new ones. This weighs decidedly upon the organic farm's electric consumption.

Regarding the use of chemical products within the wine cellar, the organic farm utilizes them at a minimum, consistent with their regulations, while the semi-industrial farm uses a relatively high quantity, but given the simplicity of their components no substantial differences are found in the emissions.

For the bottling phase the semi-industrial farm has its own bottling plant, while the organic one rents the plant from a firm. During this phase the main inputs are the glass for the bottles, the steel for the machinery and a power supply for the machines. The main difference between the plants is the energetic input they need. The semi-industrial one uses only electric power for the bottling phase, the organic one uses fuel.

There are some other inputs required for this phase to take place (corks, labels, etc.), but their contribution to the total emissions is very low and hardly appreciable. Following the basic principles of the organic method, the organic farm uses lighter bottles than the semi-industrial one. On the other side, the semi-industrial one pays more attention to the market needs than to the environmental ones.

In this phase, the glass used represents a hot spot for the wine production. As we can see from Fig. 1, the amount of glass needed to sustain the two production systems is much higher for the semi-industrial one.

A recycling scenario has been taken in consideration. This scenario refers to the Italian reality. About 39% of the glass used for the bottling phase is recycled; the remaining part is burned and the ashes are put in waste disposal. The amount of fuel needed for the glass collecting has been taken into account.

Table 1 lists total emissions due to all processes involved in wine production. Values are between two and three times higher for the semi-industrial farm than for the organic one, demonstrating a relevant difference in the production processes from this viewpoint.

4.2. Emergy

The two production systems present different energetic input flows (see Fig. 1a and b), reflecting the production method chosen by each farm. Fig. 2 shows a system diagram of a typical vineyard and its wine-making process.

Table 1
Total emissions in wine production in the two farms

Emission	Semi-industrial farming	Organic farming
NO_x (g/FU)	8.52×10^3	3.70×10^3
VOC (g/FU)	2.63×10^3	1.49×10^3
CO (g/FU)	2.28×10^3	8.77×10^2
Particle content (g/FU)	7.81×10^3	4.98×10^3
H_2O (g/FU)	1.81×10^5	6.90×10^4
CO_2 (g/FU)	9.92×10^5	5.49×10^5
SO_x (g/FU)	4.02×10^3	2.45×10^3

Functional unit (FU) is 1 t of final product.

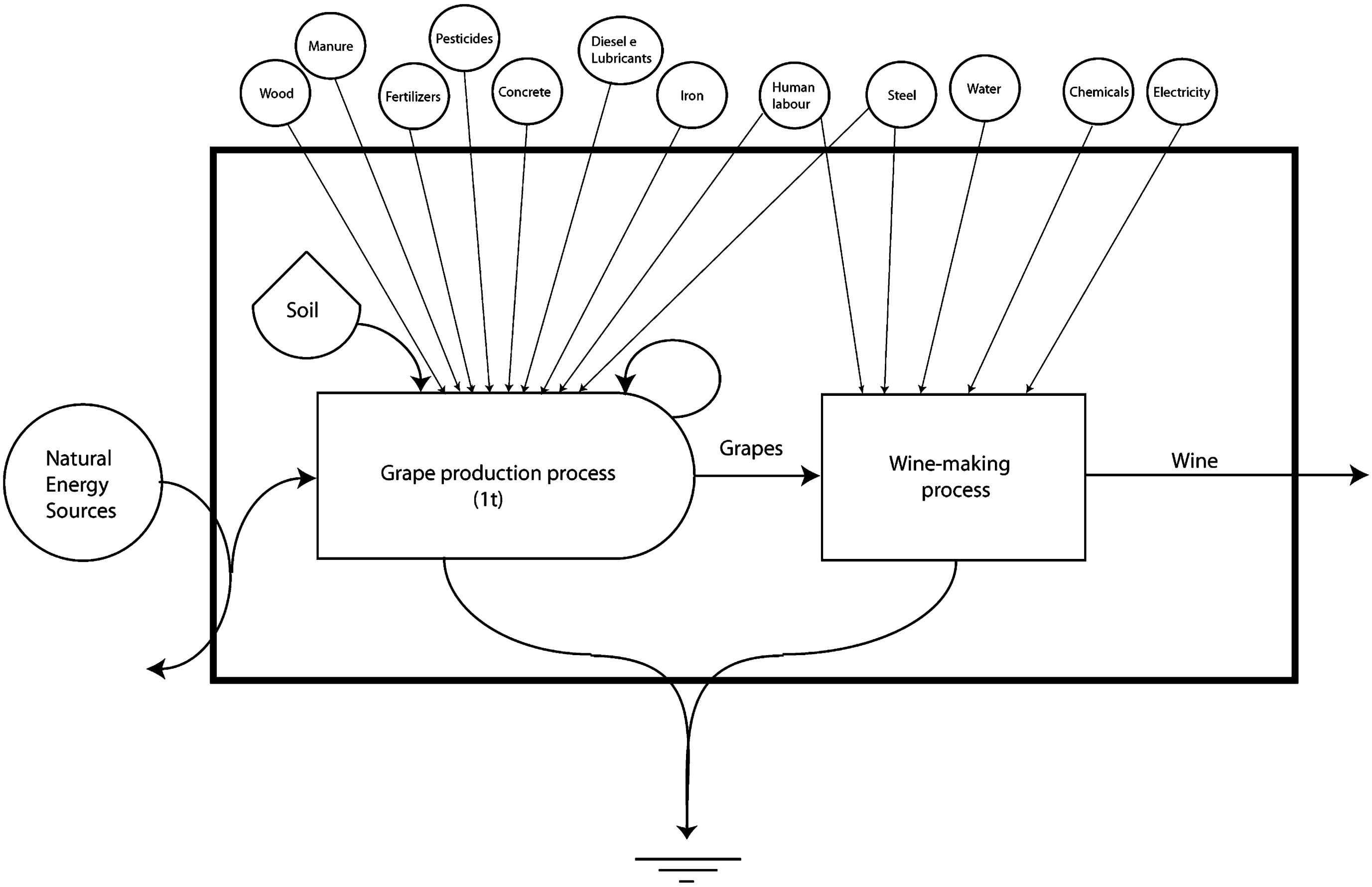

Fig. 2. System diagram of a typical vineyard.

Tables 2 and 3 summarize the emergy flows of the entire cycle of production of the two farms. These two tables describe the emergy flows that feed the two systems. In addition to the inputs that are also considered by the LCA (in italics in the tables), other inputs are recorded. Among these are the flows of renewable and non-renewable environmental goods and services (Tables 2 and 3 notes 1–5). The erosion of the soil emerges as a primary difference between the energy flows in the comparison of these two vineyards. Conventional methods result in a more intensive soil use. In fact, the intensive use of trucks on this hilly ground highly affects soil erosion (Tables 2 and 3, note 5). Moreover, through the application of cultivation practices that completely exclude or reduce the need to resort to chemical substances (both fertilizers and pesticides, and furthermore trucks for the fertilizer spreading), it is possible to further reduce soil erosion. The high amount of soil erosion for the semi-industrial farm reflects its non-renewable environmental contribution, which is highlighted by the emergy method (Bastianoni and Marchettini, 1996). The organic farm does not utilize chemical fertilizers (Table 2, notes 6–8).

A greater amount of labour is required in this organic agricultural system (Table 2, note 10); on the other hand, the semi-industrial farm demonstrated an overuse of agricultural machinery and fuel (Table 3, notes 9–11).

The organic method only utilizes natural products for antiparassitic purposes (mineral substances), thus avoiding the impoverishment of the soil (Table 2, note 15). In other words, it controls infestation and parasites through the use of appropriate cultivation methods, using substances with a low environmental impact. On the contrary, the semi-industrial industry uses chemically synthesized substances; the majority of the chemical substances used as pesticides are toxic, and the main arguments against this use are the health risk factors and the danger of environmental pollution (Table 3, note 15). The varying chemical origin of the inputs in the Pesticides entry of the two farms has brought us to choose a different specific emergy, or *transformity* of 1.85×10^9 sej/g (Odum, 1996) for the organic farm; and 2.49×10^{10} sej/g (Brandt-Williams, 2002)[1] for the semi-industrial farm.

The organic farm makes use of substances that act positively on the balance of the organic substance of the

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[1] Transformity for pesticides used in Emergy of Florida Agriculture (Folio #4) is 1.48×10^{10} sej/g (Brown and Arding, 1991); we corrected this Transformity by a factor of 1.68 (Odum et al., 2000).

Table 2
Raw inputs and emergy evaluation of organic farm (Inputs are for 1 t of wine)

Note	Item	Unit	Inputs (t/yr)	Emergy per unit (sej/unit)	Emergy flow (sej/t/yr)	Ref. for tranformities
Renewable inputs						
1	Sunlight	J	9.18E+12	1.00E+00	9.18E+12	Odum, (2000)
2	Rain	g	1.19E+09	1.51E+05	1.79E+14	Odum, (2000)
3	Wind	J	1.76E+10	2.52E+03	4.45E+13	Odum, (2000)
4	Earth cycle	J	6.30E+09	4.28E+03	2.70E+13	Odum, (2000)
Non-renewable inputs						
5	Loss of topsoil	J	1.36E+08	1.24E+05	1.69E+13	Odum et al. (2000)
Purchased inputs						
6	Nitrogen fertilizers	g	0.00E+00	2.41E+10	0.00E+00	Brandt-Williams (2002)
7	Phosphate fertilizers	g	0.00E+00	2.02E+10	0.00E+00	Brandt-Williams (2002)
8	Potash fertilizers	g	0.00E+00	1.74E+09	0.00E+00	Brandt-Williams (2002)
9	Diesel and lubrificants	J	5.29E+09	1.10E+05	5.82E+14	Odum (1996)
10	Human labour	J	3.75E+07	1.24E+07	4.65E+14	Brandt-Williams (2002)
11	Steel	g	1.44E+04	1.13E+10	1.63E+14	Brandt-Williams (2002)
12	Iron	g	3.20E+03	4.44E+09	1.42E+13	Brandt-Williams (2002)
13	Concrete	g	1.02E+04	7.48E+08	7.63E+12	Brandt-Williams (2002)
14	Wood	g	1.07E+05	6.79E+08	7.24E+13	Brandt-Williams (2002)
15	Pesticides	g	1.64E+04	1.85E+09	3.03E+13	Odum (1996)
16	Organic manure	g	2.00E+05	2.13E+08	4.26E+13	Bastianoni et al. (2001)
17	Water	g	2.24E+07	1.25E+06	2.80E+13	Brandt-Williams (2002)
18	Electricity	J	7.62E+07	2.00E+05	1.52E+13	Brandt-Williams (2002)
19	Chemicals	g	1.00E+01	3.80E+08	3.80E+09	Brandt-Williams (2002)
20	Glass	g	5.33E+05	2.69E+09	1.43E+15	Brown and Bardi (2001)

	Output	Emergy per unit (sej/t)	
21	Wine	3.08E+15	3.08E+15

	Solar emergy (sej/t/yr)	
Renewable resources	2.65E+14	8.6%
Nonrenewable storages	1.69E+13	0.5%
Purchased inputs	2.79E+15	90.8%
Total emergy	3.08E+15	

soil. It utilizes a notable amount of organic manure equal to 4.26×10^{13} sej/t/yr (Table 2). In the emergy analysis, 29% of the organic manure invested in an agricultural production is valued as renewable (Panzieri et al., 2002). Furthermore, the use of organic manure as opposed to chemical fertilizers requires a lower emergy loss. The value of the specific emergy of the organic manure is much lower than the chemical fertilizer.

The glass represents the major external input that the systems need. The weight of this input in the organic farm is lower than in the semi-industrial one. This happens for one reason, the organic farm uses bottles that are lighter than the semi-industrial ones, according to the organic method principles that limit the use of the glass for the bottling-wine phase.

Tables 2 and 3 summarize also the main emergy flows, which feed the systems. Figs. 3 and 4 summarize the same flows as percentages of the total value.

The environmental cost, or, in other words, the emergy, per unit of weight of wine in the semi-industrial farm is greater than that of the organic farm: the transformity of the wine from organic grapes is lower than the value of that of the wine produced by the semi-industrial method. Therefore, since we are considering products of the same type and the same quality, we conclude that there is a greater efficiency for wine production in the organic farm. The semi-industrial farm suffers from the fact that it may only select the best bunches of grapes for their wine production, eventually utilizing only 50% of the grapes available.

The emergy flow, related to the economic external inputs, is greater for the semi-industrial farm (Figs. 3 and 4). The semi-industrial farm requires a quantity that is more than double the investments in market goods, measured in emergy, in order to use every unit of local environmental resources, and therefore displays a greater level of dependence on exogenous systems (Table 4).

The high level of ELR of the semi-industrial farm demonstrates a disproportion between the use of

Table 3
Raw inputs and emergy evaluation of semi-industrial farm (inputs are for 1 t of wine)

Semi-industrial farm Note	Item	Unit	Inputs (t/yr)	Emergy per unit (sej/unit)	Emergy flow (sej/t/yr)	Ref. for tranformities
Renewable inputs						
1	Sunlight	J	1.10E+13	1.00E+00	1.10E+13	Odum, (2000)
2	Rain	g	1.42E+09	1.51E+05	2.15E+14	Odum, (2000)
3	Wind	J	2.12E+10	2.52E+03	5.33E+13	Odum, (2000)
4	Earth cycle	J	7.56E+09	4.28E+03	3.24E+13	Odum, (2000)
Non-renewable inputs						
5	Loss of topsoil	J	1.63E+08	1.24E+05	2.03E+13	Odum et al. (2000)
Purchased inputs						
6	Nitrogen fertilizers	g	1.84E+04	2.41E+10	4.44E+14	Brandt-Williams (2002)
7	Phosphate fertilizers	g	1.84E+04	2.02E+10	3.72E+14	Brandt-Williams (2002)
8	Potash fertilizers	g	1.84E+04	1.74E+09	3.20E+13	Brandt-Williams (2002)
9	Diesel and lubrificants	J	4.52E+09	1.10E+05	4.97E+14	Odum (1996)
10	Human labour	J	3.08E+07	1.24E+07	3.82E+14	Brandt-Williams (2002)
11	Steel	g	1.85E+04	1.13E+10	2.09E+14	Brandt-Williams (2002)
12	Iron	g	0.00E+00	4.44E+09	0.00E+00	Brandt-Williams (2002)
13	Concrete	g	0.00E+00	7.48E+08	0.00E+00	Brandt-Williams (2002)
14	Wood	g	2.57E+05	6.79E+08	1.75E+14	Brandt-Williams (2002)
15	Pesticides	g	4.77E+03	2.49E+10	1.19E+14	Brandt-Williams (2002)
16	Organic manure	g	0.00E+00	2.13E+08	0.00E+00	Bastianoni et al. (2001)
17	Water	g	1.20E+05	1.25E+06	1.50E+11	Brandt-Williams (2002)
18	Electricity	J	1.26E+08	2.00E+05	2.53E+13	Brandt-Williams (2002)
19	Chemicals	g	2.61E+02	3.80E+08	9.90E+10	Brandt-Williams (2002)
20	Glass	g	8.10E+05	2.69E+09	2.18E+15	Brown and Bardi (2001)

	Output	Emergy per unit (sej/t)	
21	Wine	4.70E+15	4.70E+15

	Solar emergy (sej/t/yr)	
Renewable resources	2.85E+14	6.1%
Nonrenewable storages	2.03E+13	0.4%
Purchased inputs	4.39E+15	93.5%
Total emergy	4.70E+15	

non-renewable and renewable resources: the use of non-renewable resources is approximately 15 times greater than that of renewable, while in the organic farm this level is only 10 times greater (Table 4, Figs. 3 and 4).

A production process with a lower emergy content—the organic farm—is an indicator of efficiency. This affirmation is validated by the emergy density index, which is lower for the organic farm (Table 4).

Through the emergy evaluation we have seen how, on the semi-industrial farm, the regulation or alternation of the agroecosystem for productive ends is performed by increasing the energetic inputs of external goods and services (Tables 2 and 3, and Fig. 5). The emergy indicators summarized in Table 4 suggest a greater level of sustainability for the organic farm. The emergy evaluation demonstrates, therefore, the primary importance that the organic farm holds in today's agricultural context. Emergy should be introduced with the objective of improving our comprehension of agricultural systems' dependence on renewable and non-renewable resources.

The organic farm is sustained by a good quantity of renewable environmental resources (8.6%). On the contrary, the flow of renewable resources for the semi-industrial farm is lower (6.1%) (see Figs. 3 and 4).

Evaluation methods that are not able to offer this precious information, with regards to both environmental energetic flows and those originating from external markets, and that also do not consider the quality of the energy involved, should be integrated with other methods. The farm with the greater dependence on the flows of non-renewable resources (N + F) generates negative impacts, for both human activities and for the environment.

The increase in agricultural productivity has historically depended on the increase of non-renewable energetic inputs (petrochemical derivates, such as fuels, fertilizers, etc.). The use of agricultural machinery is one of the main factors; more machinery, fertilizers and pesticides have been used in

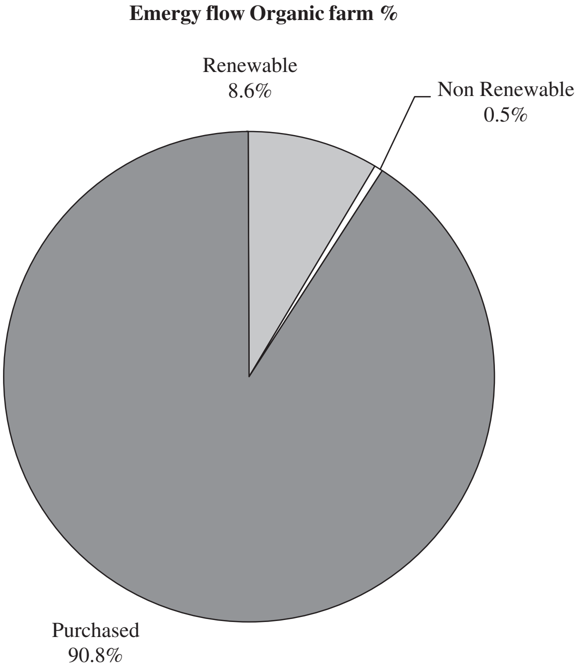

Fig. 3. Emergy flow for the semi-industrial farm (%).

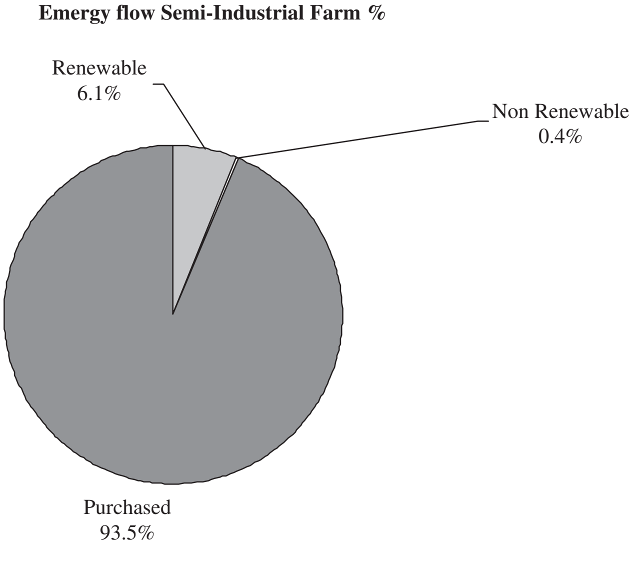

Fig. 4. Emergy flow for the organic farm (%).

Table 4
Emergy indices

Wine	Organic farm	Semi-industrial farm
Transformity	3.08E + 15	4.70E + 15
Emergy investment ratio	9.90	14.37
Environmental loading ratio	10.59	15.46
Empower density	1.08E + 16	1.96E + 16

order to increase farms' output. The transition towards agriculture that involves energetic investment optimization in the productive process, and computes the impacts that derive from these, should be less dependent on non-renewable resources. Cultivation must be organized so that it favours rotation, in order to generate useful outputs, at the same time maintaining soil fertility. In this sense, the emergy evaluation is useful, because it has the ability to demonstrate the different qualities of the resources that feed a system, starting from the evaluation of their different positions in the energetic hierarchy. This characteristic provides a further means of understanding a system's dependence on environmental goods and services provided freely by nature.

5. Conclusions

It is very important to evaluate agroalimentary productive systems from the point of view of environmental sustainability, as these systems represent the base of our sustenance, and the human population, already oversized, is destined to grow even further in the future, producing even greater environmental impacts. Over the past years different methods have been developed for the analysis of various productive systems, but the majority have been specifically devised for the study of systems that are either only industrial or only environmental.

This paper highlights how the LCA method is also a valid tool to investigate environmental systems behaviour. The benchmark that this approach offers for the treatment of data and their disaggregation represents a solid foundation for the comprehension of a productive system, as well as for its evaluation with other systems of analysis. An estimate of emissions, correlated to a specific functional unit, further allows for an easy interpretation of results, and a comparison between these results and those relative to similar productions.

The emergy evaluation, from one side, offers a wider survey than the LCA because it inserts the productive cycle into the environmental context in which it is found, and, further, quantifies in terms of energy flows its relations with the environment. On the other side, emergy with respect to LCA, aggregates the "gate" phase, losing sometimes details needed for actions to be taken, while it quite neglects the "cradle" phase. Through an accounting method of the services offered by the ecosystems, it estimates the degree of renewability of a system under study, and its dependence upon local and imported goods. It must also be remembered that emergy is not a function of state, and therefore allows for a comparison of the efficiency of diverse ecosystems as they provide the same service or product.

The integration of these two methods in the evaluation of agroalimentary systems has proved to be very useful, and has provided a much wider range of directly usable information when compared to their use separately. The aim of this article, to compare and integrate two evaluation methods of agroalimentary systems in order to promote a wider united vision, has been achieved. It demonstrates how an indispensable multidisciplinary approach towards complex environmental problems should consider the path of integration among various useful methods.

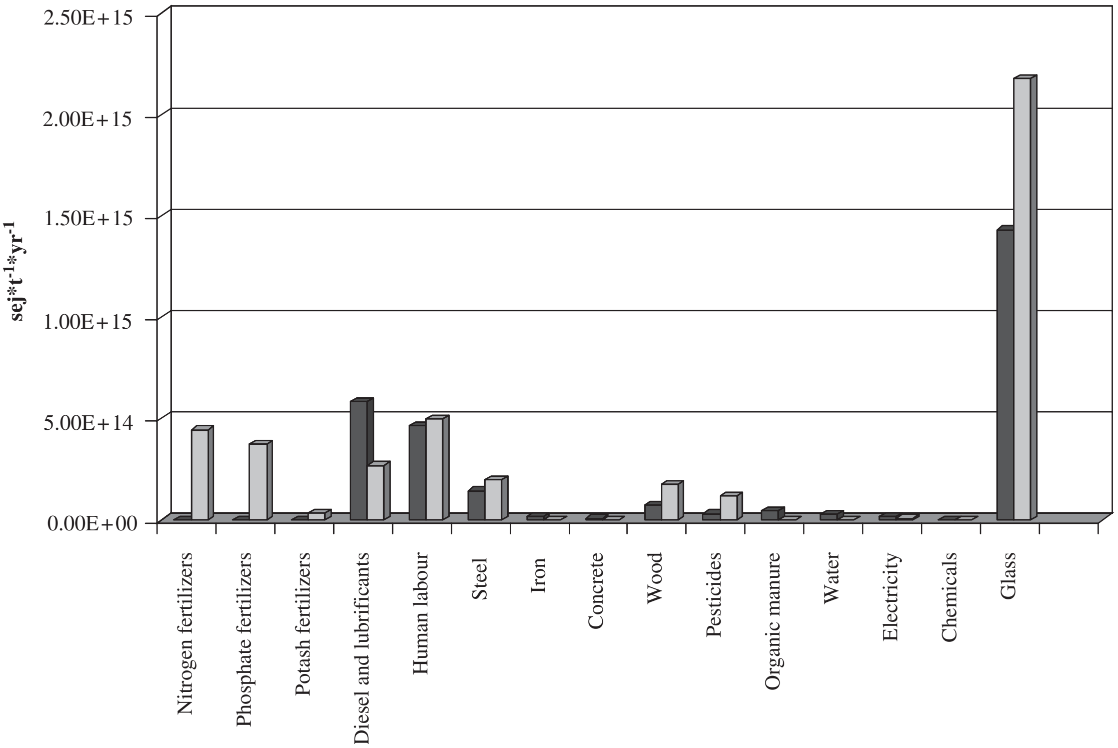

Fig. 5. Histogram of the purchased inputs (F) for the two vineyards. The organic farm is represented by the darker columns.

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