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The Ecological Footprint Analysis Applied to Two Different Italian Wine Productions

Niccolucci V.,[1*], Galli A.,[1,2] Kitzes J.,[2] Pulselli R.M.,[1] Borsa S.[1] and Bastianoni S.[1]

[1] Dept. of Chemical and Biosystems Sciences, University of Siena, via della Diana 2A, 53100 Siena, Italy
[2] Global Footprint Network, 1050 Warfield Avenue, Oakland, CA, 94610, USA.

Abstract

Wine is one of the most famous and exported Italian products, around the world. In this paper an Ecological Footprint Analysis of a typical Tuscan (Italy) wine was performed consistently with the footprint standards 2006 edition. Two different wine productions, one organic and one conventional were evaluated and compared. All inputs needed to support the agriculture, winery and packing phases were accounted and converted into biological space, to estimate the natural capital demand for the production in terms of global hectares. Furthermore, in order to consider the process in its entirety, Nature's expense due to wine distribution, from the production to the consumption site, was included. Finally, to minimize calculation errors and natural fluctuations, a 6 years time series analysis has been proposed to evaluate sensitivity in Footprint accounting.

Keywords: ecological footprint, wine, organic production, sustainable farming

[*] Corresponding author. Phone +39-0577-232044; Fax +39-0577-232004; e-mail: vniccolucci@unisi. it.

1. **Introduction**

In the current debate on sustainability and sustainable consumption (e.g. Wiedmann et al. 2006, Lenzen et al. 2007), the analysis of the environmental pressure of production processes is of fundamental importance. The application of sustainability indicators to production systems aims at analyzing productions' resource requirements, efficiency and environmental consequences, therefore guiding product designers and producers in integrating sustainability issues into their decision-making processes (Grönroos et al 2006, Kronenberg 2007, Waage 2007). This allows to satisfy final consumers' needs as well as safeguarding natural resources. In this paper, an ecological footprint analysis of two different wine productions is carried out to account for all natural capital requirements, making visible all the indirect requirements usually invisible.

Ecological Footprint is an area-based indicator recently introduced by Wackernagel and Rees (Wackernagel and Rees, 1996; Rees, 1992) to measure the demand of natural capital for human activities. As an "ecological camera" the Ecological Footprint documents for resource consumption and waste assimilation that are, directly and indirectly, necessary to maintain a population lifestyle or to sustain an economy or a production, in terms of biologically productive land required to support these flows. Thus inputs of different kind are accounted into a common basis by using conversion factors and expressing results in a common standardized unit that is global hectare. Footprint has a consumer-based approach and follows a principle of responsibility according to which citizens are responsible for their consumption.

Biocapacity (BC) is the counterpart of the footprint: the supply (BC) as opposite to the demand (EF) side. BC represents the theoretical maximum resource capacity, in terms of bioproductive lands. It is considered as a threshold value which can be used as a benchmark (Wackernagel and Rees, 1996). Also BC is expressed in terms of biological productive area or global hectares (gha) (Monfreda et al., 2001). Each global hectare represents an equal amount of biological productivity. Six lands categories are usually included in the calculation, according to the World Conservation Union classification (World Conservation Union, 1991): cropland, pasture land, forest, energy land, built up land and fisheries.

In order to convert hectares of bio-productive area into global hectares two coefficients were used: equivalence and yield factors (Wackernagel and Rees, 1996). The equivalence factor reflects the difference in the productivity among the land-use categories, while the yield factor captures the difference between local and global average productivity of the same bioproductive land type (Monfreda et al., 2001; Galli et al., 2007).

By comparing human consumption of natural resources (footprint) and the Earth regenerative capacity (biocapacity) an ecological balance can be assessed. The target is to promote recognition of the ecological limits of the biosphere, without which development could not be sustainable.

The Ecological Footprint is widely used as environmental indicator to show the (un)sustainability of consumption pattern at different scale: individual, country, nation or global (WWF, 2006; Bagliani et al., 2006; Van Vuuren and Bouwman, 2005; Erb, 2004; Wackernagel et al., 2004; Lenzen and Murray, 2003). Footprint is also compared with economic indicators (Jorgenson and Burns, 2006; Niccolucci et al., 2007) or integrated with thermodynamic based method (Zhao et al 2005, Chen and Chen, 2006a,

2006b, Nguyen and Yamamoto, in press). Recently, an integration of the Footprint method and the Costanza Natural Capital concept has also been proposed (Torras 2003, Bastianoni et al. in press) for environmental accountings.
Applications on industrial or agriculture system are still rare. Nevertheless footprint has been applied to production processes such as marine aquaculture of reef fish, shrimp and tilapia, salmon and mussels as well as agriculture productions as tomatoes or potatoes (Kautsky, 1997; Deumling et al., 2003; Tyedmers, 1992; Wada, 1993; Warren-Rodes et al., 2003).
Footprint application to production systems allows evaluating natural capital appropriation as well as efficiency in natural resource use and pressure excited on the environment. Several authors proposed to use footprint jointly to a variety of methods, such as Life Cycle Assessment, Emergy Analysis, Economic Cost and Return Estimation and Input-Output accounting of nutrients. Evaluations of the environmental impacts of farms (van der Werf et al., 2006;) or dairy production systems (Thomassen, M.A. and de Boer, I.J.M., 2005) as well as the assessment of economic and ecological carrying capacity of agricultural crops (Cuandra M. and Björklund J., 2006) have been proposed.

The aims of the paper are: i) to evaluate the total demand of bioproductive areas needed to support agriculture productions by means of the ecological footprint method, ii) to propose a time series (6 years) analysis in order to give a more reliable value avoiding seasonal changes, iii) to make a comparison between an organic and a conventional production.

2. **The case study**

Italian wines are well known and appreciated everywhere. In the last years, a growing attention rose on more sustainable agricultural practices such as organic wine productions. These productions are characterized by not using chemical fertilizers, weed killers, insecticides, and other synthetic chemicals in the grape's growth phase. This lowers detrimental effects on the environment without compromising the quality and the flavor of the final product.
In this paper, two quite different productions, an organic and a conventional one, were analyzed and compared. Both the farms are located in the heart of Tuscany (central Italy), in a characteristic wine-area called Chianti, where some of the most famous Italian wines are produced.
The first one is a small farm (about 63 ha) essentially dedicated to wine (approximately 10 ha) and olive oil production. The farm is family managed so there are only few permanent employs but a lot of occasionally hired hands. According to the old farming tradition, most of the operations are performed by hand, with little machinery used. The production respects the organic farming procedure according to which only natural fertilizer and antiparasitics are accepted. The main product is a DOCG (Denominazione di Origine Controllata e Garantita) red wine. The average annual yield of wine is about 3500-5000 l/ha. Most of the wine produced is locally sold and only minor quantities are exported in Italy and Europe.
The second farm (200ha, 120 ha of which dedicated to grape production) represents one of the most important farms of the region. The wine production is semi-industrial with fertilization and standard defense from pathogenic agents. Most of the operations are

mechanized with high technology machinery, and several employees are hired to take care of all activities in the farm. The average annual yield of wine is approximately 2000-3500 l/ha. Most of the wine is bottled and exported around the world.

3. ***Methods***

3.1 Ecological Footprint applied to wine production

Wine production from two different agricultural cultivations (organic and conventional) is analyzed by Ecological Footprint approach. The overall process is divided in three different phases of production:

- the agriculture phase refers to the vineyard activity which include vineyard preparation, grape growing, treatments and harvesting;
- the winery activity consists of different stages such as fermentation, crushing and stabilization;
- the packing phase includes several processes: bottling, corking, labeling;

Each of them requires energy and material inputs. Data were collected in 2005 for organic as well as conventional farm. All these information were kindly provided by the farms.

In table 1 the inventory of raw data for both the production systems is reported according to the phase distinction above.

Table 1: *Raw data for the two wine production systems.*

Input	Unit	Organic Farm	Conventional Farm
Agricolture Phase			
Growing area	ha	10	120
Fertilizers	g	-	1.45E+07
Diesel and Lubricants	J	1.75E+11	1.19E+12
Human Labour	hours	2.56E+03	1.66E+04
Steel	g	5.57E+04	9.29E+05
Iron	g	1.12E+05	-
Concrete	g	3.57E+05	-
Wood	g	3.73E+06	7.22E+07
Pesticides	g	5.74E+05	1.25E+06
Organic manure	g	7.00E+06	-
Vinery Activity Phase			
Water	l	9.72E+05	3.91E+04
Electricity	J	2.67E+09	1.04E+10
Chemicals	g	3.50E+02	6.85E+04
Steel	g	3.89E+05	3.68E+06
Human Labour	hours	6.04E+02	4.16E+03
Packing Phase			
Glass	g	1.87E+07	2.13E+08
Cork	g	4.83E+05	3.62E+06
Paper	g	1.37E+05	1.03E+06
Glue	g	1.43E+04	1.07E+05
Aluminium	g	7.19E+04	5.39E+05
Steel	g	6.13E+04	2.52E+05
Diesel and Lubricant	J	1.01E+10	-
Electricity	J	-	2.27E+10
Product			
Wine	g	3.50E+07	2.63E+08

All inputs were converted into biological space through conversion factors. Some factors were directly accessible in literature (Chambers et al, 2000). When they were not available, data were converted in energy unit through energy intensity coefficients (Bousted and Hancock, 1979) that represent the total direct and indirect energy inputs per unit output of a specific product. In this way each input can be converted in the equivalent amount of CO_2 emitted and then in forest area needed to absorb those emissions. A world-average carbon absorption factor was used.
Furthermore, all inputs that are not entirely consumed in the annual production as materials and machineries were considered on the basis of their lifetime. The life spans

ware estimated by interviewing farmers and they ranged from 10 to 20 years for machinery, and from 5 to 10 years for materials (such as wood).
Human labor contribution was also included in the footprint account according to what was proposed by Tyedmers (1992). The footprint of an average Italian people (Living Planet Report Europe, 2005) was allocated on the basis of the number of workdays per year.
Equivalence and yield factors were used (Global Footprint Network, 2004) to consider the different productivity among the various lands as well as scaling local to world-average productivity.
The Ecological Footprint for agriculture production is usually given by the sum of:

- cropland, mainly due to the growing area (the land covered by the vineyards),
- pasture land,
- forest (area for wood production),
- energy land (area required for CO_2 assimilation),
- built up (area occupied by farm buildings, wine cellars, storage for machinery or equipment, roads,..) and
- fishing.

For this case study fishing and pasture land categories are not relevant and their contribution is only due to the human labor which also requires a small quantity of cropland for food and fiber consumption.
Both the visible occupied area (growing area) as well as the land equivalent for all other inputs needed for the wine production were included in the account (Wada, 1993).
The ecological footprint of the growing area (EF_{GA}) was here assessed using the "calculated area" method (Kitzes et al 2007). The required area for grape's growth has been calculated by multiplying the ratio between tonnes produced by the farm and farm yield[†] for both yield factor (YF) and equivalence factor (EQF) as reported below.

$$EF_{GA} = \frac{T}{Y_l} * YF * EQF = A_l * YF * EQF$$

Where T is the annual amount (in tonnes) of grapes produced in and used by the farm, Y_l is the local grape yield.
The joint use of YF and EQF is essential to properly convert local actual land values in global hectares (Galli et al., 2007).
The equivalence factor for cropland was directly obtained by Living Planet Report (2005) while the yield factor was calculated for this specific case by comparing the farm grape yield (Y_l) with the world average grape yield for the same year (Y_w):

$$YF = \frac{Y_l}{Y_W}$$

The world average grape yield was extracted by FAO data by considering grape production and harvested area for all the nations.
For all the other footprint components, which depend on world average (Y_w) instead of local yield, the previous equation can be written as follows:

$$EF = \frac{T}{Y_l} * YF * EQF = \frac{T}{Y_w} * EQF$$

[†] Note that for agricultural products the amount of tonnes produced in a year is equal to the amount extracted/consumed since all the agricultural production is harvested.

Results were expressed in terms of total area requirement (gha) per unit of output (tonnes of wine or bottle of wine), gha t_{wine}^{-1}, as well as total area per visible hectare, gha $(gha_{GA})^{-1}$.

3.2 Ecological Footprint applied to wine distribution

In the globalized economy of today, where environmental pressure has more to deal with location of consumption than that of production (Barrett et al., 2005), food transportation appears to be increasingly relevant with significant environmental, economic and social consequences (Deumling et al., 2003). Thus the inclusion of distribution phase, which refers to the transportation from the production to the consumption site, was proposed to provide a more complete footprint value. A convenient way to express these impacts, especially the environmental ones, is by means of the Food Miles indicator (Watkiss et al., 2005) that is the distances travelled by foodstuffs from farm gate (where it is grown) to where it is ultimately purchased or consumed by the final consumer. Food Miles (FM) takes care of three key aspects: transport distance, vehicle size and transport efficiency as reported in the following formula:

$$FM = D * W * T$$

where: D is the average source distance travelled in kilometres, W is the weight in tonnes for each foodstuff and T is the direct environmental impact of transport mode.

Food Miles are measured as tonnes per kilometres ($t\ km^{-1}$) or carbon dioxide emissions from fuel used during the transport.

FM tries to include direct transport impacts, including congestion, pollution, greenhouse gas emissions, accidents and infrastructure costs, and also wider social and economic effects including the impact on rural communities.

In Italy, greenhouse gas emissions are dominated by road transport; however, the contribution of air and sea transport is also significant, and is growing.

Specific coefficients to express the Food Miles in terms of footprint or in terms of an equivalent forest land needed to absorb all the emissions were assumed. For road transport a coefficient of 0.07 ha km^{-1} $(1000\ t)^{-1}$ was used to directly convert the food miles in terms of actual area (Chambers et al., 2002). This area has been therefore converted in global hectares by using forest EQF. For sea transport an average coefficient of 0.0153 $kgCO_2\ t^{-1}\ km^{-1}$ (Watkiss et al., 2005) was used. Then, the value has been converted in hectares of forest according to the world-average carbon adsorption factor of 0.271 ha tCO_2^{-1} (GFN, 2006). As reported above the actual area has been finally translated in global hectares by the use of forest EQF. Furthermore, the road contribution from farm site to harbour has been estimated. Note that the sea coefficient underestimate the real value with respect to the road coefficient that takes into account for maintenance, built up for road and infrastructures and highway rates.

4. **Results and Discussion**

4.1 organic vs conventional wine production

The yield factor calculated for organic farm is 0.56 $ha_w\ ha_l^{-1}$ while for conventional farm is 0.70 $ha_w\ ha_l^{-1}$, where the subscript “w” refers to world average hectares and “l” to local. This means that both the farm have lower yield with respect to the world

average even if conventional farm yield for grape growth is 25% higher than the organic farm.
Results obtained from the ecological footprint accounting of the two wine productions are summarized in Table 2.

Table 2: *Wine footprint for the two productions.*

	Unit	Organic Farm	Conventional Farm
Ecological Footprint of total production	gha	39.36	575.76
Ecological Footprint per t of wine produced	gha t^{-1}	1.12	2.19
Ecological Footprint per bottle of wine	gm^2 per bottle of wine	7.17	13.98
Ecological Footprint per gha of vineyard	gha $(gha_{GA})^{-1}$	3.21	3.13

Total wine footprint per unit of output from conventional production (2.19 gha t^{-1} or 13.98 gm^2 per bottle of wine) is more or less double than the organic one (1.12 gha t^{-1} or 7.17 gm^2 per bottle of wine) (see Figure 1).
The main footprint components are cropland (32.8% for organic and 32.7% for conventional), and energy land (52.5% for organic and 48.4% for conventional).

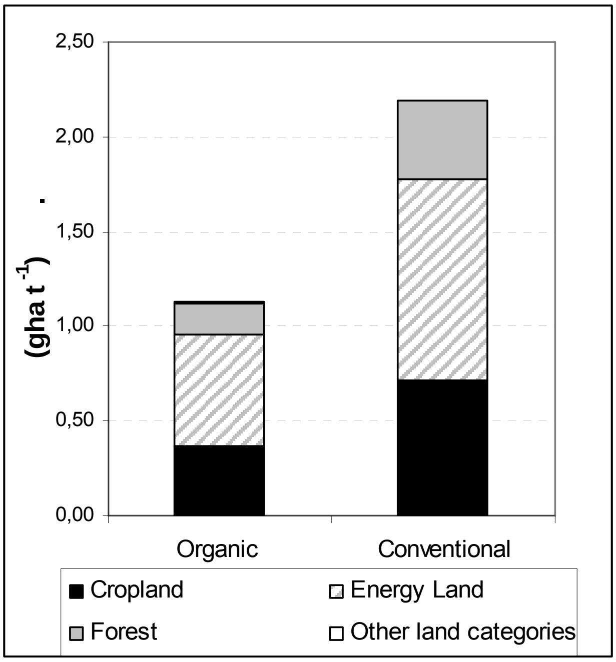

Figure 1: *Ecological Footprint for the two wine productions sorted by land categories.*

The agriculture phase is the most relevant for both the productions with 67% for organic and 76% for conventional, while the winery activity is the less important (see Figure 2).

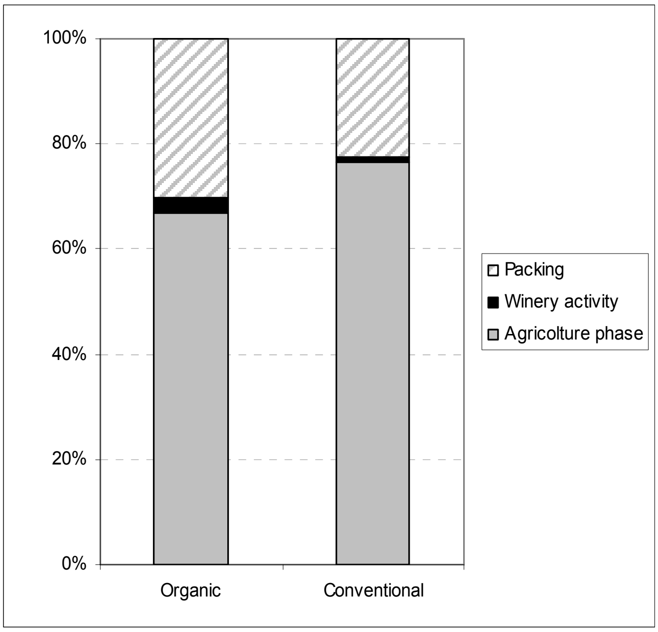

Figure 2: *Contribution of the single phase to the overall footprint for both the production.*

A detailed analysis of the agriculture phase components shows that the growing area is the highest item for both, but the conventional cultivation requires 50% more area than the organic due to the high selection of the bunch of grapes (see Figure 3).

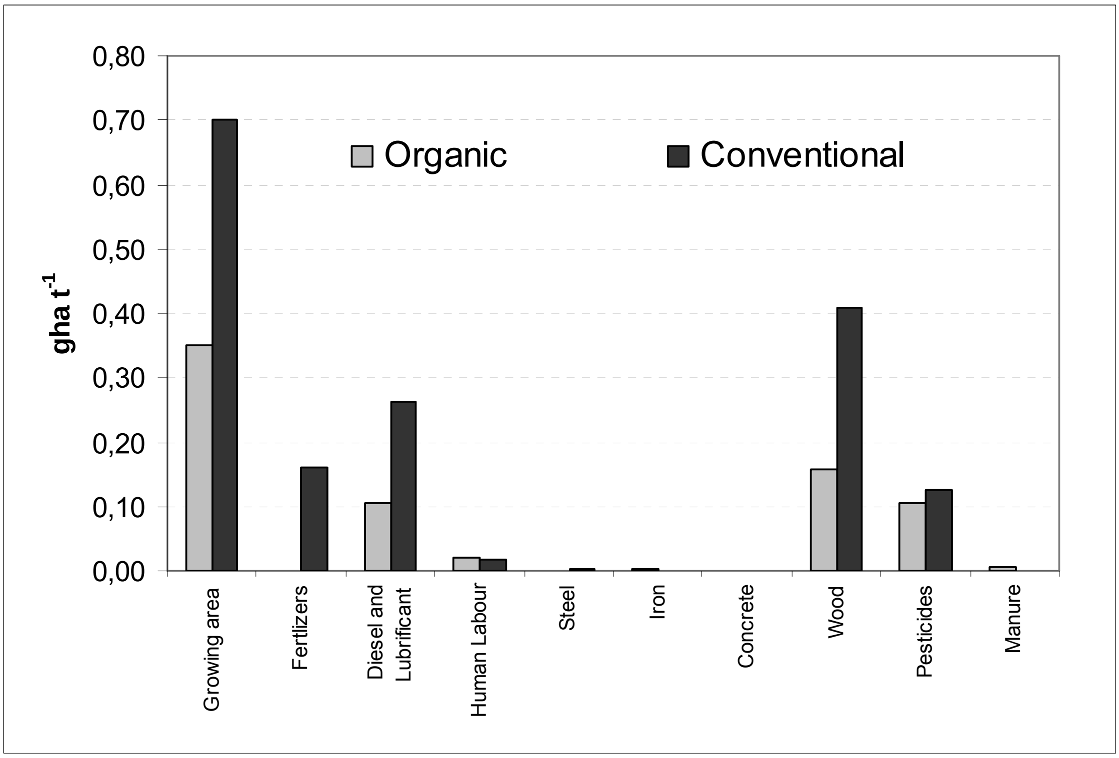

Figure 3*: Comparison between components of the agricultural phase for both the two productions.*

The farmer assessed that about a half of the total grapes harvested are suitable for winery activity in order to produce high selected wine. This results in a lower effective grapes' yield for the conventional production.
As a consequence all inputs related to agricultural phase are higher for the conventional farm with respect to the organic one (e.g. wood, diesel and lubricant).
The use of chemical fertilizers is another important difference among the two productions. Organic practices do not imply the use of fertilizers since it only attempts to enrich soil nutrients through agronomic practices.
A clarification is further need for pesticides. The quantities appear to be quite similar. This is due to the fact that the conventional farm uses chemical pesticides effective at lower doses but with higher energy content as synthetic product. The organic farm uses conventional sulphur or copper based pesticides which are less effective and invasive of the former class but needed in a more quantity.
The conventional farm uses new tools and machineries, very efficient and with low consumption but practices a more mechanized agriculture with respect to the organic farm where most of the work is made by hand (human labour contribution for organic case is a bit higher than the conventional one).
In the last phase, the packing phase, the major footprint component for both the productions is the glass. The relative amounts are quite different for the two cases. The conventional farm takes care of every single aspect of the wine production from the agriculture phase to market, always using the top product in commerce. This is especially valid for glass since dark not recycled glass is used. Organic farm prefers lighter glass bottles according to the limitation imposed by organic procedure. Glass has very important environmental consequences, and they become especially important when glass is not recycled as for the case of Italian wine production.
Summarizing, the higher footprint value for the conventional farm is essentially due to this main points: i) the very high selection of its grapes; ii) the more mechanized and energy-based production; iii) the use of chemical fertilizers (nitrogen as well as phosphorous based) and pesticides.
The ratio between the total Footprint value and the growing area, both expressed in terms of global hectares, reveal the demand of natural capital with respect to the biocapacity. Results show that a three times higher area is necessary to support both the productions. This confirms that often the real price doesn't reflect the real environmental cost of a product.
In an agriculture more and more industrialized and energy based this ratio is rapidly increasing.

4.2 *time series analysis*

One of the aims of this paper was to produce a reliable Ecological Footprint value for the analyzed wine productions. It is known that the yield of any agriculture production, and especially wine production, is strongly dependent on several factors, such as natural factors, climatic conditions as well as changes in parasitic attacks. For this reason, a direct relation between input and output is not often observed. The organic production is the most sensitive to natural variations since it is characterized by lower anthropogenic inputs. Therefore the Ecological Footprint accounting for organic production was repeated over the time, from 2000 to 2005.

For each year, different yield factors were used in order to account for changes in the annual production yield. Both the local and global yields were recalculated each time as mentioned in the previous section. So the ratio between them is not constant over the considered period due to variation in world yields.

During this period, critical meteorological events were not registered and extra-ordinary maintenance was not performed. Small change in the use of input per tonnes of wine produced were registered.

The statistical approach shows that the average ecological footprint value for organic farm is 1.26 gha t^{-1} with a standard deviation of 0.15. The variation coefficient was found of 12%, lower than a similar footprint analysis realized for dairy production (Thomassen et al., 2005). The low value found for standard deviation confirms that input are not so changed over the period analyzed.

The temporal analysis is proposed as a convenient way to appraise the accuracy of the footprint calculation for agricultural products because, as we have seen, they are more dependent on changes (for example the variability of climate) with respect to the industrial one. A more reliable ecological footprint value for the specific wine was given. Perhaps the period of time analyzed is quite short and a 6 years interval is not sufficient to produce significant results but yet, the application is a proxy to test how variable a footprint accounting for a given agriculture production can be.

In absolute terms, it should be noted that while the required actual land is constant over the time, the demand on bioproductivity is changing in the same period (see Figure 4). In other words, in the organic farm, the required growing area, expressed in actual hectares, is always the same, since 2000 to 2005, and it is equal to 10 ha. No changes in the annual yield are taken into account. On the contrary, by expressing results in terms of global hectares, changes in bio-productivity are also considered by the use of yield and equivalence factors. The same 10 hectares correspond to 19.93 gha in 2002 and 7.88 gha in 2003 due to annual changes in the local yield.

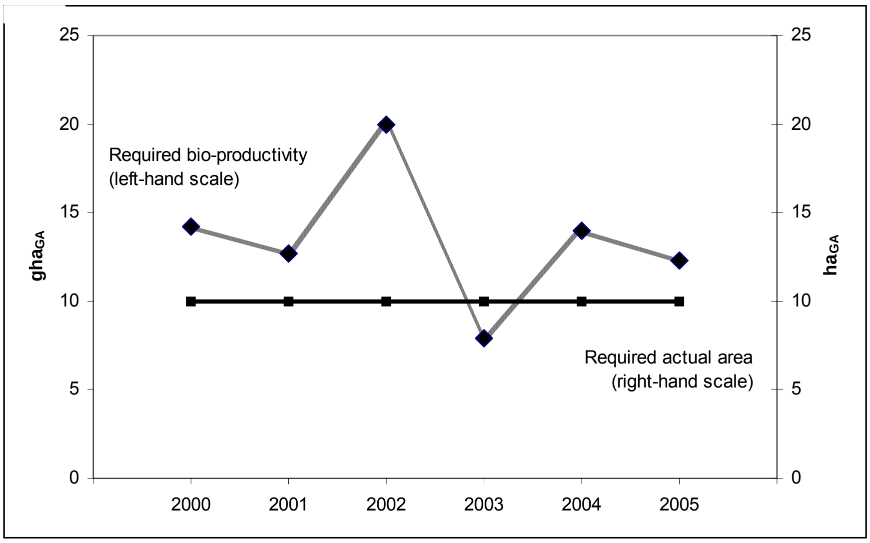

Figure 4: *Time series comparison between actual land (right-hand scale) and bioproductivity requirement (left-hand scale).*

4.3 Inclusion of the transport

The transport contribution to the total Ecological Footprint has been added, in order to give a more comprehensive footprint evaluation for wine.

In this case a bottle of wine was used as unit to better allocate the contribution among the wine production (which comprises agriculture, vinery activity and packing phase) and distribution phases.

Firstly, an average source distance (expressed in km per bottle of wine) between the farm and the consumer was evaluated. The final destinations were grouped in three different groups: Italy, Europe (Belgium, France, Germany, Holland and Switzerland) as well as Extra-Europe (USA and Japan), according to the real shipping of the farms. The average distance was calculated from the farm to the capital of the nation.

Regarding the mode of transport, it was considered by road (i.e. heavy goods vehicles) for Italian regions as well as the European countries while by sea for extra-European country, as reported by the farmers.

The weighted average footprint of distribution phase was found of 0.96 gm^2 per bottle of wine exported. In table 3 data per three average destination countries (Italy, Europe and Extra-Europe) were reported.

Table 3: *Ecological footprint of transport for three different destinations.*

	Mode of tranport	**Average distance** (km)	**EF per bottle of wine** (gm^2)
Italian countries	road	331.6	0.40
European countries	road	1,187.8	1.28
Extra European countries	sea	12,434.5	0.95

Data confirms that sea transport is relatively more efficient with respect to the road transport with lower CO_2 emissions and consequently lower footprint (15 times lower).

Figure 5 allows us to appraise the phase contribution to the overall footprint of the organic wine bottle for the three average destinations considered.

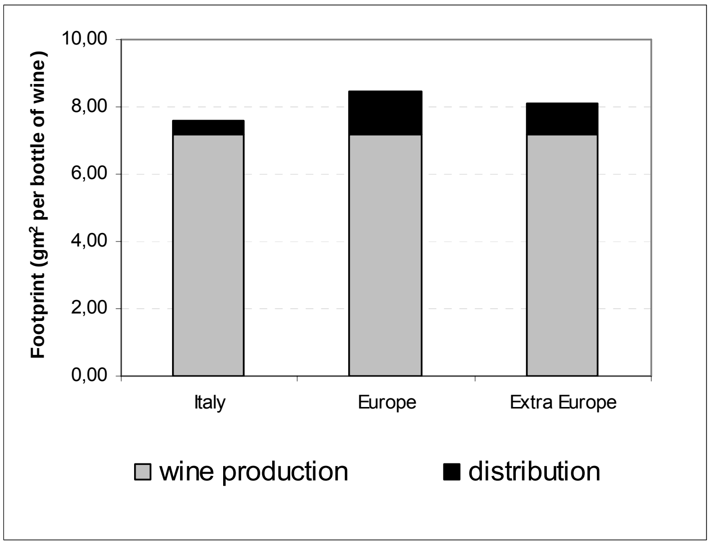

Figure 5: *Total Footprint of a wine bottle including the contribution of all production phases and distribution.*

Results show that the dominant phase is the wine production while the transport contribution is not as relevant as supposed.
This is probably due to the fact that wine is not a fresh and perishable good and it is not need to be purposely distributing as soon as produced with an improving of the efficiency. Moreover, the small size of the good transported, produce an important footprint saving per unit.

5. **Conclusion**

This paper reports an ecological footprint applications to a typical Italian agriculture product. The Ecological Footprint indicator offers an ecological perspective of sustainability: the main goal of this tool is to make the human dependence on nature visible. Agricultural productions are becoming more dependent on external energy-based input and on more technological practices, with a consequent footprint rising. Two different wine productions, a conventional and an organic one, were analyzed. Results show that the conventional farm produce a double impact, with respect to organic one, in order to sustain the wine production because it requires a double amount of natural capital, expressed in terms of global hectares. The main input to the overall process is the growing area, but the importance of energy land is growing from organic to conventional practice. The energy land is strictly related to indirect effects, such as greenhouse gas emissions, that often occur off-farm.
Ecological Footprint has never been presented with a confidence interval because of lacking of margin of error on raw data. To overcome this limitation the footprint computation of organic wine production was repeated over the time. In this way, the total ecological footprint, with standard deviation and coefficient of variation, is reported in order to minimize calculation errors and natural fluctuations and to make it more reliable and reproducible. Note that variations in global hectares values for the growing area depend on world yield changes.
The contribution of distribution, from production site to final consumer, was also included to give a more comprehensive final wine footprint value. Transport was found as not relevant as supposed: in terms of land equivalent the growing area necessary for the harvest is the most important contribution to the footprint.
Nevertheless the Ecological Footprint approach does not distinguish between sustainable and unsustainable land use practices, so it underestimated the real situation. Further efforts should be spent in this direction.

6. **Acknowledgement**

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