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Ecological footprint analysis applied to a sub-national area: The case of the Province of Siena (Italy)

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Abstract

This work is part of a larger project, which aims at investigating the environmental sustainability of the Province of Siena and of its communes, by means of different indicators and methods of analysis. The research presented in this article uses ecological footprint and biocapacity as indicators to monitor the environmental conditions of the area of Siena, thus complementing previous studies carried out using Emergy, greenhouse gases balance and other methods. The calculations have been performed in such a way as to enable a disaggregation of the final results according to the classical categories of ecologically productive land and of consumption, but also according to citizen's and public administration's areas of influence. This information allows us to investigate in detail the socio-economic aspects of environmental resource use. Among the notable results, the Siena territory is characterized by a nearly breakeven total ecological balance, a result contrasting with the national average and most of the other Italian provinces. Furthermore, the analysis has been carried out at different spatial scales (province, districts and communes), highlighting an inhomogeneous territorial structure consisting of subareas in ecological deficit compensated by zones in ecological surplus.

Keywords: Ecological footprint; Biocapacity; Environmental sustainability

1. Introduction

This work is part of a larger project, which aims to study the environmental sustainability of the Province of Siena and its communes, through the use of different indicators and methods of analysis. Complementing the other studies that have been realized using Emergy (Pulselli et al., 2006a), greenhouse gases balance and other methods (Ridolfi et al., 2006), the research presented in this article utilizes the ecological footprint as an indicator for monitoring the environmental conditions of the area of Siena.

This multiple analysis of sustainability is characterized by the concurrent use of various inquiry methods applied to the same area of study and it represents an interesting opportunity to investigate the performance levels of these indicators. Indeed, it allows to highlight their limits and their qualities, and to compare and critically discuss their definitions, the assumptions they are based on, the implied methodology, their scientific robustness. Along with these theoretical aims, the entire project provides a description of the local territory, which could be easily utilized by local administrators for planning and implementing specific policies aimed at decreasing environmental impact.

The ecological footprint has been calculated considering three different spatial scales, in order to analyze in detail the relationships between local inhabitants and global ecosystems: (1) the whole province; (2) the districts (aggregate of several communes grouped following some territorial homogeneity); (3) the single communes (the smallest administrative Italian territorial partition ranging usually from the dimensions of a small village to those of a town). This special analysis allows a deeper understanding of some geographical properties, such as spatial

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uniformity, territorial homogeneity, and the different configurations and spatial patterns characterizing both the allocation and the withdrawal of natural resources. Finally, the work is carefully structured in order to obtain both the global values of footprint and biocapacity, and their breakdown into different categories (ecologically productive land, consumption categories, areas of influence). A first description of the ecological footprint calculation for the province of Siena is reported in Bagliani et al. (2003), while a more complete discussion of the entire project can be found in Pulselli et al. (2006b).

2. Ecological footprint and biocapacity

Introduced by Rees (1992) and developed by Rees and Wackernagel (1994), the ecological footprint is a synthetic indicator used to estimate a population's impact on the environment due to its consumptions; it quantifies the total area of the terrestrial and aquatic ecosystems necessary to supply all resources utilized in a sustainable way, and to absorb all emissions produced, always in a sustainable way.

Ecological footprint analysis essentially inverts the logic of carrying capacity, defined as the maximum load exerted by the population of a certain specie that a territory can support, without compromising its productivity. The ecological footprint focus is not to determine the maximum human population that an area can support, but to evaluate the productive territory actually used by residents, recognizing the fact that this ecosystem area does not coincide with the area where that same population lives.

Nowadays, the studies and analyses that utilize such indicators are extremely numerous and they regard very different geographical regions and spatial scales. Also, the scientific literature on this subject is quite extensive and rapidly expanding. A complete and systematic review is outside the scope of this article. We would like to mention here, along with the initial pioneering works (Rees, 1992, 1995, 1996; Rees and Wackernagel, 1994, 1996; Wackernagel and Rees, 1996), the monographic issue of the journal Ecological Economics (2000), a critical examination of the limits and potentials of this indicator. Of great relevance are also the various editions of the Living Planet Report (WWF and UNEP-WCMC, 2000, 2002, 2004) that report the calculations for the world nations with populations higher than 1 million inhabitants, and that have contributed to the systematization and in-depth study of the calculation formalism. Furthermore the Final Report, written for the European Common Indicators Project EUROCITIES (Lewan and Simmons, 2001) examines methods and criteria to apply the ecological footprint analysis to territories on a sub-national geographical scale, and provides 14 criteria and 5 recommendations, all of which have been strictly followed throughout the realization of the present calculations for the area of Siena. Finally, in 2004, Wackernagel and collaborators founded the Global Footprint Network, a network of research institutions, scientists and users of this indicator, which aims to further improve the calculation methods and bring them to higher standard levels, therefore fostering its scientific robustness and its diffusion.

In the classic formulation, proposed by Wackernagel and Rees (1996), the ecological footprint calculation is based on the average population consumptions data that are translated into uses of productive land. The land is divided into 6 categories, following the classification of the World Conservation Union: (1) cropland; (2) grazing land; (3) forest; (4) fishing ground; (5) built-up land; (6) energy land.

Each kind of land is characterized by a different productivity and this factor has to be taken into account when calculating the ecological footprint final value. In order to make the six different kinds of land comparable with each other, the classic formulation of the ecological footprint introduces a normalization process, in which the areas of different types of land are weighted by specific equivalence factors, based on the different bio-productivities. The measurement unit for these areas is the global hectare (gha), as opposed to the hectare used for real surfaces.

An important part of the ecological footprint analysis of a region is represented by the calculation of its biocapacity, that takes into account the surfaces of ecologically productive land located within the area under examination. Therefore biocapacity represents the "endowment" of ecologically productive territory that is locally available and it indicates the local ecosystems potential capacity to provide natural resources and services. This quantity can be compared with the ecological footprint, which provides an estimation of the ecological resources required by the local population. It is then possible to define an ecological balance for the territory: this balance is obtained by subtracting from the local population's needs for natural resources (the ecological footprint), the local availability of those resources (biocapacity). A positive (or negative) balance indicates a condition of ecological deficit (or surplus): this would outline a situation of unsustainability (or sustainability), in which the rate of consumption of natural resources is greater (or less) than the rate of production (regeneration) by local ecosystems (Rees, 1996). Therefore, an ecological deficit or surplus provides an estimation of a local territory's level of environmental sustainability or unsustainability.

3. Calculation methods and data

The ecological footprint's calculation requires a significant amount of information about natural resources consumptions, economic goods and services, industrial processes, technological and energetic efficiency, agricultural productivity, etc. While these data are generally available at a national level, it is difficult to obtain them at the regional, and especially at the local level. Therefore, in applying this study to the local level (province, district and commune scale), estimations and approximations were necessary.

In order to limit these approximations and possible inaccuracies as much as possible, the whole calculation method for the sub-national area of Siena was conceived considering the already available data at the communes level. Indeed at this level, it was possible to find data regarding different kinds of consumptions such as housing (electricity, gas, fuel oil), water, waste production and land occupation. Energy consumptions related to transportation (gasoline, fuel oil, LPG) were estimated from provincial values. For all other kinds of consumption it was decided to refer to ISTAT (Istituto nazionale di STATistica) statistics, which provides annual data on family average consumptions, according to the employment condition, and broken down in various categories such as foodstuffs (22 items) and other economic goods and services (66 items), at a high level of spatial resolution (regional and macro-regional). In order to better estimate a real scenario, the average consumptions were calculated for each commune by weighting the average regional consumptions on the basis of the composition of each commune by employment conditions (census data). This estimation differs from the formalism adopted by CRAS (Centro Ricerche Applicate per lo Sviluppo sostenibile) (Bilanzone et al., 2002) in which the ecological footprint of the communes of the Province of Bologna was estimated by weighting the average regional consumptions on the basis of the family's average income.

In calculating the ecological footprint, conversion factors are of great relevance: they allow to translate a local population consumption of goods and services into the corresponding area of land that is directly or indirectly used for their production. When the analysis of the Province of Siena (year 2001) was performed, the Global Footprint Network and its activity of standardization did not yet exist; at that time, a great variety of inhomogeneous and conflicting conversion factors were used in the relevant literature. Homogeneous and updated conversion factors were chosen whenever available, in order to make the calculation as accurate and coherent as possible. Therefore the calculation has been performed referring to the most recent works of Wackernagel and collaborators, while introducing conversion factors from previous years (always from Wackernagel) whenever recent revisions were unavailable. For a more in-depth discussion of the conversion factors and their sources, the reader can refer to the detailed publication about the Spin-Eco project (Amministrazione Provinciale di Siena, 2002).

Special attention has been given to the calculation of the energy consumption ecological footprint, which represents the greatest contribution to the final result. We have therefore referred to several different data sources from which it was possible to deduce the consumption values for solid, liquid, gas combustibles, for electric energy (either thermoelectric, hydroelectric, and obtained from other renewable sources), identified according to their final uses. In order to provide more precise estimates of such consumptions, we have also decided to keep track of production, transformation and transportation losses (for example in the case of electric energy) for each kind of energy source. The actual value of the consumed energy has been calculated by weighting each source final use by the primary or secondary source gross consumption, so that all sustained losses were taken into account. All these values have been straightforwardly taken from the national energy balance BEN (Bilancio Energetico Nazionale) 1999, which provides the allocation of gross energy consumption and net loss, for each of the primary energy sources.

The conversion factor for electric energy was not derived from previous studies by Wackernagel or collaborators, but it was expressly calculated, since the environmental impact generated by the use of electric energy depends on how it is produced. In order to provide a correct estimate of this ecological footprint component, we have considered the percentage composition of the different energy sources utilized for the production of electric energy in Italy, therefore succeeding in calculating the conversion factor for a unit of electric energy produced with the national mix. This factor has been further corrected in order to keep track of the average percentage of electric energy loss due to different types of production and transport. It is important to stress that the calculation of the average ecological footprint per joule has been performed at the national level, and not only at the level of the Province of Siena. Indeed, electric energy cannot be stored and it is put into the national network as soon as it is produced: therefore every consumer that draws electric energy from the network uses energy produced by the national mix.

We accounted for biodiversity in our calculation of biocapacity available to humans in the Province of Siena using the standard (but not scientifically well-founded) approach. This method (Wackernagel and Rees, 1996) requires that we set aside 12% of the total productive land and water area to provide reserve areas for local biodiversity conservation.

In calculating both the ecological footprint and the biocapacity, we used the Living Planet Report 2000 for the equivalence and yield factors; this implies that the yield factors used to weight Siena's biocapacity do not reflect the specific productivities of Siena's ecosystems but the average national value.

Moreover, in evaluating the ecological footprint of the Province of Siena, we took the 1999 data as reference, as in the other parallel studies (such as the emergy analysis), all of which converge to delineate the picture of environmental sustainability of the Siena area. Finally, in order to avoid systematic errors and to minimize approximations, a special effort was made to maximize homogeneity in the choice of data. The main data sources are reported in Table 1.

Table 1
The main data sources used to calculate the ecological footprint and the biocapacity of the Province of Siena

Data	Source	Year
Waste production and recycling	Sienambiente	1999
Water consumption	Fiorentina gas, Intesa, Publiser, Nuove Acque, Cigaf, Asav, In Economia	1999
Food categories prices	Department of chemical and biosystem sciences and technology of the University of Siena	2002 reported to 1999
GIS coverage	CORINE Land Cover	1999
Gasoline, fuel oil and LPG consumptions related to transportation	ENEA (Ente Nazionale Energia e Ambiente)	2000
Electric energy consumption	GRTN (Gestore della Rete di Trasmissione Nazionale	1999
Family consumption	ISTAT (Istituto nazionale di STATistica)	1999
Gas and fuel oil consumption related to heating	MICA (Ministero dell'Industria, del Commercio e dell'Artigianato)	1999
Primary and secondary energetic sources consumption related to electric energy production	BEN (Bilancio Energetico Nazionale)	1999
Gas consumption	SNAM (Società NAzionale Metanodotti) Rete Gas	1998

4. Results

4.1. Different methods for reading the results

When structuring the calculations of a territory ecological footprint and biocapacity, it is important to ensure an adequate degree of disaggregation so as to allow the analyst to derive a multiple and insightful reading of the final data. We have therefore elaborated our results in different ways, summarized as follows.

4.1.1. Aggregated results

When analyzing a sub-national area, the ecological footprint final value cannot be particularly significant if considered in itself. However, when compared with other quantities, such as biocapacity on different spatial scales, this value may offer important insights about the "level of sustainability" of the examined territory and about the scales that characterize the level of natural resources appropriation. Therefore the present study compares ecological footprint with the following quantities:

- Local biocapacity: a comparison between the ecological footprint and the local biocapacity (both as per capita and as total values) allows to evaluate a local ecological balance, and therefore the ecological deficit or surplus relative to the given territory. This information provides an estimate of the amount of ecological resources used by residents, identifying how much is drawn from local ecosystems and how much comes from imported land.
- Average national biocapacity: this comparison allows to estimate the local per capita ecological footprint in the national context, comparing it with the average amount of land available per capita at the Italian level.
- Average worldwide biocapacity: the comparison between the local per capita ecological footprint and the average worldwide per capita biocapacity allows to connect the consumption levels of natural resources, and therefore the lifestyle of the inhabitants of the province of Siena, with the globally sustainable consumption level, represented by the average amount of land available per capita worldwide.

4.1.2. Disaggregated results

We have chosen to disaggregate the results according to the following categories:

- *Consumption*: We refer to the classic subdivision, first proposed by Wackernagel and Rees (1996), that focuses on the causes (the different types of consumption) that require the use of natural resources.
- *Ecologically productive land*: These categories have also been proposed by Wackernagel and Rees (1996), and they refer to the types of ecosystems that are affected by anthropic impacts.
- *Areas of influence*: We have introduced this disaggregation in order to distinguish between the factors ascribable to habits, actions and behaviors of the individual citizen, and those that depend upon, or that may be at least partially influenced by, the policies and the decisions of the public administration. Beside facilitating the interpretation of the results by the local administration, this new category may be a useful tool in planning for actions that would reduce the present unsustainable environmental situation.

4.1.3. Spatially disaggregated results

This consists of a geographical analysis that considers the territory on different spatial scales. In the present case, the calculations have been performed on the province, districts and communes levels. This allows to highlight on the one hand the areas of spatial uniformity, on the other hand the possible inhomogeneous configurations that characterize the territory in the allocation and withdrawal of natural resources. This specific analysis provides a further level of insight when combined with other kinds of geographical information such as economic, demographic, social, etc.

4.2. Aggregated results analysis

Table 2 reports the per capita values of the ecological footprint (disaggregated according to ecologically productive land categories) and those of the biocapacity and the ecological deficit for the Province of Siena, compared with those for Italy and for the world.

4.2.1. Comparison with local biocapacity

As mentioned above, we have started our analysis by comparing the local biocapacity, that calculates the area of the ecologically productive land in the Province, with the ecological footprint, which estimates the ecological resources demanded by the local population. The local bioproductivity is able to cover 5.74 out of the 5.80 gha per capita of ecological surface (i.e., ''ecosystems'') required by the inhabitants of the Province of Siena. The result is a small ecological deficit, of about 0.06 gha per capita, which, however, is not significant when compared to the error range of the calculations and of the data. One may therefore claim that the Province of Siena is characterized by a nearly breakeven total ecological balance. This means that almost the whole demand of natural resources by local inhabitants could be achieved locally, but does not necessarily imply that this really happens, because ecological demand could be met locally both through imports or through ruinous practices. In order to tackle this issue, we have extended our analysis of the ecological balance to the individual categories of ecologically productive land. Fig. 1 shows that the Province of Siena is a net exporter of economic goods and services related to cropland and a net importer of those related to forest (all energy imports fall within this category), while the others categories have a nearly breakeven balance.

A further interesting step would be extending this analysis to incorporate also trade flows for each category of productive land. This would allow not only to estimate the net value of the import/export, but also to reconstruct all the individual input and output flows, thus allowing to diagnose the possible occurrence of local ruinous practices. We could not perform this kind of calculation due to the lack of data regarding the economic goods and services flows through the boundary of the Province of Siena.

4.2.2. Comparison with the average national biocapacity

By comparing the data reported in Table 2 we find that the ecological footprint for the Province of Siena is greater than the average Italian value by approximately 5%. In order to evaluate this result, it is important to consider that the two values are not fully comparable, as we are working with two studies on quite different scales (provincial–national) and therefore we utilize data, methods and approximations that can vary greatly. Nonetheless, keeping these limitations in mind, the two values can be read in parallel, leading to the conclusion that the lifestyle (and therefore the consumption trend) that characterizes the

Table 2
Per capita values of the ecological footprint (disaggregated according to ecologically productive land categories) of the biocapacity and of the ecological deficit for the Province of Siena, compared with those for Italy and for the world (data from Living Planet Report 2000)

	Energy land	Cropland	Grazing land	Forest	Built-up land	Fishing ground	Ecological footprint	Biocapacity	Ecological deficit
Prov. Siena	3.92	0.73	0.52	0.37	0.20	0.04	5.80	5.74	−0.06
Italy	2.34	1.33	1.24	0.36	0.18	0.08	5.51	1.92	−3.59
World	1.41	0.69	0.31	0.28	0.12	0.04	2.85	2.18	−0.67

All data are in gha per person.

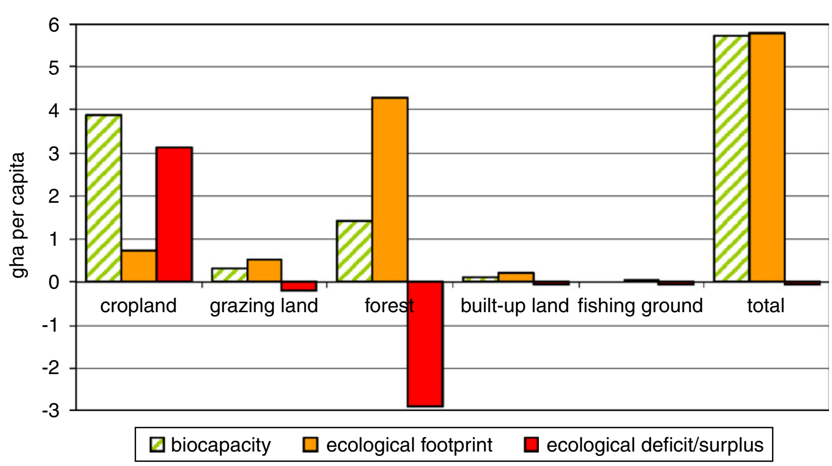

Fig. 1. Biocapacity, ecological footprint and ecological deficit/surplus per capita of the Province of Siena disaggregated in categories of ecologically productive land.

Siena inhabitants is very close to the one of the average Italian. What changes in a very notable manner is the result of the ecological balance: while the Province of Siena is characterized by a nearly breakeven one, values for Italy show that the average biocapacity can only cover 30.8% of the national ecological footprint, leaving an ecological deficit of 69.2%. Such percentages demonstrate a substantially different situation for Italy, characterized by high levels of import of natural resources from abroad. It should, however, be noted that the Province of Siena exhibits a virtuous ecological behavior, not really because of its low ecological footprint (close to the Italian one), but because of its high levels of biocapacity per capita, correlated to the low population density that characterizes the Siena territory.

Table 3
Comparison among the ecological footprint, the biocapacity and the ecological deficit of some Italian provinces

	Ecological footprint	Biocapacity	Ecological deficit
Prov. Siena	5.80	5.74	−0.06
Prov. Ancona	6.11	2.07	−4.04
Prov. Venezia	5.71	2.33	−3.38
Prov. Pesaro-Urbino	6.32	3.43	−2.89
Prov. Cagliari	5.43	4.03	−1.39
Prov. Forlì Cesena	7.43	2.56	−4.87
Prov. Ascoli Piceno	6.54	2.42	−4.12

All calculations refer to equivalent and yield factors of the Living Planet Report 2000. All data are in gha per person.

4.2.3. Comparison with the average worldwide biocapacity

Here we compare the Siena situation with the average worldwide ecological footprint and biocapacity, reported in Table 2. This shows, primarily, the great difference between the average worldwide ecological footprint (2.85 gha per capita) and the one of the province of Siena; the latter being approximately double, a definitely high value, close to the Italian one, the 26th out of 152 nations (WWF and UNEP-WCMC, 2000).

This comparison of the Siena territory with average worldwide data allows us as well to highlight the vast difference between the ecological footprint of the Province of Siena and the average worldwide biocapacity, which amounts to the value of 2.18 gha per capita. This implies that the inhabitants of the Siena territory consume, on average, a much greater amount of ecological resources and goods than the sustainable withdrawal rates on the worldwide level, therefore contributing to the trend of impoverishment and erosion of the global natural capital.

4.2.4. Comparison with other Italian situations

This section compares the results for the Province of Siena with those of other Italian provinces. The comparison is quite interesting because the systems under consideration have the same geographical scale and the studies have been undertaken by the same research group, which adopts identical methods of calculation and offers results that are perfectly comparable with each other.

An examination of Table 3 shows rather similar values of ecological footprint. Although placed above the Italian average, the Province of Siena does not represent one of the highest cases of ecological footprint; it is in fact surpassed by all remaining provinces considered here, except for Cagliari and Venezia. This set of values, essentially high and similar to each other, further confirms the substantial homogeneity of Italians' lifestyles, which are all characterized by an elevated demand of natural resources, both direct and indirect. The biocapacity values are more heterogeneous compared to the corresponding values of the ecological footprint, testifying how variable the socio-demographic situation is among the various analyzed provinces. Indeed, biocapacity, besides depending on the endowment of the ecosystems present in the territory, is also strongly related to the population density. These two factors determine the mixed situation of Table 3. Among the most important examples, one may observe the Province of Siena itself, which has a higher biocapacity than the other provinces, due to both a large area of highly productive land (more than 90% of the biologically productive territories are used as agricultural land, pastures and forests) and a low population density (66 inhabitants/km^2). On the contrary, situations such as those of the Provinces of Ancona and Venezia, suffer most of all from a high population density (for instance, approximately 330 inhabitants/km^2 for the Province of Venezia).

Finally, it is interesting to note that, except for the Province of Siena, characterized by a nearly breakeven total ecological balance, all other provinces have a negative balance, that is a more or less considerable environmental deficit. The Province of Siena is, therefore, a positive exception in an overall negative scenario in which all of the analyzed territories are unable to meet their inhabitants' needs for natural resources if considering local ecosystems only.

4.3. Disaggregated results analysis

4.3.1. Ecological footprint and ecologically productive land categories

Fig. 2 shows the ecological footprint of the Province of Siena disaggregated according to the categories of ecologically productive land. It is immediately evident that a vast percentage of land is utilized as energy land (67.7%), that is the forest land needed to absorb all the CO_2 emissions caused by the use of energy by the inhabitants of the province. In general, one may say that the Province of Siena follows a trend that is typical of other industrialized areas, in which such a percentage represents between one and two thirds of the entire value of the ecological footprint.

Within this type of land, we have accounted for both energy direct uses, such as fuel consumption for

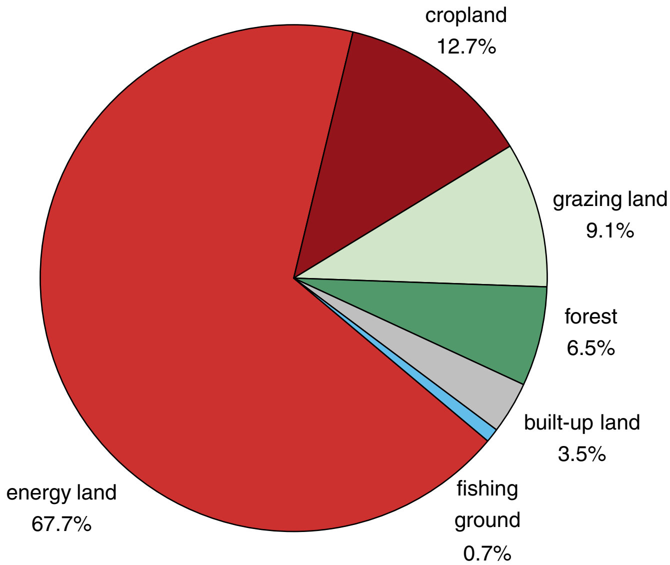

Fig. 2. Percentage distribution of the ecological footprint of the Province of Siena disaggregated according to categories of ecologically productive land.

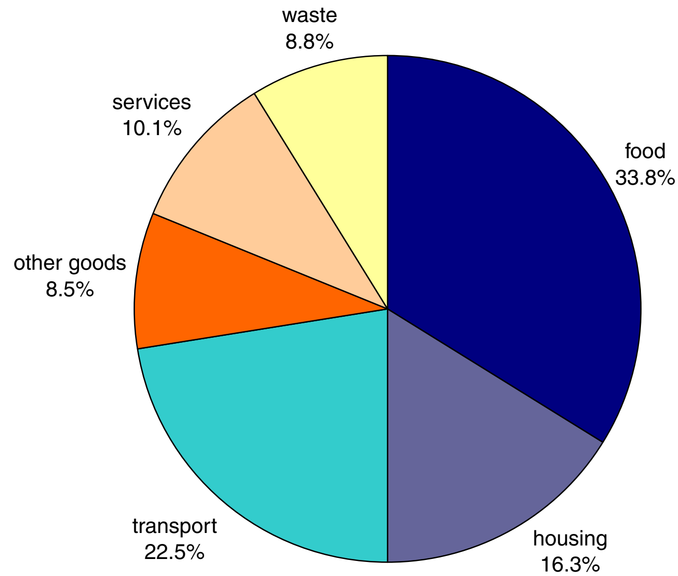

Fig. 3. Percentage distribution of the ecological footprint of the Province of Siena disaggregated according to consumption categories.

transportation or heating or the use of fossil combustibles for the production of electric energy, and indirect energy uses, such as the energy utilized in manufacturing and transporting goods and in providing services.

4.3.2. Ecological footprint and consumption categories

The disaggregation of the ecological footprint according to the consumption categories allows to focus more effectively on the origin of different contributions, and therefore to better investigate the causes of environmental unsustainability. Fig. 3 reports such subdivisions; it may be observed that the greatest contribution (33.8%) is caused by food consumption, followed by transportation (22.5%) and housing (16.3%). Such a situation is qualitatively similar to the results of the other Italian provinces, considered in Table 3.

It is interesting to further investigate the categories that contribute the most to the ecological footprint, as this may help to individuate the real causes of environmental impact and induce the undertaking of corrective actions. By matching the information included in the consumption categories to that included in the ecologically productive land categories, we demonstrate (Fig. 4) that the types of consumption that most contribute to the energy component of the ecological footprint are transportation (1.23 gha per capita) and housing (0.86 gha per capita), both of which are indeed energy intensive, followed by food consumption (0.71 gha per capita). Note that moreover, this last component amounts to almost the total of the cropland and grazing land categories of the ecological footprint. This was reasonable to expect because most of the products obtained from agriculture and breeding end up in food consumption, except for animal fibers (wool, silk) and vegetable fibres (jute, cotton) used by textile industry.

Furthermore, from Fig. 4, one can deduce that the energy component represents the greatest contribution of all the consumption categories; in particular for transportation, housing and services it matches almost completely the whole category value.

It is possible to analyze the energy component in more detail, by highlighting the individual contributions of the ecological footprint that derive from different combustibles used for different types of consumption (transportation, heat, light and household electrical appliances, etc.), as shown in Fig. 5. First of all, it stands out that a high percentage of energy (almost half of the total) is used by the population in an indirect manner, both as embodied in food products (19%) and in other goods and services (28.8%). We then find the other footprint components related to the consumption of liquid combustibles (19.5%), electric energy (18.7%), gas combustibles (7.1%) and to waste treatment (6.9%).

4.3.3. Ecological footprint and areas of influence

We introduce here a new disaggregation of the results according to ''areas of influence'', which aims at distinguishing the contributions that may be, partially or completely, influenced by the public administration, from those that depend upon individual decisions. The citizens areas of influence refer to food products consumption, private use of other goods and services and land uses related to housing. Private transportation and heating are however excluded from this category as they are, at least partially, influenced by public policies and are therefore included in the public administration areas of influence together with public transportation, waste collection and disposal, and public services. It is important to remind that this subdivision does not represent the results of a different calculation, but rather a different way of breaking down

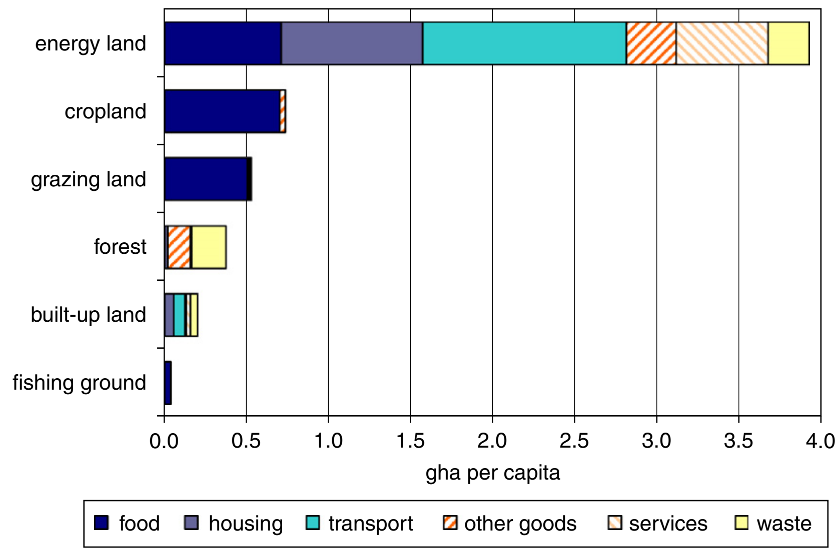

Fig. 4. Distribution of the ecological footprint of the Province of Siena disaggregated according to ecologically productive land and consumption categories.

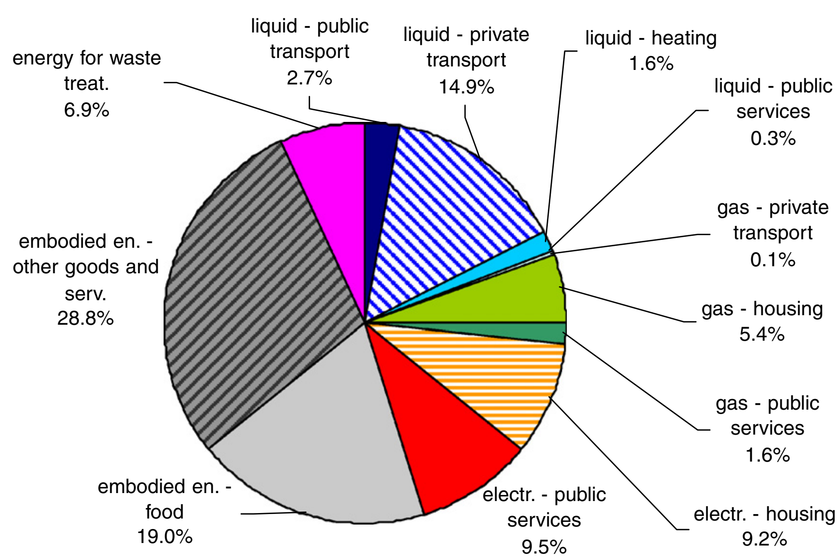

Fig. 5. Percentage distribution of the ecological footprint energy component of the Province of Siena.

and regrouping the different components of the ecological footprint.

Fig. 6 shows that the percentage of the citizen areas of influence (striped sections) covers in total precisely 60% of the ecological footprint of the Province of Siena, while the remaining 40% refers to the public administration components (solid colors).

Given this disaggregation, it is possible to construct and analyze a variety of scenarios for each area of influence, thus allowing us to calculate benefits and drawbacks of different actions and policies for decreasing the ecological footprint. One might consider, for example, the component related to waste disposal, which constitutes 8.8% of the total ecological footprint. Fig. 7 shows the ecological footprint distribution according to the waste composition, and compares the current situation of the waste management with two scenarios: one in which there is no recycling at all and the other corresponding to a recycling program hypothetically extended to the whole amount of waste. In this way it is possible to highlight the efficiency and the limits of a good recycling program. Indeed the green striped area represents, in fact, the ecological footprint "saving" (and therefore the environmental impact reduction) compared to the no recycling scenario. The current waste management program of the province of Siena ensures a 5.0% ecological footprint saving, whereas in the complete recycling scenario, a maximum of 32.1% ecological footprint saving can be reached. In this case, the ecological footprint could only be further reduced by acting on the upstream causes, that is by reducing the waste production, and, in addition, by lowering the downstream effects, through the adoption of reuse policies (applied to glass bottles, plastic boxes, packaging, etc.) as opposed to simply recycling the primary and secondary materials.

4.4. Spatially disaggregated results analysis

Given the previous examination of the socio-economic aspects of the ecological footprint and biocapacity (such as consumers' choice, lifestyles, levels of efficiency in the production of energy, etc.), we have decided to introduce a geographic-territorial analysis. This further step allows to investigate the contributions mostly related to spatial distribution and to identify the areas of uniformity, discontinuity, and more generally, the spatial configuration of ecological resources and of their use by the local inhabitants.

We needed then to increase the ''resolution power'' of our analysis in order to better examine the spatial properties of the Siena area by performing our calculation of the ecological footprint, the biocapacity and the ecological balance not only at the level of the entire province, but also at smaller scales. Therefore, we have decided to carry out the calculations also at the following two scales: the district scale, which divides the province into 7 subareas (Chianti Senese, Crete Senesi Val D'Arbia, Val di Chiana, Val d'Orcia, Val Di Merse, Val d'Elsa, City of Siena) physically and socio-economically homogeneous, and the scale of the 36 single communes, that represents the smallest territorial level at which it is possible to perform a calculation from statistical data not gathered ad hoc.

Thanks to this analysis, it is possible to understand if the values of the ecological footprint and biocapacity obtained at the provincial scale are representative of the whole territory or if, instead, there are irregularities, breaks, or polarizations. One can also recognize if the ecological balance derives from a substantial homogeneity both in the availability and in the use of ecologically productive land, or if it arises from compensations among different areas.

Fig. 8 represents the results of the analyses at the level of the individual communes, while Fig. 9 translates the numbers into territorial maps that allow to identify sub-areas and configurations smaller than the provincial scale. An interesting situation, that would not have been deducible utilizing only provincial analyses, emerge from these figures: indeed not all the communes in the Province of Siena share the same territorial characteristics. For example, if we focus our attention on biocapacity, it is possible to observe that there is a large range of variability from one commune to another in the final values per capita (from 40.7 gha per person in Radicondoli to 1.0 in the city of Siena). Furthermore, as opposite to the provincial average, approximately one third of these communes (11 out of 36) is characterized by an ecological deficit, which is compensated, at the provincial level, by the ecological surplus of the other communes. These communes are not randomly distributed, but are grouped in two main areas:

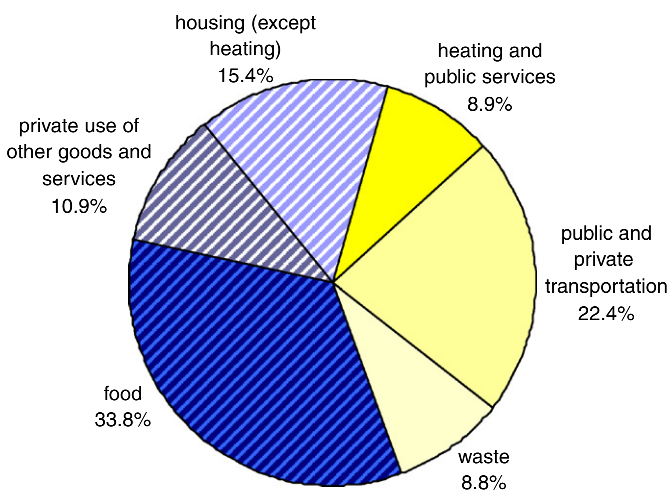

Fig. 6. Percentage distribution of the ecological footprint of the Province of Siena disaggregated according to the areas of influence.

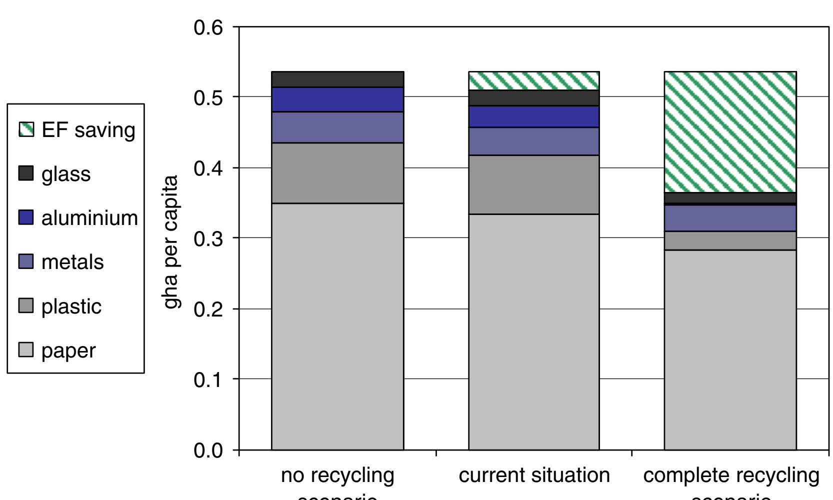

Fig. 7. Ecological footprint distribution according to waste composition, and to three waste management scenarios: current situation, no recycling and completely recycling

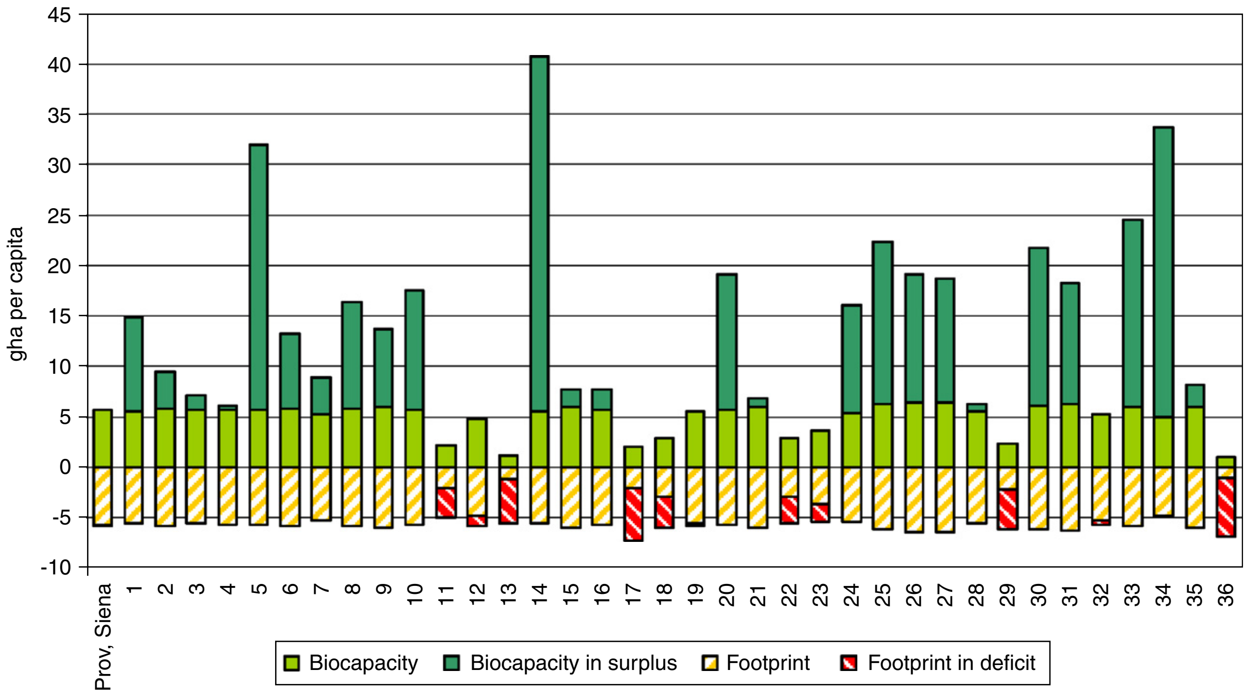

Fig. 8. Ecological footprint, biocapacity and ecological deficit/surplus per capita for the Province of Siena and for the individual communes in it. The number corresponds to the commune in the following order: 1-S Gimignano; 2-Poggibonsi; 3-Castellina in Chianti; 4-Radda in Chianti; 5-Gaiole in Chianti; 6-Colle Val d'Elsa; 7-Monteriggioni; 8-Castelnuovo Berardenga; 9-Casole d'Elsa; 10-Siena; 11-Radicondoli; 12-Sovicille; 13-Monteroni d'Arbia; 14-Asciano; 15-Rapolano Terme; 16-Chiusdino; 17-Murlo; 18-Sinalunga; 19-Monticiano; 20-Buonconvento; 21-S Giovanni d'Asso; 22-Trequanda; 23-Torrita di Siena; 24-Montalcino; 25-S Quirico d'Orcia; 26-Pienza; 27-Montepulciano; 28-Chianciano Terme; 29-Chiusi; 30-Castiglione d'Orcia; 31-Sarteano; 32-Radicofani; 33-Abbadia San Salvatore; 34-Cetona; 35-Piancastagnaio; 36-S. Casciano.

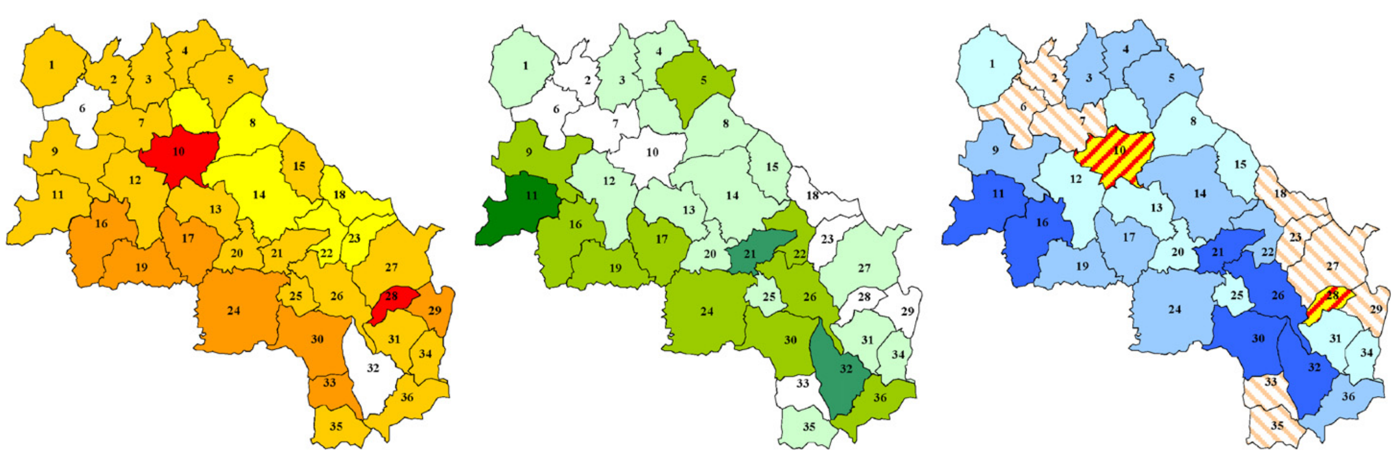

Fig. 9. Territorial maps of the ecological footprint (left), the biocapacity (center) and the ecological deficit/surplus (right) per capita, for the individual communes of the Province of Siena. The numbers correspond to the communes according to the order listed in Fig. 7. In the maps to the left and centre, the darkest colours indicate the highest levels with respect to the ecological footprint and the biocapacity per capita; in the map to the right, the striped sub-areas indicate progressively worsening ecological deficit (darker stripes), while those in solid blue identify progressively increasing ecological surplus (darker blue).

the first, located in the northwest zone of the Province, includes the city of Siena and part of the district of Val d'Elsa, while the second is included in northeast zone of the district of Val di Chiana. Thanks to this analysis, it is possible to relate this behavior with some territorial characteristics and, in particular, with the local density of inhabitants, that shows very similar patterns. These two districts are in fact the most densely populated areas of the Province: 85.4 inhabitants per square kilometer in the Val di Chiana district up to 457.9 inhabitants per square kilometer in the commune of Siena, compared to the average provincial value of 66.3 inhabitants km^2.

5. Conclusions

This article has presented the results of the analysis of the ecological footprint and the biocapacity of the Province of Siena. This is a particularly interesting area because, as opposed to the national average and to most of the other Italian provinces, it is characterized by a nearly breakeven total ecological balance, showing that almost the whole demand of natural resources by local inhabitants could be achieved locally. A deeper analysis of Siena's ecological balance, according to its productive land components, shows a more complex configuration of input/output flows, characterized by a net export of economic goods and services related to cropland and a net import of those related to forest.

The calculations have been performed in such a way as to ensure a high range of possible disaggregations of the final results, according to categories of productive land, consumption and areas of influence. This information has allowed for a detailed investigation of the socio-economic aspects correlated to the use of environmental resources (local inhabitants consumption choices, lifestyles, waste management policies, etc.). Along with this information, this study has been structured to investigate the geographic properties in relation to the distribution and the use of ecological resources. The analysis has therefore been carried out at different spatial scales: provincial, district and commune. An inhomogeneous territorial structure, consisting of ecological deficit subareas compensated by ecological surplus zones, emerges. A simple explanation of this configuration has been proposed by relating it to the local population density.

The methodology adopted for the calculations at the sub-national level has been conceived to best adapt to the available data at the communes and at the provincial level, therefore minimizing ad hoc approximations and assumptions.

Finally, we remind that the results obtained with the analysis of the ecological footprint are included in the more extensive Spin-Eco project Amministrazione Provinciale di Siena, 2002. By matching these results to those coming from the other Spin-Eco sustainability indicators, it is possible to delineate a coherent and exhaustive quantitative picture of the complex relationships between society and environment in the Province of Siena and to provide the public administrations and decision makers with an overall perspective on the problem of resources and natural capital consumption.

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