The evaluation of the Ecological Footprint of the Province of Siena (Italy)

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Abstract

The SPIN-ECO Project has analysed the environmental sustainability of the Province of Siena (Italy). A set of different methodologies has been applied to better check the state of the environment. This work discusses the calculation of the Ecological Footprint and the biocapacity, that has enabled us to acquire a deeper understanding of the state of the environment.

The Ecological Footprint is an indicator of environmental sustainability, proposed by Wackernagel and Rees in 1996 [1], that evaluates the global surface of productive ecosystems necessary to sustain the consumption of goods and resources and to absorb the emissions made by a population. This indicator provides information on the use and consumption of natural services and can be compared with the measure of local biocapacity, which evaluates the entity of natural services that the local ecosystems are able to produce. Thanks to these two indicators it is possible to make out an ecological balance-sheet for the region and estimate the ecological deficit/surplus.

In order to make the analysis more helpful in addressing local policies and actions towards a greater sustainability, the evaluation of the Ecological Footprint and biocapacity has also been applied to each of the various municipalities of the Province of Siena. In this way it has been possible to identify and to stress, for each municipality, the cases of best practices and those of greater environmental weakness, and to provide information on the environmental impact of the different sectors of public administration and of citizens’ consumption.
1 Introduction

This study is part of a wider project whose main object is to examine the environmental sustainability of the Province of Siena and its municipalities. It is based on different but complementary indicators and methods of analysis. Running parallel to the studies carried out using emergy [2], exergy [3], the account of greenhouse gases and other methodologies [4], this study makes use of the Ecological Footprint to monitor the environmental conditions of the Province of Siena. The analysis has been conducted both for the whole area of the Province, to get a general view of the zone, and at the level of the individual municipalities, to get a more detailed representation of the local state of the environment and to bring the situation of lesser sustainability more clearly into focus, at the same time identifying their causes.

This multiple analysis of sustainability is characterized by the simultaneous use of different methods of enquiry and by the different levels of discretion with which it is carried out. It represents an extremely interesting opportunity to compare the performance of the various indicators, bringing out their limitations and strengths and highlighting the changes in performance as the geographical scale to which they are applied varies.

Besides these theoretical results we should also mention the objectives at the level of application. The whole project has been organised so as provide a picture of the environmental sustainability of the local territory which could easily be used by local administrative authorities to plan and carry out policies which aim to achieve a greater environmental sustainability.

2 The Ecological Footprint

The Ecological Footprint is a synthetic indicator of environmental sustainability proposed by Rees and Wackernagel in the nineties [1]. It assesses the impact that a population and its consumption have on the environment, quantifying the total area of land and water ecosystems necessary to provide, in a sustainable way, all the resources used and to absorb, again in a sustainable way, all the emissions produced.

The Ecological Footprint has been adopted in a great number of studies to assess the environmental sustainability of specific activities, regions and nations [5], [6], [7]. The Ecological Footprint has also been calculated for almost all the nations of the world [8].

In a sense, the analysis of the Ecological Footprint upsets the concept of Carrying Capacity, defined as the maximum load, exerted by the population of a certain species, which a given territory can bear, without permanently compromising the productivity of the land itself. The accent is not placed on determining the maximum human population that an area can support, but on the calculating the productive land actually used by the residents, whether or not this surface area coincides with the territory on which the population lives.

In the classical formulation, proposed by Wackernagel and Rees, the calculation of the Ecological Footprint is based on the average consumption of
the population, starting from the assumption that every unit of material or energy consumed corresponds to one or more ecosystems, which guarantees the given supply of resources to be consumed and/or emissions to be absorbed. The kinds of activity, connected with the consumption of the population, which generate an impact on the environment are the production of goods and merchandise consumed, the energy used, the disposal of waste and the emissions produced by the various types of consumption (see for example the surface area necessary to absorb the CO₂ emitted), the land taken up by infrastructures, factories and plants, houses, etc. These activities involve different uses of the land. Following the classification used by the World Union for Conservation, the Ecological Footprint formulation subdivides the use of ecologically productive land into six main categories: 1) energy land; 2) crop land; 3) grazing land; 4) forest; 5) built-up areas; 6) sea.

The actual calculation of the Ecological Footprint can be synthesized as follows:

1. Calculation of average consumption \( C_n \) (expressed in kg/year) for each type of goods or product \( n \) consumed by the resident population in the region under examination.

2. Calculation of the surface area \( S_n \) (expressed in hectares) necessary for the production of the specific good \( n \), obtained by dividing the average annual consumption of that good \( C_n \) by its productivity or average annual yield \( p_n \) expressed in kg/(ha year):

\[
S_n = \frac{C_n}{p_n}
\]

The accounts of the territories must also include those productive areas that are not directly linked with the consumption of goods, but to those natural services indispensable to absorb the emissions produced. In this case the average productivity \( p_n \) is understood in a generalized sense, as the quantity, given in kilograms (or grams), of the polluting substance \( n \) which can be absorbed by an hectare of productive land.

3. Calculation of the Ecological Footprint \( F \) (expressed in hectares) by adding the contribution of the various surface areas \( S_n \) concerning all the \( n \) goods consumed.

4. Calculation of the Ecological Footprint per capita \( f \) (expressed in hectares per capita), by dividing the total Ecological Footprint \( F \) by the population \( P \) resident in the region under examination.

5. Calculation of the equivalent surface area. By multiplying the areas of the six different types of land by the weights \( r_i \) proportional to their global average yield we obtain the Ecological Footprint \( E \) expressed in equivalent hectares and the Ecological Footprint per capita expressed in equivalent hectares per capita:

\[
E = \sum_{i=1}^{6} r_i \sum_{n} \left( S_{n} \right)_i
\]

where \( (S_n)_i \) represents the \( i \)-th component of land of the surface area \( S_n \).
3 Biocapacity

An integral part of the analysis of the sustainability of a territory using the Ecological Footprint consists in the calculation of biocapacity. This term indicates the surface area of ecologically productive land to be found within the region under examination. The calculation is based on the definition and mathematical formalism of the Ecological Footprint and follow the equation:

\[ B = \alpha \sum_{i=1}^{6} r_i a_i \]

where \( B \) represents biocapacity, \( a_i \) the areas of the six categories of ecologically productive land found in the region, \( r_i \) the weights proportional to their average global yield and \( \alpha \) is a coefficient which decreases the total biocapacity by a percentage which represents the minimum indispensable area left to ecosystems in their natural state for the conservation of biodiversity (here we use the value of 12% suggested by Rees and Wackernagel [1]). Like the Ecological Footprint, biocapacity too is expressed in equivalent hectares.

Hence biocapacity represents the total extension of ecologically productive land in the region, or the potential capacity to supply natural services starting from local ecosystems. This entity has to be compared to the Ecological Footprint which gives an estimate of the ecological services required by the local population. A real environmental balance-sheet can be made out by subtracting from the local supply of natural services (biocapacity) the demand of the local population for services (the Ecological Footprint). An ecological deficit (surplus) corresponds to a negative (positive) value of the balance-sheet. This indicates an unsustainable (sustainable) situation in which consumption of natural resources is greater (less) than the levels of regeneration we get by starting from the local ecosystems. Hence the entity of the ecological deficit or surplus represents an estimate of the level of environmental sustainability/unsustainability of the local territory.

4 The results

Let us consider, first of all, the value of the Ecological Footprint for the territory of the Province of Siena. Table 1 shows the results in absolute and per capita values (equivalent hectare), together with biocapacity and ecological deficit.

One of the first analyses to be made is the comparison between the local biocapacity, which calculates the extent of the ecological productive territories in the Province, i.e. the capacity to supply natural services starting from local ecosystems, and the Ecological Footprint, which provides an estimate of the ecological services required by the local population. Of the 1466153.7 equivalent hectares of ecological surface area required by the inhabitants of the Province of Siena, which correspond to a per capita Ecological Footprint of 5.80 eq ha, the local bioproductivity is able to cover 141782.7, which corresponds to 5.74 eq ha per capita. Starting from these data a real environmental balance-sheet can be
made out and an ecological deficit/surplus can be estimated by subtracting the Ecological Footprint from the biocapacity.

Table 1: The values of biocapacity, Ecological Footprint and ecological deficit for the Province of Siena and for Italy (the values are in eq ha and eq ha per capita).

<table>
<thead>
<tr>
<th></th>
<th>Biocapacity</th>
<th>Biocapacity per capita</th>
<th>Ecological Footprint</th>
<th>Ecological Footprint per capita</th>
<th>Ecological deficit</th>
<th>Ecological deficit per capita</th>
</tr>
</thead>
<tbody>
<tr>
<td>Province of Siena</td>
<td>1451782</td>
<td>5.74</td>
<td>1466153</td>
<td>5.80</td>
<td>-14370</td>
<td>-0.06</td>
</tr>
<tr>
<td>Italy</td>
<td>110061982</td>
<td>1.92</td>
<td>316239246</td>
<td>5.51</td>
<td>-206177263</td>
<td>-3.59</td>
</tr>
</tbody>
</table>

This calculation gives us the result of -14370.9 eq ha. It is a negative value, which however corresponds to only 1.0% of the total value (figure 1) and which falls fully within the margins of uncertainty with which the final value of the Ecological Footprint and the biocapacity are estimated. Hence it can be said that the ecological accounts of the Province of Siena are practically balanced. This in itself is a positive result, but it emerges with even greater clarity if it is compared with the results for the whole Italy.

A comparison with the average value for Italy (see table 1), obtained from the calculation of the Living Planet Report 2000 [5], shows an average biocapacity of 1.92 eq ha per capita and an ecological deficit of -3.59 eq ha per capita. The average Italian biocapacity is thus only able to cover 34.8% of the Ecological Footprint, leaving an ecological deficit equal to 62.2%, a decidedly worse
situation than the Province of Siena. It should however be emphasized that the balancing of the ecological accounts is not due so much to the low value of the Ecological Footprint as to the vast surface of the ecologically productive land in the Province, as the high value of the biocapacity shows. From comparison with the Italian average it can be said that the Province of Siena has a slightly higher Ecological Footprint than the national average. In her turn, Italy holds the 26th place among 152 countries [8], having a high level of Ecological Footprint, much higher than the average world biocapacity, which is estimated, by the same Report as 2.18 eq ha per capita. Thus, on average, the residents within the territory of the Province consume goods and services (and so use, directly and/or indirectly the natural services) to a slightly greater extent than the national average, by far surpassing the average threshold of consumption and emission sustainable at the world level. Unfortunately all the industrialized countries, characterized by life-styles based on high rates of consumption and a wide use of natural resources, have in common qualitatively similar values of the Ecological Footprint.

Figure 2: The division, in percentage, of the Ecological Footprint of the Province of Siena into the various categories of ecologically productive land.

If we observe figure 2 on the Ecological Footprint by category of land, it emerges clearly that a large percentage of land is taken up by the use of energy. This figure represents the area of forest necessary to reabsorb all the emissions of CO₂ caused by the use of energy by the inhabitants of the Province of Siena. It should be noticed that within this category account has been taken both of direct uses of energy, such as the consumption of fuel for transport or heating or the use of fossil fuel to produce electric power, and indirect uses, such as the energy used in the manufacture and the transport of consumed goods or that used to provide services. To achieve greater precision in the calculation of energy consumption, it has been decided to take into account also energy losses suffered during the various stages of production, transformation and transport.
It can be said that the Province of Siena follows the trend typical of industrial countries where a large proportion (between one or two thirds) of the Ecological Footprint can be attributed to the consumption of energy. Energy-saving policies and policies for greater efficiency in the production of goods and services could help to reduce this component of the Ecological Footprint. To decrease the CO₂ emissions, that is the environmental impact due to consumption of energy, we can also intervene before the energy is used, that is during the production stage. Lastly it is to be emphasized that a reduction in the direct consumption of energy (transport, heating, lighting, household appliances, etc.) and indirect consumption (of good and services requiring a high expenditure of energy) on the part of private consumers and public administration, may be a valid way of dealing with the prime causes of unsustainability.

![Ecological Footprint by consumption categories](image)

Figure 3: The division of the Ecological Footprint of the Province of Siena into the various categories of consumption (in percentage).

It is interesting to analyse further which categories contribute most to the Ecological Footprint, so as to identify the real causes of environmental impact. Figure 4 shows that the energy component weights most heavily on all the categories and more especially that it represents practically the whole figure as far as transport, housing and services are concerned.

The results concerning the Ecological Footprint for the Province of Siena have been aggregated and presented not only according to the classical categories of kinds of consumption and types of ecologically productive land, but also according to the subdivision by area of responsibility. This was done to make the examination and the interpretation of the data easier for the Local Authorities and, above all, to provide a tool useful for outlining the situation of the environmental sustainability and effective in planning steps capable of improving it. Figure 5 shows, in dark grey, the subdivision of Ecological Footprint caused directly by the behaviour of private citizens; whereas those that depend on or can, at least, be partially influenced, more or less directly, by policies and the decisions of the Public Administration are marked in light grey.
Figure 4: The division of the Ecological Footprint of the Province of Siena into the categories of ecologically productive land and consumption. All the values are given in eq ha per capita.

Figure 5: The division of the Ecological Footprint into areas of responsibility.

An analysis of the Ecological Footprint has also been made for each of the municipalities in the Province of Siena. This allows us to obtain a more detailed representation of the local state of the environment and focus more clearly on the less sustainable situations and, at the same time, to identify their causes. Here, as an example, we show in figure 6 the biocapacity, the Ecological Footprint and the surplus/deficit for the whole Province of Siena and nine of its municipalities. A very interesting situation emerges even from the data of these few municipalities. The balance in the ecological account found at the provincial
level does not appear at the level of the individual municipalities, since it is the result of compensation for situations characterized by ecological surplus and ecological deficit.

![Biocapacity, Ecological Footprint and ecological deficit/surplus](image)

Figure 6: The biocapacity, the Ecological Footprint and the ecological surplus/deficit for the whole Province of Siena and nine of its municipalities.

5 Conclusions

From the analysis of the Ecological Footprint of the Province of Siena it appears that the environmental accounts are practically balanced. Thus, with respect to the average national values, the situation of the Province of Siena is absolutely positive. This result is not however due to the low levels of the Ecological Footprint but to the high biocapacity, i.e. to the great extent of ecological land in the province compared to the number of inhabitants. The consumption of natural services by the inhabitants of the Province of Siena is in any case not sustainable if compared to the average world rate of regeneration of ecosystems. This characteristic is common to many western countries and can be changed for the better, on the one hand by policies which aim to educate citizens to achieve lower levels of consumption and, and on the other, by introducing more ecoefficient standards of production.
Finally, it should be remembered that the analyses carried out for the Province of Siena by using the Ecological Footprint fall within the SPIN-ECO Project. By comparing the results obtained from the application of other indicators of environmental sustainability used in the project, the Public Administration can be provided with a global view of the problem concerning the consumption of resources and natural capital. It is to be hoped that a deeper knowledge of the causes of unsustainability will lead to short, medium, and long-term planning of suitable policies.

References