Transactions on Ecology and the Environment vol 63, © 2003 WIT Press, www.witpress.com, ISSN 1743-3541

# The analysis of the environmental sustainability of the economic sectors of the Piedmont Region (Italy)

M. Bagliani, F. Ferlaino & S. Procopio
*IRES (Istituto Ricerche Economiche e Sociali) Piemonte*

## Abstract

The analysis presented in this paper takes into consideration the environmental sustainability of the Piedmont Region based on the use of the Ecological Footprint. This indicator of sustainability considers the impact that a population has on the environment by calculating the productive surface necessary to produce, in a sustainable way, all the utilized resources and to reabsorb, also in a sustainable way, all the emissions released.

This study develops a work of Bicknell and collaborators [1]. We propose a method of calculation that keeps the main characteristics of the Ecological Footprint definition but restructures the mathematical formalism on the basis of Leontief's Input–Output matrices. This new version of the Ecological Footprint allows deeper insights into the sustainability of the economic system by considering the environmental sustainability of each economic sector and the sustainability of the input–output flows through the different sectors.

To test the new method we have applied it to the case study of the Piedmont Region. The analysis, applied to each of the Piedmont Provinces, comprises a detailed description of the environmental sustainability of the economic system. Furthermore, it illustrates the performances, advantages and limits of applicability of our method.

## 1 Introduction

Since UNEP published the Brundtland Report in 1987 and the Rio Summit met in 1992, studies on environmental sustainability have taken on ever greater importance. This research goes into the effects of human activities on the environment, through simultaneous analysis of ecological, economic and social features. The importance of these studies lies not only in the technical-scientific information they provide, but also, and above all, in the possible influence they have in the economic and social field. Indeed it is through them that we can study the relationships between economy and environment and highlight the use of natural resources that are more sustainable. The knowledge thus obtained can be used to evaluate economic and social situations, and to put forward new development strategies aimed to reach a sustainable use of the resources and, at the same time, satisfactory living standards for all the inhabitants of the earth.

One of the greatest difficulties that these studies have to face lies in the assessment of the degree of environmental sustainability/unsustainability of a given human activity, a socio-economic system or a specific region, starting from data on extremely different environmental impacts. One has to consider and to put together, in as coherent and complete way as possible, such disparate information as the emission of micrograms of highly toxic products to the millions of tons of earth removed every year from the mines, from the extraction of various non-renewable resources to the uses of numerous renewable resources. Some studies have dealt with the problem of defining a synthetic indicator of the environmental impacts by proposing an accounting system based on the identification of a common denominator, which enables us to translate and reduce the different impacts to a single type of measure. In this way information obtained from very different kind of environmental effects can be coherently added together. The Ecological Footprint, adopted in this study to assess the environmental sustainability of the socio-economic system of Piedmont uses, as the common denominator to which all kinds of pressure on the environment are to be referred, the surface directly or indirectly used by human activities.

In this study we propose a new method for calculating the Ecological Footprint which, by developing the work of Bicknell and collaborators [1], restructures the usual mathematical formulation to obtain an assessment of environmental sustainability of the various economic sectors. Our analysis of the sustainability of the socio-economic system of Piedmont, used as a case study to test the validity of our method of calculation, has been carried out by dividing the region into eight sub-systems, represented by the various Provinces, and applying the analysis of the Ecological footprint separately, to each of them, sector by economic sector.

## 2 The Ecological Footprint: the classical formulation

The Ecological Footprint was first proposed by Wackernagel and Rees [2] of the University of British Columbia, Canada. It is a synthetic indicator of environmental sustainability, which assesses the effect that a population has on the environment, by calculating the area of productive land necessary to provide, in a sustainable way, all the resources used and to reabsorb, 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 [3], [4], [5]. The Ecological Footprint has also been calculated for almost all the nations of the world [6]. A complete issue of the journal *Ecological Economics* has been devoted to the in-depth study of the potentialities and limits of this indicator [7].

In the classical formulation of Wackernagel and Rees, the calculation of the Ecological Footprint is based on the average consumption of the population. Let us consider a region whose total Ecological Footprint we wish to assess. If $C_i$ is the total average consumption, expressed in kilograms, of the i-th category of goods within the territory under examination, the total Ecological Footprint $F$ is calculated by the following formula:

$$F = \sum_i E_i = \sum_i C_i q_i \tag{1}$$

where $E_i$ is the Ecological Footprint obtained from the consumption of the i-th good and $q_i$ is the conversion factor, expressed in hectars / kilogram, which is the inverse of the average productivity for the i-th category of goods. This conversion factor represents the area of productive land necessary to produce a kilogram of the i-th product. Starting from equation (1) it is easy to get the per capita Ecological Footprint $f = F/N_P$:

$$f = \sum_i e_i = \sum_i \frac{E_i}{N_P} \tag{2}$$

where $e_i$ is the per capita Ecological Footprint resulting from the consumption of the i-th product and $N_P$ the population living in the region under consideration.

The uses of productive land which do not derive from consumption of resources but from the energy and the natural services used to reabsorb the emissions produced, can easily be included in this formulation. In this case the average productivity $q_i$ will have to be considered in a generalized sense, as the area necessary to absorb a kilogram of the i-th substance emitted.

More in general the formulation of the Ecological Footprint could be structured to calculate all the uses of productive land that are necessary to bring the whole system under consideration back to its initial condition. This would mean not only taking into account all the pollutants emitted, but also all the variations of human origin of the biogeochemical cycles of the elements [8]. Actually, the calculation procedure really used is able to take into account only a small part of these effects, thus providing an underestimation of the value of the Ecological Footprint which would be obtained from the more general theoretical formulation.

Wackernagel and Rees's formulation for the calculation of the Ecological Footprint, based on the classification used by the World Conservation Union considers the use of the following main categories of land:

1) Land for energy. The surface necessary to produce, using sustainable methods (e.g. the cultivation of biomass), the quantity of energy used. Actually, Wackernagel and Rees use a different definition, based on the area of forest necessary to reabsorb the $CO_2$ emitted by the production of energy from fossil fuels.
2) Arable land. Land (fields, vegetable gardens, etc.) used for the production of food products and non–food agricultural products (e.g. cotton, jute, tobacco, etc.).
3) Pasture. Grazing land devoted to the production of meat, dairy products, eggs, wool, etc.
4) Forest. Areas of modified natural systems given over to the production of timber.
5) Built-up land. Degraded land that takes into account infrastructures for housing, transportation, and industrial production.
6) Sea. Fishing grounds necessary to produce the amount of fish consumed.

The data on such different kinds of land have to be added together to get a final assessment of the Ecological Footprint and hence the problem of the levels of productivity typical of the above-mentioned categories. In practice the most productive land is generally used for agricultural crops, while the less productive areas are used as pastureland. The difference between the productivity of a sea area and a cropland area is on average in the order of 1 to 50. To make the various kinds of land comparable with each other, the formulation of the Ecological Footprint introduces a normalization procedure, by which the different kinds of land can be weighted according to their average world productivity. The area calculated in this way no longer represents the land surface used directly or indirectly by a given population, but the equivalent area that would be necessary to produce, on land with world average productivity, the quantity of biomass actually used by the population under consideration. The Living Planet Report [6] rightly suggests that hectares, which refer to real surfaces, should not be used as units of measure for such areas; the more generic "units of area" or "equivalence hectares" will be used instead.

## 3 The formulation of Ecological Footprint by economic sector

By using Wackernagel and Rees's formulation of the Ecological Footprint we obtain a final synthetic result (the equivalent surface), from which the level of the environmental sustainability of the region under consideration can be assessed. This information, though important, is often too aggregated to allow of a clear identification, within the local socio-economic system, of the real causes of unsustainability, that is those sectors and those productive processes which contribute most to the impact on the environment. To provide indications useful to the activation of local policies for the promotion of sustainability, we really need a system of evaluation not limited to providing the final value of the environmental effect caused by the socio-economic system, but which, starting from the latter, is capable of monitoring, through the various stages of economic production, the whole path of the generation of products and services and the environmental effects caused by it.

For this purpose we have elaborated a different formulation of the Ecological Footprint which can satisfy the above mentioned requirements. The new method, that starts from the work of Bicknell and collaborators [1], keep the definition of the Ecological Footprint, but restructure the calculation completely using Leontief's Input–Output matrices [9], [10], by means of which the flows of capital through the various sectors of the economy can be described and quantified. By using this mathematical formulation a system of environmental accounting, parallel to that for capital, can be introduced to give a quantitative description of the environmental sustainability of each economic sector and the flows of environmental sustainability between one sector and another. In this new version the Ecological Footprint can be used as a tool able to identify the components of unsustainability of the socio-economic system and track their origins.

Instead of the calculation based on the average consumption of the population, the new formulation takes into account the consumption in each economic sector. In this case the equation that substitutes (1) to calculate the Ecological Footprint $F$ is:

$$F = \sum_{n} H_n \tag{3}$$

where $H_n$ is the Ecological Footprint of the n-th economic sector. At first sight the calculation of $H_n$ seems extremely difficult. The various sectors of the economy are characterized by extremely different activities and hence by different environmental impacts. Actually the calculation of $H_n$ can be reduced to very general categories, which are valid for all economic sectors. The decomposition chosen identifies the uses of productive land as a function of the activities of a generic economic sector that, as a net result, uses energy and material to create goods and services and produces different kinds of output. More in detail we have the following categories.

1) Use of energy $(S_n)_{EN}$: for production, creation of services, marketing activities, research, etc.
2) Use of material $(S_n)_{MAT}$. This includes the direct use of material through: i) the extraction of raw material from nature (only two economic sectors deal with this extraction respectively for the biotic and abiotic material. They are agriculture, stock-breeding and fishing and mining activities) and ii) the use of manufactured goods to be subjected to further processing. Furthermore we have the indirect use of material through the use of tools, machines etc. necessary for production.

3) Use of land $(S_n)_{OUT}$ to reabsorb the net output produced by the economic sector: i.e. that part of the output that is not reprocessed by other economic sectors like emissions (but not waste that is considered to be one of the inputs of the economic sector of public services).
4) Use of land $(S_n)_{INF}$ for infrastructures (houses, productive areas, roads, etc.)

The calculation uses these four components, that include all the possible sources of environmental impact, and follows the equation:

$$H_n = (S_n)_{EN} + (S_n)_{MAT} + (S_n)_{OUT} + (S_n)_{INF} = \sum_M (S_n)_M \,. \tag{4}$$

The analogue of equation (2), which provides, for the classical formulation, the Ecological Footprint per capita $f_P$, is now given by:

$$f_P = \sum_n h_{Pn} = \sum_n \frac{H_n}{N_P} = \sum_n \sum_M \frac{(S_n)_M}{N_P} \tag{5}$$

where $h_{Pn}$ is the per capita Ecological Footprint of the n-th economic sector. Within this new framework it is also useful to calculate $h_{An}$, the Ecological Footprint per worker assigned to the n-th sector:

$$h_{An} = \frac{H_n}{N_{An}} = \sum_M \frac{(S_n)_M}{N_{An}} \tag{6}$$

where $N_{An}$ indicates the number of workers assigned to the n-th economic sector.

So far it has been implicitly assumed that the economic system is a closed system, with no outside exchanges of resources, products, services and information. The equations (3) and (4) hold only for closed systems; in the more general case of an open system (i.e. with outside exchange of energy, material and information) it is also necessary to consider the fluxes deriving from imports and exports. Indeed for a generic economic system not all the production of the various sectors is intended to satisfy internal demand, because part of it is exported abroad or to other regions of the same country. In the same way we have to take into account the imports by various sectors which purchase goods and services outside the region.

In general terms, in an open system, local production $P$, local consumption $C$, imports $I$, exports $E$ and variations of local stocks $S$ (positive sign indicates a stock increase) are linked by the following equation:

$$C = P + I - E - S \,. \tag{7}$$

Thanks to this formula we can extend the procedure for calculating the Ecological Footprint, that is centred on consumption, to a general open economic system: the surface area derived from local production, obtained with equation (4), must be corrected by adding the Ecological Footprint components deriving from imports and subtracting those related to exports and to variations of stocks. The mathematical formulation is easily obtained by applying (7) to (4), from which we obtain the equation actually used for the calculation of the Ecological Footprint $H_n$ of the n-th economic sector in an open economic system:

$$H_n = (S_n)_{EN} + (S_n)_{MAT} + (S_n)_{OUT} + (S_n)_{INF} + \\ + (S_n)_{IN} - (S_n)_{EX} - (S_n)_S \qquad (8)$$

where $(S_n)_S$, $(S_n)_{IN}$ and $(S_n)_{EX}$ indicate the surface of productive land added or subtracted to the stock, imported and exported by the n-th sector.

## 4 The case study of the Piedmont Region

In order to test its correctness and validity, the new formulation of the Ecological Footprint has been applied to the Piedmont Region. An analysis of the sustainability of the various economic sectors has been carried out for each of its eight Provinces. For each of them the economic system has been subdivided into 18 different sectors and the Ecological Footprint has been calculated for each of them. The economic sectors taken into account are: 1) agriculture, stock-breeding and fishing; 2) mining and quarry; 3) food industry; 4) textile and clothing industry; 5) petrochemical and chemical industry; 6) paper and design industry; 7) production of building materials and glass and ceramics industry; 8) iron and steel industry and industry for the processing of non-ferrous metals; 9) industry producing mechanical machines; 10) industry producing electrical machines; 11) industry for the production of means of transport; 12) other manufacturing industries; 13) building industries and civil engineering; 14) trade and crafts; 15) public administration and public services; 16) transport; 17) consumption and losses incurred in the production and transport of energy; 18) domestic uses. The limited availability of data has greatly influenced the extent to which the sectors could be subdivided. The 18 sectors chosen reflect the greatest disaggregation possible in view of the amount of data available and the need to maintain a high level of significance in the approximation made. In this section we present some examples of the results that can be obtained by applying the Ecological Footprint by economic sector. This new formulation has enabled us to analyse the environmental impacts of the various sectors of the economy and to quantify the fluxes of environmental sustainability through the Piedmont border by examining the Ecological Footprint composition of imports and exports.

The total Ecological Footprint of the Piedmont Region is 7,53 ha eq. per capita. It may be interesting to compare this results with the values of the Living Planet Report 2000 [6] that, for Italy, gives 5,51 ha eq. per capita. The

Ecological Footprint of Piedmont is expected to be superior of the Italian average because of the industrial nature of the region and its higher living standards. This hypothesis is confirmed by the comparison with the analysis of another wealthy Italian area: the Province of Bologna, that has an Ecological Footprint of 7,45 ha eq. per capita, the same magnitude as Piedmont.

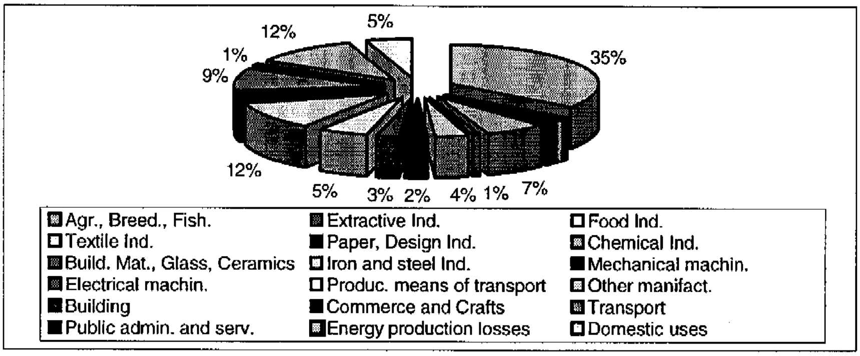


Figure 1: The Ecological Footprint of the different economic sectors for the Piedmont Region.

Figure 1 shows the Ecological Footprint of the different economic sectors for the Piedmont Region. The sector that contributes most is that of agriculture and stock breeding (35%). This is not surprising: this sector is highly land-intensive because it is the sector that accounts for the extraction of all the biotic material that goes through the whole economy. Studies are being made for the redistribution of this value between all the sectors of the economy by using Leontief's inverse matrix.

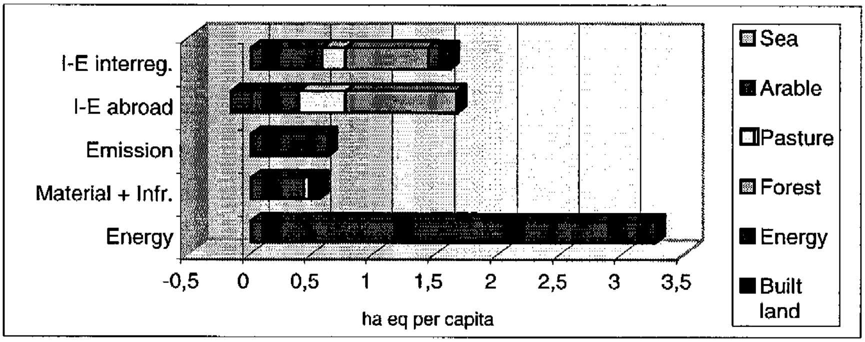


Figure 2: The Ecological Footprint of the Piedmont Region by contributions.

Transactions on Ecology and the Environment vol 63, © 2003 WIT Press, www.witpress.com, ISSN 1743-3541



The various components that make up the Ecological Footprint in the formulation by economic sector are illustrated, for the Piedmont Region, in figure 2, which shows the contributions per capita made by energy, by material (which also groups together the infrastructures), by emission, by the balance between imports and exports abroad and to the other Italian regions.

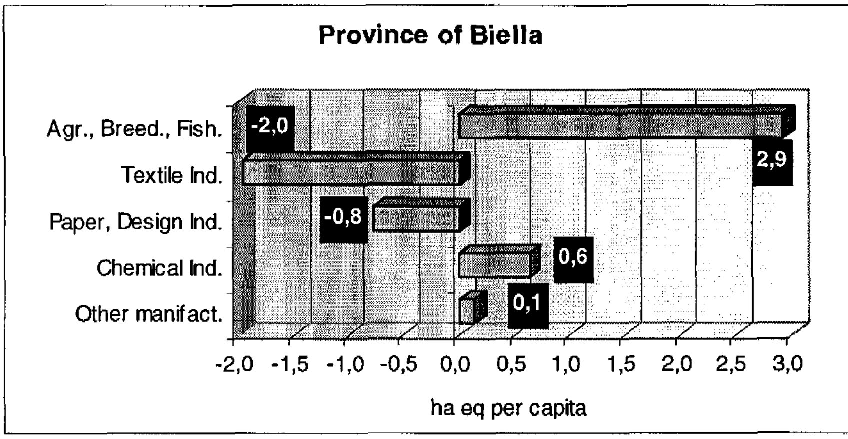


Figure 3: The Ecological Footprint for the imports and exports abroad for some of the economic sectors of the Province of Biella.

Finally figure 3 shows a further example of the studies that can be made using the new methodology for the calculation of the Ecological Footprint. It illustrates the results concerning the analysis of the imports and exports abroad of the Province of Biella, a famous industrial district in the textile sector. The study has been able to highlight the very high value of the Ecological Footprint of the imports for agriculture and stock-breeding, deriving from the great amount of imported wool, and the almost comparably large quantity of exports from the textile sector, caused by the sale of clothes and other textile products.

## 5 Conclusions

This study presents an analysis of the environmental sustainability of the Piedmont Region, based on the use of a new formulation of the Ecological Footprint for the calculation of each of the economic sectors.

This formulation has been tested out successfully on the case study of the Piedmont Region, allowing us to calculate the Ecological Footprint at various levels of aggregation: 1) the eight Provinces of Piedmont; 2) the various economic sectors of each Province; 3) the different components of the Ecological Footprint (energy, material, emissions, infrastructures, imports, exports) for each economic sector of each province; 4) further details of each of the single factors, for example the impacts of the different sources of energy, or those caused by the various kind of emissions, or the different uses of the land by infrastructures or, yet again, the import and export impacts, with details of 236 different kinds of goods.

A complex picture emerges from the analysis of the economy of the Piedmont Region. A very high value of the Ecological Footprint is highlighted, which is a strong indication of great impact on the territory.

Finally, is worth noting that the formulation proposed in this work can be successfully applied to quite large areas, that is large enough to have flows of capital and goods across their borders which are lower than those within them.

## References


[1] Bicknell, K., Ball, R., Cullen, R. & Bigsby, H. New methodology for the ecological footprint with an application to the New Zealand economy, *Ecol. Econ.* (27)2, pp. 149–160, 1998.

[2] Wackernagel, M., & Rees, W. Our ecological footprint, New Society Publisher, Gabriola Island, British Columbia, 1996.

[3] Proops, J., Atkinson, G., Schlotheim, F. & Simon, S. International trade and the sustainability footprint: a practical criterion for its assessment, *Ecol. Econ.* (28)1, pp. 75–97, 1999.

[4] Wackernagel, M., Onisto, L., Bello, P., Callejas, L.A., López, F.I., García, J., Guerriero, A. & Guerrero, S. National natural capital accounting with the ecological footprint concept, *Ecol. Econ.* (29)3 pp. 375–390, 1999.

[5] Simpson, R., Gasche, K. & Rutherford, S. Estimating the ecological footprint of the south-east Queensland Region of Australia, Faculty of environmental study, Griffith University, 1995.

[6] UNEP-WCMC, WWF, Living Planet Report 2000, Jonathan Loh Editors, 2000.

[7] Ecological Economics, (32)2, 2000.

[8] Schlesinger, W.H. Biogeochemistry. An analysis of global change, Academic Press, San Diego, 1991.

[9] Leontief, W. Input–Output Economics, Oxford University Press, New York, 1986.

[10] Hewings, G.J. & Jensen, R.C. Regional, Interregional and Multiregional Input-Output Analysis, Handbook of Regional and Urban Economics, North Holland, 1996.

[11] Bilanzone, G., Pietrobelli, M., Munafò, M., Asprella, A., Valerio, R. & di Laurenzio, A. Valutazione dell'impronta ecologica della Provincia di Bologna, WWF Italia, 2002.