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Development of a smart methodology to account the Ecological Footprint of a city – The Lisbon case

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Abstract

The study presented here, develops a smart method for the calculation of the Ecological Footprint. This approach uses the Material Flow Accounting as a starting point, since the result of this instrument represents a material balance. The Material Flow Accounting calculates the total quantity of natural resources and products used by an economy.

The Ecological Footprint Analysis measure the demand of ecological goods by the human economies and how this demand exceeds or is on the limit to produce goods and services by the biosphere. Therefore, the ecological footprint represents the environmental consequences of the consumption expressed in one standardised unit.

In that sense, National Flow Accounting may work as a database for the calculation of the Ecological Footprint.

The approach developed in this study contributes for the simplification of the traditional methods to calculate the ecological footprint, since it may exclude data collection, as long there are Material Flow Accounting databases available.

The approach developed is going to be use to account the Ecological Footprint of urban areas, in this case Lisbon, using as database the material balance recent developed to Lisbon by Ferrão *et al*., 2007.

Keywords

Ecological Footprint, Material Flow Accounting, Sustainability, Resource Consumption

Introduction

The MFA measures the weight of all the materials that enter and leave an economy within one year, using the mass balance principle in a way that is analogous to economics accounts (Kowalski, 2004). In fact MFA of a city works as an indicator wich indicates if the throughput of resources is growing in a city (Curran *et al*, 2004).

Since it accounts for the material inputs of a city, it may work as a usefull starting point for the calculation of the Ecological Footprint.

The ecological Footprint is a resource accounting tool that measures how much biologically productive land and water area an individual, a city, a country, a region, or humanity uses to produce the resources it consumes and to absorb the waste it generates, using prevailing technology and resouces management (Wackernagel *et al*, 1996). To calculate the Ecological Footprint we must estimate the consumption level. By far, many researchers calculate the Ecological Footprint through a large variety of statistical data. In this case the data colection is avoided because it is used avaible MFA databases.

Any area of every kind of productive land can be accumulated in this assumption:

$$PE_p = N(pe) \times Fe \quad \textbf{[1]}$$

Where PE_p is the total ecological Footprint, N is the number of population, pe is the average ecological footprint, i is the the type of consumption and Fe is the equivalence factor. The average ecological footprint, pe, is given by the expression:

$$\boldsymbol{pe = \sum_{i=1}^{i=n} aa_i} \quad \textbf{[2]}$$

Where aa_i is the area of productive land to produce the consumption *per capita*. And finally aa_i is represented by the following expression:

$$\boldsymbol{aa_i = {c_i}/{p_i}} \quad \textbf{[3]}$$

Where, c_i is the consumption *per capita* and p_i is the global average production capacity of consumption.

Thus, c_i corresponds to the balance acquired from MFA, wich matches with the expression 4:

$$\boldsymbol{c_i = \frac{domestic}{extraction} + imports - exports} \quad \textbf{[4]}$$

Methodologies for the calculation of the Ecological Footprint

There are several methodologies for the calculation of the Ecological Footprint. The most used are the Compound and the Component Approach. The first one – Compound approach – deveoped by Wackernagel and Rees, has as prupose the comparison between the Ecological Footprints of diferent countries. It is usually presented on a report, firstly published under the name “Footprint of Nations” (Wackernagel *et al*, 1997) , later evolved to “National Footprint Accounts” (NFA).

The results are presented in 6 different land types (Kitzes, *et al*., 2007):

- Cropland
  The area for growing crops for food, animal feed, fibre and oils.
- Grazing land
  The area necessary for raising animals, hides, wool and milk.
- Fishing grounds
  The area required to harvest fish and other marine products.
- Forest area
  The area for harvest timber products and fuelwood.
- Built-up land
  The area accupied for infrastucture for housing, trasportation, and industrial production.
- Energy land
  Area of forest necessary for carbon sequestration, derived from fossil fuel combustion.

The methodology known as Component approach was develop by the consultant Best Foot Forward in 1996 and is today

named EcoIndex™. This approach assesses the ecological footprint for areas smaller than a country. The name component derives from the way how the methodology breaks the Ecological Footprint in different activities (or components) and accounts for the contribution of each component to the total Ecological Footprint. Those activities are (Chambers, *et al*., 2005):

- Direct energy (domestic and service)
- Materials and waste
- Food and drink
- Personal transport
- Water
- Built land

Recently there are new approaches to calculate this instrument such as the one developed for sub-national geographical areas, known as SGA. Other are based on input-output tabels, and finally, one developed by the Stockholm Environmental Institute, that accounts the embodied energy.

Ecological footprint of Portugal

The Ecological Footprint of Portugal was calculated to help validate the methodology used for Lisbon. Portugal is used for the development of this approach because the value of the portuguese footprint is publish by the WWF on the *The Ecological Footprint - Europe 2005* (Wackernagel, *et al*., 2005).

The approach applied is mostly similar to the Compound approach, even using data from the NFA.

As expressed above the data for the calculation of the Ecological Fooptprint with this approach derives mostly from MFA. For Portugal this data originates from the MFA reported by Niza (2007) this data source compiles the domestic extraction, imports and exports from 1980 to 2000.

Since the Ecological Footprint is dated from the 90's and it's a conservative measure static in a period of time (year) the year 2000 was elect.

MFA includes data from biomass, fossil fuels and other materials, only the renewable materials like the biomass were used. Other materials were excluded becuse the Ecological Footprint does not account for that.

Data for built land was taken from Caetano, *et al*. (2005).

The productive data corresponds to the yield of each item of consumption. To each material/item is associated a yield in units of mass by units of area. The most common is t/ha. This represents the mass that is possible to extract from a certain area.

The yield factors or productivity data were taken from the NFA developed by the Footprint Network edition 2006, for Hungary in the year 2003. (Footprint Network, s.d.), the only ones avaiable.

After the compilation of data the next step is dedicated to the calculation of each fragment of the consumption: domestic extraction, imports and exports.

Since domestic extraction presents a higher level of disaggregation, a calculation sheet was created where the calculations were made using the equations 1, 2 and 3, for each item, except for the fossil fuels category.

The equivalence factors applied are the ones expressed on table 1.

Table 1– Equivalence Factors.

Source: Wackernagel, *et al*. (2005)

	Equivalence Factors (gha/ha)
Cropland	2,2
Forest	1,4
Grazing land	0,5
marine	0,4
Inland waters	0,4
Built land	2,2

For the imports and exports, given that this data is too aggregate it was not possible to use the yield factor as for the domestic extraction.

To overcome this constraint pondered average yield factors based on domestic extraction were create, given by equation 5:

$$p_{ponder} = \frac{\sum_{i=i}^{i=n} Quantity_i \times p_i}{\sum_{i=1}^{i=n} Quantity_i} \quad \textbf{[5]}$$

These are presented in table 2:

Table 2 – Pondered Yield Factors

	Unities	Ponder Average Yield Factors
Biomass from agriculture	t/ha	12,6
Biomass from forest	m^3 ub/ha	4,7
Fisheries	t/ha	5,7
Biomass from Grazing	gha/t	1,3

It was possible to use expression 5 because each category presented in the fragment for the domestic extraction has more or less the same distribution for imports. About exports, there were no problems with the use of those factors because exports derive from imports and domestic extraction.

So far is just missing the fragment related to energy, i.e. to calculate the area for sequestration of CO_2. This portion was calculated by the following equation:

$$\boldsymbol{CO_2\ seq} = \frac{\left(\begin{matrix}\boldsymbol{carbon} \\ \boldsymbol{emissions}\end{matrix} - \begin{matrix}\boldsymbol{\%\ not\ abs} \\ \boldsymbol{by\ oceans}\end{matrix}\right)}{\begin{matrix}\boldsymbol{CO_2\ seq} \\ \boldsymbol{by\ forests}\end{matrix}} \times \boldsymbol{Fe_{forests}} \quad \textbf{[6]}$$

Where "% not abs by oceans" represents the percentage of CO_2 that the oceans can not absorb, "carbon emissions" are the carbon emissions from fossil fuel combustion, "CO_2 seq by forests" corresponds to the amount of CO_2 that is possible to absorb by the forests, finally Fe_{forets} represents the equivalence factor from forests tabled on table 1 by 1,4 gha/ha.

The percentage of carbon not absorbed by oceans is obtained through the Footprint Network (Footprint Network, s.d.), as well as the CO_2 sequestrated by the forests.

Carbon emissions were taken from the International Energy Agency (IEA) (IEA, s.d.), following the methodology of the NFA. Therefore, the results from MFA considering the fossil fuels were not use. This way is more safe the comparison between the results of this methodology and the one adopted by the WWF, once the results from WWF are calculated according to the IEA data.

Finally, the results obtained for the Ecological Footprint of Portugal were the ones tabled on the table 3:

Table 3 – Ecological Footprint of Portugal, 2000

	Ecological Footprint (gha/habitant)
Cropland	2,33
Forest	0,37
fisheries	0,09
Grazing land	0,72
Energy land	1,67
Built land	0,05
Total	**5,2**

Comparing the results with the Ecological Footprint obtained by the WWF (Wackernagel, *et al*., 2005) (table 4) it is possible to conclude that the total results are pretty similar, which points for the validity of the method adopted.

Table 4 – Ecological Footprint of Portugal in 2001 by the WWF

	Ecological Footprint WWF (gha/habitant)
Cropland	0,85
Forest	0,53
fisheries	1,25
Grazing land	0,22
Energy land	2,4
Built land	0,02
Total	**5,3**

However considering the distribution of the different types of land (figure1) it is possible to understand that the results per category show a big difference in some categories. A reason for this differences has to do with the assumptions made during the estimation of the Ecological Footprint, such as: the fact that the equivalence factors were from the year 2003 also from Hungary and not Portugal, the use of pondered factors because of the aggregation of imports and exports.

Ecological Footprint of Lisbon

Data collection for the Ecological Footprint of Lisbon was essentially taken from the document that accounted the Material Balance of Lisbon (MBL) (Ferrão, *et al*., 2007). The MML consistes on a material balanced based on the MFA methodology dessimated by EUROSTAT (2001).

The problemas faced by the autors of urban areas MFA's is the fact that these are places where there is a low production, and little or none extraction. Hence, most of the materials consumed in the city are imported. Thus, the portion dedicated to domestic extraction is considered residual so negleted in this study (Ferrão, *et al*.,

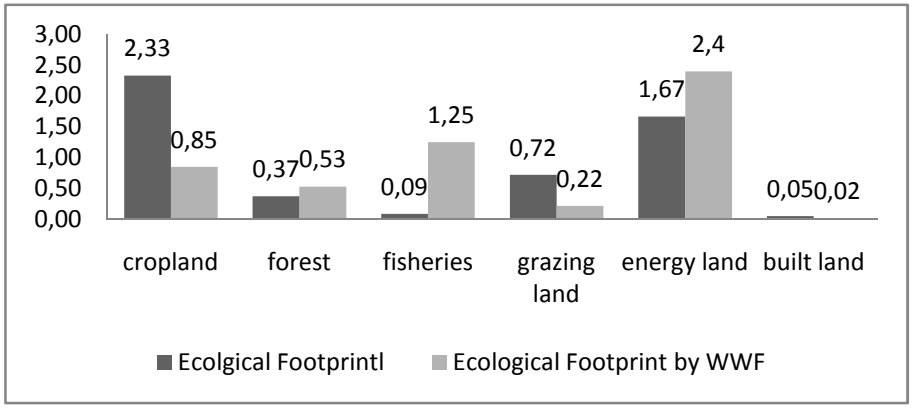

Figure 1 - Comparative analysis of the results of the Ecological Footprint

2007).

Since there is usually, no extraction and local production in the city there are also any exports of materials from the city.

The methodology used for Lisbon resembles to the methodology adopted for the Portugal, previously described.

Considering the built land, once more the MBL does not provide this kind of data, so it's used the area of the city 84 km^2 (CML, s.d.).

About the energy area, since there is no data available of the CO_2 in Lisbon, was used the result of fossil fuels combustion provided by Ferrão *et al.* (2007).

The MBL authors assumed that cattle is fed by agriculture products, thus they included meat in biomass from agriculture.

The results of the Lisbon Ecological Footprint are presented in the next table.

Table 5 – Lisbon Ecological Footprint, 2000

	Ecological Footprint (gha/habitant)
Cropland	0,498
Forest	0,280
Built land	0,034
Fisheries	0,002
Energy land	2,275
Total	**3,1**

Since there is not value to compare the ecological footprint with, like with Portugal, it is interesting to compare the value with other cities Footprints.

However, the fact of existing many methodologies to estimate the Ecological Footprint, i.e. no standard methodology makes the comparison hard.

In fact, the Ecological Footprint of London published by the Best Foot Forward (BBF) (BBF, 2002) presents different categories analysed because it follows the Component Approach:

Table 6 – London Ecological Footprint, 2002

	London Ecological Footprint (gha/habitant)
Direct energy	0,69
Materials and Waste	3,05
Food	2,8
Transport	0,34
Water	0,02
Built land	0,05
Sub-total	6,95
Tourism Ecological Footprint	-0,32
Total	**6,63**

In a new attempt to make a comparative analysis for the results, they were compared to a city that based the estimative in the same approach as Lisbon's, the Barcelona Ecological Footprint (Relea, *et al*., 1996).

Table 7–Barcelona Ecological Footprint, 1996

	Ecological Footprint (gha/habitant)
Cropland	0,49
Forest	0,08
Built land	0,005
Fisheries	0,65
Grazing land	0,99
Energy land	1,02
Total	**3,23**

Since both Ecological Footprints (Lisbon and Barcelona) are based on the same methodology, the results are possible to compare.

Even if the distributions are not similar, the objective of this comparison was not to evaluate these values but to assess if results for Lisbon are reasonable.

Barcelona's study (Relea *et al*., 1996) also presents Ecological Footprints of other cities. Authors conclude that there are small differences in the results of those cities, besides the comparison problems due to the use of different approaches:

- Santiago de Chile – 2,6 gha/ habitant
- Vancouver – 4,3 gha/ habitant
- Munich – 3,5 gha/ habitant

Conclusions

Even if the assumptions made through the calculations transform the methodology developed in a not completlly precise approach, the results of both Ecological Footprints (Portugal and Lisbon) allows the conclusion that the approach developed points to acceptable values.

Use of simplifications may lead to imprecision of the results. However, most of these assumptions results from the lack of transparency of the adapted approach (NFA – Compound approach).

Nevertheless is possible to verify that the Material Flow Accounting indicates to be a powerful data source and has a strong relation to the Ecological Footprint.

In fact, comparing the results obtained for Portugal (53 million and 500 thousand global hectares) with the ones obtained for Lisbon (about 1 million and 700 thousand global hectares) is possible to conclude tat the area occupied by Lisbon represents 3% of the area of Portugal.

The same way is possible to compare the material consumption. With this exercise, we conclude that the materials consumed in Lisbon represent 7% of the materials consumed in the country.

Even if apparently it represents a good indicator of the global impact, it should not be use as a tool for acting local against the environmental pressures of the consumption, because ecological footprint as a tool for policymaking is related with the lack of a standard methodology, which difficults comparisons.

Other reason is related with the fact that results presented for both cases were made according to the compound approach. Consequently, it is difficult to verify which areas contribute for the consumption at the component level. Therefore, we conclude that the Component approach points to a disaggregation of the Ecological Footprint that allows the division in categories more interest on policymaking.

Having in mind all the disadvantages of the Ecological Footprint, we should not forget that it presents a great potential as a communication tool, since it is a concept that the public appears to understand.

In a near future, it might be possible to solve the problem related to the lack of a standard methodology. However, there are still significant issues to solve as the follow (DEFRA, 2005):

- The consideration of environmental impacts is limited to land use and CO2 emissions;

- The current practice of using carbon sequestration as the basis for converting CO2 emissions to land is contorversial;
- The fact that most of the methodologies do not account for the embdied energy;
- It is likely that biocapacity (i.e. supply) is understimated , particulary because land uses are considered to be mutually exclusive;
- The level of unsustainable land management, and its associated impacts, is likely to be masked by other chages within the ecological footprint calculations;
- The lack of tansparency in the results, wich implies dobts on the results.

Once these constrains are overcome and after the election of a standard methodology the Ecological Footprint will be more accepted and it potentially will be recognized.

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