ECOLOGICAL FOOTPRINT BASED ON EMERGY (EEF): PERU AS CASE STUDY

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Abstract (reference number: 0001 – 53)
In recent years, two scientific tools for measuring human impact on nature appeared: Ecological Footprint (EF) and Emergy Analysis (EMA). Their methods are different, but they aim to solve the same problem: estimate the gap between natural resources production and human demand. Our hypothesis is that it is possible to combine them; thus, in this study the impact of Peruvian society on environment was analyzed using Ecological Footprint based on Emergy (EEF). The biocapacity was estimated as a function of primary renewable resources available for Biosphere (Solar radiation, Earth deep heat and Moon gravity force). The consumption was calculated as Production plus Imports minus Exports. The consumption was grouped in categories: cropland (including cultivation and soil loss), grazing, forest, fishing, built-up, fossil energy, hydroelectricity and domestic water. All the exergy flows of Peruvian Economy were calculated in joules and transformed into solar emergy (seJ/year) using the conversion factor called "Transformity" (seJ/J). The emergy flows were divided by the "global emergy density" (seJ/gha) to obtain "equivalent global area". Biocapacity was estimated as being 58.8 gha/capita and footprint as 20.5 gha/capita, with data of 2004. According to EEF, Peru can support a population 2.87 times bigger (present life style maintained), in opposition to the value of 4.26 obtained with conventional EF, therefore the result reveals a worse situation. EEF is easy to calculate if data is available. The limitations of new method are: (a) the values of transformity and renewability need to consider production model and show variation with time; (b) comparison of ecological gap within categories should be made possible by research effort.

Keywords: Emergy, renewable resources, transformity, footprint, Peru.

Abbreviations

BC:	Biocapacity
EF:	Ecological footprint
EF-GAEZ:	Ecological footprint based on GAEZ suitability indices
EF-NPP:	Ecological footprint approach that employs net primary productivity
EEF:	Ecological footprint approach based on emergy
EMA:	Emergy Analysis
ENPP:	Emergy net primary productivity
EQF:	Equivalence factor
GAEZ:	Global agricultural ecological zone
GDP:	Gross domestic product
gha:	Global hectare
Gt C:	10^9 ton of carbon
NPP:	Net primary productivity

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1. Introduction

A standard for the world scientific community concerning a methodology to evaluate the sustainability of a national economy don't exist (Siche et al., 2006), but two methodologies are considered as good alternatives: Ecological Footprint (EF) and Emergy Analysis (EMA). The first one is able to transmit its results in a language that people can understand easily, while the strong point for the second one is the capacity to account all the work done by nature in the production of resources used by the economy.

The EF is a tool very used by world community, stimulated by its didactic way to show the impact of society on the nature as the area needed to support consumption. Even so the EF received very criticisms, as it happens with all the tools that evaluate the sustainability (Levett, 1998; van den Bergh and Verbruggen, 1999; Ayres 2000; Moffatt 2000; Opschoor 2000; Rapport 2000; van Kooten and Bulte 2000; Pearce, 2000; Venetoulis and Talberth, 2007; Wiedmann and Lenzen, 2007; Lenzen et al., 2007).

The Ecological Footprint also known as EF-GAEZ because it uses indices from Global Agricultural Ecological Zones prepared by FAO (Food and Agriculture Organization of United Nations Organization). The GAEZ indices are used to calculate the Equivalence Factor. But, this factor underestimates important processes that increase footprint and reduce biocapacity. The EF authors recognize these faults (Wackernagel et al., 2002). EF-GAEZ deficiencies are described in the following lines:

(a) The method accounts each area only one time, even if the area supplies two or more ecosystem services (except for forest areas that are accounted two times: one as bioproductive area to supply forest products and as available area to absorb CO_2 emissions (Monfreda et al., 2004)). Even so the forest areas supply other ecosystems services that aren't accounted in biocapacity as: maintenance of hydrologic cycle; top soil conservation; filtration of solid and atmospheric pollutants; etc. The ocean, the crop lands and the pasture areas also absorb CO_2 from atmosphere and need be accounted, even in low proportion confronted to forest areas. The ecosystems areas that have low productivity (mountain; desert; tundra; ice land; etc.) aren't accounted in EF-GAEZ (Venetoulis and Talberth, 2007), but must be considered in the biocapacity calculation because they produce ecosystems services. Thus, the EF-GAEZ use to make a conservative estimative;

(b) The EF-GAEZ accounts fossil fuel through CO_2 emissions even it is possible to evaluate this footprint by the area demanded to sustain the alternative production of bio-fuel (fuel from biomass). This methodology assume a carbon sequester ratio of the 0.95 tC/ha/year (Wackernagel et al., 2005). This ratio is based in the quantify of CO_2 absorbed by forests from 1980 to 1990, not considering the CO_2 absorbed by others ecosystems and assuming that the ratios did not change at that time period;

(c) The EF-GAEZ tool does not consider the embodied energy in materials and services. Some studies about embodied energy suggested that current footprint could be approximately 30% larger (Loh, 2002). This author recognizes the importance of improving the methodology in this sense. This will result in more accurate indices;

(d) The EF-GAEZ doesn't account the footprint derived from water use. Water capture can be considered a secondary function in some places of the world, but in others as arid zones (where water is a limited factor) the human use competes with primary functions of ecosystem. Besides that, today, half of the water supplied by rivers and lakes is used in human processes (Hassan et al., 2005);

(e) The EF-GAEZ doesn't considers some important aspects of sustainability as top soil loss, production of solid residues, liquid effluents and gas emissions (nowadays, it only considers CO_2 emission). The soil erosion and excessive production of garbage can damage primary functions of ecosystems, thus, it's very important to know the impact about these processes. However is hard to find data about these impact and the results underestimate the true impact on the environment due to human activities.

Emergy Analysis (EMA) is a more robust tool than EF because it accounts other flows that influence sustainability as wastes, soil loss, deforestation, etc. Even so, the EMA presents deficiencies related to criteria and accuracy that are discussed in the following lines:

(a) EMA don't define which one is its sustainability indicator, it could be the Renewability (REN) (Brown e Ulgiati, 2004) or Emergy Sustainability Index (EmSI) (Ulgiati e Brown, 1998);

(b) Nowadays, EMA don't possess standards. For example, some authors indicates that in a long time perspective systems with high values of REN are sustainable (Brown e Ulgiati, 2004), but what is the minimum value of REN to be considered sustainable? For process and products the use of EmSI index is more enlightening. Brown e Ulgiati (2002) indicate that for EmSI below 1, the products and processes aren't sustainable at a long time period, while they are rather sustainable if EmSI attains 1, and clearly sustainable for EmSI above 5;

(c) Until this moment, for country evaluation, EMA doesn't have a satisfactory method to determine the volume of renewable flows. EMA considers only the biggest renewable flow among the renewable flows to avoid double account (Odum, 1996). This may be a temporary solution to estimate the extern renewable inflows used by systems, but right now the methodology does not consider the flows from natural capital stocks (environmental services) that contribute for the health of economic systems without monetary payments;

(d) One limitation of EMA is scarcity of information on emergy indicators (mainly transformity and renewability) for many resources and processes. Moreover, transformity changes with time and, because of that, when studying the system dynamics through time, the results could lack accuracy.

By far, strong points overcome weakness of these two methodologies but to know their limitations and advantages allow their mutual improvement. The objective of this work is a proposal for a convergent methodology between EF-GAEZ and EMA that we call Ecological Footprint Based on Emergy (EEF).

2. Proposed method

A new methodology based on EF-GAEZ and EMA was originally proposed by Zhao et al. (2005) and used by Siche et al. (2007) to make a diagnosis of Peru national system using 2004 data. The method proposed by Zhao et al. (2005) is very interesting because introduces EMA on EF, but maintains the problems detected in the original methodologies. The work of these researchers presents many conceptual deficiencies as to consider the biocapacity as the biggest renewable emergy flow. From the point of view of Emergy Methodology (Odum, 1996) this procedure could be valid only to calculate the quantity of the renewable resources that the systems consume, but not to calculate the total quantity of natural capital (biocapacity). In other words, the proposal of Zhao et al. (2005) considers a biocapacity based on the renewable external flows and does not include the flows derived from available internal stocks.

In this paper, it was used the Zhao et al. (2005) proposal with some conceptual ideas from EF-GAEZ (Wackernagel et al., 2005). The Zhao et al. (2005) proposal is simple and consist in calculating biocapacity as renewable resources and the footprint as the system consumption. All the flows were calculated as energy flows, in Joules (J) and after that converted to solar Emjoules (seJ) using the transformity as conversion factor. Finally, using emergy density (seJ/ha – global for biocapacity and local for consumption), the flows were converted into area (ha). It is necessary to point out that the EF-GAEZ and EMA deficiencies still remain. We introduce in the present work only four changes to improve the proposal of Zhao et al. (2005):

(a) Calculation of biocapacity as function of renewable resources available, considering solar energy, geothermal energy, gravitational energy and biomass stock energy. We propose here a standard procedure to calculate the biocapacity of a system. This procedure is the basis of the biocapacity calculation in the present paper;

(b) To consider the total area of evaluated systems. The EF-GAEZ considers only a fraction of the total area;

(c) A percentage of 14.2% in biocapacity area to cover other species needs. It corresponds to the size of protected territories in Peru for biodiversity preservation (INRENA, 2006). It could be more, for instance 25% or 50%;

(d) To include two important categories concerning natural resources use: top soil loss and water consumption. These categories aren't accounted by EF-GAEZ but are very important to obtain more accurate results.

2.1. Biocapacity (BC) calculation

The biocapacity should be calculated as function of available renewable resources. The quantity of renewable resources for Peru was calculated accounting the following sources: solar; gravitational; geothermal and biomass. EF-GAEZ accounts the sum of bioproductive areas of a national system. The calculation for Peru can be observed in Appendix 1.

The conversion of energy to emergy flows is realized using the transformity:

Emergy (seJ) = Energy of resource (J) x Transformity of resource (seJ/J).

After that, the emergy per capita is calculated through the division of the each emergy flow by population of the country. To obtain the biocapacity per capita (BCp) in units of area, we divide the emergy of biocapacity per capita (EMBp) of each flow by global emergy density (GED) which it 3.1E+14 seJ/gha (Zhao et al., 2005).

BCp (gha/people) = EMBp (seJ/people) / GED (seJ/gha)

Finally, the flows in global hectares per capita are added to subtract the 14.2% destined to preservation of other species. The value obtained represents the biocapacity available in global hectares per capita of the evaluated system.

2.2. Footprint (EF) calculation

The consumption was divided in seven categories: agricultural (food and soil loss); pasture; fishing; wood and firewood; nonrenewable energy resources; hydroelectricity; water for human use. The consumption of each category (except for soil loss and water) was calculated through the following expression:

Consumption = Production + Importation – Exportation.

The soil loss category (SL) in Joule was obtained using the following equation where organic matter is estimated as 3%:

$$SL\ (J) = SL\ (g/m^2/year) \times \text{area of crop}\ (m^2) \times \text{organic matter} \times 22604.4\ (J/g)$$

Water category was accounted as treated water (1.68 billon m^3 or 8.30E+15 J) that supplies domestic consumption. Water is used also by industries, agriculture and cattle production, but we assumed that this quantity was small when compared with the domestic use. This hypothesis should be confirmed in future studies.

The procedure to convert each flow in global hectares is similar to that used to calculate BC in this paper. Each consumption category was expressed in Joules and converted into emergy through transformity. The emergy per capita was obtained dividing by the number of Peruvian population. The global emergy density (GED) was used to convert each category to global hectares.

The use of GED is different than the use of local emergy density (LED) as proposed by Zhao et al. (2005). In other words, to use LED (in seJ/ha, where ha is equivalent to local hectares) correspond to obtain a footprint in local hectares and to use GED (in seJ/ha, where ha is equivalent to global hectares) corresponds to obtain a footprint in global hectares. The footprint obtained using GED has the same basis used for biocapacity, so they can be compared.

3. Results and Discussion

As mentioned before, the objective of this work was to introduce new issues in the conventional EF calculation and reduce some deficiencies criticized in papers, but always looking for the convergence between EF-GAEZ and EMA.

In the EEF methodology, EMA has more importance than EF-GAEZ because all flows are used in emergy units, but the result is expressed in global hectares.

The biocapacity is the biosphere regenerative capacity (WWF, 2005). In a different way than conventional footprint calculation, the biocapacity can be calculated as function of renewable resources.

Table 1 shows the biocapacity calculation and the Figure 1 shows the emergy diagram for Peru. In terms of energy (Joule) the sun supplies the biggest quantity of energy (96.1%) but in terms of solar emergy (solar Emjoules) it supplies only 1.3%. The renewable emergy flows, that define biocapacity, are: biomass, gravitational and geothermic sources (48, 30 and 20%, respectively).

Table 1. Biocapacity calculation for Peru through EEF methodology, 2004.

Note (i)	Item	Quantity (ii) (J)	Transformity (seJ/J) (i)	Total emergy (seJ)	Emergy per capita (seJ/people)(iii)	Biocapacity (gha/people) (iii)
Renewable resources						
1	Solar	7.26E+21	1	7.26E+21	2.67E+14	0.86
2	Gravitational	2.39E+18	73 700	1.16E+23	6.47E+15	20.84
3	Geothermic	9.68E+18	12 000	1.76E+23	4.27E+15	13.75
4	Biomass	2.79E+20	1000	2.79E+23	1.02E+16	33.07
Total of renewable resources						68.52
Other species (14.2%) (iv)						9.73
Total						58.79

(i) The additional information and Transformity are presented in Appendix 1;
(ii) Quantity of resource available for the system;
(iii) Population for Peru in 2004: 27 219 264 people (INEI, 2006);
(iv) This ratio corresponds to territory protected for biodiversity preservation (INRENA, 2006).

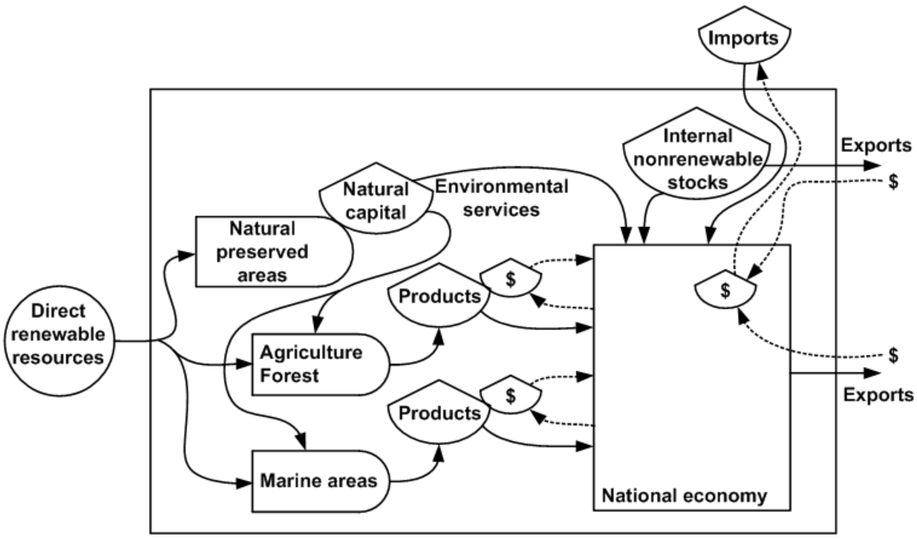

Figure 1. Simplified emergy diagram for Peru country.

Peru Biocapacity obtained using EEF method is 58.8 gha/Peruvian. As it can't be separated in the same categories used in footprint calculation, they can't be compared that way. Biocapacity calculated through the EF-GAEZ resulted in 3.6 gha/Peruvian in 2004 (Siche, 2007). Venetoulis and Talberth (2007) obtained a biocapacity of the 30.1 gha/Peruvian considering the EF-NPP methodology with data for 2001. We believe that the biocapacity calculated through EF-GAEZ underestimates Peruvian resources, because some ecosystems weren't accounted.

A controvertible element is the ratio considered for biodiversity protection. Many papers suggest a ratio of in accordance with biologic diversity conservation, cultural and landscape maintenance and ecosystems services (Rojstaczer et al., 2001; Levin and Levin, 2002; Rodrigues, et al., 2003; Mittermeier et al., 2005). The natural areas protected In Peru corresponds to 14.2% of the total territory (INRENA, 2006) and we decided to subtract this ratio on the biocapacity calculation (9.73 gha/people – Table 1). Venetoulis and Talberth (2007) used a ratio of 13.4%. Even so we believe that this ratio is low to warrant maintenance of ecologic well-being.

Table 2. Footprint categories for Peru through EEF methodology, 2004.

Item	Raw data (J)	Transformity [a] (seJ/J)	Total emergy (seJ)	Emergy by person (seJ/person)	Footprint (gha/person)
1. Agriculture			8.99E+22	3.30E+15	10.6401
1.1. Food	2.44E+17	336 000	8.21E+22	3.02E+15	9.7194
1.2. Soil loss	6.26E+16	124 320	7.78E+21	2.86E+14	0.9207
2. Cattle production	7.91E+15	3 360 000	2.66E+22	9.77E+14	3.1461
3. Fishing	2.44E+15	3 360 000	8.19E+21	3.01E+14	0.9697
4. Wood and firewood	8.36E+16	22 100	1.85E+21	6.79E+13	0.2187
5. Energy resources			3.04E+22	1.12E+15	3.5926
5.1. Coal	2.23E+16	66 900	1.49E+21	5.48E+13	0.1766
5.2. Petroleum	2.96E+17	89 000	2.63E+22	9.68E+14	3.1181
5.3. Natural gas	4.28E+16	58 800	2.52E+21	9.25E+13	0.2979
6. Hydroelectricity	6.51E+16	111 000	7.23E+21	2.65E+14	0.8553
7. Water [b]	8.30E+15	1 118 880	9.29E+21	3.41E+14	1.0991
Total			1.56E+23	5.74E+15	20.5215

[a] Transformity sources: Brown and MacClanaham (1996); Odum (1996); Romitelli (2000); Brown and Ulgiati (2004); Ortega (2002);
[b] Water for domestic use.

Table 2 shows the footprint results of Peru consumption using EEF and data for 2004. The most important category is food from agriculture (9.7 gha/Peruvian) that corresponds to 47.4% of total footprint; the second one is non-renewable energy resources (3.6 gha/Peruvian) that correspond to 17.5% of total footprint. These results are in accordance with some papers published that indicate the crop category as the most important in total footprint of nations (41% of total footprint: Loh & Wackernagel, 2004; 45% of total footprint: Hails et al., 2006). It is important to point out that in EEF it was accounted the subcategory soil loss (inside the crop category) as one element that has large influence in sustainability. Even small, the soil loss footprint has almost the same value (0.92gha/person) than the water consumption footprint (1.1 gha/person) and the fishing products footprint (0.97 gha/person). Moreover, it is larger than some fossil fuel footprint (0.18 gha/person by coal; 0.3 gha/person by natural gas).

One result that needs attention is the small value obtained by fishing footprint (0.97 gha/person or 4.7% of total footprint). It is recognized that this activity in Peru became unsustainable (Pascó-Font, 1999; Talberth et al., 2006) but in accordance with the results obtained in this paper, the impact of this activity isn't alarming as those authors claim. A possible answer for this contradiction is that those authors considered fishing production and not the fishing consumption as is made by EEF and EF-GAEZ that consider exported footprint (consumption = production + imports - exports). For INEI (2006) approximately 95% of fishing extraction by Peru is exported or, in other words, 95% of the Peru fishing footprint is exported.

The forest resources consumption footprint possess the minor value between the categories analyzed (1.1% of total footprint). This result is in accordance with other papers (Loh and Wackernagel, 2004; Hails et al., 2006).

The petroleum consumption is the most important category of the energy resources (87% of total energy resources footprint) and shows that Peru depends on this resource. This fact will not change soon because politics adopted by governments do not consider the long range period. Many researches believe that the “Camisea” gas project will change the energy base in next years (CAN, 2004) but the Peruvian economy will continue dependent from nonrenewable energy resources.

The hydroelectricity footprint (0.86 gha/person) represents 4.2% of total footprint. This value is different from value found by Loh and Wackernagel (2004) and by Venetoulis and Talberth (2007) (1.1% by EF-GAEZ; 1.6% by EF-NPP). We believe that exist a distortion element in the calculation of these category and that could be the transformity used (1.11E+05 seJ/J, Brown and Ulgiati, 2004). These authors calculated the hydroelectric power transformity accounting labor and other services for produce it. Odum (1996) used for USA system in 1983 a electric power transformity of the 1.59E+05 seJ/J, that actualized by 1.68 factor is equivalent to 2.67E+05seJ/J. The development countries possess biggest Transformity than countries more poor, so the hydroelectric energy Transformity used in the footprint calculation for Peru would have to be lesser. We can affirm that each country needs to have its Transformity because its characteristics (technology; labor; energetic base; etc.) has influence on the emergy used and consequently in its Transformity.

A new category accounting in EEF is water for domestic consumption that includes collection, treatment, transport and supply. Water for industrial and agricultural consumption wasn't accounted because its footprint is small (Jenkin and Stentiford, 2005). The footprint for water consumed by Peru population was 1.1 gha/person (5.4% of total footprint). This value is similar to fishing footprint (0.97 gha/person or 4.7% of total footprint).

Through the same criteria used in traditional Ecological Footprint assessment (ecologic balance = biocapacity – footprint), the EEF shows that Peru has a positive ecologic balance: 58.8 - 20.5 = 38.3 gha/person (Figure 2). This means 38.3 gha/person of ecological surplus. This value is very greater than the values published using traditional Ecological Footprint (3.4 gha/person in 2001, Loh and Wackernagel, 2004; 3.0 gha/person in 2003, Hails et al., 2006).

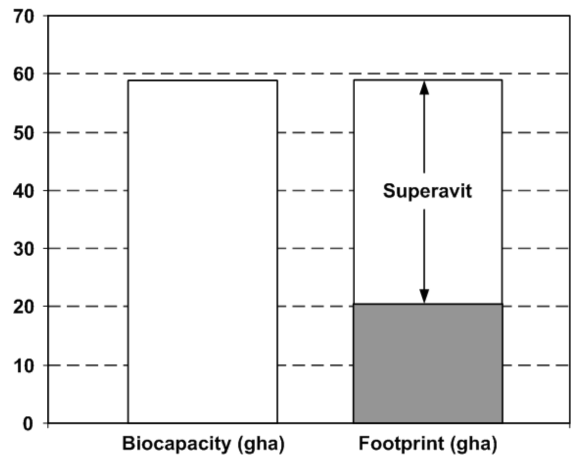

Figure 2. Ecologic balance for Peru in 2004, using EEF.

We can't conclude that the results are best through the EEF than traditional Ecological Footprint. Venetoulis and Talberth (2007) obtained an ecologic balance of the 23.1 gha/person for Peru using the EF-NPP method, while Hails et al. (2006) obtained 3.0 gha/person using the EF-GAEZ method. In the present paper the value obtained was 38.3 gha/person. One better analysis is realized through the division of biocapacity values by footprint values (BC/EF) called the load capacity factor.

BC/EF answers: The territory can support its population with its present life stile?
BC/EF > 1 means that the system is sustainable.
BC/EF < 1 means that it is unsustainable.

Analyzing BC/EF ratio obtained with different methodologies (Figure 3) it is possible to observe that Peru ecological situation shows best performance through the EF-NPP (BC/EF = 4.26). This means that in 2001 the Peruvian territory had the capacity to support 4.26 times its population without causing damage to the environment and considering the life stile of that year. The Emergy Analysis (EMA) where biocapacity is accounted as renewable resources flow (seJ) and footprint as emergy used by the country (seJ), showed the worst value because the load capacity factor was 1.21 (Siche, 2007), close to the borderline of sustainability.

Ferguson (2003) calculated the load capacity for 147 countries around the world through data obtained from Living Planet Report 2002 (Loh, 2002). The author found the value of 4.35 gha/citizen for the Peru biocapacity so, we can to estimate that the load capacity factor obtained by Ferguson is close to 4.05 as was calculated by Hails et al. (2006) using the EF-GAEZ method.

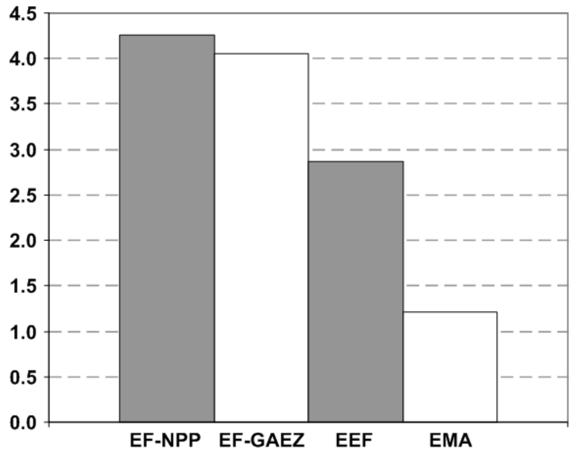

Figure 3. Load capacity factor (biocapacity/footprint) obtained with different Footprint methodologies.

The EFF method proposed in this paper shows an intermediary value for load capacity factor (2.87), a value between EF-GAEZ and EMA, maybe as result of the convergence of these two methodologies, but more close to EMA than to EF-GAEZ.

4. Conclusions

The ecologic balance results obtained with Ecological Footprint Based on Emergy (EEF) for Peru show a worst performance than EF-GAEZ and EF-NPP.

The EEF have some limitations that demand future discussion. Mainly the impossibility to do comparisons between the categories, as is common in EF-GAEZ and EF-NPP. Other limitation is transformity values used to calculate the footprint, that need to represent the complete process of product transformation and its variation on time. On the other hand, a strong positive point is its easiness of application in global scale because the data on renewable resources and consumption is available.

Using EEF for Peru with 2004 data, the load capacity factor is 2.87. This means that Peru territory had capacity to support almost three times its population without causing damage on environment, considering the population life stile in that year

References

Ayres R.U. 2000. Commentary on the utility of the ecological footprint concept. Ecological Economics 32, 347-349.

Brown, M.T., Ulgiati, S. 1997. Emergy-based indices and ratios to evaluate sustainability: monitoring economies and technology toward environmentally sound innovation. Ecol. Eng. 9, 51–69.

Brown, M., Ulgiati, S. 2004. Emergy Analysis and Environmental Accounting. Encyclopedia of Energy, 2:329-353.

CAN – Comunidad Andina de Naciones. 2004. Bases de la Alianza Energética Andina - Antecedentes para su formulación. Disponível em: http://intranet.comunidadandina.org/Documentos/DTrabajo/SGdt256_R1.doc

FAO. 2005. Global Forest Resources Assessment. Extent of forest and other wooded land 2005.

Ferguson, A. 2003. Sustainable populations by country. Optimum Population Trust. Disponível em: http://www.optimumpopulation.org/opt.sustainable.numbers.html

GFN – Global Footprint Network. 2006. Humanity's Footprint 1961 - 2003. Disponível em:http://www.footprintnetwork.org/gfn_sub.php?content=global_footprint

Hails, C., Loh, J., Goldfinger, S. (Eds). 2006. Living planet report 2006. World Wide Fund for Nature International (WWF), Zoological Society of London (ZSL), Global Footprint Network, Gland, Switzerland.

Hassan, R., Scholes, R., Ash, N. (Eds). 2005. The Millennium Ecosystem Assessment. ISLAND PRESS. NW, Washington, DC. Disponível em: http://www.millenniumassessment.org/

Haden, A. 2003. Emergy evaluation of Denmark and Danish Agriculture – Assessing the limits of agricultural systems to power society. Centre of Sustainable Agriculture Sciences, Swedish University of Agricultural Sciences, Uppsala. Ecological Agriculture 37.

INEI – Instituto Nacional de Estadística e Informática. 2006. Peru: Compendio Estadístico 2005. Disponível em: http://www.inei.gob.pe/biblioinei.asp

INRENA – Instituto Nacional de Recursos Naturales. 2006. Sistema Nacional de Áreas Naturales Protegidas por el Estado. Lima, Peru. Disponível em: http://www.inrena.gob.pe/index_inicio.htm

Jenkin, N., Stentiford, C. (Eds). 2005. Stepping Forward: A resource flow and ecological footprint analysis of the South West of England. Technical report. Best Foot Forward Ltd, The Future Centre, Oxford, United Kingdom. Disponível em: http://www.steppingforward.org.uk/ef/index.htm.

Lassen, K., Friis-Christensen, E. 1995. Variability of the solar cycle length during the past 1ve centuries and the apparent association with terrestrial climate. Journal of Atmospheric and Solar-Terrestrial Physics 57, 835–845.

Laut, P. 2003. Solar activity and terrestrial climate: an analysis of some purported correlations. Journal of Atmospheric and Solar-Terrestrial Physics 65, 801– 812.

Lenzen, M., Borgstrom, C., Bond, S. 2007. On the bioprodutivity and land-disturbance metrics of the Ecological Footprint. Ecological Economic 61, 6 - 10.

Levett R. 1998. Footprinting: a great step forward, but tread carefully. Local Environment 3(1), 67-74.

Levin, P., Levin, D. 2002. The real biodiversity crisis. American Scientist 90, 6-6.

Loh, J. (Ed). 2002. Living planet report 2002. World Wide Fund for Nature International (WWF), UNEP World Conservation Monitoring Centre, Redefining Progress, Center for Sustainability Studies, Gland, Switzerland.

Loh, J., Wackernagel, M. (Ed). 2004. Living planet report 2004. World Wide Fund for Nature International (WWF), UNEP World Conservation Monitoring Centre, Global Footprint Network, Gland, Switzerland.

Mittermeier, R., Robles, P., Hoffman, M., Pilgrim, J., Brooks, T., Mittermeier, C.G., Lamoreux, J., da Fonseca, G., e Seligmann, P. 2005, Hotspots Revisited : Earth's Biologically Richest and Most Endangered Terrestrial Ecoregions, Conservation International, Washington, D.C.

Moffatt, I. 2000. Ecological footprints and sustainable development. Ecological Economics 32, 359-362.

Monfreda, C., Wackernagel, M., Deumling, D. 2004. Establishing national natural capital accounts based on detailed ecological footprint and biological capacity accounts. Land Use Policy 21, 231 – 246.

Odum, H.T., 1996. Environmental Accounting, Emergy and Decision Making. J. Wiley, NY.

Odum, H.T., Brown, M.T., Brandt-Williams, S. 2000. Handbook of Emergy Evaluation Folio 1: Introduction and Global Budget. Center for Environmental Policy, University of Florida, Gainesville. 16p

Opschoor, H. 2000. The ecological footprint: measuring rod or metaphor? Ecological Economics 32, 363-365.

OSO MARINE. 2005. Disponível em: http://www.osomarine.com/indexspa.htm.

Pascó-Font, A. 1999. Desarrollo Sustentable del Perú. Editorial Valenzuela. Agenda: Peru. 118pp.

Pearce, D. 2000. Public Policy and Natural Resources Management, Draft paper for DGXI, European Commission.

Produce et al. 2006. Lineamientos estratégicos para impulsar el desarrollo forestal en el Peru. Lima - Perú. 75 p.

Rapport, D.J. 2000. Ecological footprints and ecosystem health: complementary approaches to a sustainable future. Ecological Economics 32, 381-383.

Rodrigues, A.S.L., Andelman, S.J., Bakarr, M., Boitani, L., Brooks, T., Cowling, S.A., Fishpool, L., da Fonseca, G.A.B., Gaston, K.J., Hoffmann, M., Long, J., Marquet, P.A., Pilgrim, J.D., Pressey, R., Schipper, J., Sechrest, W., Stuart, S., Underhill, L.G., Waller, R.W., Watts, M.E.J., Yan, X. 2003. Global Gap Analysis: Towards a representative network of protected areas. Advances in Applied Biodiversity Science 5, 73-74.

Rojstaczer, S., Sterling, S., e Moore, N.: 2001, 'Human appropriation of photosynthesis products,' Science 294, 2549-2552.

Siche, J.R., Ortega, E., Romeiro, A., Agostinho, F.D.R. 2006. Sustainability of nations: comparative study between the Environmental Sustainability Index, Ecological Footprint and the Emergy Performance Indices. Ecological Economics. Aceito para publicação.

Siche, J.R. 2007. Avaliação ecológica-termodinâmica e econômica de nações: o Peru como estudo de caso. Tese de Doutorado, Universidade Estadual de Campinas, SP, Brasil.

Siche, J.R., Ortega, E., Rodríguez, H. 2007. Contabilidad de la huella ecológica basada en la emergía - caso Peruano. Revista ECI-Peru. ISSN 1813-0194. Aceito para publicação.

Talberth, J., Venetoulis, J. e Wolowicz, K. 2006. Recasting Marine Ecological Fishprint Accounts. Technical Report, Redefining Progress. Disponível em: http://www.rprogress.org/newprograms/sustIndi/fishprint/index.shtml

Ulgiati, S., Brown, M.T. 1998. Monitoring patterns of sustainability in natural and man-made ecosystems. Ecological Modelling 108, 23-26.

van den Bergh J.C.J.M. e Verbruggen H. 1999. Spatial sustainability, trade and indicators: an evaluation of the ecological footprint. Ecological Economics 29(1), 61- 72.

van Kooten G.C., Bulte E.H. 2000. The ecological footprint: useful science or politics? Ecological Economics 32, 385-389

Venetoulis, J. e Talberth, J. 2007. Refining the Ecological footprint. Environment Development and Sustainability DOI 10.1007/s10668-006-9074-z.

Wackernagel, M., Schulz, N., Deumling, D., Callejas, A., Jenkins, M., Kapos, V., Monfreda, C., Loh, J., Myers, N., Norgaard, R. e Randers, J. 2002. Tracking the ecological overshoot of the human economy. Proc. Natl. Acad. Sci. USA, Vol. 99 (14): 9266-9271.

Wackernagel, M., Monfreda, C., Moran,D. Wermer, P., Goldfinger, S., Deumling, D., Murray, M. 2005. National Footprint and Biocapacity Accounts 2005: The underlying calculation method. Global Footprint Network. 33pp.

Wiedmann, T., Lenzen, M. 2007. On the conversion between local and global hectares in Ecological Footprint analysis. Ecological Economic. In press.

WWF - World Wide Fund. 2005. Europe2005 The Ecological Footprint. World Wide Fund for Nature European Policy Office, Brussels, Belgium.

Zhao, S.; Li, Z.; Li, W. 2005. A modified method of ecological footprint calculation and its application. Ecol. Model. 185, 65–75

Appendix 1. Renewable flow of Peru .

1 Solar energy:

Area	=	1,94E+12	m^2	(sum of land and marine area)	
Insolation	=	1,28E+02	$Kcal/cm^2/yr$		
Albedo	=	30,00		(% of insolation)	
Energy(J)	=	(area incl shelf)*(avg insolation)*(1-albedo)			
	=	$(\_\_\_\_m^2)(\_\_\_\_Cal/cm^2/y)(E{+}04cm^2/m^2)$			
		(1-0.30)(4186J/kcal)			
	=	7,26E+21	J/yr		
Transformity	=	1			Odum (1996)

2 Tidal energy:

Marine area	=	6,52E+11	m^2		
Avg Tide Range	=	1,00	m	(Average)	OSO MARINE (2005)
Density	=	1,03E+03	kg/m^3		
Tides/year	=	7,30E+02		(estm. of 2 tides/day in 365 days)	
Energy(J)	=				
	=	$(\_\_\_\_m^2)(0.5)(\_\_\_\_/yr)(\_\_\_\_m)^2(\_\_\_\_\_kg/m^3)(9.8m/s2)$			
	=	2,39E+18	J/yr		
Transformity	=	16 842			Odum (1996)

3 Earth cycle:

Area	=	1,94E+12	m^2		
Heat flow	=	5,00E+06	J/m^2		
Energy (J)	=	(area)(heat flow)			
	=	9,68E+18			
Transformity	=	34 377			Odum (1996)

4 Natural capital

Forest area	=	68742000	ha		FAO (2005)
Biomass	=	336.69	ton/ha		Produce et al. (2006)
	=	(___ha)*(___ton/ha)*(2879185kcal/ton)*(4187 J/kcal)			
Energy	=	2.79E+20	J		
Transformity	=	1000	seJ/j		Odum (1996)