EMERGY NET PRIMARY PRODUCTION (ENPP) AS BASIS FOR CALCULATION OF ECOLOGICAL FOOTPRINT

Raúl Siche[a, b], Feni Agostinho[b] and Enrique Ortega[b, *]

[a] Escuela de Ingeniería Agroindustrial – Facultad de Ciencias Agropecuarias. Universidad National de Trujillo, Av. Juan Pablo II s/n. C. Universitaria, Trujillo, Peru.
[b] Ecological Engineering Laboratory, Food Eng. School, State University of Campinas (Unicamp). Cx. Postal 6121, CEP 13083-862, Campinas, SP, Brazil.

Abstract (reference number: 0001 – 54)
Society needs urgently good tools to understand the biosphere mechanisms, get conscious of Earth's biophysical limits and make appraisals of environmental performance of human dominated systems. In this context, the Ecological Footprint (EF) appears as one of the most important tools. But, according to calculations based on emergy analysis, the indicators of EF could underestimate the problem of human carrying support. EF does not consider the work of untouched nature in productivity and ecosystems services. To improve this, we propos: (a) to include the ecosystems non considered in EF: tundra, deserts and zones covered by ice; (b) to consider the value of NPP (in emergy units: seJ/m^2/yr) as the base for calculation of Equivalent Factors (EQF); because several publications argue that NPP is particularly relevant in sustainability analyses, because human beings appropriate NPP to fuel production and consumption activities and because these activities, in turn, will affect NPP in the future; (c) to include in EF, as carbon emissions (in ton C/m^3 of water), the consumption of fossil energy used in collection, treatment and distribution of water for domestic use. Introducing these changes to conventional EF and taking as reference the Peruvian economy (during 2004) the Biocapacity was 14.6 gha/capita and the Footprint 6.6 gha/capita. It means that Peru can support 2.2 times its population if present life style is maintained, in opposition to the 4 times ratio obtained with conventional EF. The results obtained with improved approach show a worse situation of than that revealed by conventional EF.

Keywords: Emergy, NPP, sustainability, footprint, Peru.

Abbreviations

EF:	Ecological footprint
BC:	Biocapacity
EF-GAEZ:	EF based on GAEZ suitability indices
EF-NPP:	EF approach that employs net primary productivity
EF-ENPP:	EF approach that employs net primary productivity based on emergy
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
ENPP:	Emergy net primary productivity

1. Introduction

The Ecological Footprint (EF) is a tool that is being used for world-wide scientific community, stimulated for its didactic form to transmit the impact of the society on the nature through a measure of easy understanding.

* Tel.: +55 19 3521.4058; Fax: +55 19 3521.4027; E-mail: ortega@fea.unicamp.br

They are two the main reasons for which the EF has become very popular: (a) It uses a mathematical formula to consider the effect of the consumption of the society (footprint) in its natural environmental (biocapacity); (b) It incorporates a vast amount of information in a simple quantitative measure (land area in global hectares) to express its results.

The EF-GAEZ calculates "biocapacity" as the availability in bioproductive land area and "footprint" as the consumption of the evaluated system, both in global hectares. Details of the calculations can be obtained in Monfreda et al. (2004). This method has serious deficiencies and as result EF-GAEZ values underestimate human impact.

As the majority of the existing methods that evaluate the sustainability of systems and processes, the EF-GAEZ (called thus because it uses the Global model Agro-Ecological Zones of FAO) has been extensively criticized (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). Main critics on EF-GAEZ are commented below:

a) It accounts for carbon emissions as area of forest necessary to absorb CO2, but the carbon sequestering occurs also in areas of agriculture, pasture, ocean, etc. (Venetoulis and Talberth, 2007). The forests not only have the function to absorb CO2, but also the ocean, vegetable cultures, grazing lands, etc. Even these areas absorb CO2 in lesser ratio that forests, they need to be accounted. Areas considered nonproductive or with low productivity (mountains, deserts, tundra, zones covered by ice) are not accounted in EF-GAEZ (Venetoulis and Talberth, 2007), but they produce environmental services that must be accounted in the biocapacity. Nevertheless, the EF-GAEZ make conservative estimates when calculations do not have sufficient data;
b) EF-GAEZ only accounts once for an area, although the area may be supplying two or more ecological services, with exception of the forests that are accounted two times, one as bioproductive area to supply forest products and another as available area to absorb CO_2 emissions (Monfreda et al., 2004). Even so, the forests also supply other ecological services that are not accounted, as the maintenance of the hydrologic cycle, soil formation and conservation, filtering of solid, liquid and gaseous pollutants, etc;
c) In EF-GAEZ approach, the use of energy is accounted as fossil fuel by means of carbon dioxide emission, even it is also possible to evaluate EF from the use of the required land area to support the biofuel production. The EF-GAEZ assumes a carbon sequestrion of 0.95 t C/ha/year (Wackernagel et al., 2005). Thus, for each ton of emitted carbon the EF-GAEZ assumes a footprint of 1.05 hectares (diminishing the quantity catched by the oceans - 65%). The carbon sequestrion ratio is based on the forests absorbed amount of CO_2 during the period between 1980 and 1990, disrespecting CO_2 absorbed by other ecosystems and assuming that the sequestrion rate does not changed with time;
d) As EF-GAEZ doesn't include the contribution of important ecosystems (as ocean, 2/3 of the planet) in the calculation of the biocapacity. Therefore, it underestimates the ecosystem work that has specific functions in the global and local biological cycles (Venetoulis and Talberth, 2007). For example, the EF-GAEZ does not include the open ocean, an important ecosystem that absorbs great amounts of CO_2. It also doesn't include non productive areas, as deserts and ice covered lands, even these ecosystems produce environment services essential to the welfare of the humanity;
e) It does not include fresh water in footprint accounting, even this is a consume that influences greatly the sustainability (Chambers et al., 2000). Collection of fresh water can to be a secondary function in some places of planet, but in

other places (arid zones where water is a limiting factor), the use of the water competes directly with other primary functions of the ecosystem. Moreover, currently half of the water that supplies rivers and lakes is used in anthropic processes (Hassan et al., 2005);

f) It doesn't include other species, besides human, in the calculation of biocapacity (Chambers et al., 2000). Part of biocapacity should provide other species needs;
g) EF-GAEZ doesn't incorporate the work made by nature in the production of natural and human resources. EQF' s should incorporate this work, but they are based on the potential of land to supply resources to humans, without considering the quality of energy nor the work made by nature to generate resources.

Emergy Analysis (EMA) is a more robust tool than EF, because it allows accounting other flows that influence sustainability (as wastes, soil loss, deforestation, etc.). Even so, EMA still has deficiencies. Main critics on ENA are commented in the following items:

a) EMA not yet has defined clearly which is the sustainability indicators, it could be Renewability (REN) (Brown and Ulgiati, 2004) or Emergy Sustainability Index (EmSI) (Ulgiati and Brown, 1998);
b) EMA does not possess a standard of what is sustainable or unsustainable. For example, some authors indicate that in a long period of time, systems or processes with high values of REN are sustainable (Brown and Ulgiati, 2004), but which is the minimum value of REN to be considered sustainable? Similar situation occurs with the EmSI;
c) One main limitation of EMA is the lack of information on values of transformities of many resources. Besides that, transformities change with the time, and there is no significant research on that subject, excepting emergy/money ratio in national economies.

After discussing methodologies limitations, we propose a method to improve the precision of EF-GAEZ final indicators, redefining its equivalence factors (EQF). For this, the EMA and some suggestions of Venetoulis and Talberth (2007) were used.

2. Previous and proposed method based on NPP

Previous to this work a method to calculate EF-GAEZ based on NPP was proposed by Venetoulis and Talbert (2007). The authors called it Ecological Footprint based on Net Primary Production (EF-NPP) and use scientific criteria and solve some weak points of conventional EF.

In order to improve it, we propose a new method that we call Ecological Footprint based Emergy Net Primary Production or EF-ENPP, since its main novelty in is the calculation of new EQF's based on NPP in emergy units. Thus, EF-ENPP uses ideas from three methods EF-GAEZ (Wackernagel et al., 2005), EF-NPP (Venetoulis and Talberght, 2007) and EMA (Odum, 1996).

Characteristics of EF-ENPP

We suggest five changes in the calculations of EF-GAEZ. These changes allow to solution in part the deficiencies cited before:

a) To calculate EQF's as function of the Emergy Net Primary Production (ENPP). NPP in emergy units (seJ/m^2/year) is calculated through the use of Transformity (seJ/g) using the software BIOMASSv1.0 (Siche et al., 2006a);

b) To consider the total area of the evaluated system, including open ocean and areas of low biological productivity (desert, tundra, land covered with ice);
c) To include the consumption of fresh water for domestic consumption as collected, treated and transported water;
d) To consider 14.2% of the total biocapacity, for the necessities of other species. This percentage was chosen because 14.2% of the Peruvian territory are protected for the preservation of biodiversity (INRENA, 2006);
e) To update carbon sequester rate with the data published for the IPCC (2004).

2.1. New Equivalence Factors (EQF)

The EF-GAEZ used NPP data to calculate Equivalence Factors in some studies, but didn't prosper due to the low quality of available data at that time (BRASS, 2006). EF-GAEZ method intends to retake this procedure in the future; as NPP is being esteemed through satellite images, it could facilitate future work.

On the other hand, the Biomassv1.0 model (Siche et al., 2006a) appears as an option to esteem the NPP. For calculation of EQF's in EF-ENPP method, diverse models were used to calculate the transformity of biomass produced in ecosystems (Table 1).

Table 1 shows biomass (NPP in g/m^2/year) and transformities (seJ/J) for each ecosystem, and the calculated EQF's. In this work the EQF indicates the relation between the net primary production of a terrestrial or marine ecosystem (average global value expressed in emergy) and the net primary production correspondent the sum of all terrestrial and marine ecosystems NPP (in emergy).

In the EF-ENPP the pasture zones include: chaparral (NPP = 360 g C/m^2/year), tropical savanna (NPP = 790 g C/m^2/year), temperate grassland (NPP = 350 g C/m^2/year).

The forest zones include: tropical forest (NPP = 925 g C/m^2/year), temperate and plantation forest (NPP = 670 g C/m^2/year), boreal forest (NPP = 355 g C/m^2/year) and temperate woodland (NPP = 700 g C/m^2/year).

The low productivity zones include: arctic and alpine tundra (NPP = 105 g C/m^2/year), semi-desert (NPP = 67 g C/m^2/year) and extreme desert (NPP = 11 g C/m^2/year).

The NPP of terrestrial systems was obtained from the work of Amthor et al. (1998). It is interesting to observe the highly productivity of wetlands (NPP = 1180 g C/m^2/year).

Wetland is an environment at the interface between truly terrestrial ecosystems and truly aquatic systems making them different from each yet highly dependent on both (Mitsch and Gosselink, 1986). Wetlands host considerable biodiversity and endemism. For these reasons wetland was separated of other biomes to evaluate its biocapacity.

The biomes "lakes and streams" and "perpetual ice" were joined and considered in the same category, since for Peru great part of the freshwater consumption in the coast comes of the thawing of the glaciers of the high Andean zones.

Marine biomes considered in this analysis were the continental platform (zones of intense fishing) and open ocean. The continental platform has relatively high productivity when compared with open ocean (NPP = 111 g C/m^2/year). The open ocean presents a small net productivity (NPP = 46 g C/m^2/year), however fulfills an important ecosystem function: to absorb 77% of the CO_2 emissions (IPCC, 2004). NPP data of marine systems was taken from Thom et al. (2001).

The EQF for the built zones was calculated through the difference between cropland NPP (944.44 g/m^2/year) and cities NPP (222.22 g/m^2/year) (Table 1), differently of Venetoulis and Talberth (2007). The result (722.22 g/m^2/year) represents the impact of cities occupying productive area (cropland). If cities occupy areas different to cropland, this information would have that to be considered in the calculation of the built NPP.

Table 1. Calculation of Equivalence Factors (EQF) for global ecosystems based on NPP expressed in solar equivalent Joules ($seJ/m^2/year$).

Zones	NPP_{MASS} (i) ($g/m^2/year$)	NPP_{ENERGY} (ii) ($J/m^2/year$)	Tr_{NPP} (iii) (seJ/J)	ENPP (iv) ($seJ/m^2/year$)	EQF (v) (gha/ha)
Cropland	944.44	14232400	3253.54	4.6306E+10	1.9661
Pasture land	1111.11	16744000	1995.06	3.3405E+10	1.4183
Forest	1472.22	22185800	855.41	1.8978E+10	0.8058
Low productivity	135.56	2042768	9960.00	2.0346E+10	0.8639
Wetland	2622.22	39515840	150.57	5.9501E+09	0.2526
Continental and glacial water	222.22	3348800	9960.00	3.3354E+10	1.4162
Built land (vi)	722.22	10883600	3253.54	3.5410E+10	1.5035
Terrestrial Total:	868.89			2.3552E+10 (vii)	
Fishing	246.67	3717168	9000	3.3455E+10	2.0293
Open ocean	102.22	1540448	9000	1.3864E+10	0.8410
Marine Total:	126.67			1.6486E+10 (vii)	

(i) NPP data of terrestrial ecosystems was obtained from Amthor et al. (1998) and in the case of marine ecosystems from Thom et al. (2001). It was assumed that the biomass has 45% of C;
(ii) NPP_{ENERGY} ($J/m^2/year$) = NPP_{MASS} ($g/m^2/year$) * 3.6(Kcal/g) * 4186(J/kcal);
(iii) NPP transformity (Tr-NPP) for terrestrial biomes was calculated with the equation: $Ln(Tr_{NPP}) = 28.703 - 3,0093\ Ln(NPP_{MASS})$ (Siche et al., 2006a). For marine ecosystems, a transformity of 9,000 seJ/J was considered (Odum, 1996);
(iv) $ENPP_{(EMERGY\text{-}NPP)} = NPP_{ENERGY} * Tr_{NPP}$;
(v) Equivalence Factor (EQF) = $ENPP_{BIOMA}$ ($seJ/m^2/yr$) / $ENPP_{GLOBAL}$ ($seJ/m^2/yr$);
(vi) $NPP_{MASS\_BUILT\ LAND} = NPP_{MASS\_CROPLAND} - NPP_{MASS\_HUMAN\ AREA}$. Where: $NPP_{MASS\_HUMAN\ AREA}$ = 100/0.45 = 222.22 $g/m^2/year$ (Amthor et al., 1998);
(vii) NPP total emergy of terrestrial ecosystems (3.03E+22 seJ/yr) on the terrestrial total area (1.29E+12 m^2), and NPP total emergy of marine ecosystems (1.07E+22 seJ/yr) on the terrestrial total area (6.52E+11 m^2).

2.2. Yield Factors (YF) and Global Average Productivity (GAP) for Peru, 2004

Table 2 shows the data used in BC and FP calculation for the EF-ENPP method.

Table 2. Equivalence and Yield Factors and Global Productivity used in EF-ENPP, 2004.

Biome	Equivalence factor gha/ha	Yield Factor (i)	Productivity (i) (global average values)	
Cropland	1.9661	1.6090	4.7525	t/ha
Pasture land	1.4183	0.2444	0.5172	t/ha
Forest	0.8058	0.3825	5.6887	m^3/ha
Low productivity	0.8639	0.2444 (ii)	-	
Wetland	0.2526	1.0000 (iii)		
Continental and glacial water	1.4162	1.0000 (iii)	0.00018 (vi)	t C/m^3 water
Built land	1.5035	1.6090 (iv)	1.6090 (v)	
Fishing areas	2.0293	2.7310	0.0541	t/ha
Open ocean	0.8410	2.7310	-	

(i) Yield factor = National productivity of an area / Global productivity of same productive area;
(ii) Considered equal to pasture zone, for possessing minor Yield Factor than terrestrial biomes;
(iii) Due to lack of data for these biomes, we assume that the productivity of continental water, glaciers and wetlands of Peru is the same than that of continental water, glaciers and wetlands of the World;
(iv) Since built land generally are in areas adequate for the food production, the EF considers that they posses the same Equivalence Factor;
(v) Global Average Productivity is considered equal to the Yield Factor;
(vi) Suggested by Jenkin and Stentiford (2005). It corresponds to the sum of collected water (0.1 t C/ml) and treated water (0.08 t C/ml).

2.3. Calculation of the biocapacity

For the calculation of biocapacity of Peru, all biomes were considered because all of them fulfill functions that must be accounted. It was considered: tundra, deserts, zones covered with ice and open ocean (Table 3). The value of built land was obtained from EF-GAEZ report (Hails et al., 2006) for year 2003.

In the EF-ENPP approach, the CO_2 absorption zone include all the areas (terrestrial and oceanic), except built land. In accordance with the models of the Intergovernmental Panel on Climate Change (IPCC, 2004), annually the oceans sequester 2.3 Gt C and continental zones 0.7 Gt C. For each ton of emitted carbon, the EF-ENPP supplies a footprint of 17.97 ha, in other terms: 0.0556 t C/ha versus 0.95 t C/ha of the EF-GAEZ.

This work accounts separately of lakes, stream and glaciers for CO_2 absorption, with the objective to compare with footprint of fresh water consumption. The BC of fresh water was calculated in the following form: $BC_{\text{FRESH WATER}} = \text{Area} \times EQF_{\text{FRESH WATER}} \times YF_{\text{FRESH WATER}}$ + Area for CO_2 absorption

The CO_2 absorption area is the same that of fresh water (2.90E+06 ha). Thus, the first part of this equation corresponds to the function to produce foods and second part to its function to absorb CO_2. All the values are divided by the population of Peru for year 2004 (27.22E+06 inhabitants). Finally, the areas per capita (gha/person) are added and deducted 14.2% of the total. The obtained value represents the available biocapacity (in gha/person) of the evaluated system.

Table 3. Area of the zones considered in the calculation of the biocapacity.

Zone	Area (ha)	Observations	Reference
Cropland	2.72E+06	Area of surface harvested in year 2004	Cilloniz, 2006
Pasture	3.61E+07	Addition of natural pasture, prairies, grasslands, and new areas of pastures product of the deforestation.	Castro, 2001 Produce, 2006
Forest	6.87E+07	Natural and reforested forests	FAO, 2006
Low productivity	1.03E+07	Zones do not considered in previous categories (tundra and desert) and calculated by difference between the total extension of Peru (1.28E+08) and cropland, pasture, forest, continental and glacial water, wetland and built land.	
Wetland	6.45E+06	Zones of swamp and marsh.	Inrena and Minag, 2005
Continental and glacial water	2.90E+06	Surface occupied by lakes and streams (2.73E+06 ha) added of glacier (1.69E+05 ha)	Inrena and Minag, 2005
Built land	1.19E+06	Deduced value	Hails et al., 2006
Fishing	8.72E+06	Surface occupied by continental platform.	
Open ocean	5.64E+07	Difference between the extension of ocean that legally corresponds to Peru (6.51E+07 ha) deducted of continental platform (8.72E+06 ha).	Silva, 2006
C absorption	1.89E+08	Terrestrial area (without including continental water, glacier and built) added to marine.	

The Biocapacity (BC) of each ecosystem "i" is calculated with the following equation: $BC_i = A_i * YF_i * EQF_i$, where: A_i : Area of biome (s) under study, ha; YF_i : Yield Factor of each area, dimensionless (Table 2) ; EQF_i : Equivalence Factor of each area, gha/ha (Table 2).

2.4. Calculation of the footprint

The consumption, in this work, was divided in seven categories: (1) agriculture, (2) grazing, (3) fishing, (4) wood and fuel wood, (5) fossil energy resources, (6) built and (7) fresh water. The consumption of each category, with exception of energy, built and fresh water, was calculated with the following expression: Consumption = production + importation – exportation.

The following relation was used to calculate the EF of each category (EF_i) in gha: EF_i = $(Consumption)_i$ * (EQF_i / GAP_i), where: $Consumption_i$ = The consumption of each category in ton or m3 per year; EQF_i = Equivalence Factor of each category, gha/ha (Table 2); GAP_i = Global Average Productivity of each category, t/ha or m3/ha (Table 2).

The footprint of fossil energy use (EF_f) was calculated of the following form: EF_f = Emissions of C (t C) * Global Area for emissions (gha/t C).

The global area (land and sea) responsible for C emissions was considered as 17.97 gha/t of C (IPCC, 2004). To convert values of CO_2 to C it was used the factor 12/44.

To calculate the footprint of built land was applied same equation that served to calculate its biocapacity.

The footprint of the category fresh water (EF_{FW}) was calculated as follows:

a) The volume of consumed domestic water (DW) was identified as being of 1.68E+09 m^3 for year 2004 (Aquastat database, 2004);
b) The following equation to determine the footprint of fresh water supply (EF_{FW}):
$EF_{FW} = DW * (EMC_S + EMC_T) * (1-CES) * (EQF_{WATER}/CAT)$, where:
EMC = Emissions of C (tons of C per m^3 of domestic water) due to the use of fossil fuel in the collection and distribution (EMC_S) and in the treatment (EMC_T) of domestic water for final consumers. The value used was of 0.1 ton of C for each mega-liter of supplied water (0.0001 t C/m^3) and 0.08 tons of C for each mega-liter of treated water (0.00008 t C/m^3) (Jenkin and Stentiford, 2005);
CES = Percentage of CO_2 emissions sequestered by ocean (77%) (IPCC, 2004);
CAT = CO_2 absorption in terrestrial systems (0.049 tons of C per hectare).

3. Results and Discussion

The zone for CO_2 absorption shows to be the biggest bio-productive area of Peru in the EF-ENPP approach with a value of 6.9 gha/person (Table 4). This value is 5 times bigger that 1.3 gha/person (Siche, 2007) for zones for CO_2 absorption calculated with EF-GAEZ. In the EF-GAEZ, forests area is used to calculate the biocapacity for CO_2 absorption (Monfreda et al., 2004). In EF-ENPP for CO_2 absorption it is considered all the country areas able to do photosynthesis (forest, ocean, desert, continental waters, etc.).

The open ocean constitutes the second component in importance for the biocapacity of Peru (4.7 gha/person, Table 4). This area and others of low productivity (tundra, glacial waters and wetlands) aren't considered in the EF-GAEZ method, but they are taken into account by the EF-NPP method of Venetoulis and Talberth (2007) and supply a more a better value for biocapacity, but not complete. Considering all ecosystem services in the BC calculation will result in better value of load capacity of the country under evaluation.

The fishing and forest zones appear with 1.7 and 0.7 gha/person, respectively. Continental and glacial waters appear as another important contribution to the BC of Peru (0.5 gha/person). It is necessary to note that it is very important to include the biocapacity of fresh water zones, a key element in the sustainability of a country (WWAP, 2006).

These results contradict the reported values for Loh and Wackernagel (2004) and Hails et al. (2006); according with them, forest, pasture and fishing zones possess greater biocapacity. According with Hails et al. (2006) the forest zones possess 64% of Peru's biocapacity, followed by pasture (14%) and fishing (10%), due to double function that forest and fishing zones possess (supplying raw material and absorbing CO_2).

In this work, the biocapacity of these areas was separated in accordance with function. Thus, the forest and fishing zones of Table 4 are accounted as raw material supply zone. All areas are accounted as CO_2 absorption zone, (including forest and ocean). We believe that this consideration is important to differentiate and to account the ecosystem services that each one of these areas supplies to the country.

Table 4. Biocapacity of Peru (2004) using EF-ENPP approach.

Biome	Area (ha)	Total Biocapacity (gha/person)	Biocapacity for others species (-14.2%)	Net Biocapacity (gha/person)
Cropland	2,728,481	0.3171	0.0450	0.2721
Pasture	36,180,000	0.4608	0.0654	0.3953
Forest	68,742,000	0.7784	0.1105	0.6678
Low productivity zones	10,311,803	0.0800	0.0114	0.0686
Wetland	6,458,500	0.0599	0.0085	0.0514
Continental and glacier water	2,904,274	0.5194	0.0737	0.4456
Built land	1,196,542	0.1063	0.0151	0.0912
Fishes zones	8,720,000	1.7754	0.2521	1.5233
Open ocean	56,430,000	4.7613	0.6761	4.0852
CO_2 absorption zones	189,570,784	6.9646		6.9646
Biocapacity		15.8232	1.2579	14.5652

Built land, low productivity zones and wetland zones possess minor biocapacity: 0.1, 0.08 and 0.05 gha/person, respectively. Although the wetlands posses a small amount of biocapacity (0.05 gha/person) are important due to hosting of a considerable biodiversity and endemism and that it would have to be considered in the EF analyses.

From a total available biocapacity of the Peruvian system (15.8 gha/person), 14.2% (INRENA, 2006) is reserved for the necessities of other species (1.2 gha/person). This value was deducted from total resulting in a net biocapacity of 14.6 gha/person for human use.

The report of Hails et al. (2006) obtained with 2003 data, reveals, for Peru, a biocapacity of 3.8 gha/person. The report of Venetoulis and Talberth (2007) presents a biocapacity of 30.11 gha/person. In the first case, we believe that authors underestimate BC, because they didn't include ocean, desert, zones covered of ice, lakes and streams, etc. In the second case, these important areas are considered, but the conceptual differences in the calculation of equivalence factors (EQF) produce distortion of results in comparison with the present work. Venetoulis and Talberth (2007) used as base in their calculations the NPP in mass units ($g/m^2/year$), while this work use NPP in units of embodied energy or solar emergy ($seJ/m^{2/}year$).

Currently, energy resources are the key factor in the discussion on social-economic well-being. Fossil fuel energy allows mobility and development, but they contribute with a enormous pressure on environment: climate change, resources exhaustion and adverse effects for the human health.

Instead of using available energy, embodied energy (or emergy) offers a better measure of energy involved in resources production. Emergy considers all the available energy (exergy) used in the processes of production of resources. Incorporating the emergy concept in the NPP, we include all the energies that made possible the formation of biomass in ecosystems. Therefore, the new EQF's depends on energy quality and not only in mass. The energy quality is measured by transformity, defined as the emergy used in the production of certain energy (Jorgensen et al., 2004).

Table 5 shows footprint of Peru calculation using categories with EF-ENPP method. The CO_2 emission shows the biggest footprint (4.9 gha/person), almost 75% of total FP. This percentage makes evident a dramatic situation of Peru concerning the use of energy that liberates CO_2. This high value results from carbon sequestering rate assumptions. The Intergovernmental Panel on Climate Change (IPCC, 2004) considers that oceans sequester 2.3 Gt C and continental zones 0.7 Gt C annually. This means that for each ton of emitted carbon the EF-ENPP shows a footprint of 17.97 ha (17.97 ha/t C) or 0.0556 t C/ha, differently of the 0.95 t C/ha of the EF-GAEZ method.

Table 5. The footprint of Peru in EF-ENPP approach, 2004.

Category	Amount	Unit	Footprint (gha/person)
Agricultural products	18,244,700	ton	0.2773
Grazing products	2,300,000	ton	0.2317
Forest			0.0882
Wood, paper, etc.	9,653,916	m^3	0.0502
Fuel wood	7,300,000	m^3	0.0380
Fish products	582,492	ton	0.8027
Built	1,196,542	ha	0.1063
Fresh water	3,360,000,000	m^3	0.1477
CO2 emissions	7,450,480	ton	4.9194
Footprint			6.5734

The fishing consumption footprint is the category most important (0.80 gha/person or 12.2% of the total footprint) after the CO_2 emissions. With lesser values appear the categories: agriculture (0.28 gha/person or 4.2% of the total footprint), grazing (0.23 gha/person or 3.5% of the total footprint) and fresh water (0.15 gha/person or 2.3% of the total footprint).

Venetoulis and Talberth (2007) calculated CO_2, fish, agriculture and grazing footprints as being 52.5% (3.71 gha/person), 21.0% (1.48 gha/person), 6.1% (0.43 gha/person) and 17.0% (1.20 gha/person) of total footprint of Peru with 2001 data.

As noted, a new category was included in the approach presented here: fresh water. Up to now, the supply of water for human consumption is not identified nor measured in the national accounting of footprint. In this study, the water footprint was calculated measuring the energy used to supply, collect and treat the water, as well as the treatment of waste-water as suggested by Jenkin and Stentiford (2005). The footprint of consumed water for the Peru´s population was 0.15 gha/person, a value 15 times bigger that the value found by Jenkin and Stentiford (2005) for England Southeast with 2001 data (0.01 gha/person). These results suggest two interpretations: the use of domestic water in England (Southeastern) has minor impact on the environment that the use of domestic water in Peru; or, footprint calculated by Jenkin and Stentiford (2005) is underestimated. According to our interpretation, the footprint for the England Southeast is underestimated.

The EF-ENPP approach accounts for the work of nature in recycling resources, beyond collecting and water treatment. The area of capture of water must be included in the water footprint, but the inclusion of this area would result in a double counting the existing areas (arable, energy, pasture, forest and sea), since all these lands have the function of water collecting (Chambers et al., 2000). Calculation of the fresh water footprint considered here is questionable due the possibility of double counting[1], but it is important to consider this category in future evaluations of sustainability (WWAP, 2006).

The consumption of forest resources has the lesser footprint (0.09 gha/person or 1.3% of the total footprint). The two methodologies (EF-GAEZ and EF-NPP) indicate low footprints for Peru in the case of forests (0.04 gha/person in EF-GAEZ for 2003). This not necessarily means that Peru is taking advantage of sustainability of forest resources. It will be necessary to analyze BC and EF for this category (or ecological balance, Figure 1).

[1] To account the used energy in the collection, treatment and supply of water for domestic use, could be already computed in the CO_2 emission accounting supplied by FAO.

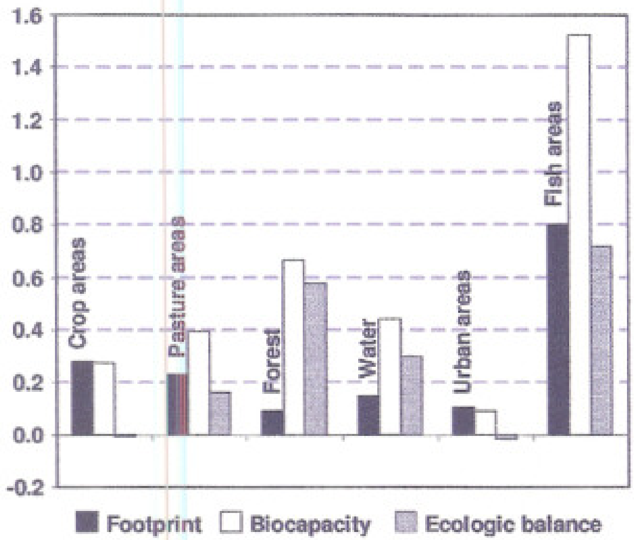

Figure 1. Peru Ecological balance for categories using EF-ENPP, in gha/person.

In the analysis made for categories (Figure 1) it is possible to observe that almost all of them possess a favorable balance, with exception of built zones (- 0.02 gha/person) and cropland (- 0.005 gha/person). This indicates that although Peru still has a favorable ecological balance, its cities (or built zones) are unsustainable and agriculture is exceeding its limits.

The EF-GAEZ approach calculates equal values of biocapacity and footprint for built zones (Loh, 2002; Loh and Wackernagel, 2004; Hails et al., 2006). In the EF-ENPP, as well as proposed for EF-NPP of Venetoulis and Talberth (2007), the ecological balance of built zones gives negative values due to 14.2% (13.4% in the EF-NPP) deducted for the preservation from the biodiversity of the cities. The cities appropriate of the area where they are seated and, also, of the areas that would serve to preserve biodiversity.

The biggest ecological balance is represented by the open ocean (4.1 gha/person) due its great extension and inexistence of footprint. The available biocapacity of open ocean for human use is 4.1 gha/person, but this data can be overestimated, since part of Peruvian fishing is located outside the continental platform, 50 and 600 marine miles away (Mamani, 2005), but in this approach only continental platform was considered.

The fish category in our calculations presents an ecological balance (0.7 gha/person) bigger of what the balance calculated with EF-GAEZ (0.27 gha/person; Loh and Wackernagel, 2004; Hails et al., 2006).

There are several studies on sustainability of Peru and worldwide fishing (Pascó-Font, 1999; Talbert et al., 2006; OCEANA, 2006; Worm et al., 2006). For year 2003, Talberth et al. (2006) calculated for fishing of Peru a BC of 48.1 gha/person and a footprint 6.5 times bigger (311.1 gha/person), that represents a negative ecological balance of 263 gha/person. Talberth et al. (2006) calculations are based on the fishing production, differently of the calculations of the present work and EF-GAEZ, where the footprint is calculated in function of consumption. Thus, being consumption our calculation basis and, as in Peru almost 95% of the fishing extraction is exported (INEI, 2006), it is possible to say that approximately 95% of the Peru fishing footprint is exported to other countries.

Of fishing analysis we can conclude that a sector (region or country) could be sustainable if we use the consumption to calculate the footprint, and unsustainable if we use the production. We believe that to calculate a footprint in function of production (without considering importation and exportations) would be a better form to obtain the true impact of the economy on its environment.

It exists an ecological surplus in favor of Peru of 8.0 gha/person, a value lower than the balance found by EF-NPP (23.1 gha/person) (Venetoulis and Talberth, 2007), but superior to that found using traditional calculations of the footprint: 3.4 gha/person for 2001 (Loh and Wackernagel, 2004) and 3.0 gha/person for 2003 (Hails et al., 2006). Apparently, situation of the country shows to be better with EF-ENPP approach, but this not necessarily the truth.

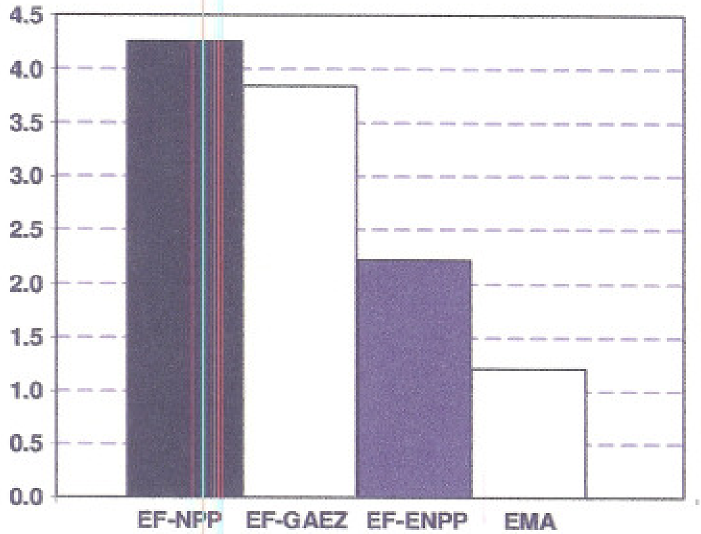

Figure 2. Comparison of BC/EF relation for the analyzed methods.

One better analysis could be obtained dividing the values of Biocapacity and footprint (BC/EF) to get an index that we call Load Capacity Factor (LCF).

BC/EF (Load Capacity Factor) means: "how many times a territory could support the size of its human population, with its current life style, without degrading its physical and ecological environment".

It the BC/EF value is bigger than 1 means that the system is sustainable; a value lower than 1 means that the system is unsustainable. BC/EF equal to 1 indicates that the system is on the critical limit.

Analyzing BC/EF relation for each approach studied (Figure 2), we have better result for methodology EF-NPP (BC/EF = 4.26), meaning that: "in 2004 year, the Peruvian territory possessed capacity to support 4.26 times its population, without degrading its physical and ecological environment, considering the lifestyle of that year".

In a previous EMA applied to Peru (Siche, 2007), Biocapacity was accounted as the available renewable resources (seJ) and the Footprint as emergy used in the system, (seJ), and a worse performance was obtained (BC/EF = 1.21) showing that Peru was next to the sustainability limit.

Ferguson (2003) made a calculation of the "load capacity" of 147 countries, including Peru, using as base the data the report Living Planet Report 2002 (Loh, 2002). He concluded that Peru, with its current lifestyle, is able to support 4.35 times its population, a value next value to that found in EF-GAEZ approach.

The EF-ENPP approach (BC/EF = 2.22) appears as an intermediate value between EF-GAEZ and EMA approaches, perhaps as product of the convergence of these two approaches.

4. Conclusions

In the case of the country analyzed as study case (Peru) the EF-ENPP method proposed in this work indicates a worse situation in the ecologic balance than that obtained with EF-GAEZ. We believe that the EF-ENPP is a more robust tool when confronted to EF-GAEZ, so the Peru's environmental performance is worst than the some published data.

The EF-ENPP approach could be a good alternative in future calculations of ecological footprint because it uses data and other tools easily available, lacking only improvement in the calculation of transformities of NPP´s for aquatic systems. The main quality of this approach is that it accounts for nature work in the NPP flows that serve as basis to calculate the equivalence factors.

Taking in consideration the proposed approach, with 2004 data, Peru has a capacity to support 2.22 times its population without degrading its physical and ecological environment, considering current lifestyle.

Finally, we believe that the method considered here can solve some deficiencies of the Ecological Footprint, but it is still necessary to account another flows so that it can interpret more exactly the anthropic impact on the nature: to consider the negative externalities and the environmental services.

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