

TRUE ECOLOGICAL FOOTPRINT FOR SMALL FARMS IN BRAZIL

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Abstract (reference number: 0001 – 51)

Ecosystems support capacity is a necessary parameter to adjust our life style to Earth's biophysical limits. Ecological Footprint (EF) assessment allows us to calculate the area needed to supply goods and ecological services for direct and indirect human consumption, as well as the land needed to produce food and absorb urban and industrial wastes (liquid effluents, gas emissions and solid residues). Our hypothesis is that the EF concept can be applied to farms. In Brazil, only a small number of rural units use ecological methods; farms usually produce food using industrial chemicals. Therefore, farms are dependent on petroleum in the form of fuel and petrochemicals. Farms show large values of negative externalities as well. Nowadays, Ecological Footprint considers the land area for fossil fuel gas emissions but ignores the land area for: dilution of industrial wastes (acids, heavy metals), gas emissions, effluents and solid wastes resulting from the production of fertilizers and pesticides, land use to regenerate soil fertility, solve migration problems, and produce water for human use. The objective of this work is to discuss the insertion of these additional land demands in the calculation of the ecological footprint, mainly for farming. As study cases, small farms that use chemical and ecological techniques were analyzed and compared. We used an equivalence factor based on Net Primary Productivity (NPP) values of each rural ecosystem. We explain how to calculate the ecological balance for the cases under study, considering both the traditional EF method and an enhanced EF method. The results obtained with this new approach show an increase in Footprint and in Biocapacity. We observed a significant increase in the Biocapacity value in ecological farms. The Biocapacity/Footprint value for ecological farms (3.9) was twice larger than that for chemical farms (1.7). Therefore ecological systems could support more people.

Keywords: Sustainability, Ecological Footprint; Environmental Indicators; Agriculture, Energy.

1. Introduction

It took a long time before we recognized that human economy without fossil fuel will depend on Earth's natural capital (now under destruction), which provides vital ecological services and renewable resources. The implication of this ecological maxim is obvious: in order to be sustainable, humanity must live within nature's carrying capacity (Wackernagel *et al.*, 1999). Sustainability has now become a universal policy goal.

Sustainability depends on the preservation of environmental resources, self-regulation of consumption and the change of production models to decrease negative externalities and increase environmental services. Both at local and global levels, the main challenge is to change our life style in order to adjust social patterns to

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sustainable models of production and consumption, especially in urban areas of rich countries, where pressure on the environment is greater (Siche *et al.* "a", in press).

In order to reach those objectives it is necessary to have scientific tools to evaluate scenarios and projects, which will provide indicators for decision making processes. In several assessment methods, sustainability measurements have undergone an evolution going from qualitative to quantitative analysis to synthesis. In the last two decades there has been intensive progress in the use of two appraisal tools: Ecological Footprint (Wackernagel & Rees, 1996) and Emergy Accounting (Odum, 1996). They use different approaches but both aim to solve the same problem through accounting resources and throughput, estimating the gap between demand by humanity and natural services, evaluating resource utilization by humans.

Because footprint embodies a vast amount of information in a single quantitative measure using the concepts of carrying capacity and sustainability, its popularity is burgeoning in academic, government, non-profit, education, and business circles (Costanza, 2000; Siche *et al.* "b", in press).

The ecological footprint of any defined population (from a single individual to a whole city or country) is the area of biotically productive land appropriated to produce goods and services consumed by humans and also to assimilate the wastes generated by the population (Wackernagel & Rees, 1996).

Comparing the footprint of a given population in a discrete area with the amount of biologically productive space available to that population provides a way to estimate whether or not a population's consumption is sustainable. When a population's footprint is smaller than the available biocapacity, then it is sustainable. When the footprint is larger, that population is said to be engaging in unsustainable ecological overshoot or running a negative ecological balance (Venetoulis & Talberth, 2005).

Anyhow, footprint analysis still has a number of serious shortcomings, e.g. not including important issues such as water supply, toxic substances impact, space reserved for consumption by other species, contribution of biomes that occupy 2/3 of the Earth, and accounting carbon absorption only as forest area while the carbon cycle includes the entire planet. Criticisms of ecological footprint assessment assumptions, methods, and data have been presented in literature (Levett, 1998; van den Bergh & Verbruggen, 1999; Ayres, 2000; Moffatt, 2000; Opschoor, 2000; Rapport, 2000; van Kooten & Bulte, 2000; Pearce, 2000; Venetoulis & Talberth, 2005; Wiedmann & Lenzen, 2007; Lenzen *et al.*, 2007).

For footprint calculation of small farms in Brazil we will consider that conventional farms emit combustion gases from the use of diesel in tractors and are responsible for negative externalities linked to the production of fertilizers and pesticides such as dilution of industrial effluents (acids, heavy metals), CO₂ emission and solid waste problems, regeneration of native vegetation in phosphate surface mines, several social problems, reduction of water flow for human use, etc. On the other hand, ecological farms produce positive externalities including soil preservation, water infiltration and percolation, local biodiversity interaction in biomass production, fauna and flora protection in forested areas, etc. These benefits are called environmental services and must be accounted for in the biocapacity calculation.

The objective of this work is to discuss the insertion of those additional land demands in the calculation of the ecological footprint and biocapacity for agricultural production.

2. Negative externalities and environmental services produced by farms

Ecological Footprint is a scientific tool that supplies sustainability indicators for the planet, for a country or for an individual, whose use has spread worldwide. Therefore, it is very important that this tool can analyze systems with different characteristics (size,

region, country, watershed, agricultural handling) because the accounting of a certain resource can be important for a system while it could be ignored for another one.

In the sustainability evaluation of farms, negative externalities should be considered in the Ecological Footprint to obtain more precise results and also to educate people to observe the true impact of farming on environment. Important works in this regard were published by Pretty *et al.* (2000; 2005). The authors used ecological economy tools to estimate the monetary value of negative externalities produced by agriculture in the UK (360 USD/ha/year). In the same way, Ortega *et al.* (2005) made an appraisal of negative externalities produced by conventional soybean farming in Brazil and obtained 345 USD/ha/year, including soil erosion; nutrient loss due to erosion; carbon dioxide, methane and nitrous oxide emissions; effluent treatment; intoxication, disablement and deaths by pesticide use; rural exodus.

A key work on positive externalities was published by Costanza *et al.* (1997; 1998). The authors showed that environmental services (climate regulation, water regulation, erosion control, sediment retention, genetic resources maintenance, pollination, soil formation, etc.) are extremely valuable for humanity. We currently ignore those services because we assume they are for free and unlimited. The authors used contingent analysis to estimate the value of environmental services for the entire planet, obtaining a total value of USD 33 trillion per year (577 USD/ha/year for the marine biome; 804 USD/ha/year for the terrestrial biome). The values mentioned make it evident that the inclusion of negative externalities and environmental services in the Ecological Footprint assessment is commendatory. Negative externalities currently exceed ecosystem services. For this reason Wackernagel *et al.* (2005) believe that pressure on environment is underestimated.

In the following paragraphs, we describe the negative externalities produced by conventional (chemical) farms as well as the ecosystem services produced by ecological farms. Some of those were accounted for in Ortega *et al.* (2005).

Dilution of industrial wastes (acids, heavy metals and gas emissions)

Conventional farms buy chemical inputs made from petroleum by chemical and pharmaceutical industries. The amount paid corresponds to the expenses with materials and services to produce and commercialize the chemicals. But in many cases the industries do not take on the expenses related to the treatment of residues; a great deal of the biological stabilization is made by the ecosystems. Furthermore, petroleum price is below its real value due to political and military international pressures. We can say that cheap oil sustains industrial civilization throughout the globe, but probably not for many decades ahead.

Recycling of plastic packages (with toxic substances)

Moreover, industries and farms must be particularly careful regarding empty packages after pesticide use. This does not occur in many cases due to the absence of gathering and information about health hazard. Thus, the society and the environment are harmed, since they have to cope with the negative externality produced by industry and chemical farming (a case of social responsibility).

Soil fertility regeneration

As a consequence of intensive mechanization and the use of acid substances and biocides on top soil, a decrease of soil fertility is observed. This loss of biological productivity is alleviated, temporarily, by intensifying the use of chemical fertilizers and lime, but when degradation is too high, the cost of inputs does not compensate

farming. Thus, the farmer sells the land to buy a new one and repeats the harmful handling. This practice is known as “walking agriculture” and has transformed large areas into unproductive soils. After many years, those areas have not fully recovered (Romeiro, 2004).

Soil erosion

Soil loss in farms is a key point when sustainability is concerned. Inadequate soil handling causes desegregation of soil particles that contain organic substances, minerals and chemicals. Those particles and their solutes migrate to water courses (subsoil streams, rivers, lakes, etc.), known as runoff. The soil loses its fertility according to soil characteristics and time of aggression, making it necessary to use more fertilizers and lime. Thus, the system becomes dependent on economy resources and highly unsustainable. Minerals lost from run-off harm the quality of water resources, causing eutrophication (mainly due to phosphorus) and, in some cases, kill the aquatic life by poisoning. Moreover, the great amount of sediments deposited in water channels cause a decrease in the height of the water column. Biological treatment of water then becomes necessary before supplying to the population, since the organic matter reduces the concentration of dissolved oxygen, increases the growth of algae and anaerobic microorganisms and causes the death of aquatic life (Santos *et al.*, 2000).

Carbon dioxide, methane and nitrous oxide emission

The main atmospheric pollutants generated by farms are CH₄, N₂O, and CO₂. Methane (CH₄) is produced by the enteric fermentation of cattle, animal manure, flooded rice plantations and the burning of agricultural residues. This gas has a greenhouse-effect potential 23 times bigger than CO₂. Nitrous oxide (N₂O) is originated from nitrogen fertilizers. It contributes for the destruction of the ozone layer and has a potential 296 times bigger than that of CO₂ when greenhouse effect is concerned. Carbon dioxide (CO₂) receives the main focus in relation to global climatic changes. In Brazil, the biggest portion of CO₂ emission is due to land use change, when forests are burnt in order to be converted in pasture (Watanabe, 2006). The practice of sugar-cane burning before harvest is also a common practice in São Paulo state that generates CO₂, but nowadays it is being modified through legislation and the diffusion of new technologies (mechanical harvest).

Social problems

Modern agriculture is responsible for massive loss of work places in rural areas. According to the Brazilian Institute of Geography and Statistics (IBGE, 2007), from 1994 to 2003, the agricultural sector showed a reduction in the number of workers from 18.2 million to 16.4 million in a context where the agriculture area increased from 52.1 million to 56.7 million ha. For soybean production, Ortega (2007a) estimates that the herbicide model can generate only 190,000 work places, while the organic model could create 480,000 jobs and the ecological model 685,000; which means that the number of jobs depends on the production model. In Brazil, big farmers advance over small farmers, buying their lands to establish monoculture plantations and export commodities. Land concentration and poverty are a direct consequence of this agricultural model devoted to the sole objective of exporting. Brazil is the country with the strongest land concentration: 0.9% of land owners possess 35.8% of the agricultural lands (118.4 million ha). It follows that wealth is concentrated in few hands, while many people are impoverished. In 1990, the 20% richest possessed 65% of

circulating money (IBGE, 2007). Land concentration produces migration to urban areas, increasing slums (Ehlers, 1996). As a result, social problems increase: urban violence, illnesses due to the lack of basic sanitary conditions, drug traffic as a substitute for legal jobs, etc. Thus, conventional chemical farming has a direct influence on social problems.

Water production for human use

The external energy of the biosphere through its interaction with biomes supplies water for the hydrologic cycle. After reaching the soil and its vegetation cover, rain water can follow four different ways: evaporation, plant transpiration, infiltration into the ground, and run-off. When the precipitated water finds areas without plant protection for mulching, agricultural production or natural vegetation, it initially transfers its energy to the ground, breaking the soil aggregates and enhancing erosion, and it runs off instead of percolating into the ground. The run-off water drains superficially and carries on organic matter, valuable minerals and agrochemicals. This action could be reduced if soil handling adopted ecological concepts, such as crop association and rotation, plantation in level curve and use of mulch. Those practices induce water infiltration and improvement of water quantity in reservoirs to be used by the population. Thus, farming methods influence the amount and quality of water supply (Manzatto & Hernani, 2002).

Biodiversity loss

Bigger farms adopt the chemical agriculture monoculture model and produce only products of economic importance: sugar-cane, coffee, orange, soybean, pasture cattle. This results in an enormous biodiversity loss: animals, plants, insects, etc. This loss causes an ecological imbalance, which can be initially local, but in short time periods becomes regional and global. The farm owner usually solves the problem of biological imbalance (“plagues”) in agricultural production through the intensive use of toxic chemicals, but by proceeding in that form other problems reach the society: animals and insects are displaced to urban areas. Thus, one more time the society has to pay for the damage through public cleaning and health care systems. Other problems exist, e.g. native plants and animals are endangered and genetic potential is lost.

3. Case studies

In this work two models of agricultural production were studied and compared: (a) the conventional model and (b) the agroecological model. For this study we selected three small agricultural properties located in Amparo County, São Paulo State, Brazil (Figure 1): Duas Cachoeiras farm (29.7ha), Santa Helena farm (15.5ha) and Três Lagos farm (25.2ha). The first one uses agroecological concepts, while the two others produce in a conventional way. The three farms have the same climate (solar radiation, wind speed and direction, amount of rain, relative humidity), the same soil characteristics, the same land relief, approximately the same area, and are all family managed. The main difference between the farms is the production model adopted (conventional or agroecological).

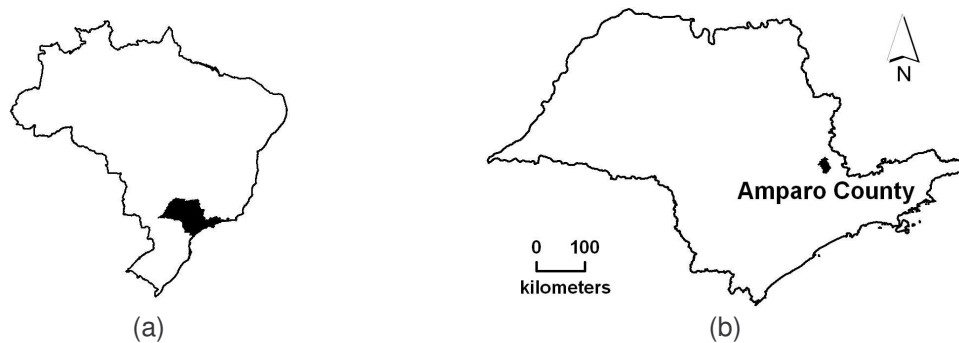


Fig. 1. Study area. (a) São Paulo state in Brazil; (b) Amparo County in São Paulo state.

Figure 2 shows the energy flows that in and out, internal flows and feedback flows in the system that use ecologic concepts in its agricultural production. Behind areas occupied with crop production, the system possesses large areas for preserved native forest, because these systems need the environmental services produced by them. The primary products are, many times, transformed inside of the farm through local labor. The negative externalities produced by these systems are low, while the environmental services are largest. These key points make positive the trade balance to the ecologic system in a true trade, where the energy embodied are accounted.

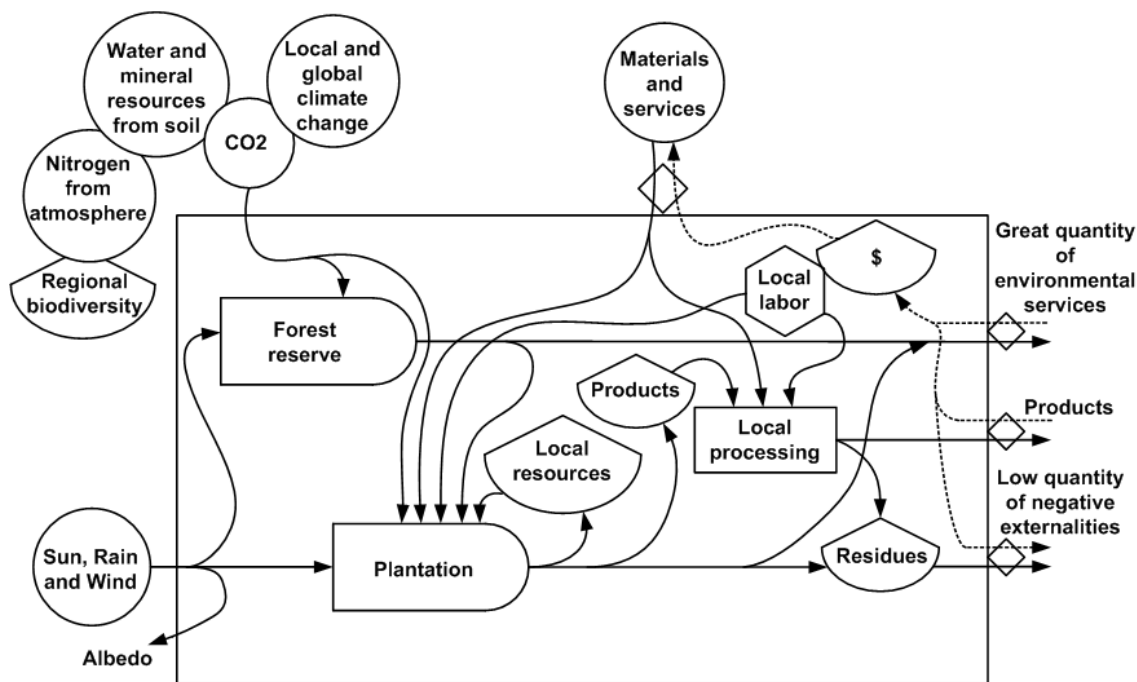


Figure 2. Diagram representing the ecological model of agricultural production (adapted from Ortega, 2007c).

The characteristics of the conventional model of agricultural production (Figure 3) are very different when confronted to agroecological model: small or inexistent areas of preserved forest and large areas for crop production, resulting a low environmental services; do not use local labor and aggravates the social problems; do not process the primary product inside the system; use large quantity of materials and services from economy; produce large quantity of negative externalities. Accounting these flows, the system has a negative trade balance in a true trade.

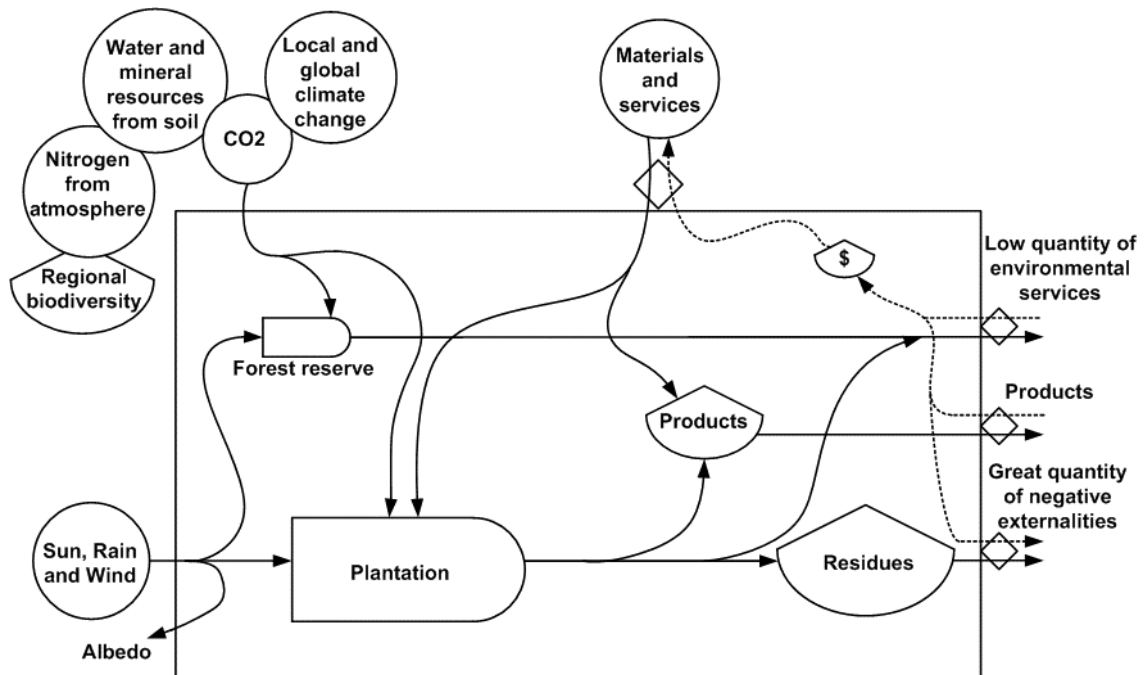


Figure 3. Diagram representing the conventional model of agrochemical production.

Ecological Footprint assessment was used to make the diagnosis of the studied farms. This methodology is explained in detail in Loh (2002), Monfreda *et al.* (2004), Loh & Wackernagel (2004), Wackernagel *et al.* (2005), Hails *et al.* (2006), Venetoulis & Talberth (2005) and those papers were taken as a basis for the present work. Although the methodology is mostly used for countries, this kind of study can be applied at other scales (small and big farms, watersheds, etc.), provided that some care is taken, especially because the quality of available data varies too much.

In this paper some changes in the methodology were made:

- (a) The Equivalence Factor (EQF) was calculated through the Net Primary Productivity (NPP) data of each biome, as suggested by Venetoulis & Talberth (2005). The EQF for each farm's land use was calculated through the division of its NPP by the system's NPP. The system's NPP was obtained by adding the NPP of each land use multiplied by its respective area and then dividing by the system's total area. The NPP values considered for each land use were obtained from several research works (Aber & Melillo, 2001; Barbosa & Ferreira, 2004; Santos *et al.*, 2004; Winrock, 1997);
- (b) For the accounting of negative externalities (in ecological footprint) and ecosystem services (in biocapacity) the Emergy Methodology (Odum, 1996) was used, as suggested by Zhao *et al.* (2005). The monetary values of negative externalities (Ortega *et al.*, 2005) and world ecosystem services (Costanza *et al.*, 1997) were converted to solar energy Joules (seJ/year for the ecological footprint and seJ/ha/year for the biocapacity) using the Brazilian em-dollar ($3.30E+12$ seJ/USD; Ortega, 2007b). After that, the values were divided by the Brazilian emergy density ($3.26E+15$ seJ/ha/year; Ortega, 2007b) to get an indicator in national hectares (nha). National hectares were used instead of global hectares (gha), since the database used was national,

not global. Moreover, the analyzed systems have small areas, thus we believe that this approach is more convenient;

- (c) The construction areas of the studied systems are represented by family houses, farm sheds and terraces for coffee drying, they don't have biocapacity;
- (d) In the lake areas, production was considered negligible and the Yield Factor (YF) was considered unitary. One of the farms uses the lake's water to irrigate the crop area and this was taken into account in the ecological footprint. The lake NPP is small ($450 \text{ g/m}^2/\text{year}$; Aber & Melillo, 2001) so its EQF is small too;
- (e) With the exception of farm buildings, farm areas were added to calculate the area for atmospheric CO_2 absorption. This area (ha) was considered to be the same for biocapacity (nha), as suggested by Venetoulis & Talberth (2005). The value of 49 kgC/ha/year (IPCC, 2004) for absorption by vegetation cover was used to calculate the ecological footprint for CO_2 emissions;
- (f) The areas occupied with forest, pasture, meadows, lake and annual crops were accounted for as areas that produce ecosystem services. The monetary values of these services were extracted from the work of Costanza *et al.* (1997) and converted in national hectares through Emergy Analysis (Odum, 1996), as explained in item "b". Food production and CO_2 absorption were already considered in Costanza *et al.*'s (1997) work as ecosystem services. Thus, those services were subtracted from the total to avoid double account;
- (g) Emergy methodology (Odum, 1996) was used to measure the contribution of fertilizers, pesticides and vaccines in the footprint calculation for conventional farms. Annual consume was multiplied by transformity ($4.78\text{E}+13 \text{ seJ/kg}$ for fertilizers, Brandt-Williams, 2002; $2.49\text{E}+13 \text{ seJ/kg}$ for pesticides, Brown & Arding, 1991; $3.30\text{E}+12 \text{ seJ/USD}$ for vaccine, Ortega, 2007b) and, after that, divided by Brazilian emergy density ($3.26\text{E}+15 \text{ seJ/ha/year}$; Ortega, 2007b). Embodied energy of these inputs is important because they produce large environmental impact, that varies according farm size and technology used.

4. Results and discussion

Table 1. Footprint, biocapacity and ecologic balance calculated in a traditional and enhanced way for the studied systems*.

| Results in nha (national hectares) | Duas Cachoeiras farm | Santa Helena farm | Três Lagos farm |
|---------------------------------------|-------------------------|----------------------|--------------------|
| 1. Traditional method | | | |
| Biocapacity | 56.22 | 27.30 | 42.18 |
| Ecological footprint | 17.38 | 17.99 | 21.50 |
| Ecologic balance | 38.84 | 9.30 | 20.69 |
| 2. Enhanced method | | | |
| Biocapacity | 73.63 | 37.46 | 52.54 |
| Ecological footprint | 18.66 | 25.74 | 28.94 |
| Ecologic balance | 54.97 | 11.72 | 23.61 |

* The raw data can be seen in Appendix B, C, D and E.

Ecological Footprint indicators for each category are shown in Appendix A, after adoption of changes proposed by authors (negative externalities and ecosystem services accounting). The results of Table 1 indicate a positive balance for all systems, either ecological or not, because they are small agriculture family farms and are not included in the Brazilian agribusiness market.

Duas Cachoeiras farm obtained the best ecological balance, footprint and biocapacity when compared to the other two systems. This happens because organic farming causes lower impacts to the environment than conventional farming. When the two footprint methods (traditional and enhanced) were compared, Duas Cachoeiras farm footprint increased by 1.28 nha, because it has a low value for negative externalities and its biocapacity increased in 17.41 nha because it produces a high amount of ecosystem services; thus there is an increase in the ecological balance of 16.13 nha.

For Santa Helena farm the footprint increased by 7.75 nha, its biocapacity increased by 10.16 nha and its ecological balance increased by 2.42 nha. The footprint for Três Lagos farm resulted in an increase of 7.44 nha, its biocapacity increased by 10.36 nha, both resulting in an increase in ecological balance of 2.92 nha.

The best performance in respect to biocapacity in the enhanced method comes from the monetary value of ecosystem services. The work by Costanza and co-workers (1997) received many criticisms in relation to the scientific procedures adopted (Masood & Garwin, 1998; Seidl & Moraes, 2000; Nunes & van den Bergh, 2001), but the publication is of great importance since it makes evident humanity's dependence on natural ecosystem services.

In the current work we considered the following biomes and values of natural services: Tropical Forest (1745 USD/ha/year); Grass/Rangelands (158 USD/ha/year); Lakes/Rivers (8457 USD/ha/year); Cropland (38 USD/ha/year). The data is in hectares, so it is evident that the bigger the area, the greater will be the value of its ecosystem services and biocapacity. To avoid double account for all biomes considered, food production and CO₂ absorption were subtracted from ecosystem services values.

For the negative externalities it is important to observe that Duas Cachoeiras farm needs 1.29 nha (Appendix A) to absorb its damage, since it accounts for 96.60 USD/ha/year of top soil loss and nutrient loss due to erosion. Três Lagos farm needs 5.63 nha, since all the following items were taken into account: CO₂ emission (due to biomass firing practice), methane and nitrous oxide emission, effluent treatment, intoxication, disablement and deaths by pesticide use (total of 246.86 USD/ha/year). Santa Helena farm needs 2.23 nha.

It is important to make this division on negative externalities, because Duas Cachoeiras farm uses agroecology methods and does not cause the same damage as the conventional agricultural system. Pretty *et al.* (2005) shows that for the UK agriculture, the conventional system produces approximately USD 3000 millions per year of negative externalities while organic farming produces USD 744 millions per year.

Table 1 shows that an agro-ecological farm can support 3.9 times its footprint, while conventional systems can support approximately 1.7 times their respective footprint. This important fact is confirmed by BC/F ratio (biocapacity/footprint). The BC/F for Duas Cachoeiras farm increased by approximately 22% between the two methodologies (enhanced and traditional), while Santa Helena and Três Lagos farms had a decrease of 5% and 8% respectively.

Figure 4 shows the footprint and biocapacity of Duas Cachoeiras farm divided in categories. We can observe that the main part of footprint comes from CO₂ emission, pasture and Napier grass. The biocapacity is derived from CO₂ absorption area, ecosystem services and forest area. The excellent ecological balance (55 nha, in Table 1) is a characteristic of systems that adopt ecological concepts in production (no use of

industrial chemicals, crop rotation and association, nutrient recycling). The ecological farm has forested areas where native products can be extracted in a sustainable way, which avoid soil erosion, produce water by infiltration and percolation in shrub and tree areas, preserve local biodiversity, maintain soil moisture and low temperature (local and regional climate), etc. Agroecology should be adopted by systems that produce in a conventional way.

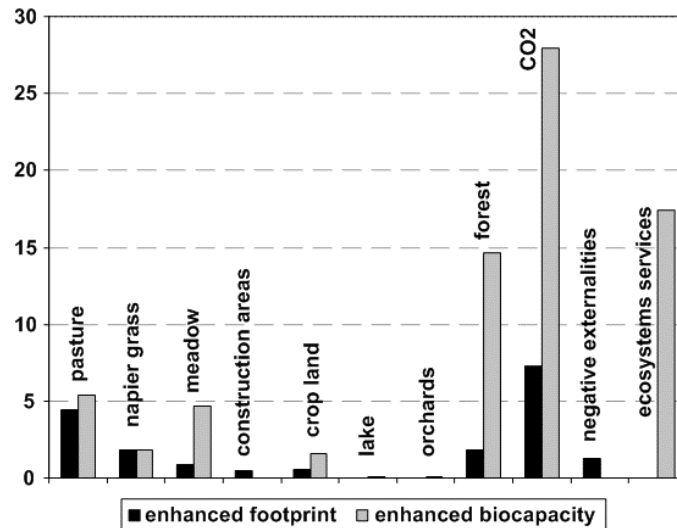


Figure 4. Footprint and biocapacity (in nha) for Duas Cachoeiras farm categories.

For Santa Helena farm (Figure 5) the biggest contribution for footprint are CO₂ emissions, use agrochemical (plague control) and negative externalities. Biocapacity derives mainly from CO₂ absorption areas, ecosystem services and forest areas.

Três Lagos farm (Figure 6) has CO₂ emission, negative externalities and Napier grass areas as its most important factors to footprint. CO₂ absorption areas, ecosystem services and pasture areas are important for this farm's biocapacity.

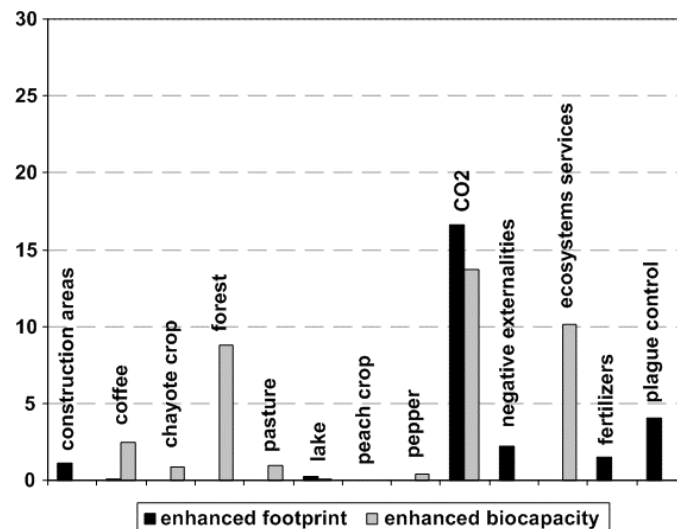


Figure 5. Footprint and biocapacity (in nha) for Santa Helena farm categories.

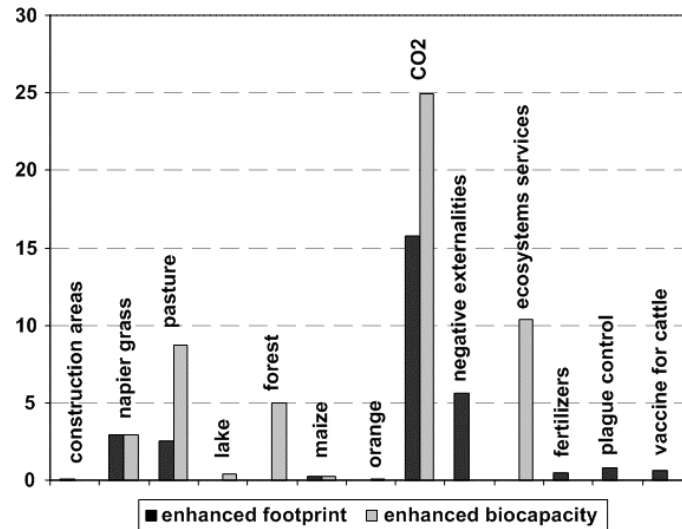


Figure 6. Footprint and biocapacity (in nha) for Três Lagos farm categories.

Conventional agricultural properties, represented here by Santa Helena and Três Lagos farms, have small forest areas, use agrochemicals and do not handle the soil properly. This results in many environmental damages: soil erosion, decrease of water resources' quality, decrease of water infiltration to supply the aquifers and reservoirs, biodiversity loss, environmental imbalance, etc. This characteristic is showed in this paper by the large importance that negative externalities represented in the footprint of conventional systems.

An agro-ecological farm depends on ecological equilibrium to produce. It thus handles the soil in such a way that it can produce ecosystem services. For the farms studied in this work, this category represented 17.41 nha for Duas Cachoeiras farm, 10.17 nha for Santa Helena farm and 10.36 nha for Três Lagos farm.

The best performance was obtained by the ecological farm, but it is important to say that the other two properties show a relatively good performance because they have some preserved areas that produce ecosystem services. A rather different situation from that of farm businesses (big plantations) that do not obey Brazilian environmental laws.

5. Conclusions

The results obtained indicate that Agroecology improves farm sustainability, by reducing ecological footprint and increasing biocapacity.

The ecological model studied (Duas Cachoeiras farm) obtained the best performance on ecological balance (55 nha) when compared to two conventional small farms (12 and 24 nha). It constitutes an example to be followed for those systems that produce in a conventional way.

The systems under study show a better performance when evaluated through Enhanced method of Ecological Footprint. Negative externalities and ecosystem services proved to be important factors in EF calculations. It is thus extremely necessary to carry on further studies on their benefits and costs for more accurate Ecological Footprint calculations.

The categories considered in this paper were chosen due to system characteristics (small farms with great diversity on agricultural production). The Ecological Footprint methodology needs to be flexible in this aspect, where each system evaluated must have its peculiar categories number.

The three systems evaluated in this work are small agricultural family farms and are not included in the Brazilian agribusiness market. Their products are sold locally, and all the farms have diversity. Profit is small and it is used to maintain the system under production. These facts explain why the indicators were similar for the three farms studied.

It is urgent to evaluate the big conventional agricultural production in Brazil (especially soybean, sugar-cane, orange, coffee and pasture for cattle) using Ecological Footprint, but considering all negative externalities and ecosystem services produced by those systems. We will then have more precise results for decision making processes, considering sustainable development as an imperative.

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Appendix A. Ecological footprint and biocapacity calculated by traditional and enhanced methods for the three studied systems.

| farm / land use | area, ha | traditional biocapacity, nha | traditional footprint, nha | enhanced biocapacity, nha | enhanced footprint, nha |
|------------------------------|-------------|------------------------------------|----------------------------------|---------------------------------|-------------------------------|
| Duas Cachoeiras farm: | 29.70 | 56.217 | 17.376 | 73.635 | 18.663 |
| 1. pasture | 8.53 | 5.354 | 4.464 | 5.354 | 4.464 |
| 2. napier grass | 2.90 | 1.857 | 1.857 | 1.857 | 1.857 |
| 3. meadow | 3.96 | 4.639 | 0.855 | 4.639 | 0.855 |
| 4. construction area | 1.72 | 0.000 | 0.494 | 0.000 | 0.494 |
| 5. crop land | 4.30 | 1.546 | 0.564 | 1.546 | 0.564 |
| 6. lake | 0.16 | 0.100 | 0.000 | 0.100 | 0.000 |
| 7. orange | 0.34 | 0.073 | 0.008 | 0.073 | 0.008 |
| 8. forest | 7.79 | 14.667 | 1.833 | 14.667 | 1.833 |
| 9. CO ₂ | 27.98 | 27.980 | 7.301 | 27.980 | 7.301 |
| 10. negative externalities | - | - | - | - | 1.288 |
| 11. ecosystem services | - | - | - | 17.418 | - |
| Santa Helena farm: | 15.54 | 27.298 | 17.995 | 37.464 | 25.741 |
| 1. construction area | 1.84 | 0.000 | 1.090 | 0.000 | 1.090 |
| 2. coffee | 5.57 | 2.473 | 0.040 | 2.473 | 0.040 |
| 3. chayote crop | 0.87 | 0.878 | 0.001 | 0.878 | 0.001 |
| 4. forest | 4.59 | 8.820 | 0.000 | 8.820 | 0.000 |
| 5. pasture | 1.43 | 0.916 | 0.000 | 0.916 | 0.000 |
| 6. lake | 0.18 | 0.115 | 0.212 | 0.115 | 0.212 |
| 7. peach crop | 0.13 | 0.032 | 0.005 | 0.032 | 0.005 |
| 8. pepper (greenhouse) | 0.93 | 0.364 | 0.001 | 0.364 | 0.001 |
| 9. CO ₂ | 13.70 | 13.700 | 16.646 | 13.700 | 16.646 |
| 10. negative externalities | - | - | - | - | 2.232 |
| 11. ecosystem services | - | - | - | 10.166 | - |
| 12. fertilizers | - | - | - | - | 1.466 |
| 13. plague control | - | - | - | - | 4.048 |
| Três Lagos farm: | 25.23 | 42.184 | 21.497 | 52.544 | 28.935 |
| 1. construction area | 0.29 | 0.000 | 0.099 | 0.000 | 0.099 |
| 2. napier grass | 3.39 | 2.899 | 2.899 | 2.899 | 2.899 |
| 3. pasture | 18.36 | 8.722 | 2.519 | 8.722 | 2.519 |
| 4. lake | 0.44 | 0.369 | 0.000 | 0.369 | 0.000 |
| 5. forest | 1.98 | 4.979 | 0.000 | 4.979 | 0.000 |
| 6. maize | 0.51 | 0.200 | 0.200 | 0.200 | 0.200 |
| 7. orange | 0.26 | 0.075 | 0.009 | 0.075 | 0.009 |
| 8. CO ₂ | 24.94 | 24.940 | 15.770 | 24.940 | 15.770 |
| 9. negative externalities | - | - | - | - | 5.627 |
| 10. ecosystem services | - | - | - | 10.361 | - |
| 12. fertilizers | - | - | - | - | 0.440 |
| 13. plague control | - | - | - | - | 0.764 |
| 14. vaccine for cattle | - | - | - | - | 0.607 |

Appendix B. Raw data used to calculate the traditional and enhanced biocapacity in national hectares (nha).

| Household/Land use | Area ha | Actual productivity | Unit/year | National productivity | Unit/year | Yield factor ^A | Local NPP ^B kg/m ² /year | Equivalence factor ^C | Biocapacity ^D nha |
|--|------------|------------------------|-------------|--------------------------|-------------|------------------------------|---|------------------------------------|---------------------------------|
| Duas Cachoeiras farm | 29.70 | | | | | | 0.717 | | 73.635 |
| 1. Pasture | 8.53 | - | - | - | - | 1.000 | 0.450 | 0.628 | 5.354 |
| 1.1. Wool | - | 3 | kg/cattle | 3 | kg/cattle | - | - | - | - |
| 2. Napier Grass | 2.90 | 38000 | kg/ha | 48000 | kg/ha | 0.792 | 0.580 | 0.809 | 1.857 |
| 3. Meadow | 3.96 | - | - | - | - | 1.333 | 0.630 | 0.879 | 4.639 |
| 3.1. Honey | - | 20 | kg/bee hive | 15 | kg/bee hive | - | - | - | - |
| 4. Construction areas | 1.72 | - | - | - | - | - | 0.000 | 0.000 | 0.000 |
| 5. Agricultural crops | 4.30 | 1467 | kg/ha | 3300 | kg/ha | 0.445 | 0.580 | 0.809 | 1.546 |
| 6. Lake | 0.16 | - | - | - | - | 1.000 | 0.450 | 0.628 | 0.100 |
| 7. Orchards | 0.34 | 10000 | kg/ha | 37620 | kg/ha | 0.266 | 0.580 | 0.809 | 0.073 |
| 8. Forest | 7.79 | - | - | - | - | 1.000 | 1.350 | 1.883 | 14.667 |
| 9. CO ₂ absorption ^E | 27.98 | - | - | - | - | - | - | - | 27.980 |
| 10. Ecosystem service ^F | - | - | - | - | - | - | - | - | - |
| 10.1. Forest | 7.79 | 5.76E+15 | seJ/ha | 3.26E+15 | seJ/ha | - | - | - | 13.760 |
| 10.2. Pasture/Meadow | 12.49 | 5.21E+14 | seJ/ha | 3.26E+15 | seJ/ha | - | - | - | 1.998 |
| 10.3. Lake | 0.16 | 2.79E+16 | seJ/ha | 3.26E+15 | seJ/ha | - | - | - | 1.370 |
| 10.4. Cropland | 7.54 | 1.25E+14 | seJ/ha | 3.26E+15 | seJ/ha | - | - | - | 0.290 |
| Santa Helena farm: | 15.54 | | | | | | 0.703 | | 37.464 |
| 1. Construction areas | 1.84 | - | - | - | - | - | 0.000 | 0.000 | 0.000 |
| 2. Coffee plantation | 5.57 | 1111 | kg/ha | 2066 | kg/ha | 0.538 | 0.580 | 0.826 | 2.473 |
| 3. Chayote crop | 0.87 | 73333 | kg/ha | 60000 | kg/ha | 1.222 | 0.580 | 0.826 | 0.878 |
| 4. Forest | 4.59 | - | - | - | - | 1.000 | 1.350 | 1.922 | 8.820 |
| 5. Pasture | 1.43 | - | - | - | - | 1.000 | 0.450 | 0.641 | 0.916 |
| 6. Lake | 0.18 | - | - | - | - | 1.000 | 0.450 | 0.641 | 0.115 |
| 7. Peach crop | 0.13 | 5000 | kg/ha | 16875 | kg/ha | 0.296 | 0.580 | 0.826 | 0.032 |
| 8. Pepper (greenhouse) | 0.93 | 55000 | kg/ha | 40000 | kg/ha | 1.375 | 0.200 | 0.285 | 0.364 |
| 9. CO ₂ absorption | 13.70 | - | - | - | - | - | - | - | 13.700 |
| 10. Ecosystem service | - | - | - | - | - | - | - | - | - |
| 10.1. Forest | 4.59 | 5.76E+15 | seJ/ha | 3.26E+15 | seJ/ha | - | - | - | 8.108 |
| 10.2. Pasture/Meadow | 1.43 | 5.21E+14 | seJ/ha | 3.26E+15 | seJ/ha | - | - | - | 0.229 |
| 10.3. Lake | 0.18 | 2.79E+16 | seJ/ha | 3.26E+15 | seJ/ha | - | - | - | 1.541 |
| 10.4. Cropland | 7.50 | 1.25E+14 | seJ/ha | 3.26E+15 | seJ/ha | - | - | - | 0.288 |

Appendix B. Raw data used to calculate the traditional and enhanced biocapacity in national hectares (nha) - continuation.

| Household/Land use | Area ha | Actual productivity | Unit/year | National productivity | Unit/year | Yield factor | Local NPP kg/m ² /year | Equivalence factor | Biocapacity nha |
|-------------------------------|------------|------------------------|--------------|--------------------------|--------------|-----------------|--------------------------------------|-----------------------|--------------------|
| Três Lagos farm: | 25.23 | | | | | | 0.537 | | 52.544 |
| 1. Construction areas | 0.29 | - | - | - | - | - | 0.000 | 0.000 | 0.000 |
| 2. Napier grass | 3.39 | 38000 | kg/ha | 48000 | kg/ha | 0.792 | 0.580 | 1.080 | 2.899 |
| 3. Pasture | 18.36 | - | - | - | - | 0.567 | 0.450 | 0.838 | 8.722 |
| 3.1. Meat | - | 381 | kg/ha | 816 | kg/ha | 0.467 | - | - | - |
| 3.2. Milk | - | 1460 | liter/cattle | 2190 | liter/cattle | 0.667 | - | - | - |
| 4. Lake | 0.44 | - | - | - | - | 1.000 | 0.450 | 0.838 | 0.369 |
| 5. Forest | 1.98 | - | - | - | - | 1.000 | 1.350 | 2.514 | 4.979 |
| 6. Maize | 0.51 | 2000 | kg/ha | 5500 | kg/ha | 0.364 | 0.580 | 1.080 | 0.200 |
| 7. Orange | 0.26 | 10000 | kg/ha | 37620 | kg/ha | 0.266 | 0.580 | 1.080 | 0.075 |
| 8. CO ₂ absorption | 24.94 | - | - | - | - | - | - | - | 24.940 |
| 9. Ecosystem service | - | - | - | - | - | - | - | - | - |
| 9.1. Forest | 1.98 | 5.76E+15 | seJ/ha | 3.26E+15 | seJ/ha | - | - | - | 3.497 |
| 9.2. Pasture/Meadow | 18.36 | 5.21E+14 | seJ/ha | 3.26E+15 | seJ/ha | - | - | - | 2.936 |
| 9.3. Lake | 0.44 | 2.79E+16 | seJ/ha | 3.26E+15 | seJ/ha | - | - | - | 3.767 |
| 9.4. Cropland | 4.16 | 1.25E+14 | seJ/ha | 3.26E+15 | seJ/ha | - | - | - | 0.160 |

^A Yield factor = Actual productivity / National productivity;

^B Local NPP calculation is explained in item "(a)" of the item "3. Case studies" present in main text;

^C Equivalence factor = NPP category / NPP household;

^D Biocapacity = Area * Yield factor * Equivalence factor;

^E CO₂ absorption biocapacity has the same value of the area in hectares that absorbs CO₂. In this work were accounted all areas occupied with vegetal covering because all of them absorb CO₂. See item "(e)" of the item "3. Case studies" present in main text;

^F Ecosystem services correspond to values published by Costanza et al. (1997). For the national productivity value of this new category was used the Brazilian emergy density: 3.26E+15 seJ/ha/year (Ortega, 2007b). The biocapacity for ecosystems service category were obtained through the division between actual productivity by national productivity and multiplied by area in ha.

Appendix C. Raw data used to calculate the traditional and enhanced footprint in national hectares (nha) for Duas Cachoeiras farm.

| Household/Land use | Consume = Production + Importation - Exportation | | | | Unit/year | National productivity | Unit/year | Equivalence Factor ^A | Footprint ^B nha |
|--|--|-------------|-------------|----------|-----------|-----------------------|-----------|---------------------------------|----------------------------|
| | Production | Exportation | Importation | Consume | | | | | |
| Duas Cachoeiras farm | | | | | | | | | 18.658 |
| 1. Pasture | - | - | - | - | - | - | - | 0.628 | 4.464 |
| 1.1. Wool | 1279.5 | 1179.5 | 0.0 | 100.0 | kg | 14 kg/ha | - | - | - |
| 2. Napier Grass | 110200.0 | 0.0 | 0.0 | 110200.0 | kg | 48000 kg/ha | 0.809 | 1.857 | - |
| 3. Meadow | - | - | - | - | - | - | 0.879 | 0.855 | - |
| 3.1. Honey | 2376.0 | 2361.4 | 0.0 | 14.6 | kg | 15 kg/ha | - | - | - |
| 4. Construction areas ^C | - | - | - | 1.7 | ha | 0.355 | 0.809 | 0.488 | - |
| 5. Agricultural crops | - | - | - | 2300.0 | kg | 3300 kg/ha | 0.809 | 0.564 | - |
| 5.1. Cereal | 800.0 | 400.0 | 0.0 | 255.5 | kg | - | - | - | - |
| 5.2. Maize | 2400.0 | 1400.0 | 0.0 | 73.0 | kg | - | - | - | - |
| 5.3. Beans | 600.0 | 300.0 | 0.0 | 182.5 | kg | - | - | - | - |
| 5.4. Tubers | 2000.0 | 500.0 | 0.0 | 110.0 | kg | - | - | - | - |
| 5.5. Vegetables | 1000.0 | 900.0 | 0.0 | 100.0 | kg | - | - | - | - |
| 6. Lake | - | - | - | - | - | - | 0.628 | 0.000 | - |
| 7. Orchards | 3400.0 | 3035.0 | 0.0 | 365.0 | kg | 37620 kg/ha | 0.809 | 0.008 | - |
| 8. Forest | - | - | - | - | - | - | 1.883 | 1.833 | - |
| 8.1. Honey | 2376.0 | 2361.4 | 0.0 | 14.6 | kg | 15 kg/ha | - | - | - |
| 9. CO ₂ emission ^D | - | - | - | 357.7 | kg C | 49 kgC/ha | - | 7.301 | - |
| 9.1. Fuel | - | - | - | 500.0 | liters | - | - | - | - |
| 10. Neg. Externalities ^E | - | - | - | 4.20E+15 | seJ | 3.26E+15 seJ/ha | - | 1.288 | - |
| 10.1. Soil erosion | - | - | - | 83.00 | USD/ha | - | - | - | - |
| 10.2. Soil nutrients lost | - | - | - | 13.60 | USD/ha | - | - | - | - |

^A The equivalence factor is the same values used in the biocapacity calculation. For the construction areas, the equivalence factor is the average between the crop equivalence factors and its footprint is: consume * equivalence factor * national productivity;

^B Footprint = Consume * (Equivalence factor / National productivity);

^C The footprint of construction areas is equal to its area in ha. Its national productivity are the average between the yield factor for crop areas, because we assumed that the construction areas are occupying the ground that could be used to crop production;

^D Consume of CO₂ emission were calculated in a following way: consume of fuel (liter/year) * 2.72 (kgCO₂/liter of fuel) * 0.263 (kgC/kgCO₂). The value of 49 kgC/ha/year (IPCC, 2004) was used as national productivity because represents a mean for CO₂ absorption by vegetal covering in Brazil country. CO₂ emission footprint = consume / national productivity;

^E Negative externalities = USD/ha/year * ha (area with crop production) * 3.30E+12 seJ/USD (Brazilian emdóllar; Ortega, 2007b). National productivity for negative externalities was considered the Brazilian emergy density: 3.26E+15 seJ/ha/year (Ortega, 2007b). The footprint for negative externalities category were obtained through the division between consume by national productivity.

Appendix D. Raw data used to calculate the traditional and enhanced footprint in national hectares (nha) for Santa Helena farm.

| Household/Land use | Consume = Production + Importation - Exportation | | | | Unit/year | National productivity | Unit/year | Equivalence Factor ^A | Footprint ^B nha |
|--|--|-------------|-------------|----------|----------------|-----------------------|--------------------|---------------------------------|----------------------------|
| | Production | Exportation | Importation | Consume | | | | | |
| Santa Helena farm: | | | | | | | | | 25.719 |
| 1. Construction areas ^C | - | - | - | 1.8 | ha | 0.86 | - | 0.690 | 1.068 |
| 2. Coffee plantation | 6200.0 | 6100.0 | 0.0 | 100.0 | kg | 2066 | kg/ha | 0.826 | 0.040 |
| 3. Chayote crop | 63800.0 | 63700.0 | 0.0 | 100.0 | kg | 60000 | kg/ha | 0.826 | 0.001 |
| 4. Forest | - | - | - | - | - | - | - | 1.922 | 0.000 |
| 4.1. Wood (paper) | 400 | 400 | 0.0 | - | plant | - | - | - | - |
| 5. Pasture | - | - | - | - | - | - | - | 0.641 | 0.000 |
| 6. Lake | - | - | - | - | - | - | - | 0.641 | 0.212 |
| 6.1. Water for irrigation | - | - | - | 3890.0 | m ³ | 11769 | m ³ /ha | - | - |
| 7. Peach crop | 650.0 | 550.0 | 0.0 | 100.0 | kg | 16875 | kg/ha | 0.826 | 0.005 |
| 8. Pepper (greenhouse) | 2750.0 | 2650.0 | 0.0 | 100.0 | kg | 40000 | kg/ha | 0.285 | 0.001 |
| 9. CO ₂ emission ^D | - | - | - | 815.5 | kg C | 49.00 | kgC/ha | - | 16.646 |
| 9.1. Fuel | - | - | - | 1140 | liters | - | - | - | - |
| 10. Neg. Externalities ^E | - | - | - | 7.27E+15 | seJ | 3.26E+15 | seJ/ha | - | 2.232 |
| 10.1. Soil erosion | - | - | - | 83.00 | USD/ha | - | - | - | - |
| 10.2. Soil nutrients lost | - | - | - | 13.60 | USD/ha | - | - | - | - |
| 10.3. CO ₂ emission | - | - | - | 7.84 | USD/ha | - | - | - | - |
| 10.4. Gas emission | - | - | - | 52.52 | USD/ha | - | - | - | - |
| 10.5. Effluent | - | - | - | 39.70 | USD/ha | - | - | - | - |
| 10.6. Intoxication | - | - | - | 0.20 | USD/ha | - | - | - | - |
| 10.7. Rural exodus | - | - | - | 50.00 | USD/ha | - | - | - | - |
| 11. Fertilizers (NPK) ^F | - | - | 1000 | 1000 | kg | 3.26E+15 | seJ/ha | - | 1.466 |
| 12. Plague control ^G | - | - | 530 | 530 | kg | 3.26E+15 | seJ/ha | - | 4.048 |

^{A, B, C and D} See the footnote in Appendix C;

^E See Appendix C. This category include for this household: Methane and nitrous oxide emission; Effluent treatment; Intoxication, invalidity and deaths by pesticide use;

^F Fertilizer calculation: NPK (10-10-10) in mass unit = 10% of nitrogen, 10% of phosphorus and 10% of potassium. Footprint (nha) = 0.1 * Consume (kg/year) * Transformity (4.78E+13 seJ/kg – estimated through Brandt-Williams, 2002) / National productivity (3.26E+15 seJ/ha/year; Ortega, 2007b). NPK = nitrogen, phosphorus and potassium;

^G Plague control calculation: Footprint (nha) = Consume (kg/year) * Transformity (2.49E+13 seJ/kg – Brown and Arding, 1991) / National productivity (3.26E+15 seJ/ha/year; Ortega, 2007b).

Appendix E. Raw data used to calculate the traditional and enhanced footprint in national hectares (nha) for Três Lagos farm.

| Household/Land use | Consume = Production + Importation - Exportation | | | | Unit/year | National productivity | Unit/year | Equivalence Factor ^A | Footprint ^B nha |
|--|--|-------------|-------------|----------|-----------|-----------------------|-----------|---------------------------------|----------------------------|
| | Production | Exportation | Importation | Consume | | | | | |
| Três Lagos farm: | | | | | | | | | 29.920 |
| 1. Construction areas ^C | - | - | - | 0.3 | ha | 0.315 | - | 1.080 | 0.102 |
| 2. Napier grass | 128820.0 | 0.0 | 0.0 | 128820.0 | kg | 48000 | kg/ha | 1.080 | 2.899 |
| 3. Pasture | - | - | - | - | - | - | - | 0.838 | 2.519 |
| 3.1. Meat | 7000.0 | 6000.0 | - | 1000.0 | kg | 816 | kg/ha | - | - |
| 3.2. Milk | 58400 | 57962 | 0.0 | 438.0 | liters | 246 | liters/ha | - | - |
| 4. Lake | - | - | - | - | - | - | - | 0.838 | 0.000 |
| 5. Forest | - | - | - | - | - | - | - | 2.514 | 0.000 |
| 6. Maize | 1020.0 | 0.0 | 0.0 | 1020.0 | kg | 5500 | kg/ha | 1.080 | 0.200 |
| 7. Orange | 2600.0 | 2300.0 | 0.0 | 300.0 | kg | 37620 | kg/ha | 1.080 | 0.009 |
| 8. CO ₂ emission ^D | - | - | - | 772.6 | kg C | 49.00 | kgC/ha | - | 15.767 |
| 8.1. Fuel | - | - | - | 1080 | liters | - | - | - | - |
| 9. Neg. Externalities ^E | - | - | - | 1.83E+16 | seJ | 3.26E+15 | seJ/ha | - | 5.613 |
| 9.1. Soil erosion | - | - | - | 83.00 | USD/ha | - | - | - | - |
| 9.2. Soil nutrients lost | - | - | - | 13.60 | USD/ha | - | - | - | - |
| 9.3. CO ₂ emission | - | - | - | 7.84 | USD/ha | - | - | - | - |
| 9.4. Gas emission | - | - | - | 52.52 | USD/ha | - | - | - | - |
| 9.5. Effluent | - | - | - | 39.70 | USD/ha | - | - | - | - |
| 9.6. Intoxication | - | - | - | 0.20 | USD/ha | - | - | - | - |
| 9.7. Rural exodus | - | - | - | 50.00 | USD/ha | - | - | - | - |
| 10. Fertilizers (NPK) ^F | - | - | 300 | 300 | kg | 3.26E+15 | seJ/ha | - | 0.440 |
| 11. Plague control ^G | - | - | 100 | 100 | kg | 3.26E+15 | seJ/ha | - | 0.764 |
| 13. Vaccine for cattle ^H | - | - | 600 | 600 | USD | 3.26E+15 | seJ/ha | - | 0.607 |

^{A, B, C and D} See the footnote in Appendix C;

^{E, F and G} See the footnote in Appendix D;

^H Vaccine for cattle calculation: Footprint (nha) = Consume (USD/year) * 3.30E+12 seJ/USD (Brazilian emdóllar; Ortega, 2007b) / National productivity (3.26E+15 seJ/ha/year; Ortega, 2007b).