Scientific Papers Series Management, Economic Engineering in Agriculture and Rural Development
Vol. 13, Issue 3, 2013
PRINT ISSN 2284-7995, E-ISSN 2285-3952

ECOLOGICAL FOOTPRINT FROM THE SUSTAINABILITY PERSPECTIVE

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Abstract

The paper studied the importance of Ecological Footprint (EF) for estimating the biologically productive area. Since the Ecological Footprint is a measure of renewable biocapacity, we argue that some dimensions of ecological sustainability should not be included in the Ecological Footprint. These include human activities that should be phased out to obtain sustainability, such as emissions of persistent compounds foreign to nature and qualitative aspects that represent secondary uses of ecological areas and do not, therefore, occupy a clearly identifiable additional ecological space. We also conclude that the Ecological Footprint is useful for documenting the overall human use or abuse of the potentially renewable functions and services of nature. Particularly, by aggregating in a consistent way a variety of human impacts, it can effectively identify the scale of the human economy by comparison with the size of the biosphere.

Key words: *ecological area, ecological footprint, impact, renewable biocapacity, sustainability*

INTRODUCTION

The Ecological Footprint (EF) concept, introduced by Rees and Wackernagel (1994), measures the biologically productive area necessary to support current consumption patterns, given prevailing technical and economic processes.[20] Dividing all the biologically productive land and sea on this planet by the number of people inhabiting it results in an average of 2,3 ha per person, less than one third of what is necessary to accommodate a typical Canadian footprint. If we put aside 12% of the biologically productive space for preserving the other 30 million species with whom we share this planet (WCED, 1987) which, by the way, is politically ambitious but ecologically insufficient, the available space per capita shrinks to 2 ha. With an anticipated global population of 10 billion for the year 2050, the available space will be reduced to 1,2 ha per person. Already, the average Italian uses 210% more than is available per capita worldwidw, or 320% more than is available per Italian within their national territory. Sweden is still one of the fortunate few counties whose ecological footprints are smaller than their national biologically productive space. Worldwide, however, humanity's footprint may exceed global carrying capacity by 30% - in other words, humanity consumes more than what nature can regenerate and is decreasing the globe's natural capital stock. It is not only the non-renewable and renewable resources that are declining but also the ability of nature to assimilate the waste (for example, emissions of carbon dioxide or acidifying substances). The ecological footprint builds on a variety of earlier analytical attempts to measure human load in order to estimate the dependence of human life on nature (see for example, Martinez-Alier, 1987 and Cohen, 1995). [15], [4]. Much intellectual groundwork for more recent studies was laid in the 1960s and 1970s, particularly by initiatives such as Georg Borgstrom's analysis of "ghost acreage" (1973), Howard Odum's energy analysis examining systems through energy flows (1994), Jay Forrester's advancements on modelling world resource dynamics as presented by the Club of Rome (Meadows et al, 1972; Meadows et al, 1992), John Holdren

and Paul Ehrlich's IPAT formula (1974), or, in the spirit of the International Biological Programme, Robert Whittaker's calculation of net primary production of the world's ecosystems (Whittaker, 1975; Lieth and Whittaker, 1975).[2], [18], [16], [17], [13], [6]
The last ten of fifteen years have witnessed exciting new developments of tools that measure people's use of nature: life cycle assessments, energy analyses and energy-based lifestyle appraisals (Pimentel et al, 1994; Hofstetter, 1991), environmental space calculations going back to ideas of Johann Opshoor and further developed by the Friends of the Earth (Buitenkamp et al, 1993), human appropriation of net primary production (Vitousek et al, 1986; Fischer-Kowslaski, 1997), documentation of regional and industrial metabolisms, mass intensity measures such as Mass Intensity per Unit of Service (MIPS) (Schmidt-Bleek, 1994), measures of human processes such as the Sustainable Process Index (SPI) (Krotscheck and Narodoslawsky, 1996), socio-ecological indicators, resource accounting input-output models (Duchin and Lange, 1994), computer based spatial models analyzing land-use developments and ecological potentials, computer-based scenario models such as "PoleStar" (Gallopin et al, 1997), or the above-mentioned ecological footprint assessment (Wackernagel and Rees, 1996; Folke et al, 1997), to name a few. [19], [12], [3], [22], [8], [21], [14], [5], [10], [23].

MATERIALS AND METHODS

In this section, we discuss how the EF relates to the four principles for sustainability described in the previous section. We also explain how the EF could be developed to incorporate more aspects of the principles for sustainability. Further, we discuss which aspects of the principles are more relevant to measure using other methods. Before we relate the EF to the four principles, we present, as background, some general properties of the EF concept.
The main question that the footprint answers is how much biologically land would be required on a continuous basis to provide the necessary energy and resources consumed by a population and to absorb the wastes discharged by the population. An EF analysis, therefore, is close to an assessment of human appropriation of net primary production (or NPP). The principal difference from other NPP studies is that the footprint expresses the results in spatial measurement units rather than energy or mass equivalents.
EF esimates are calculated to account for as many ecological impacts as possible without exaggerating humanity's current impact. For example, optimistic yield figures are used and some impacts are not yet included in the calculations. In addition, the estimates do not double count areas that can give several services simultaneously, since this would exaggerate people's true use of nature. Underestimating human use of nature's productivity ensures that the EF results do not depict the ecological situation as more severe than it. This chosen strategy secures the widest possible acceptance of the results.
Both people's EF and the biosphere's areas of biologically productive land are expressed in common units: world average land with world average productivity. In most assessments, official data are used – not because they are the most accurate, but to delegate responsibility and show that even with the official data, once interpreted from an ecological perspective, significant new conclusions can be generated.
The EF calculations have so far included land for energy supply, food, forest products, and the built environment, degraded areas, and sea space for fishing. For the waste side, the land needed for sequestering CO_2 is included in the EF. There are attempts to include more aspects of the waste side, such as phosphorus retention and denitrification (Folke et al, 1997; Wackernagel et al, 1998).[9]

RESULTS AND DISCUSSIONS

Fossil fuels and carbon dioxide
There are three different approaches to calculate the footprint of fossil fuel consumption – and all three results in

approximately the same area. All three are motivated by the idea that, in order to be sustainable, humanity must not undermine functions and biodiversity of the ecosphere. This is the essence of the first three principles for sustainability.

One way to calculate the EF for fossil fuels would be to account for the corresponding area needed for the sustainable production of biofuels. The rationale for this way of calculating would be the close relationship between fossil fuels and bio-fuels, such as methane or ethanol. They have the same origin (photosynthesis), they are of similar quality and they can be applied in almost the same technological systems (in combustion engines for instance). The required productive area for that type of energy supply, built on closed carbon cycle (i.e. no net increase of CO_2 in the atmosphere), would then be the rational basis for the EF calculation. This method would lead to the biggest footprint estimates for fossil fuel. However, there is some considerable controversy about the degree to which bio-fuels can substitute for the global use of fossil fuels considering the competition for land areas for other purposes like food, materials and biodiversity (Berndes, 1997; Giampietro et al, 1997; Hall et al, 1997). [1], [11]

Another way of calculating the fossil fuel footprint would be to calculate the area needed to compensate only the biochemical energy of the burned fossil, without taking into account that the biochemical energy in the woods has not the same technical quality as fossil fuel or bio-fuels. This would lead to slightly lower ecological footprints for fossil energy.

The third method is based on CO_2 sequestration, arguing that the amount of fossil fuel may not be the limiting factor but rather the absorption of the waste gases. In this method, the area is calculated by assessing the extension of newly planted forest required for sequestering the CO_2 released by the combustion of fossil fuel. Such land serves as a CO_2 sink during a period of between 40 to 100 years, depending on climate and species of forest. In order not to release the sequestered CO_2 the mature forest would have to be left for the future with no harvest, so spontaneously renewing itself. As the absorbing forests mature, additional forest areas for CO_2 sequestration would be needed in order to avoid increasing levels of CO_2 in the atmosphere in the case of continued use of fossil fuels. Obviously, this third method leads to the smallest footprints for fossil fuel. It is chosen because it avoids results which could exaggerate human impact of fossil fuel use. Nevertheless, the accumulation of CO_2 in the atmosphere from the use of fossil fuels is only one of many impacts this energy system has in the ecosphere. Therefore, the current conversion rate of 71 gigajoules per hectare and year for liquid fossil fuel-based on sequestration estimates published by the Intergovernmental Panel of Climate Change – are still significant underestimates of this energy's true ecolofical load on the biosphere (Wackernagel et al, 1997). In addition, no significant land area is set aside exclusively to sequester CO_2 from fossil fuel burning (or for the replacement of fossil fuels by wood biomass). [24]

In conclusion, all three methods described above have their limitations. For example, a real transition from fossil fuels to bio-fuels should lead to a smaller footprint area – current footprint accounting practice, however, should show the opposite. These methods are, though, helpful for the monitoring of increased overall efficiencies of the energy system, as well as the transition towards much more area-efficient sources of energy, like photovoltaics.(Besides being area-efficient, photovoltaics have the additional benefit of not needing to occupy biologically productive surfaces). The third method has the advantage of giving the smallest area of the three methods and does not, therefore, exaggerate the area needed. This method is also more relevant whwn considering emissions of CO_2 from other sources than fossil fuels (for example, cement production since it is not based on a substitute for the energy supply).

Waste assimilation (apart from carbon dioxide)

The waste assimilation, apart from CO_2, has hitherto not generally been considered in EF assessments. Only some newer assessments of the EF include the use of space for breaking down biodegradable waste, particularly in water (Wackernagel et al, 1998). For example, the area of ponds and protective wetland areas which should be needed for effective reduction of the load from leaching plant nutrients from productive agricultural land have been included in a detailed calculation of the Swedish national footprint. [25]

A systematic inclusion of such waste in EF calculations is difficult because the assimilation capacities in the ecosphere are known only for a few of the naturally occurring substances. In these cases, the anthropogenic flows of such a substance can be converted to an area needed for assimilating the substance.

Relevant anthropogenic flows to consider are actual emissions of substances to the ecosphere or, alternatively, the potential emissions estimated from the extraction rate of virgin substances from the lithosphere or, in the case of human made products, the amounts of these substances manufactured. For a region, the net import of substances should be added to the extraction and production of substances within the region.

When assimilation capacities are not known, it can be possible to indirectly estimate them, for example, by considering some natural flows. The assimilation capacities of metals are usually not known, but can be assumed to be proportional to their natural flows, such as in their weathering and sedimentation rates. If the anthropogenic flows of a metal are much larger than the natural flows, the risk increases that such flows will cause accumulation in the ecosphere. The anthropogenic flows of a metal could be converted to an area proportional to an area from which the same amount of metal will be weathering. A difficulty is that the natural concentrations and weathering rates vary for different regions.

To avoid double counting of productive areas and erroneously large footprints, it is necessary to consider that the area needed for assimilation of substances can still be made applicable for other purposes, for instance, productive forests and crop land, provided that these areas are not destroyed because of high concentrations of the emitted compounds. Further, the same area can be applied for the assimilation of more one compound. We define additive aspects as those that can be added to each other when calculating the total footprint without risk of double counting of area, e.g. food and fibre production. In contrast to exclusive (primary or additive) aspects, the secondary (or non-additive) aspects should not be added to each other since the same area can be used for several of these aspects, e.g. assimilation of substances can be done on the same area as is used for fibre production. Note that built-up land is also an additive aspect but this area cannot be used for assimilation of substances.

If none of the emissions of compounds exceed their assimilation capacities corresponding to the productive area needed for additive aspects, there is no need to add any productive area occupied by this function to the footprint area, i.e. $A_{footprint} = A_{additive\ aspects}$. On the other hand, if some of the emissions of compounds exceed their assimilation capacities of the productive area needed for additive aspects, the footprint should increase the more the assimilation is exceeded. The most appropriate strategy would then be to calculate how much the productive area for assimilation of the most dominant compound would need to be extended in order not to have accumulation of that compound:

$A_{footprint} = A_{assimilation} + A_{built\text{-}up\ land}$

The assumption that then needs to be made is that the various compounds would not influence each other's assimilation thresholds in the ecosystems, or each other's impact on the ecosystem. That assumption is often true, but not always. It is definitely not true for various compounds that lead to acidification (like emissions of SO_2 and NO_x), and that add to each other's negative effects on area productivity. On the other hand, this could be adjusted for by simply adding the corresponding areas for such compounds that have additive impacts on the ecosystems productivity into a sum. Here, H^+ equivalents from different compounds could be used. If that sum exceeds the needed extension of the assimilation area for any of the other compounds that can be estimated to be independent of each other, this sum should then be applied to the footprint. And conversely, if any of the 'independent' compounds – say a plant nutrient – has a needed extension of area that exceeds all other areas calculated, including the sum of H^+ assimilating areas, that would be the appropriate area for the footprint.

Substances for which it is not possible to estimate their assimilation capacities cannot be considered in the EF method and have to be accounted for in some other way. Also, substances that have such low assimilation rates that the EF would become absurdly large may not be compatible with a sustainable society. Since the EF only includes potentially renewable aspects of the human economy, these not-sustainable substances cannot be included in the accounting. Another assessment problem for potentially renewable substances, however, can be to find data for anthropogenic flows of substances such as emissions and the net intake of substances.

A shift to a substance with lower equivalent impacts (for example a more naturally abundant metal) would give a smaller area for the same amount of anthropogenic flows. This way of calculating substances could thus be used as an indicator measuring the progress towards sustainability.

Compounds foreign to nature

Often compounds that are not normally occurring in the ecosystems cannot be made part of footprinting calculations because assimilation capacities for such substances usually cannot be indentified.

Built-up land

Paved-over land, built upon land and hydropower dams are counted according to the space they occupy in the present EF method. Areas lost (or damaged) because of industrial activities, including mining, should also be included, but are still left out because of unavailable data.

Forestry and agriculture

Present timber and crop yields are used in most EF analyses, optimistically assuming that these could be maintained. Hence, anthropogenic influence on long-term productivity and biodiversity is underestimated when analyzing forestry and agricultural productivity. Still, badly eroded or otherwise degraded land where the total productivity has been lost is deducted from the bioproductive areas. Biodiversity is considered to the extent that the bio-productive land is decreased by a (probably too small) area set aside to preserve biodiversity.

The production capacity of forests and agricultural land varies depending on natural factors such as climate and soil. Anthropogenic influence can also affect the production capacity. These effects are covered in EF accounts by including factors that compare local bio-productivity to the global average. When production capacity has been systematically deteriorated on a long-term basis by current practice, the loss should be reflected in the EF assessments. This, however, has not yet been included, which once more underlines that EF results are underestimates. Loss of conditions for maintenance of biodiversity should also be reflected in the bio-capacity accounts. When lost production capacity and lost biodiversity are known for a specific forestry area or agriculture, an area needed to compensate for these losses could be added to the actual forest area or agricultural land in the footprint value. When the losses are not known, template values for losses based on practices used in forestry or agriculture could be used. For example, a smaller area is needed to compensate for losses when site-adapted forestry is practiced rather than when large-scale conventional forestry is practiced. And, an even smaller area is needed to compensate for losses when environmentally certified forestry is practiced. In agriculture, for example, the decrease of long-term productivity caused by soil compacting could be estimated based on soil type and machine pressure.

The production capacity can increase when a large amount of fertilizer is used in agriculture. This means that less agricultural land is needed for the same yield. It should be noted that additional areas are needed (such as ponds and protective zones to avoid nutrient leakage) and land to supply the energy (or to assimilate CO_2 emissions) is required for the production of fertilizers.

For more accurate results, forestry and agriculture should be supplemented by other indicators documenting losses of production capacity and conditions for maintenance of biodiversity, both of which have not yet been captured by EF accounts.

Fisheries

In earlier footprint analyses, we did not include sea space, because the sea does not provide a significant proportion of the food or any other resource humanity consumes (.To be more complete, however, present EF analyses now include sea areas to the extent that they provide for food. The footprint of fisheries is calculated by comparing the fish harvest with the ecological production within an average sea area. Obviously, this is not a sophisticated reflection of the role of the sea but helps to document the magnitude of the various uses of nature.

Studies with a specific focus on the EF of fisheries have been completed by Folke et al (1998). [9]

For more detailed future studies, one could consider not only the amount of fish but also what species are caught because different species have different sustainable yields, and also to what extent sea space is lost because of excessive waste loads. This approach would more clearly point out the potential for over-harvest and extinction of fish species, and would make the EF more relevant for indicating the sustainability of humanity's use of the sea. However, because there is significant controversy about the sustainability of fisheries and the impact of waste, and as far more sophisticated assessment methods exist for analyzing marine resources, it may not be particularly effective to use the footprint as an additional assessment tool. Rather, the footprint methodology is effective as a means to present the research results of these more sophisticated assessments in an ecological context.

Water use

Freshwater available in nature can be divided into two forms (which are both recharged from precipitation):

(1) As 'green' water in the soil, returning to the atmosphere, and

(2) As 'blue' water in aquifers and rivers flowing towards the sea.

The green water directly supports the process of biomass production. Since the transformation of harvested biomass to an ecological footprint has already been covered in the agriculture and forestry section, this water does not need to be accounted again for the footprint analysis. The blue water, on the other hand, can supply households with domestic water, the industry with water for cooling and other processes, and agriculture with irrigation water. The ecological footprint of such a use can be calculated in relation to the amount of the water used.

There are two main categories of the use of blue water:

(1) Evaporative (consumptive) water use sending the used water back to the atmosphere after use (i.e. the use of water for irrigation). The ecological footprint of evaporative water use can be calculated as the catchment area that corresponds to the amount of water used. An example of non-sustainable evaporative water use is the decline, caused by irrigation, of ground water in large agricultural areas in the US. The ecological footprint of declining ground water can be calculated as the recharge area of the aquifer that corresponds to the excess use of the actual recharge (renewable yield) of the aquifer.

(2) Through flow-based use (just circulating the water through the societal system), returning it back to the landscape or river after use with a load of pollutants added during use. The ecological footprint of such a use can be based on the pumping energy used and the pollution added and not on the use itself since no water is evaporated.

Besides the actual use of water, the actual supply it decreased through various means of manipulation. Examples are surface hardening through, for instance, growing constructed areas within the technosphere, 'natural' loss of productivity, deforestation, or hardening after adding the exclusive bioproductive areas necessary to capture the water, the area necessary to compensate for lost bioproductivity caused by deviated water and areas to cleanse the water again. These areas are not only calculated for the water directly used by a population, but also for producing the goods and services this population receives from elsewhere.

Qualitative impacts on freshwater that will not directly require an additional bioproductive area necessary to remediate it, as in the case of contamination with persistent human-made compounds, requires other measures to track them.

Area efficiency

Besides these flow-related aspects, the area efficiency, for example, in agriculture, forestry and energy systems, will become more and more important. Even though most EF results are expressed in global average forest and agricultural productivities, variations of area efficiency between regions and regional changes of area efficiency over time can be documented if specific yield factors replace average figures in footprint calculations.

Transmaterialization and dematerialization

For the flows that are included in the EF calculation, transmaterialization and dematerialization are indirectly considered. If a material that needs less area for assimilation substitutes for a material that needs more, the area for that application will be smaller. And, obviously, if less of a material is needed through dematerialization, the area needed to assimilate the flow will ne smaller. This means that the progress towards sustainability for transmaterialization and dematerialization can be measured for certain flows.

Distribution of resource use

The distribution of resource use can partially be documented by the EF. In some projects, the distribution of the EF within societes has already been calculated.

It is possible to reflect intergenerational justice of distribution of resource use within regions if the EF is calculated for different groups within society, e.g. different income groups, rather than whole regions. Even though the EF reports about the ecological capacities currently occupied, it does not document whether these spaces are actually sufficient for meeting the needs of people. Intergenerational justice is considered in as far as ecological deficits are identified. These deficits lead to an accumulated ecological debt burden for future generations.

Population growth

Population growth is indirectly considered since the available productive area per capita will decrease when the population grows.

CONCLUSIONS

An essential part of sustainable development is to reduce the throughput of resources in relation to the added human value. All processes degrade the quality of energy, and more or less waste is generated. From a thermodynamic point of view, those „bills" must be paid for through processes run by energy from outside the ecosphere. The sun-driven biogeochemical cycles of nature are essential to maintain life on Earth. Therefore, most of those bills must, in the end, be paid for by productive areas receiving sunlight. Consequently, the method of footprinting, relating various throughputs of resources to the respective fertile areas required, offers an attractive possibility of auditing sustainable development.

A culture's lifestyle, with its demands of services on the one hand, in combination with its technical and organizational skills to provide services per throughput of resources on the other, gives us the footprint, and then calculating the footprints for various options, more resource efficient way of meeting human needs can be evaluated and launched. So, the EF is not only relevant for estimating the situation with regard to the areas needed to sustain us today, but also for testing different stategies for the future.

The footprint is particularly effective for documenting human use or abuse of the potentially renewable functions and services of nature. Aspects that need to be monitored with other indicators and measures are activities that should be phased out completely, or almost completely, to obtain sustainability, and certain qualitative aspects of sustainability that are not easy or relevant to transfer to spatial measures. In other words, the EF does not cover all aspects encompassed by the systematic sustainability perspective used in this paper, but is consistent with its thrust. In addition, it offers a quantitative interpretation of central aspects of the systematic sustainability perspective and puts their more abstact criteria into a more tangible measurement. Therefore, the EF is a complementary tool to the principles for sustainability: as a yard stick for measuring the ecological bottom-line of the renewable use of the biosphere – a precondition for securing people's quality of life.

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