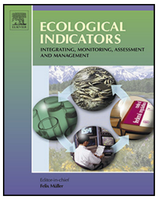
Ecological Indicators 32 (2013) 276–284

Contents lists available at SciVerse ScienceDirect

Ecological Indicators

journal homepage: www.elsevier.com/locate/ecolind



Framework for the inter-comparison of ecological footprint of universities

L.M. Nunes[a,*], A. Catarino[b], M. Ribau Teixeira[c], E.M. Cuesta[d]

[a] University of Algarve, Geo-Systems Centre, Campus de Gambelas, 8005-139 Faro, Portugal
[b] University of Algarve, Campus de Gambelas, 8005-139 Faro, Portugal
[c] University of Algarve and CENSE, Campus de Gambelas, 8005-139 Faro, Portugal
[d] University of Huelva, Facultad de Ciencias Experimentales, Campus de El Carmen, 21071, Spain

ARTICLE INFO

Article history:
Received 25 October 2012
Received in revised form 28 February 2013
Accepted 7 April 2013

Keywords:
Ecological footprint
Uncertainty
Monte Carlo simulations
Inter-comparability
University

ABSTRACT

The ecological footprint (EF) method represents the suitability of a given population on the carrying capacity of the total system. It was developed in order to measure the relationship between nature and humans, being supported on the premise that each individual requires a surface area that provides goods and services essential to life. In this article only in EF for universities is studied, but most of the underlying concepts and methods are valid for any other human activity for which EF may be applied.

In this study an uncertainty analysis of EF of universities is made. This is, to the authors' knowledge, the first time such a study is published on the subject. The intention is to demonstrate the usefulness of uncertainty analysis in the evaluation of results, inter-comparability, and on communication of EF outcomes.

Results showed that EF model uncertainties have large impact on EF estimates, in particular in what regards the decision about accounting or not the contribution of key parameters. Inclusion or not of very sensitive parameters, for which there is also high uncertainty, in the estimation of EF may have a strong impact on the estimated values and also in the inter-comparability of EF estimates. This is the case of mobility.

Uncertainty analysis, by studying model uncertainty, parameter uncertainty and variability, can provide a robust framework for the inter-comparison of ecological footprints of universities. In fact, the method may prove useful for the assessment of ecological footprints of any kind.

1. Introduction

In the introductory paragraph of the Talloires Declaration for sustainability, university presidents, chancellors, and rectors state their commitment to environmental sustainability in higher education, and their concern about the unprecedented scale and speed of environmental pollution and degradation, and the depletion of natural resources. They agreed in promoting the creation of an equitable and sustainable future for all humankind, namely by increasing awareness of environmentally sustainable development, creating an institutional culture of sustainability, educate for environmentally responsible citizenship, fostering environmental literacy for all, and practice institutional ecology. Many of these objectives are well answered by the ecological footprint (EF).

Wackernagel and Rees (1996) proposed EF as a quantitative method to measure sustainable development and impact of human activities. According to the authors, EF is the 'load' imposed by a given population on nature, being an accounting tool that enables us to estimate the resource consumption and waste assimilation requirements of a defined human population or economy. It is accounted in terms of a corresponding productive land area, as the amount of nature mankind occupy in order to live (Wackernagel et al., 1999; Wackernagel and Rees, 1996). The method represents the suitability of a given population on the carrying capacity of the total system. In theory, EF is estimated by determining how much land area would be necessary to produce all the goods consumed, and to assimilate all the wastes generated by a human activity. Thus, it expresses the load on the environment caused by the system under study. It was developed in order to measure the relationship between nature and humans, being supported on the premise that each individual requires a surface area that provides goods and services essential to life. There has been a widespread interest in the methodology, which led to it being included in the European Commission's Common Indicator set for regional sustainability (ECIP). Along with this interest also the need for standardizing methodologies has grown in order to reduce discrepancies. This has ultimately resulted in the formation of the Global Footprint Network (GFN),

---

* Corresponding author. Tel.: +351 289800900.
E-mail addresses: lnunes@ualg.pt (L.M. Nunes), aicatarino@ualg.pt (A. Catarino), mribau@ualg.pt (M. Ribau Teixeira), emoreno@uhu.es (E.M. Cuesta).

1470-160X/$ – see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.ecolind.2013.04.007

which has so far concentrated on the standardization of methodologies for EF of nations, cities, and finance. Educational facilities have not been included yet. Probably, as a result of this lack of guidance, EF accountings for university facilities vary substantially, much due to methodological differences, in particular in how some key variables are accounted.

As yet, proposed EF methodologies have concentrated in making the process of calculation as simple as possible, but in doing so, large amounts of information are discarded. In particular, the variability in the data supporting the calculations and the uncertainty inherent to the methodologies has been largely overlooked. In contrast to the classic deterministic approach, probabilistic evaluation of the EF is here proposed, with which much more information can be retrieved from the supporting data and be transposed to easily interpretable outputs. We focus on EF of educational facilities, in particular universities, but the method may be applied to any other human activity.

Due to the uncertainty, irreversibility and complexity that characterize global environmental problems, conservation messages are strengthened when people can use prior experience to assess new information, i.e., when inter-comparability is possible (Faucheux and Froger, 1995). Several authors have stated that in face of uncertainty, people increase the intertemporal flexibility of the decisional strategy, being more environmentally conservative (Borgonovo and Peccati, 2007; Vercelli, 1991), which plays in the same direction as the message conveyed by EF. Having these conclusions in mind, the following paragraphs will discuss how uncertainty analysis may contribute to strength EF message by explicitly quantifying the uncertainty about results and by providing a framework for inter-comparison of studies. Methods will be detailed for Monte Carlo simulations as the methodology here proposed does not require advanced statistical skills.

Our working question is: Is the ecological footprint of universities comparable? Or are the fundamental parameters in the model too different? In this article we state the hypothesis that uncertainty analysis can help in assessing the relevancy of parameters and in making the distinction between parameters. We test the hypothesis with a case-study similar to many others around the world, but we introduce in the analysis both epistemic and aleatory uncertainty and evaluate how these two sources of uncertainty can affect inter-comparison.

Uncertainty includes epistemic uncertainty and aleatory uncertainty. Though several other classifications have been proposed (Helton and Davis, 2003; Khuri and Mukhopadhyay, 2010; Myers, 1999; Saltelli and Marivoet, 1990; Shih et al., 2009), in general all agree about these two major divisions. Epistemic uncertainty is the scientific uncertainty about the model itself, namely on appropriateness to model a given problem, about the equation and its parameters, and about the modelling domain, boundary and initial conditions. All parameters are also subject to epistemic uncertainty as their measured values depend on decisions about data collection methods or data transformation. As a consequence, discussion about epistemic uncertainty relies on different perspectives of how the system should be represented and many times on what is it representing.

Epistemic uncertainty is related to model's strengths and weaknesses. Frequently mentioned strengths are (Rees, 2000): (i) it incorporates several defining qualities of ecological economics; (ii) is comparable to other measures of human impact, such as Ehrlich's and Holdren's (1971) definition of human impact on the environment, and human 'load' as defined by Catton (1980); and (iii) is conceptually simple and intuitive. The weaknesses of EF are Fiala (Fiala, 2008; Rees, 2000): (i) it does not capture the full range of ecologically significant impacts on the ecosphere; (ii) it over-simplifies nature and society, having little predictive value; (iii) is not dynamic modelling; and (iv) cannot be used for detailed forecasts; (v) cross-country comparisons of the ecological footprint rely on boundaries that are arbitrary, and thus potentially meaningless; (vi) arbitrariness of assuming both zero greenhouse gas emissions and national boundaries; and (vii) it is a measure of inequality as EF is strongly related to human development.

Some other problems have been referred due to incorrect implementation of EF, namely (Herendeen, 2000): (i) confounding sustainable and conventional (unsustainable) agriculture in calculating 'food land' – sustainable agriculture would require more land per unit of food, increasing EF; (ii) using the net CO_2 sequestering potential of an immature, successional forest as 'energy land', which can lead to both under and over-estimation of CO_2 uptake; (iii) considering only gross, not net, imports and impacts. This latter argument is particularly important when dealing with universities, which are activities inside a larger system (country), as it raises the problem of accountability: for instance, the atmospheric emissions made during the transport of staff, faculty and students between their place of residence and the university is a footprint of the university, or external to it? One may argue that emissions are an unavoidable consequence of its existence, in which case it should be accountable for. However, the decision about its location, transport network and residential park is usually a responsibility of the state, therefore a very significant share of the emissions is due to planning options over which the university has very little control. Then, should the university be made accountable for the emissions? Why not also account all emissions produced during the transport of other goods, such as food, paper, mail, from the energy needed to transport water, etc.? This also raises the problem of the arbitrariness of boundaries as referred by Fiala (2008): where is the system boundary? At the university walls/fence, or at some, to be defined, distance? One solution is to set the boundary at the fence and account in EF only what is effectively consumed internally. This is more in agreement with the concept of net EF as all impacts made between the production and transportation are attributed to the activity of third parties: the university accounts for EF of the production, irrespective of where it was produced. A more in depth discussion on the subject was made elsewhere (Frey, 1992).

The calculation of EF requires that a detailed mass and energy balance should be made for the activity, quantifying inputs and outputs that may have relevant impacts. The following consumption categories have been identified by authors for EF of universities (see references in Table 6): energy consumption for lighting and climatization, fuel for heating, consumption of water, paper, and food, emissions due to mobility (vehicle emissions), and built area. Production of wastewater has been either overlooked or treated together with the consumption of water (with many simplifications, namely by accounting only energy use, and not the emission of, e.g., methane and nitrous oxide). Wastewater treatment relative weight for the total EF has been indicated as equal to that of tap water production: Jenkin and Stentiford (2005) refer 0.004 ha/person for the first and 0.005 ha/person for the latter. Such a methodological simplification may be justified by the still very limited number of EF studies on the subject.

Aleatory uncertainty represents the diversity or heterogeneity in a well characterized population, refers to the natural variability of the process being evaluated, and unlike the epistemic uncertainty it cannot be reduced by further study or measurement. This is not to say that measurements are not necessary, quite on the contrary as the quantification of variability requires that a representative number of samples should be taken from the population.

Mathematical representations of both aleatory and epistemic uncertainties can be conceptualized as uncertain frequency distributions. With the proper methods one can propagate uncertainty through the model to estimate both aleatory and epistemic uncertainties in the output (Simon, 1999). Even though there are many alternative characterizations of uncertainty (e.g., possibility theory,