Ecological Indicators xxx (2015) xxx–xxx

Contents lists available at ScienceDirect

Ecological Indicators

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

Letter to the Editor

Local ecological footprint using Principal Component Analysis: A case study of localities in Andalusia (Spain)

ARTICLE INFO

Keywords:
Ecological footprint
Principal Component Analysis
Territorial disparities

ABSTRACT

The quantity and quality of available information is one of the major constraints for the calculation of the ecological footprint, particularly for sub-national or sub-regional territorial levels. At the national or even regional level, the information that allows for computing the ecological footprint is generally available. However, when trying to calculate the footprint for lower-level territorial realities (e.g., cities or municipalities), this information is insufficient or non-existent. In this article, we propose an indirect method for calculating the ecological footprint of such territorial spaces through Principal Component Analysis. The case study utilises the ecological footprint of Andalusia (a Spanish region) as a starting point for footprint assignment to each of the 771 municipalities included in the Andalusian region. A set of variables related to the consumption levels in these municipalities has been utilised and is expressed in physical units. These variables make it possible to obtain a weighting factor to determine the ecological footprint of each municipality. This procedure also makes it possible to identify which variables or indicators have the greatest impact on the ecological footprint for a given territory. According to the results, the method also shows how inappropriate it is to consider the population as a way to distribute the ecological footprint; there are relevant differences between the weight of the population in municipalities and their generated footprint. There are also significant differences between the magnitude of economic indicators, such as GDP, and the estimated ecological footprint; for municipalities with higher income levels, the ecological impact is more than proportional to the weight of the monetary indicators.

1. Introduction

In the context of the ecological footprint (hereafter EF), this article focuses on methodological aspects of its computation and applicability to a smaller scale than the national or regional level. The primary goal of this work is to provide a method to estimate the ecological footprint (EF) of territories where the standard methodology cannot be applied due to insufficient information. From an initial EF computed for a larger territory, we distribute this value among the smaller territories according to the resource consumption levels described through a set of variables or indicators.

This objective is essential and highly relevant because there are numerous places of high economic, social and environmental importance (e.g., urban areas and metropolitan areas) for which there is insufficient information for the direct calculation of the ecological footprint.

The following points describe complementary objectives of this work: (1) to further analyse the territorial disparity within the spatial units for which EF is calculated; (2) to identify the variables or indicators in each territory with the greatest impact on the EF; (3) to compare EF evolution with other indicators (e.g., GDP, occupied surface, population); and (4) to correlate the productive specialisation of a territory with the intensity of resource consumption expressed through the EF.

Various studies have tried to mitigate the limitations caused by the lack of information for the EF calculation, specifically for local and urban contexts. To provide an account of the *state-of-the-art* for such research, a number of the most relevant studies in this regard are discussed. The majority of the approximations applied to the estimation of the ecological footprint for local areas have been based on estimates of the state footprint that are weighted by the local population distribution (Folke et al., 1997; Wackernagel, 1998). As the authors have acknowledged, the main limitation of this procedure is the assumption of a homogeneous behaviour of the population across all the areas considered, when the calculation of the EF is really intended to discriminate or distinguish among the behaviours of populations in relation to resource consumption.

Other studies (Barrett et al., 2001; Pacholsky, 2003; Muñiz and Galindo, 2005; Jin and Yang, 2009; Li et al., 2010) utilised the component-based model[1] introduced by Chambers et al. (2000) as a different procedure to compute the EF, without renouncing the usage of the standard methodology. Such a procedure – according to their authors – has certain advantages compared with the

[1] "In the component-based model the ecological footprint values for certain activities are pre-calculated using data appropriate to the region under consideration. For example, to calculate the impact of car travel data on fuel consumption, manufacturing and maintenance energy, land take and distance travelled are sourced for the region in question – then an average ecological footprint estimate is derived for a single passenger-km or other appropriate unit... The aim is to account for the most consumption with a series of component analyses..." (Chambers et al., 2000:68–69).

http://dx.doi.org/10.1016/j.ecolind.2015.03.014
1470-160X/

standard approach (compound approach), it is easier to communicate and is more instructive. However, the "disadvantages can mainly be traced to problems with data variability and reliability, which make national and international comparisons problematic. Calculating the direct and indirect life cycle impacts is highly data-intensive – quite small changes in assumptions and data sources can lead to differing results. The need to carefully consider the life cycle effects of each component in detail is a definite barrier to widespread adoption of this method" (Chambers et al., 2000:69).

The method proposed here attempts to alleviate the above-mentioned limitations. On the one hand, the calculation of the ecological footprint for a territory of a larger size is based on a standard methodology. This approach ensures comparability. On the other hand, the variables included in the proposed method characterise the variations in the consumption patterns of the smaller scale local areas for which the EF is estimated. Thus, in this approach, the intensity of consumption is the weighting factor, instead of the population size.

The article is organised into five sections, including the introduction. The second section briefly reviews some methodological contributions and previous EF analysis studies; in particular, studies that refer to the local and urban scope and that are centred on specific contributions oriented to counteract the lack of information. The third section proposes a new EF computational methodology, the main point of this article. The fourth section discusses the main results of this paper. Finally, the fifth section summarises the most relevant aspects and presents the main conclusions.

2. Methodology

The research presented in this paper utilises Principal Component Analysis to estimate the scale of human activity in municipalities of Andalusia (see Appendix A).

The proposal is based on the EF computation for the whole Andalusian region. For this value, the authors have utilised the standard methodology (Wackernagel and Rees, 1998; Chambers et al., 2000; Network, 2011). This approach has been possible because the necessary information was available except for the trade balance in physical terms, which is necessary to determine apparent consumption. Regarding apparent consumption, the imports and exports in physical terms have been estimated based on monetary ratios provided by the Input-Output Tables of Andalusia. The computation of the Andalusian EF is not further developed here. Instead, what has been performed is an actualisation for the 2010 period of previously realised estimates described in previously published papers (Cano-Orellana, 2004, 2007, 2009).

Based on the regional EF, we try to spatially distribute this value among the 771 municipalities in the region (main objective or primary goal). Principal Component Analysis allows this distribution. The weighting factors (scores associated to each municipality of each component, Z_{hi}, in Appendix A) will be used to locally assign the EF. In our case, only one main component has been defined to explain most of the variance of the utilised variables (indicators of the consumption level).

The weighting factors account for the information in a set of consumption indicators (variables) quantified for each municipality. To the extent that these indicators best represent the consumption intensity in each spatial unit considered, the more reliable the EF assignment will be.

To select the consumption intensity indicators, a linear regression model has been applied, in which the indicators correspond to the independent variables. As a variable to be explained, any aggregate that reflects the total consumption in the considered spatial units could be used as a proxy variable. This method allows, in turn, as explained below, the identification of the degree of influence of these indicators or variables on the intensity of consumption for each spatial unit. Consequently, the value taken by the EF in each of the spatial units being considered can be computed.

For the case study in this paper, six variables or indicators of consumption have been used for each spatial unit (771 Andalusian municipalities): electricity consumption, urban solid wastes, vehicle stock, establishments, housing stock, and restaurants and hotels (bed-spaces). The expressiveness and representativeness of these variables has been proved adequate. The regression model has a determination coefficient of 0.9893 for a proxy variable corresponding to the municipality income (see Appendix B). The data have been obtained from the Institute of Cartography and Statistics of Andalusia.

This method also allows for a detailed analysis of the influence of indicators or variables on the weight of each municipality (see Appendix A, the "u" coefficients in Eq. (1)). As a consequence, it is possible to collect information regarding the effect of these indicators or variables on the EF of each municipality. This information might be relevant to guiding better management and sustainability planning.

3. Case study. Main results and discussion

The proposed methodology has been applied to a Spanish region, Andalusia, located in the south of the Iberian Peninsula (Lat: 38°44′ N, 36°00′ N; Long: 1°38′ W, 7°31′ W). It has a total area of 87,589.9 km^2 (17.3% of the national Spanish territory) and a population that corresponds to 17.9% of the Spanish population, as of 2011. The EF computation has been performed following the standard method, given that there is available data for this region. Once the EF was computed for the 2010 period, we applied the methodology described in Section 3 to estimate the EF for each of its 771 municipalities (main objective or primary goal).

The results obtained validate the proposed method in two ways. First, from a statistical point of view, the results are robust (see Appendix A). In second place, the method can be applied to similar cases of territorial units with existing standard EF calculations and composed of spatial units of smaller scale for which the standard EF cannot be computed.

Regarding the complementary objectives, given the methodological nature of this article, we briefly describe several of the most relevant aspects of the application of the method for illustrative purposes.

Fig. 1 shows the municipalities that exceed the average EF in Andalusia and the municipalities with EF values below the average. Clearly, the EF in Andalusia is unevenly distributed within

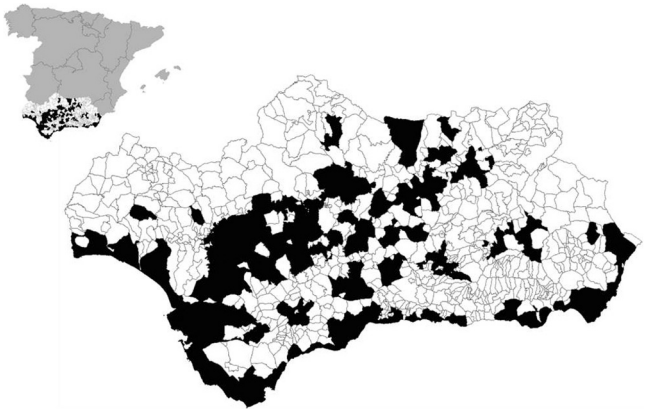

Fig. 1. Ecological footprint of the municipalities of Andalusia. Municipalities in which the EF exceeds the mean for Andalusia are coloured black.

Please cite this article in press as: Cano-Orellana, A., Delgado-Cabeza, M., Local ecological footprint using Principal Component Analysis: A case study of localities in Andalusia (Spain). Ecol. Indicat. (2015), http://dx.doi.org/10.1016/j.ecolind.2015.03.014