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A regional composite indicator for analysing agricultural sustainability in Portugal: A goal programming approach

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ABSTRACT

Sustainability in agriculture can be analysed using different types of indicators, but its quantification and aggregation into an index is still difficult. This paper proposes an approach based on goal programming to analyse sustainability at a regional level and generate a composite indicator. This approach uses several procedures in two main steps. In the first step, the weights of criteria are assigned based on the preferences of experts. In the second step, a binary extended goal programming (EGP) approach is applied to define the rankings of sustainability based on the composite indicator generated. This procedure is refined with the use of an entropy approach that overcomes difficulties already experienced by other authors. The results show that the proposed approach is an effective tool to generate composite indicators and provides an easy definition of several regional rankings of farm's sustainability at municipality level.

1. Introduction

Society considers agriculture an important way to supply environmental, social and economic goods, which are essential for human survival and well-being (Hajkowicz et al., 2009, p. 221) i.e. agriculture is an essential partner in sustainable development. Therefore, analysing the sustainability of agriculture is an important issue, namely when assessing agricultural and environmental policies (Reig-Martíınez et al., 2011). In Europe, the Common Agriculture Policy (CAP) reforms had several impacts in different agricultural systems through the years (Fragoso et al., 2011), influencing their sustainability.

Sustainability is a widely used concept, which gained popularity after the Brundtland Report that defined sustainable development as '*the development that meets the needs of the present without compromising the ability of future generations to meet their own needs*'. In the last decades, the sustainability measurement of natural systems has become of the utmost importance, despite the lack of consensus about how to address this problem (Diaz-Balteiro and Romero, 2004a, p. 401).

The landscape complexity analysis is essential for landscape management at large scales (Papadimitriou, 2012a,b) and is one of the main priorities in landscape ecology emphasizing the importance and complexity of sustainability concept (Papadimitriou, 2012b). Papadimitriou (2012c) presents a method to evaluate the algorithmic complexity of landscapes based on the notion of Kolmogorov complexity, while Papadimitriou (2013) develops three new measures of functional/hierarchical landscape complexity.

Most approaches use indicators to measure sustainability, but these tools continue to present operational problems, namely in what concerns agricultural sustainability quantification (Gómez-Limón and Sanchez-Fernandez, 2010).

A composite indicator may simplify the analysis and allow comparisons. According to Singh et al. (2012), sustainability indicators and composite indexes are being increasingly recognized as a powerful tool for policy making, providing information on countries performance, conceptualizing phenomena and simplifying complex information. Therefore, composite indicators are useful tools for policy makers, analysing information on countries performance in different areas (KEI (2005); Singh et al., 2012).

The development of composite indicators involves the selection of various techniques at different stages of development process, which may result in various issues of uncertainty (Singh et al., 2012). These authors make a deep review of the sustainability assessment methodologies and present some key aggregation methods regarding composite indicators, which include Principal Components Analysis, Factor Analysis, distance to targets, expert's opinion and Analytic Hierarchy Process. Diaz-Balteiro and Romero (2004a) highlight that the crucial

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problem for ecological economics consists on the aggregation of different individual indicators into an index and present several methodological considerations. Singh et al. (2012) and Gómez-Limón and Sanchez-Fernandez (2010), focusing particularly in agriculture, present also an analysis of several composite indicators calculus' approaches.

Therefore, several examples of studies using composite indicators for analysing sustainability may be identified in different areas of research. Singh et al. (2007) present a composite performance index for analysing the steel industries. Pérez et al. (2013) evaluate the sustainability of nature-based tourism destinations, using Principal Component Analysis, the distance to a reference point, and Data Envelopment Analysis. Sabia et al. (2016) use a composite indicator to rank the efficiency of wastewater treatment plants.

Another key question is the identification of policy goals for sustainability. Consideration of sustainability goals and their relation with selected indicators is also a difficult task, which becomes more difficult when measured in several dimensions and aggregated into a single value (Kuik and Gilbert, 1999; Singh et al., 2012).

The consideration of several goals and a considerable number of indicators can be dealt with Multicriteria Decision Analysis (MCDA) (Diaz-Balteiro and Romero, 2004a,b) that revealed promising results, providing additional/complementary information.

Previous studies addressed the creation of an agricultural sustainability composite indicator using MCDA techniques. Diaz-Balteiro and Romero (2004a) used these methods for creating a sustainability index and Diaz-Balteiro and Romero (2004b) implemented an Extended Goal Programming (EGP) approach to analyse the sustainability of forest management. Gómez-Limón and Riesgo (2008) analysed several methods to construct composite indicators for agricultural sustainability and Gómez-Limón and Sanchez-Fernandez (2010) applied several ways of constructing composite indexes, presenting also multicriteria approaches. Reig-Martínez et al. (2011) use data envelopment analysis and MCDA for ranking farms' sustainability. Voces et al. (2012) analysed the sustainability of European wood manufacturing industries using EGP with binary variables. Diaz-Balteiro et al. (2011) used a compromise programming approach for analysing the sustainability of paper industry in different EU countries. Xavier et al. (2015a) developed a methodology for analysing agricultural sustainability in Portugal considering national goals and using Extended Goal Programming (EGP). These authors also proposed a general approach using entropy for perfecting the ranking in cases in which the analysed units have similar values.

MCDA approaches that use extended goal programming (EGP) are interesting when dealing with different goals since EGP will allow considering several relevant goals for each indicator, defining not only the most aggregate sustainability ranking but also the most balanced one. Nevertheless, neither of these approaches developed specific sustainable composite indicators considering regional goals for different regions, using this innovative EGP methodology.

Thus, the objective of this paper is to propose an approach based on EGP methods to analyse agricultural sustainability at a regional level and generate a composite indicator. In addition, several procedures were carried out to implement the methodological approach automatically and in an effective way. Therefore, the main contributions of this study are the proposed methodology based on EGP for regional analysis and a way of developing quickly and in an effective way a ranking definition process. Additionally, this approach introduces entropy to overcome difficulties already experienced by other authors and solve situations of equal ranking position. In order to illustrate the proposed approach an application to the nine agrarian regions of Portugal is provided.

The remainder of this paper is presented as follows: in Section 2 the methodological approach is presented; in Section 3 the empirical implementation is analysed; in Section 4 the results are presented. Finally, in Section 5 the discussion is made and the main conclusions of this work are presented.

2. Methodological approach

Despite some general consensus about the definition of "sustainable agriculture" (Gómez-Limón and Sanchez-Fernandez, 2010), agricultural sustainability is a concept that has a huge complexity within. Based on the concept of Brundtland, we consider agricultural sustainability as the use of lands or other agricultural resources in a way and at a pace that preserves the biodiversity, productivity, vitality, and the potential to fulfil, now and in the future, relevant ecological, economic and social functions (Xavier et al., 2015a).

Considering the definition of sustainability presented, which will guide the selection of indicators, the methodological approach allows not only to define the weights regarding each indicator but also a more perfect set of rankings.

For defining the weights to be assigned to each indicator, there are several studies that use group decision methods, reviewed by Diaz-Balteiro and Romero (2008). Pairwise comparison is a good approach for defining the relative importance of several criteria (González-Pachón and Romero, 2007; Xavier et al., 2016). One of the most used techniques is the analytical hierarchical process (AHP), which is based on the human ability to estimate relative magnitudes through pairwise comparisons. (Nivolianitou et al., 2015; Xavier et al., 2016). These pairwise comparisons can then be aggregated by the geometric mean method or the weighted arithmetic mean method (González-Pachón and Romero, 2007).

An approach using EGP for the aggregation of "pairwise" comparison matrices was developed by González-Pachón and Romero (2007) and implemented by Diaz-Balteiro et al. (2009), Nordström et al. (2009), Xavier et al. (2013, 2015a). Xavier et al. (2015a) used it to define the weights of a composite sustainability indicator. This approach presents a relevant number of advantages: 1) It allows dealing with situations without satisfactory conditions regarding reciprocity and consistency; 2) It has a low computational burden; 3) It allows considering in the analysis the majority and minority consensus.

The methodological approach proposed in this paper to create the composite indicator and the municipalities' regional rankings uses an EGP approach, according to Xavier et al. (2015a), and comprises several steps of implementation (Fig. 1):

1) In a first step, the criteria weights attribution is made based on experts' opinions, which express their preferences through pairwise comparisons (Saaty, 1980). The preferential criteria weights are derived from pairwise comparisons and using EGP.
2) In a second step, a binary extended goal programming (EGP) approach is applied to define the rankings of sustainability. When there are territorial units with the same values in the ranking, a further step using an entropy approach can be implemented.
3) In a third step, the spatial indicators and rankings patterns are analysed using a Geographic Information System (GIS).

2.1. Definition of the individual indicators' weights

To define the individual indicators' weights a method proposed by González-Pachón and Romero (2007) and implemented by Xavier et al. (2015a) in this field of research is used. This method allows the aggregation of pairwise comparison matrices using the preferences scale of Saaty (1977). The objective is to obtain a consensus ratio mc_{ij} that quantifies the aggregated judgment when the *ith* criterion is compared with the *jth* criterion and then to derive the consensus w_i preferential weight attached to the *ith* criterion (Diaz-Balteiro et al., 2009). To do this the following EGP formulation was used:

$$Min_{Par} = (1-\lambda)D + \lambda\left[\sum_{s=1}^{S}\sum_{i=1}^{I}\sum_{\substack{j=1\\ j\neq i}}^{I}(p_{ij}^{s} + n_{ij}^{s})\right]\lambda \in [0,1] \quad (1)$$