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Joint carbon footprint assessment and data envelopment analysis for the reduction of greenhouse gas emissions in agriculture production

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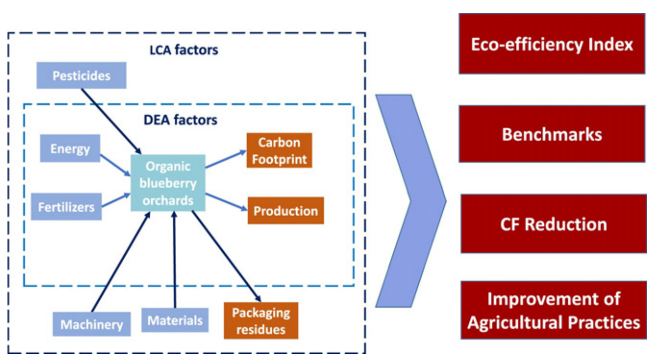
HIGHLIGHTS

- Joint use of carbon footprint (CF) assessment and Data Envelopment Analysis (DEA)
- Assessment of eco-efficiency with DEA output oriented models
- Eco-efficiency analysis with undesirable outputs
- New procedure for changing factors contributing to CF
- Improvements of eco-inefficient agricultural practices

GRAPHICAL ABSTRACT



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ABSTRACT

Operations management tools are critical in the process of evaluating and implementing action towards a low carbon production. Currently, a sustainable production implies both an efficient resource use and the obligation to meet targets for reducing greenhouse gas (GHG) emissions. The carbon footprint (CF) tool allows estimating the overall amount of GHG emissions associated with a product or activity throughout its life cycle. In this paper, we propose a four-step method for a joint use of CF assessment and Data Envelopment Analysis (DEA). Following the eco-efficiency definition, which is the delivery of goods using fewer resources and with decreasing environmental impact, we use an output oriented DEA model to maximize production and reduce CF, taking into account simultaneously the economic and ecological perspectives. In another step, we stablish targets for the contributing CF factors in order to achieve CF reduction. The proposed method was applied to assess the eco-efficiency of five organic blueberry orchards throughout three growing seasons. The results show that this method is a practical tool for determining eco-efficiency and reducing GHG emissions.

1. Introduction

The Operations Research/Management science can provide models and tools to aid, evaluate and implement actions towards a more sustainable production (Gonzalez et al., 2015). In the area of the environmental sustainability, the literature shows several examples about the

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application of operations management to food or agricultural systems. For example, Soto-Silva et al. (2016) presented a review on operational research models applied to the fresh fruit supply chain; de Mol and van Beek (1991) developed a decision support system to optimize the application of manure on farms; Accorsi et al. (2016) presented a design framework, using a linear programming model that supports strategic decision-making on agriculture and food distribution issues while addressing climate stability; and Kubota and Cantorski da Rosa (2013) applied the theory of inventive problem solving to solve cleaner production problems, identify and develop opportunities within the Brazilian dairy industry and serve as an innovative tool to search for ways to improve environmental efficiency.

Fruit farming, as does other agricultural production, has a wide range of sustainability implications and environmental impact, including contribution to greenhouse gas emissions (Page et al., 2011); energy use (Girgenti et al., 2013); water consumption (Núñez et al., 2013); land conversion and the associated loss of biodiversity (Vitousek et al., 1997) and use of pesticides, herbicides and fungicides (Cross and Edwards-Jones, 2006; Mamy et al., 2010). Moreover, consumers in developed countries demand safe food of high quality that has been produced with minimal adverse impacts on the environment (Falguera et al., 2012; König et al., 2010; Styles et al., 2012; Vázquez-Rowe et al., 2013).

Among the environmental impacts, the increase of greenhouse gas (GHG) emissions in the atmosphere has emerged as the most pressing global environmental problem. Several activities associated with fruit production contribute to GHG emissions, for example, energy consumption by farm machinery; production and application of fertilizers and production of growth regulators. The task of calculating the GHG emissions of a product can be approached methodologically with the carbon footprint (CF) tool. The tool allows estimating the overall amount of GHG emissions associated with a product or activity across its life cycle (BSI, 2011; Wiedmann and Minx, 2008). The CF is a subset of the indicators covered by the Life Cycle Assessment (LCA) methodology (EPLCA, 2007). The LCA evaluates the potential environmental impact of products and services throughout the supply chain, gathering inputs and outputs of a product system (life cycle inventory phase) and employing an impact assessment step. The LCA can be used as a decision support tool for authorities and companies and it has been applied over a wide range of agricultural studies. For example, Blengini and Busto (2009) verified the environmental impact of the rice processing chain in Vercelli, Italy; Strano et al. (2013) used this tool to assess the production of wine grapes; Lo Giudice et al. (2013) quantified the environmental impact in the production of red orange, while Keyes et al. (2015) used LCA to characterize the environmental performance and identify potential opportunities for improvement related to systems of conventional and organic apple production from Nova Scotia, Canada.

In a situation where data are available for multiple similar products/systems, the life cycle inventories of a LCA study often present high variability, a fact that could result in important differences. In this situation, two solution choices are common. The first is to use an average inventory and in this situation, it is important to quantify this variability. The second is to carry an individualized inventory. In this case, a second tool such as Data Envelopment Analysis (DEA) would be useful to carry out a data analysis to interpret the results. DEA is a non-parametric tool that uses linear programming to evaluate the efficiency of organizational units, called Decision Making Units (DMUs). In general, DEA models are oriented to inputs or to outputs. Input oriented models seek to minimize the inputs (resources) while maintaining the outputs constant. On the other hand, output oriented models aim to maximize all outputs (outcomes of the process) while maintaining the inputs constant. DMUs used in the analysis are homogenous in the sense that they use the same multiple resources, called inputs, they produce the same multiple products, called outputs, and they work under similar conditions (Dyson et al., 2001). A DMU is efficient if its score is 1 and inefficient otherwise. Besides the efficiency scores, targets and benchmarks for inefficient units are set in order to become efficient. DEA has been applied to different areas of agricultural production using variables such as energy, labor, machinery, fuel, chemicals, fertilizers, irrigation water, electricity (Chauhan et al., 2006; Khoshnevisan et al., 2013; Mohammadi et al., 2011; Mousavi-Avval et al., 2011). For example, Khoshnevisan et al. (2013) studied the energy efficiency of greenhouses for cucumber production, while Mohammadi et al. (2011) analyzed this factor in kiwifruit grown in Iran. Both studies calculate different types of efficiency, such as technical, pure technical, scale and cross efficiency based on DEA models.

The joint implementation of LCA and DEA can assess the operational and environmental performance of multiple units. The LCA + DEA approach avoids the use of average inventory data and enriches result interpretation through eco-efficiency verification (Iribarren et al., 2010). Furthermore, LCA + DEA provide quantitative benchmarks that direct the performance of any system towards environmental sustainability. In addition, this recent approach has the advantage of detecting and changing technical inefficiencies that are the source of unnecessary environmental impact. There are few examples where the LCA + DEA approach has assessed agricultural systems. Vázquez-Rowe et al. (2012) analyzed the operational and environmental performance of grape cultivation in Spain; eighty-two rice paddy fields for spring and summer growing seasons in northern Iran were assessed by Mohammadi et al. (2014); Khoshnevisan et al. (2015) used LCA, DEA and multi-objective genetic algorithms in the evaluation of watermelon producers, while the study of Ullah et al. (2015) analyzed eco-efficiency indicators in a set of cotton cropping systems in Pakistan.

Recently, the CF + DEA approach was proposed by Vázquez-Rowe and Iribarren (2015) as a combination of CF and DEA to benchmark operational and environmental performance in terms of GHG emissions in energy entities. As mentioned by the authors, the use of CF + DEA arises as an adequate tool to highlight the environmental benefits associated with GHG emission reductions through the minimization of operational inputs and, although this approach was presented for energy systems, it can also be applied to other sectors.

To the best of our knowledge, we have not found LCA + DEA or CF + DEA studies associated to agricultural systems that use DEA models oriented to the maximization of production and, at the same time, to the reduction of environmental impacts, considering the latter as undesirable outputs. In the literature, previous works deal with the environmental impacts as inputs that must be minimized. Besides, we have not found, among the LCA + DEA or CF + DEA studies, research that allows evaluating a small number of DMU, only in the specific DEA papers.

Given the above, in this study we use only one environmental indicator, CF, as was done by Vázquez-Rowe and Iribarren (2015) and we present a modified version of a LCA + DEA method proposed by Lozano et al. (2009) to estimate GHG emission reduction in agricultural production according to DEA efficiency results and benchmarks. In this sense, we propose an approach with four steps as we determine the CF, use DEA output oriented models with undesirable outputs to assess the efficiency, benchmarks and output targets (CF and production), and based on CF targets estimate the variations in the factor levels that contribute to CF. Different from previous researches, we use output oriented models considering simultaneously the economic and ecological perspectives of eco-efficiency definition. In order to illustrate this modified approach, we use data from organic blueberry orchards in Chile. Chile is the second largest blueberry producer and exporter worldwide. Moreover, organic blueberries rank as the second most important organic fruit export in Chile (SAG, 2013). The obtained results allow us to perceive this approach as a useful tool to support farmers' and policy makers' decisions towards a low-carbon production.

2. Materials and methods

In Section 2.1, we present a brief literature review of LCA + DEA with the two existing approaches focusing on case studies in agriculture