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Joint life cycle assessment and data envelopment analysis of grape production for vinification in the *Rías Baixas* appellation (NW Spain)

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ABSTRACT

An important percentage of European wine appellations base their production on a broad number of vine-growers that annually sell their grapes to the wineries under the specific Denomination of Origin. Hence, the use of average values for the environmental evaluation of this type of multiple datasets can create large standard deviations that may impede an adequate interpretation of the results. Combined implementation of Life Cycle Assessment (LCA) and Data Envelopment Analysis (DEA), known as LCA + DEA methodology, has proven to be a suitable tool for assessing multiple input/output data in several agri-food systems, such as aquaculture, farming or fisheries.

In the current study, a total of 40 vine-growing exploitations belonging to the *Rías Baixas* appellation (NW Spain) were analyzed following LCA + DEA methodology in order to determine the level of operational efficiency of each producer. Furthermore, potential reductions in the consumption levels of the material inputs were benchmarked, while calculating the environmental gains linked to these reduction targets, thus verifying eco-efficiency criteria. Results led to average reduction levels of up to 30% per material input, which translated into environmental gains that ranged from 28% to 39% depending on the selected impact category. Additionally, a super-efficiency analysis led to identify the best performing units, which were used as a source of reference values for environmental impacts. Finally, potential economic savings of 0.14 € per functional unit (i.e., 1.1 kg of grapes for the production of a common 750 ml bottle of wine) were estimated on the basis of efficient vine-growing practices.

1. Introduction

Southern European countries, such as Italy, France or Spain have traditionally been the main producers of grapes for vinification at a worldwide scale. Nevertheless, in recent decades there has been a continuous trend aiming at improving the quality, while reducing the global productions in these countries (OIV, 2010). In fact, surface area of vineyards has decreased in Europe at a much faster rate than in the rest of the world for the last 25 years, while appellations (also named Designations of Origin, DO) have nearly tripled since 1980 (FAO, 2011). These trends have occurred under the current globalization of agri-food products worldwide, generating a gradual modification of the wine production process. In this respect, pressure from governments and consumers has increased within the European Union (EU) in order to improve the environmental profile of wine production (Renaud et al., 2010). Environmental sustainability in the wine sector arises therefore as a major goal to be reached by the different actors involved in the wine supply chain (Forbes et al., 2009; Gabzdylova et al., 2009).

In this context, Life Cycle Assessment (LCA) is a well-known methodology that has been used for the environmental evaluation of a wide range of food and beverage products (Garnett, 2008). More specifically, in recent years LCA has been applied to analyze the wine sector in a variety of countries, such as Spain (Aranda et al., 2005; Gazulla et al., 2010; Vázquez-Rowe et al., 2012), Italy (Benedetto, 2010; Bosco et al., 2011; Notarnicola et al., 2003; Pizzigallo et al., 2008) or Canada (Point et al., 2012). LCA studies in this field have focused not only on the final product (i.e., wine), but also on process wastes (Ruggieri et al., 2009) and even on specific wine-related components such as cork stoppers (Rives et al., 2011).

Published LCA studies on wine production have highlighted the importance of obtaining significant on-site data for the processes included in the system (Petti et al., 2010). However, a great number of appellations in Europe base their grape production phase on a broad number of vine-growers that annually sell their grapes to the wineries under the specific DO. This situation makes environmental evaluations on viticulture (i.e., vine-growing) complicated

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since multiple data for multiple facilities have to be handled. The use of average values for this type of multiple datasets usually entails large standard deviations that may impede an adequate interpretation of the results (Reap et al., 2008a; Weidema and Wesnaes, 1996). In other words, the use of average inventory data when analyzing a multiple set of vine-growing plantations is likely to be subject to important data variability, distorting the individual performance of each of the assessed vineyards.

In order to face the assessment of multiple input/output data for a large number of similar entities, the joint application of LCA and Data Envelopment Analysis (DEA), known as LCA + DEA methodology, has been proposed as a valuable tool that avoids standard deviation concerns, while providing a detailed operational and environmental analysis of the sample (Iribarren, 2010). While LCA addresses the evaluation of the environmental aspects and potential impacts associated with a product (ISO, 2006a, 2006b), DEA is a linear programming methodology to quantify the comparative productive efficiency of multiple similar units (Cooper et al., 2007; Sarkis and Weinrach, 2001). LCA + DEA methodology has already proven to be a suitable tool for assessing multiple datasets in aquaculture (Iribarren, 2010; Lozano et al., 2009, 2010), fisheries (Vázquez-Rowe et al., 2010, 2011) and dairy farms (Iribarren et al., 2011).

The goal of the current study was to apply LCA + DEA methodology over a relevant number of Galician vineyards belonging to the *Rías Baixas* appellation, in the *Salnés* region (NW Spain; capital: Vilagarcía de Arousa, 42°35′N 8°46′W). The *Rías Baixas* wine sector contributed to 0.2% of the Galician GDP in 2010, accounting for ca. 100 million € (Xunta de Galicia, 2012). The analysis was conducted in order to (i) detect operationally inefficient grape cultivation plots, (ii) benchmark target input consumption levels for the inefficient vineyards, (iii) quantify the environmental benefits of moving towards operational efficiency in vine-growing, proving the eco-efficiency hypothesis, that is, that a reduction in input consumptions reduces potential environmental impacts, (iv) estimate the economic gains brought about by efficient operational practices, and (v) identify the best functioning vineyards to be used as operational and environmental references. The results from this study are expected to be of interest for a wide range of professionals, including LCA practitioners, researchers in the field of agriculture, policy makers and vineyard managers.

2. Materials and methods

2.1. Definition of the case study

2.1.1. Contextualization of the study

As in most Mediterranean countries, Spanish wine production is a key subsector within the agricultural sector. Galicia, a wet Atlantic region in northwest Spain, only accounts for 2% of the total land destined to grape cultivation in Spain. Despite this relative low importance, a series of Galician wines, such as *Rías Baixas*, *Ribeira Sacra* or *Ribeiro* have acquired international renown over the years. In particular, *Rías Baixas* DO accounts for a total of 3814 ha of cultivated land, administered by 6584 individual vine-growers and scattered in five distinct subzones across the province of A Coruña and Pontevedra (DO *Rías Baixas* Regulatory Council, 2010).

Vineyard exploitations in Galicia, unlike in other Spanish regions, are characterized by their small average size (0.58 ha/vine-grower) (DO *Rías Baixas* Regulatory Council, 2010). Nevertheless, these smallholdings show a high variety of sizes, as well as geographical dispersion (Lloveras-Vilamanya, 1987). In fact, *Rías Baixas* wine is produced based on grape production arriving from 5 different valleys. However, only vine-growers belonging to the *Salnés* valley, which is the most important one – 56% of the total production according to the DO Rías Baixas Regulatory Council (2010) –, were included in this study. Vineyards did not correspond to a compact plot of land in a given area, but to scattered vine-growing plantations throughout the entire valley.

2.1.2. Definition of the unit of assessment

Each homogenous entity whose input/output conversion undergoes assessment is named Decision Making Unit (DMU) or unit of assessment. The units of assessment chosen for this particular study consisted of a set of vineyards in the selected appellation. Any vineyard not included within the appellation was disregarded. Fig. 1 depicts the input/output conversion process in each vineyard, summarizing the input and output flows subject to quantification for each of the DMUs. Moreover, since DEA only involves a selection of the inputs and outputs in an LCA study, DEA and LCA elements are differentiated in Fig. 1.

LCA inputs show a thorough identification of the operational and environmental aspects of the inventoried vineyards, following an attributional LCA perspective. Primary data were collected through face-to-face questionnaires answered by a set of vine-growers in the *Salnés* valley (capital: Vilagarcía de Arousa, 42°35′N 8°46′W). These questionnaires involved key operational aspects of the vineyards, such as fertilization, pesticide use, vineyard operations, machinery, water use or the infrastructure of the vineyard. LCA outputs comprised not only the cultivation of grapes for wine production, but also waste generation as well as direct emissions associated with fuel consumption, fertilizers and pesticides.

DEA embraced exclusively those inputs and outputs that are expected to generate relevant environmental and/or economic impact. Consequently, input and output amounts as well as prices and expected impacts per input/output unit were taken into account (Benedetto, 2010; Bosco et al., 2011; Gazulla et al., 2010; Notarnicola et al., 2003; Vázquez-Rowe et al., 2012). Diesel, water, fertilizers, pesticides and concrete for infrastructure were selected as the DEA inputs, whereas commercial grapes were the unique DEA output. All the selected operational items for DEA implementation were assumed to be independent from each other. Therefore, occupied land was not included since its minimization would affect other inputs, such as fertilizers or diesel. Similarly, direct emissions to the different compartments were not included in the DEA matrix, given their direct proportion to some of the inputs included in the matrix. Hence, these emissions were indirectly minimized through direct minimization of the associated inputs (Lozano et al., 2009; Vázquez-Rowe et al., 2010). Future research on this topic could consider the inclusion of labor as an additional DEA input to provide the study with a stronger socio-economic dimension.

Despite the fact that wine is not the only product derived from winery transformation, grapes are the only product that is acquired from the cultivation phase, since all by-products are obtained once the grapes are delivered at the winery. Consequently, since a monofunctional system is involved, no allocation procedure was needed to distribute inventory data and environmental burdens.

2.2. LCA + DEA framework

Operational and environmental patterns in vine-growing in the *Rías Baixas* appellation were assessed according to the five-step LCA + DEA method (Iribarren, 2010; Vázquez-Rowe et al., 2010), outlined in Fig. 2. The first stage of the methodology (step A) is based on data collection for the life cycle inventory (LCI) of each individual vineyard. Thereafter, the life cycle impact assessment (LCIA) for every vineyard is performed based on the LCI developed in the first step, constituting the environmental characterization of