Revisiting the LCA + DEA method in fishing fleets. How should we be measuring efficiency?

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ABSTRACT

Life Cycle Assessment and Data Envelopment Analysis have been repeatedly combined in the literature as LCA + DEA method with the aim of enhancing the utility of life-cycle based methods in order to account for eco-efficiency verification and environmental impact minimization. Despite its evolution through time, it lacks specific standards that norm the combination of the two methods. In this sense, this study noted that its development has evolved in the frame of mainstream cultural perspectives to measure environmental impacts (i.e., hierarchist approaches). Therefore, the main objective of the study is to compare the benchmarking results obtained through DEA computation using different Cultural Theory approaches to calculate environmental impacts. For this, a case study for the Cantabrian purse seining fishing fleet was chosen. Hence, three different DEA matrices were constructed attending to the three main human visions on environmental issues: hierarchist, individualist and egalitarian. All three matrices represented the same set of inputs to be optimized, but differed in the nature of the output flow, representing landed fish, energy content or biomass removal. Results suggest that optimization of environmental impacts is strongly influenced by the cultural perspective selected. In the particular case of fishing fleets, benchmarking environmental impacts based on anthropocentric views may be ignoring the health of fishing stocks and the trophic complexity of the ecosystems. Methodological conclusions are directed towards the need to define more flexible and holistic frameworks in LCA + DEA modelling with the aim of enriching the set of predetermined assumptions, including the Cultural Theory, to avoid biased interpretations.

1. Introduction

Fish managers have relied on observation and research in past decades to face the challenge of improving the sustainability of dwindling fish stocks in European fisheries [1,2]. This has led to the definition of a complex fisheries management system which is imposed through relatively strict quota systems to control landings of the main fish species, as well as the development of legislation to adapt the amount and capacity of fishing vessels in fleets to the available fish stocks [3]. Based on this scenario, numerous studies have dealt with improving the performance of fishing fleets in terms of technical efficiency and capacity [4]. In this context, the Food and Agricultural Organization of the United Nations (FAO) determined that Data Envelopment Analysis (DEA), a non-parametric linear programming method to analyze the efficiency of multiple-unit systems, constitutes an adequate method to evaluate fishing capacity [5].

Nevertheless, recent studies have also been developed in terms of ensuring that efficiency is also achieved from an environmental sustainability perspective [6], based on the assumption that vessels can lower the operational inputs and, therefore, reduce the environmental impact of their activities, while maintaining the same catch levels [6–8]. For this, DEA has been combined with Life Cycle Assessment (LCA), an internationally standardized methodology that identifies the environmental impacts that are generated through the life-cycle of supply chains [9].

LCA has been repeatedly used in fisheries and seafood supply chains for over a decade as an important mechanism to elongate the current shift from single-species stock assessment to ecosystem-based frameworks, by including additional environmental impacts at a global scale, such as global warming or depletion of abiotic resources [10,11]. Given its holistic nature, integrating a wide range of environmental burdens that are characterized in impact categories, it has been shown to be an adequate decision support tool in fisheries [12]. However, LCA has shown certain limitations when it comes to monitoring the environmental performance of multiple units that present the same function. Therefore, the so-called LCA + DEA method has been developed to
expand the utility of life-cycle based methods in order to account for eco-efficiency verification and environmental impact minimization across complex sectoral systems [9].

The LCA + DEA method, when applied to fisheries, has traditionally undergone an input-oriented approach, with the aim of reducing the reliance on energy and raw materials while maintaining landings. Nonetheless, this minimization has mostly been based on a perspective in which the round fresh landings are considered on the basis of their gross mass weight [6,13], and occasionally considering the economic revenue linked to these landings [8]. However, the present study argues that minimization of operational inputs in LCA + DEA studies may deserve further analysis in terms of the output that is used for the optimization. In other words, this minimization can be interpreted in different ways depending on what is considered the main output of the production system. For instance, it could be argued that the main function of fishing vessels may not be to maintain the level of gross weight landings, but to maintain or optimize the economic revenue, the gross energy or the protection of marine biodiversity.

Consequently, the main aim of this research article is to understand how different perspectives on how to generate operational benchmarks for fishing fleets using the LCA + DEA method can alter the final results obtained and their interpretation. More specifically, these varying approaches will focus on how input/output material and energy flows are managed in the combined method, with the main objective of not only informing on eco-efficiency considerations, but also on sustainable scale-oriented environmental management through the identification of adequate biophysical flows. For this, the selected case study was a group of 32 fishing vessels that represent ca. 80% of the anchovy fishery in the region of Cantabria (Spain). These multiple units form part of a relatively homogeneous fleet/fishery fulfilling the purpose of landing fish species from the Cantabrian Sea stock, which is thereafter destined mainly to direct human consumption (DHC). The results of the study are intended to be of utility for fish managers, as well as for LCA and DEA practitioners seeking new approaches to improve the assessment of eco-efficiency and sustainability in fishing fleets.

2. Materials and methods

2.1. Benchmarking objectives of LC + DEA methods

When multiple inventory data are available in a life-cycle (LC) oriented study, a common solution is to establish an average inventory which includes the average values for the different inputs and outputs. Nonetheless, the high degree of variability reported by standard deviations is an important barrier [6]. While this approach is useful for many purposes, it poses problems to communicate the specific actions that individual units could implement to foster their environmental efficiency. To deal with this problem, the use of DEA allows quantifying in an empirical manner the comparative productive efficiency of multiple similar entities named Decision Making Units (DMUs) [14].

Current LC + DEA methods for the benchmarking of multiple DMUs can be divided into two main blocks: those that are focused on the benchmarking of environmental indicators, and those that provide benchmarks through the computation of energy methods [9]. Regarding the former, the joint application of the LCA + DEA method carries a series of synergistic effects related to the link between operational efficiency and environmental impacts.

On the other hand, the available energy LC + DEA methods can be classified according to their anthropocentric or ecocentric perspective. Anthropocentric alternatives include cumulative energy demand (CED) and cumulative exergy demand (CEDxD) coupled with DEA. These methods essentially evaluate the cumulative use of natural resources by considering their energy or exergy contents (user-side perspective). Ecocentric approaches consider the emergy (Em) concept, which is an approximation of the solar energy previously provided to generate a product and/or to support a system and its level of organization [15].

Moreover, emergy evaluates the resources according to the total (solar) energy involved in their formation [16]. All these energy LC + DEA methods involve similar steps, but different techniques to analyze the life cycle inventory (LCI) data in energy terms.

More specifically, it has been noted that the function that is described in LCA + DEA case studies tends to stick to an anthropogenic perspective of supply chains, prioritizing the market exchange that occurs (e.g., maximization of economic revenue, productivity, production, or minimization of operational inputs), with a myopic view of the underlying environmental flows that are engendered. The choice of a particular perspective provokes inevitable uncertainties in LCA studies. Assumptions can derive from lack of knowledge, whereby the choice of one option over another can be influenced by personal beliefs and values that reflect what we care about [17].

Within LCA, the Cultural Theory developed by the anthropologist Mary [30] has been used to define different modelling scenarios, as it reflects both visions of society and views on nature. This theory established that there are five existing “ways” of life or cultural theories to face environmental problems such as climate change, namely the individualist, the hierarchist, the egalitarian, the hermit and the fatalist. Each perspective reflects a hypothetical stakeholder or decision maker with a specific set of preferences and contextual values. The stereotypical individualist is a self-made person, free from control by others, who strives to impose order on his or her environment. Generally, they tend to oppose “top-down” interventions by the state or any other authority, preferring instead personal responsibility and freedom of choice. Hierarchists prefer to regard nature as tolerant within definable limits, which can be manipulated by incorporating ecological principles into all management approaches and accounting techniques. This perspective coincides with the view that impacts can be avoided with proper management, seeking a balance between manageability and the precautionary principle. Egalitarians regard the fragility of nature as part of their reason for existence. This vision gives high priority to the precautionary principle and equal importance to present and future effects. Fatalists tend to see nature as a lottery, opening and closing options and acting in unpredictable ways. Finally, hermits, also referred to as autonomists, escape any influence from society or social level and detach from what happens in the world [18]. Van Asselt and Rotmans [19] proposed to use these ethical attitudes to investigate alternative model routes for decision-making. In general, it is assumed that only the first three perspectives play part in environmental decision-making and, thus, LCA: the individualist, hierarchist and egalitarian perspectives. Both fatalist and hermit perspectives were excluded because they cannot systematically be described by any characteristic function and, moreover, they are considered to have marginal or no influence in environmental decision-making. The Cultural Theory is attractive to be applied in LCA, as it both reflects visions on society and views on nature and aids in the interpretation of results whenever trade-offs throughout environmental indicators are evident. In fact, several studies applied the Cultural Theory in life cycle thinking, showing the practicability of the approach [20–22].

Based on the existing LC + DEA literature, it was hypothesized that LCA + DEA has focused on a hierarchist approach due to the fact that it is an intermediate perspective in which the temporality is balanced based on a consensus about the short- and long-term damages [17]. However, it should be noted that some Life Cycle Impact Assessment

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exploited in processing a product [41].
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