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Enhancing the Economic Dimension of LCA + DEA Studies for Sustainability Assessment

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Abstract: The combination of Life Cycle Assessment (LCA) and Data Envelopment Analysis (DEA) has been recently proposed as a methodological framework for the sustainability assessment and benchmarking of multiple similar entities. While important benefits are associated with this combined methodology (*e.g.*, quantification of performance indicators and eco-efficiency verification), some underdeveloped aspects need to be addressed. In this respect, further efforts are required so that the LCA + DEA methodology succeeds in coping with the different sustainability dimensions in balance. In particular, previous studies pinpoint the need for further exploring the economic dimension of this type of assessment. Within this context, the present work presents different pathways to enhance the economic component of LCA + DEA studies. On the one hand, straightforward options for widening the economic scope of the LCA + DEA methodology include the calculation of economic savings and/or lifecycle costing indicators linked to the operational benchmarks calculated by the method. On the other hand, indirect pathways rely on the previous calculation of environmental or emergy benchmarks. Environmental benchmarks can be translated into economic terms through the monetization of externalities, while emergy benchmarks can be translated into market-driven indicators for the valuation of ecosystem services. These pathways (either separately or jointly) help boost the use of the LCA + DEA methodology for sustainability assessment.

Keywords: benchmarking; data envelopment analysis; life cycle assessment.

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1. Introduction

Sustainable development is progressively becoming an aspect of paramount importance for governments and companies worldwide, as well as an integral component of decision-making processes. Hence, decisions on *e.g.* product and process development or policy-making must take into account the three dimensions of sustainability (*i.e.*, the environmental, economic and social pillars) in order to favor human well-being and social equity, while significantly reducing environmental impacts [1]. Within this context, sound methodological approaches are needed when it comes to identifying and assessing current sustainability concerns, defining future scenarios and setting strategies toward sustainable production and consumption [2]. In this respect, current analytical trends focus on the potential use of holistic approaches (especially lifecycle-based methodologies) that address the interactions between the sustainability dimensions [1,3].

When evaluating the sustainability of multiple similar entities, the integration of lifecycle (LC) methodologies with Data Envelopment Analysis (DEA) is considered to be a suitable methodological approach for sustainability assessment and benchmarking [2,4,5]. DEA is a linear programming methodology that quantifies and evaluates in an empirical manner the relative efficiency of multiple similar entities (generally called Decision Making Units, DMUs) [6,7]. Among the available LC approaches, Life Cycle Assessment (LCA) and emergy analysis (Em) have already proven to be appropriate methodologies for coupling with DEA [5,8-11]. LCA is a standardized methodology to assess the environmental aspects and potential impacts associated with a product [12,13], while Em offers an approximation of the solar energy previously provided to generate a product and/or to support a system and its level of organization [11,14].

2. Method

Current LC + DEA methods for the evaluation and benchmarking of multiple DMUs are classified into “environmental” and “energy” methods [5]. On the one hand, environmental methods focus on the direct monitoring of environmental benchmarks through LCA (or alternative approaches such as carbon footprinting) and DEA. On the other hand, energy LC + DEA methods evaluate these benchmarks through the combination of DEA with the analysis of cumulative energy demand, cumulative exergy demand and/or emergy.

The vast majority of the LC + DEA studies to date use environmental methods. In particular, the five-step LCA + DEA method is the methodological approach most often selected by practitioners [5]. This five-step method has already been applied to a wide range of case studies [8-10,15-20]. Although other LCA + DEA approaches are available (*e.g.*, the three-step LCA + DEA method [21]), there is a trend toward the use of the five-step LCA + DEA method because of its methodological consistency [22].

Beyond regular applications of the five-step LCA + DEA method, novel uses of this method attempt to adapt it for the sustainability assessment of multiple similar entities [2,4]. The following five steps are defined within the LCA + DEA method oriented toward sustainability assessment and benchmarking [2]:

(i) The first step involves data collection regarding the material and energy flows and the socio-economic indicators of each DMU. Hence, this step results in the Life Cycle Inventory (LCI) of each of the DMUs.

(ii) According to the LCIs from the first step, the Life Cycle Impact Assessment (LCIA) of each DMU is carried out in the second step of the method. This leads to the current environmental profile of each DMU.

(iii) In the third step, the DEA computation of the sample of DMUs is carried out. This is done using a selection of the most relevant input/output data from the first step. In addition to the efficiency scores of the different DMUs, quantitative operational and socio-economic benchmarks are determined for the entities deemed inefficient. These benchmarks are defined as target values that turn inefficient DMUs into efficient entities.

(iv) The benchmarks from the third step entail a modification in the input/output levels of the current LCIs. Therefore, the fourth step involves the LCIA of the target DMUs using the modified LCIs. The target environmental profiles of the currently inefficient entities are thereby obtained. In other words, this step results in the environmental benchmarks of the DMUs previously identified as inefficient.

(v) The final step focuses on the combined interpretation of the environmental, socio-economic and operational benchmarks in terms of sustainability.

Even though the suitability of the five-step LCA + DEA method for sustainability assessment has been enhanced in previous studies [2,4], there is an acknowledged need for further efforts to improve the economic dimension of the assessment [2].

3. Results and Discussion

This section presents potential pathways to enhance the economic component of the five-step LCA + DEA method for sustainability assessment. These pathways are classified into (i) straightforward and (ii) indirect strategies. This classification is based on whether the additional economic indicators implemented in the method derive directly or indirectly from the operational benchmarks.

3.1. Straightforward strategies

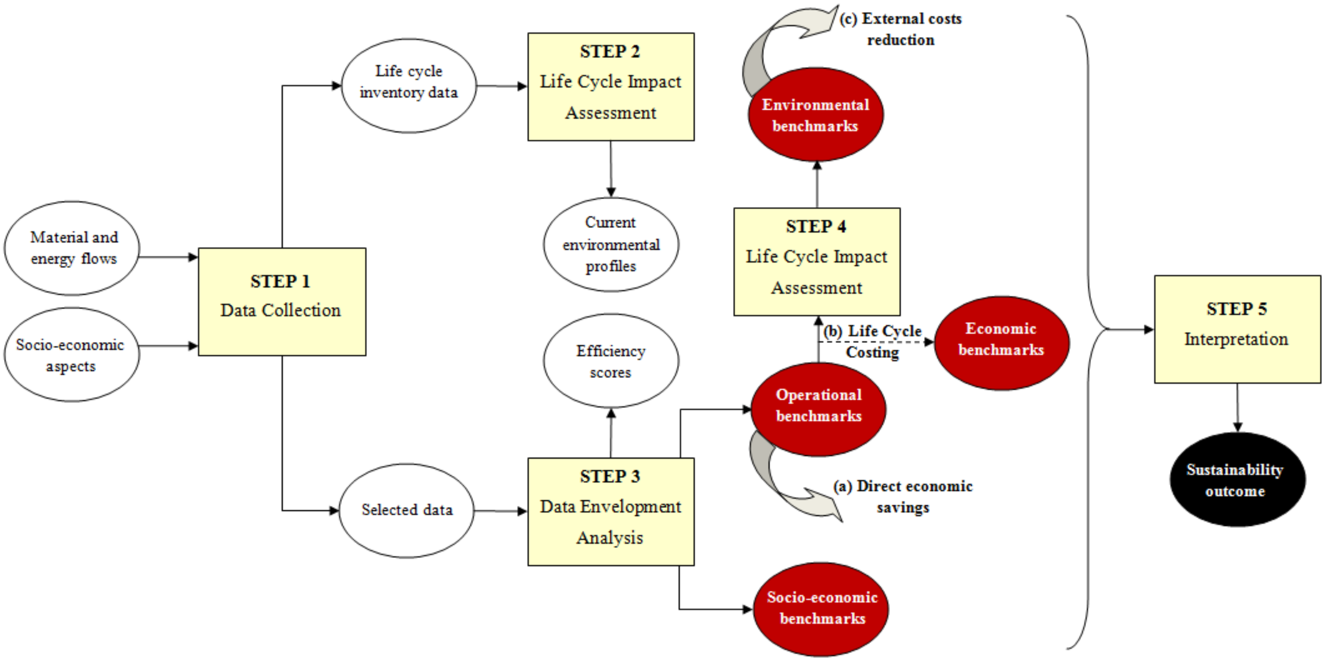
Figure 1 shows the five-step LCA + DEA method for sustainability assessment and presents potential solutions to enhance its economic dimension. As can be observed in this figure, two of these solutions (*viz.*, options “a” and “b” in Figure 1) rely directly on the operational benchmarks from the DEA step. These straightforward strategies for reinforcing the economic scope of the assessment include the calculation of economic savings and/or lifecycle costing (LCC) indicators linked to the operational benchmarks calculated by the method.

Economic reductions can be attained if the inefficient DMUs were to upgrade their performance in order to score efficient operation according to the calculated operational benchmarks [22]. The estimation of these economic savings (option “a” in Figure 1) is carried out by just taking into account the prices of a reduced set of the material and energy items inventoried in the first step of the method.

In this sense, direct economic savings are the difference between the current costs of the evaluated items and the target costs associated with the operational optimization of the assessed entities.

Additionally, the LCIs modified by the operational benchmarks computed through DEA can be evaluated using LCC (option "b" in Figure 1), which is a technique to assess the economic performance of an entity from a lifecycle perspective [23]. This LCC step is the source of economic benchmarks, *i.e.* target economic indicators for the inefficient DMUs. Furthermore, the original LCIs of the current entities can also be evaluated by LCC, thus allowing the comparison of current and target economic indicators. Finally, it should be noted that the LCC pathway does not prevent analysts from estimating the direct economic savings as previously explained.

Figure 1. Enhancement of the economic dimension of the five-step LCA + DEA method for sustainability assessment by **(a)** calculating economic savings, **(b)** evaluating target LCC indicators, and/or **(c)** monetizing external costs.



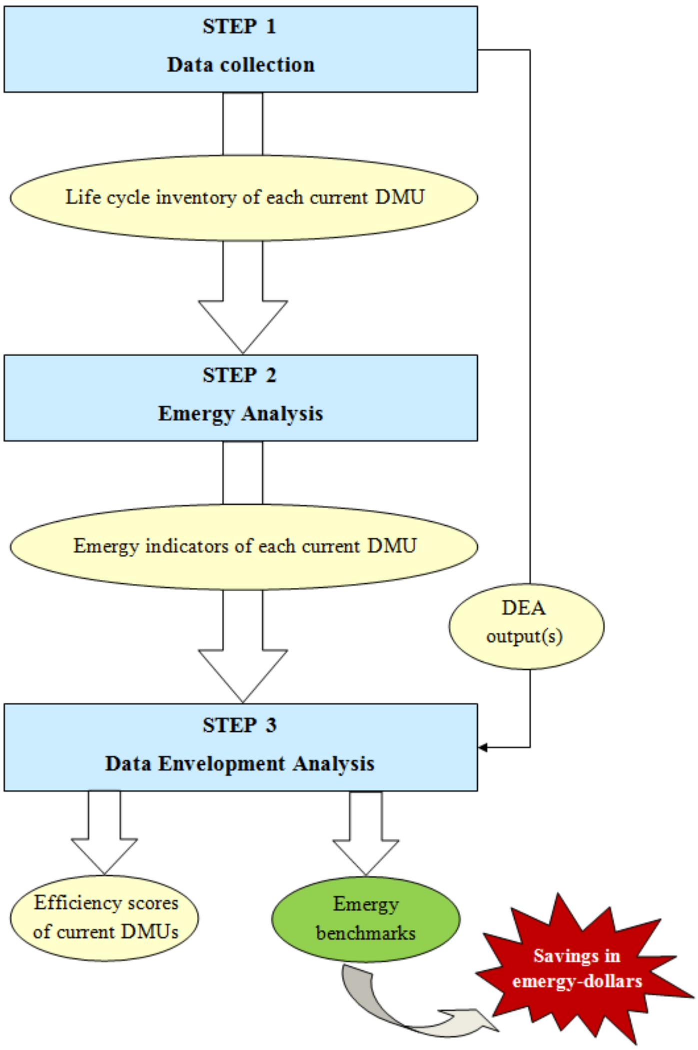
3.2. Indirect strategies

In addition to straightforward pathways for the enhancement of the economic dimension of the assessment, indirect strategies can be devised. Two indirect pathways are proposed in this work. They rely on the previous calculation of environmental (option "c" in Figure 1) or emergy benchmarks (Figure 2).

The environmental benchmarks from the fourth step of the LCA + DEA method can be translated into economic terms through the monetization of externalities (option "c" in Figure 1). The determination of the external costs caused by an entity consists in the monetary quantification of its socio-environmental damage. In this sense, an external cost arises when the social or economic activities of one group of persons impact on another group and this impact is not fully accounted for by the first group [24]. In particular, the indirect pathway proposed herein is based on the quantification of the external costs linked to environmental impacts, which impose risks on human beings, ecosystems and materials. Among the procedures for the estimation of these external costs [24,25], it is considered to be a practical option to convert the environmental impacts from steps 2 and 4 of the method into a common monetary unit via the use of damage factors [26,27]. Nevertheless, the advisability of this procedure depends on the availability of appropriate damage (cost) factors.

At the expense of increased complexity, LC + DEA approaches complementary to the five-step LCA + DEA method can also be used to enhance the economic dimension of the assessment. In particular, the emergy benchmarks calculated through the three-step Em + DEA method for ecocentric benchmarking [11] have the potential to be translated into market-driven indicators for the valuation of ecosystem services (Figure 2). The difference between current and target emergy costs provides a measure of economic savings expressed in the economic equivalent of emergy (*e.g.*, emergy-dollars) [28].

Figure 2. Inclusion of economic parameters in the Em + DEA method.



Even though the calculation of reductions in external costs implies a different rationale from the calculation of savings in emergy costs, both indirect pathways should be understood as sources of complementary information. In this respect, these indirect strategies are considered to be compatible with each other, as well as with the straightforward pathways previously explained. Hence, the use of a specific strategy, or set of strategies, will depend on the specific case study and the choice of the analyst.

Table 1 summarizes key features of the four pathways proposed in this work to enhance the economic dimension of LCA + DEA studies for sustainability assessment. In this table, the link with operational benchmarks relates to the classification of the strategies as either straightforward or indirect. The burden of data collection is also taken into account in Table 1 in terms of both data demand and data availability. Moreover, the methodological complexity of the different strategies is considered in this table, as well as the expected level of uncertainty regarding the results derived from the assessment. Under these aspects, the calculation of direct economic savings is seen as a potential strategy of regular use in LCA + DEA studies, whereas the appraisal of emergy costs is unlikely to be adopted as a regular complement to LCA + DEA results. Finally, the estimation of LCC indicators and (to a lesser extent) the quantification of external costs are seen as intermediate solutions in terms of practicality.

Table 1. Key features of potential strategies to enhance the economic dimension of LCA + DEA studies for sustainability assessment.

	Link with operational benchmarks	**Data demand**	**Data availability**	**Complexity**	**Uncertainty**
(a) Direct economic savings	Direct hard link	Moderate	High	Low	Low
(b) LCC indicators	Direct hard link	High	Moderate	Moderate	Moderate
(c) External costs	Indirect hard link	High	Moderate	High	High
(d) Emergy costs	Indirect soft link	High	Low	Very high	High

4. Conclusions

The enhancement of the economic dimension of the LCA + DEA methodology for sustainability assessment is found to be feasible. Both straightforward and indirect strategies to attain this methodological improvement can be devised. These strategies focus on the separate or combined performance of straightforward calculations (direct economic savings and LCC indicators linked to operational benchmarks) and indirect calculations (external costs linked to environmental benchmarks and emergy costs linked to emergy benchmarks). The choice of the most appropriate strategy depends on the specific case study and on user requirements. The implementation of these pathways (either separately or jointly) into the LCA + DEA methodology is expected to boost its use for sustainability assessment, dealing with environmental, economic and social aspects in balance.

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Conflict of Interest

The authors declare no conflict of interest.

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