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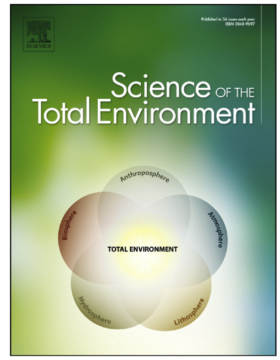

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Sensitivity of operational and environmental benchmarks of retail stores to decision-makers' preferences through Data Envelopment Analysis

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Abstract

Within the framework of multi-criteria decision analysis (MCDA), weighting methods are typically used to capture decision-makers' preferences. In this regard, the increasing use of the combined LCA (Life Cycle Assessment) + DEA (Data Envelopment Analysis) methodology as an MCDA tool requires an in-depth analysis of how the preferences of decision-makers could affect the outcomes of LCA + DEA studies. This work revisits a case study of 30 retail stores/supply chains located in Spain by applying alternative weighted DEA approaches to evaluate the influence of decision-makers' preferences (weights) on the final outcomes, with a focus on efficiency scores and operational and environmental benchmarks. The ultimate goal is to effectively capture the view of stakeholders when applying LCA + DEA for the sound, sustainability-oriented management of multiple similar entities. Different weight vectors are separately applied to three types of DEA elements: operational inputs, time terms, and divisions. Besides, preferences from three alternative standpoints are considered: company manager through direct rating, and environmental policy-maker and local community through AHP (analytic hierarchy process). A significant influence on efficiency scores and sustainability benchmarks was found when weighting decision-makers' preferences on operational inputs. Additionally, a moderate influence was observed when weighting divisions according to a policy-maker or local community perspective. Although the results are case-specific, they lead to the general recommendation to enrich LCA + DEA studies by following not only an equal-weight approach but also approaches that include the preferences of the stakeholders effectively involved in the study.

Keywords: efficiency; life cycle assessment; multi-criteria decision analysis; retail supply chain; weighting

1. Introduction

The current model of societies –based on a continuous expansion of national economies– has led to numerous environmental issues. A shift from this intensive development to one ruled by the principles of sustainable production and consumption is needed. In this sense, decision-making processes are of paramount importance to guide changes oriented towards the goal of sustainability (Bolis et al., 2017), searching for optimal and feasible solutions within a range of alternatives according to a given set of criteria. The procedure behind decision-making processes is often based on scientific methods capable of dealing with increasingly complex and uncertain concerns. Due to this complexity, the involvement of a single actor that assumes the task of deciding is not recommended (Koksalmis and Kabak, 2019). In fact, most of the decision-making problems in companies, governments and organisations are typically characterised by multiple interests and perspectives, conflicting objectives, and different types of information (Wang et al., 2009).

Within this context, multi-criteria decision analysis (MCDA) arises as an operational evaluation and decision-support approach suitable for addressing complex problems (Martín-Gamboa et al., 2017; Wang et al., 2009). Thus, MCDA methods are often used to help decision-makers synthesise and prioritise their multiple, subjective interests. In general, there is not a common recommendation about the "best" MCDA tool, but its selection depends on the specific features of the problem addressed and the preferences of the actors involved. In particular, when decision-making problems involve multiple similar entities and multiple criteria, Data Envelopment Analysis (DEA) arises as a preferred MCDA solution. DEA is a linear programming methodology that quantifies in an empirical manner the comparative productive efficiency of multiple similar entities (called decision making units, DMUs) (Cooper et al., 2007; Tone, 2017).

One of the common procedures to capture decision-makers' preferences in MCDA solutions such as DEA is the use of weighting methods (Ibáñez-Forés et al., 2014; Munda, 2005). Actually, weighting is usually considered a necessary step when performing a full MCDA (Communities and Local Government, 2009). The use of weights allows stakeholders to express their preferences for each of the criteria included in the decision analysis, with a potentially significant influence on the outcomes of the decision-making process. Hence, the assignment of weights should be based on a consistent and reliable process. In this regard, the methods for determining decision-makers' weights are generally classified into three groups: subjective, objective, and integrated methods (Dong et al., 2018). In subjective methods, weights are directly determined by one or more stakeholders according to their experience, knowledge, etc. (e.g., direct rating and pair-wise comparison in AHP – analytic hierarchy process) (Koksalmis and Kabak, 2019). On the other hand, objective methods assign weights by means of mathematical models based on the analysis of the initial data, e.g. entropy method and programming-based methods (Koksalmis and Kabak, 2019). Finally, integrated methods calculate the weights assigned to each criteria using both decision-makers' subjective information and objective decision matrix information (e.g., optimisation-based models).

In the last years, the combination of Life Cycle Assessment (LCA) –a standardised methodology for the evaluation of the environmental performance of product systems (ISO, 2006a, 2006b)– and DEA has been proven to be beneficial when integrating sustainability into decision-making problems involving multiple similar entities and multiple operational, environmental and/or socio-economic criteria (Iribarren et al., 2016). Thus, LCA + DEA as a sustainability-oriented methodological framework has already been applied to a number of case studies, e.g. within the energy sector (Martín-Gamboa et al., 2019) and the tertiary sector (Álvarez-Rodríguez et al., 2019a). Vázquez-Rowe and Iribarren (2015) and Martín-Gamboa et al. (2017) carried out review studies on the use of LCA + DEA, concluding a global growing trend towards the use of this combined methodological concept for the eco-efficiency assessment of multiple DMUs. In this sense, the potential of LCA + DEA to quantify and benchmark the life-cycle environmental advantages of minimising resource use while maintaining the level of production of desirable outputs –which is fully aligned with the sustainable development goal on sustainable production by doing more and better with less (United Nations, 2015)– was identified as a key driver of the increased interest in this specific field of research. However, despite the fact that the ultimate goal of LCA + DEA studies is to facilitate robust decision-making processes, the sample of case studies in the above-mentioned reviews shows a null or scarce participation of decision-makers.

The lack of decision-makers' involvement in the LCA + DEA case studies available in the scientific literature to date is the reason why they typically follow a default (equal-weight) approach in the MCDA component (Martín-Gamboa et al., 2017, 2019). However, the increasing use of the LCA + DEA methodology calls for an in-depth analysis of how weights from stakeholders could affect the results, e.g. in decision-making processes at the company level. In fact, if decision-makers' judgements and preferences are available, their integration into the DEA component should be a must (Mohammadi et al., 2016; Omrani et al., 2019). Given (i) the general interest in using LCA + DEA for the sustainability-oriented management and benchmarking of multiple similar entities at the company level and (ii) the knowledge gap regarding the implementation of decision-makers' preferences in LCA + DEA, this work revisits a case study within the retail sector (Álvarez Rodríguez et al., 2019a, 2019b, 2020) to explore the potential relevance of the application of alternative MCDA weighting approaches.

The purpose of this work is to evaluate the influence of decision-makers' preferences on the final outcomes of the LCA + DEA study, with a focus on the specific influence on efficiency scores and operational and environmental benchmarks. Hence, this work aims to fill the knowledge gap on the application of weights in LCA + DEA, setting new recommendations in this field. Section 2 presents the methodological framework followed for the implementation of alternative weights in LCA + DEA (Section 2.1), as well as the different weighting approaches considered in the study (Section 2.2). According to the research process devised in Section 2, Section 3 focuses on the potential influence that weights can have on the main LCA + DEA outcomes (i.e., efficiency scores and sustainability benchmarks), considering the use of weights on operational inputs (Section 3.1), time terms (Section 3.2) and divisions (Section 3.3) through the case study of retails stores and supply chains. After further discussion of the relevance of the study to foster company action enabling sustainable production patterns (Section 3.4), Section 4 presents the main conclusions of the study.

2. Material and methods

2.1. LCA + DEA methodological framework

In order to thoroughly evaluate the influence of weights on LCA + DEA outcomes, a well-defined and detailed case study of 30 grocery stores/supply chains within the Spanish retail sector was revisited (Álvarez Rodríguez et al., 2019a, 2019b, 2020). In the original case study, weights were not specified, which means that the default approach based on equal weights was followed. The choice of this case study was motivated by the fact that it has the direct support of a company manager who provided the primary data required to conduct the analysis in the previous works and weights for the present study. In this respect, direct communication with this manager led to a reliable representation of the decision-makers' preferences at the company level. Moreover, in order to further enrich the analysis of the influence of weights on LCA + DEA results, not only manager-based weights were considered, but also weights based on the preferences of a hypothetical environmental policy-maker as well as of local community. Furthermore, since different DEA models were applied in the original case study of grocery stores, the relevance of weights was explored from three different perspectives:

- Weights on operational inputs in a static LCA + DEA of grocery stores (Álvarez Rodríguez et al., 2019a).
- Weights on time terms in a dynamic LCA + DEA of grocery stores (Álvarez Rodríguez et al., 2019b).
- Weights on divisions in a network LCA + DEA of retail supply chains (RSCs), including not only the operation of the grocery stores, but also distribution stages (Álvarez Rodríguez et al., 2020).

Table 1 summarises the main features of the original LCA + DEA studies revisited. As presented in Table 1, the DEA models selected for the original case study of grocery stores involve the same features in terms of model metrics, orientation and returns to scale, using an input-oriented slacks-based measure of efficiency (SBM) model with variable returns to scale in all cases (Cooper et al., 2007). However, the specific SBM model used in each study differs according to the goal of each work: (i) static SBM model for the operational and environmental benchmarking of groceries in Álvarez-Rodríguez et al. (2019a), (ii) dynamic SBM model for the sustainability-oriented management of grocery stores in the period 2015-2017 in Álvarez-Rodríguez et al. (2019b), and (iii) dynamic network SBM model for the sustainability-oriented management of RSCs in the period 2015-2017 in Álvarez-Rodríguez et al. (2020). As shown in Table 1, the specificities of each SBM model translate into differences in the choice of DEA elements (outputs, operational and socio-economic inputs, carry-over, and link) which meet the suitability requirements set in Iribarren et al. (2016). It should be noted that, since DEA involves a mathematical optimisation procedure relying on observed data –which in this case study come directly from the involved retail company as high-quality primary data– and a reduced set of assumptions (Lozano et al., 2009), model validation is not needed (unlike other types of models such as those based on process simulation).

Table 1. Main DEA features in the original studies.

DEA feature	Álvarez-Rodríguez et al. (2019a)	Álvarez-Rodríguez et al. (2019b)	Álvarez-Rodríguez et al. (2020)
DMU	Grocery store	Grocery store	Retail supply chain
Divisions	1 (store operation)	1 (store operation)	3 (central distribution, store operation, home delivery)
Time terms	2017	2015, 2016, and 2017	2015, 2016, and 2017
Model metrics	Non-radial	Non-radial	Non-radial
Model orientation	Input-oriented	Input-oriented	Input-oriented
Returns to scale	Variable	Variable	Variable
Outputs	Turnover	Turnover	Turnover, home delivery service income
Operational elements	Electricity, receipt paper, wax paper, plastic bag, waste	Electricity, receipt paper, wax paper, plastic bag, waste	Diesel, electricity (store), receipt paper, wax paper, plastic bag, waste, electricity (van)
Socio-economic elements	Working hours	Working hours	Working hours for each division
Carry-over	-	Stock	Allocated fleet, stock
Link	-	-	Transported merchandise

Fig. 1 presents the methodological framework followed in this study, with emphasis on the implementation of weights to explore their influence on the results obtained. It should be noted that this methodological framework is not limited to the case study of grocery stores, but it is applicable to many other case studies in the tertiary sector (e.g., pharmacies, banks, etc.) as well as in other sectors (for instance, the LCA + DEA methodology has been widely applied to the primary and secondary sectors (Martín-Gamboa et al., 2017)). On the one hand, the five common stages involved in the five-step LCA + DEA methodological framework are included in Fig. 1. These common steps involve (i) data acquisition to generate the life-cycle inventory of each DMU and quantify each of the DEA elements, (ii) the use of the life-cycle inventories to characterise the environmental performance of each DMU, (iii) the computation of the relative efficiency scores and the operational and socio-economic benchmarks of each DMU through DEA, (iv) the recalculation of the life-cycle environmental profile of each inefficient DMU according to the reduction targets (operational benchmarks) from the previous step, and (v) the joint interpretation of the results under the umbrella of the sustainability concept (Vázquez-Rowe et al., 2010).

On the other hand, red lines and shapes in Fig. 1 specifically highlight the main novelty of the study in comparison with previous studies, which refers to the implementation of weights. In this regard, weights based on decision-makers' preferences were applied in this work on (i) the operational elements in Álvarez-Rodríguez et al. (2019a), (ii) the time terms in Álvarez-Rodríguez et al. (2019b), and (iii) divisions in Álvarez-Rodríguez et al. (2020). The implementation of weights in the DEA stage directly affects the computation of the specific SBM models, most likely affecting the LCA + DEA outcomes: efficiency scores (i.e., relative scores that allow discriminating between comparatively efficient and inefficient entities), operational and socio-economic benchmarks (i.e., target points that would transform inefficient entities into efficient ones), and environmental benchmarks (target carbon and non-renewable energy footprints in this study). Emphasis was laid on the relevance of decision-makers' preferences (i.e., weights) on the target carbon and energy footprints. The evaluation of these life-cycle indicators is of special interest when addressing retail (grocery) stores (Iyer et al., 2015; Seebauer et al., 2016).

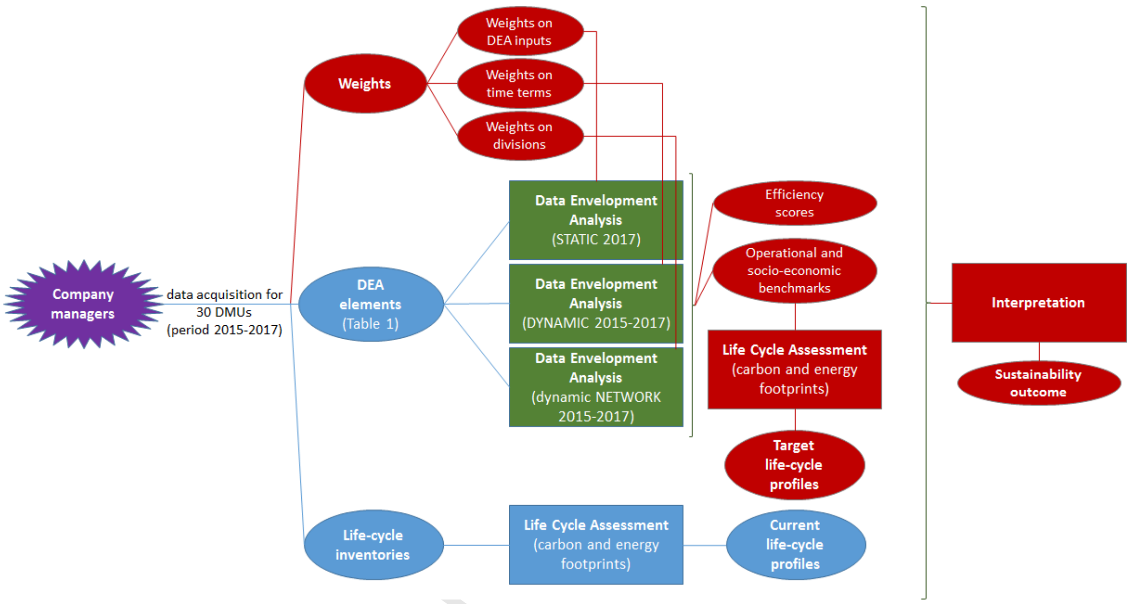

Fig. 1. LCA + DEA methodological framework.

2.2. Weighting approaches

Two subjective methods were separately applied to determine the decision-makers' weights. First, a direct-rating method was used to capture the preferences of the involved company manager as regards operational elements, time terms, and divisions. A survey was directly provided to the company manager and filled in according to (i) a 1 (very low importance) - 5 (very high importance) rating for each operational or socio-economic input, and (ii) the relative relevance of each time term and division (assuming one of the time terms and one of the divisions as references). The resulting weights are provided later in Section 3. It should be noted that –even though the original studies already incorporated, to some extent, the perspective of company managers (mainly through the choice of DEA elements) (Álvarez Rodríguez et al., 2019a, 2019b, 2020)– the use of weighted DEA models further stresses the role of these key actors in the decision-making process. The influence of this increased role on the LCA + DEA results for the sustainability-oriented management of retail stores was explored in this article (Section 3).

Since other weighting approaches and/or target decision-makers could lead to significantly different weights –probably affecting LCA + DEA results that reply to the decision goal of identifying the best-performing DMUs to quantitatively guide the management of the involved entities–, alternative weights and their influence on the results were also explored. In this regard, AHP –one of the most widespread weighting methods (Ibáñez-Forés et al., 2014)– was applied adopting either an "environmental policy-maker" (hypothetical actor based on the joint judgement –by consensus– from 2 experts in environmental management, planning and policy-making) standpoint or a "local community" one (joint judgement –by consensus– from a set of 4 local families). These alternative weights were used to illustrate how different viewpoints (weight vectors) could affect the sustainability–oriented management of grocery stores (Section 3). The AHP methodology is based on a square matrix n x n, where the rows and columns correspond to the n criteria considered in the analysis (in this case, operational and socio-economic elements, time terms or divisions) (Saaty, 1980). Each entry a_{ij} of this matrix (known as pairwise comparison matrix A) expresses the relative importance of the criterion in row i against the criterion in column j. The n criteria are compared using the Saaty's fundamental scale, which consists of a set of absolute numbers and their verbal equivalents (Table 2). If $a_{ij} > 1$, then the criterion in row i is considered to be more important than the criterion in column j, while $a_{ij} < 1$ means the opposite. If two criteria are considered to have the same importance, then $a_{ij} = 1$. The structure of the pairwise comparison matrix A based on the decision-maker's judgments a_{ij} is represented by Eq. (1):

$$A = \begin{bmatrix} 1 & a_{12} & \cdots & a_{1n} \\ a_{21} & 1 & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \cdots & 1 \end{bmatrix} \text{, where } a_{ji} = 1/a_{ij} \; i,j = 1,\ldots,n \tag{1}$$

Table 2. Scale for comparisons according to Saaty (1994).

Scale	Degree of preference
1	Equal importance
3	Moderate importance of one factor over another
5	Strong importance
7	Very strong importance
9	Extreme importance
2,4,6,8	Values for inverse comparison

Once the matrix A is built, it is possible to derive from it the normalised pairwise comparison matrix A_{norm} by dividing each entry a_{ij} in column j by the total sum of the entries in that column. Finally, the criteria weight vector w (n-dimensional column vector) is built by averaging the entries in each row i of A_{norm}. In order to avoid judgement inconsistencies, the consistency ratio (CR) of matrix A was used. The consistency ratio is given by the formula CR = CI/RI, where CI = $(\lambda_{max} - n)/(n - 1)$ and λ_{max} stands for the maximal eigenvalue of A. The random index (RI) is an experimental value that depends on n, as presented in Table 3. If CR is below a threshold value (0.1 in this study), then the consistency of judgements is considered acceptable. On the other hand, if CR exceeds the threshold value, then the judgements in matrix A need re-examination (Aragonés-Beltrán et al., 2014).

Table 3. Random index (RI) values according to Saaty (1994).

n	1	2	3	4	5	6	7	8	9	10	11	12
RI	0	0	0.52	0.89	1.11	1.25	1.35	1.40	1.45	1.49	1.51	1.54

3. Results and discussion

This section presents the weights obtained according to the procedure explained in Section 2.2 and assesses the sensitivity of the main LCA + DEA results to such decision-makers' weights on inputs (Section 3.1), time terms (Section 3.2), and divisions (Section 3.3). Table 4 presents the weights based on the company manager's preferences, as well as the alternative weights from AHP ("environmental policy-maker" and "local community" standpoints; consistency ratios < 0.1). Given the differences in Table 4 between manager- and AHP-based weights, changes in the LCA + DEA results could be expected in this case study when using alternative weighting approaches. These differences are motivated by the generally dissimilar vision of managers versus environmental policy-makers and/or local community when planning the management of retail stores. Nevertheless, it should be noted that similar preferences between decision-makers could be found when analysing other case studies.

Table 4. Weights based on the company manager's preferences, and alternative weights from AHP.

Weighted item	Manager-based weight	AHP-based weight (environmental policy-maker perspective) [a]	AHP-based weight (local community perspective) [b]
Static DEA			
Working hours	0.28	0.02	0.44
Electricity	0.22	0.31	0.10
Receipt paper	0.11	0.14	0.07
Wax paper	0.11	0.07	0.03
Plastic bag	0.17	0.39	0.23
Waste	0.11	0.07	0.13
Dynamic DEA			
Year 2015	0.17	-	-
Year 2016	0.33	-	-
Year 2017	0.50	-	-
Network DEA			
Division 1 (central distribution)	0.30	0.08	0.083
Division 2 (store operation)	0.40	0.66	0.724
Division 3 (home delivery)	0.30	0.26	0.193

[a] Consistency ratio of 0.05 (static study) and 0.03 (network study).
[b] Consistency ratio of 0.04 (static study) and 0.06 (network study).

Regarding the weights on operational and socio-economic inputs, although the general trend is similar (especially between managers and local community), the specific level of importance significantly varies from one standpoint to another (Table 4). For instance, even though the optimisation of electricity consumption and plastic bag use within the management of grocery stores is relevant to the three standpoints, the weights assigned to these inputs represent less than 40% of the total for managers and local community whereas they account for 70% of the assigned weight from an environmental policy-maker viewpoint. Concerning working hours, this socio-economic input is the pivotal point within the management of grocery stores from the standpoint of managers and local community (28% and 44% weights, respectively). In this respect, it should be noted that –for both points of view– the optimisation of working hours is understood as their reallocation to activities such as training of employees (e.g., on energy-efficient practices) (Álvarez Rodríguez et al., 2019a, 2019b).

With regard to weights on time terms, no specific values were assigned from the standpoint of environmental policy-makers or local community since the actual interest in managing the operation of the grocery stores from a dynamic (i.e., period-oriented) perspective is expected to come mainly from company managers. Finally, the assignment of weights to divisions follows a similar trend to that of operational inputs: although the three standpoints place the focus on a common division (in this case, store operation), the specific weight differs significantly from one decision-maker to another (e.g., 40% from a manager viewpoint but 72% from a local community standpoint). After this presentation of the weight vectors, the following sections (3.1-3.3) assess the sensitivity of the main LCA + DEA results to these preferences, using as reference results those from the default approach (equal weighting).

3.1. Sensitivity to weights on operational inputs

This section assesses the sensitivity of the key LCA + DEA outcomes (viz., efficiency scores, operational benchmarks, and environmental benchmarks as target carbon and energy footprints) to the decision-makers' weights on the selected operational and socio-economic inputs. A weighted SBM model (static and unidivisional) was used (Tone, 2001) and fed with the DEA matrix readily available in

Álvarez-Rodríguez et al. (2019a) and the weight vectors for static DEA reported in Table 4. This information was implemented in the optimisation model solved through the software DEA-Solver Pro (Saitech, 2019).

3.1.1. Influence on efficiency scores

Fig. 2 shows –for each DMU and decision-maker standpoint– the ratio of the efficiency scores from the weighted SBM model to those from the default approach (equal weights). Values above 1 denote a higher efficiency score when using decision-makers' weights on the operational inputs, whereas values below 1 mean a higher efficiency score when following the default approach. Values equal to 1 imply the same efficiency score, which was observed only in a reduced number of grocery stores. When the efficiency assessment includes the operation-related preferences of either the company manager or local community, an increase in the efficiency scores with respect to those from the default approach was generally found. On the other hand, the implementation of operation-related weights from an environmental policy-maker standpoint was often found to decrease the efficiency scores with respect to the default ones. Despite the influence of the operation-related weights on the efficiency scores, it should be noted that the observed variations are relatively small, typically involving less than 5 percentage points. Hence, these case-specific results should be taken with caution.

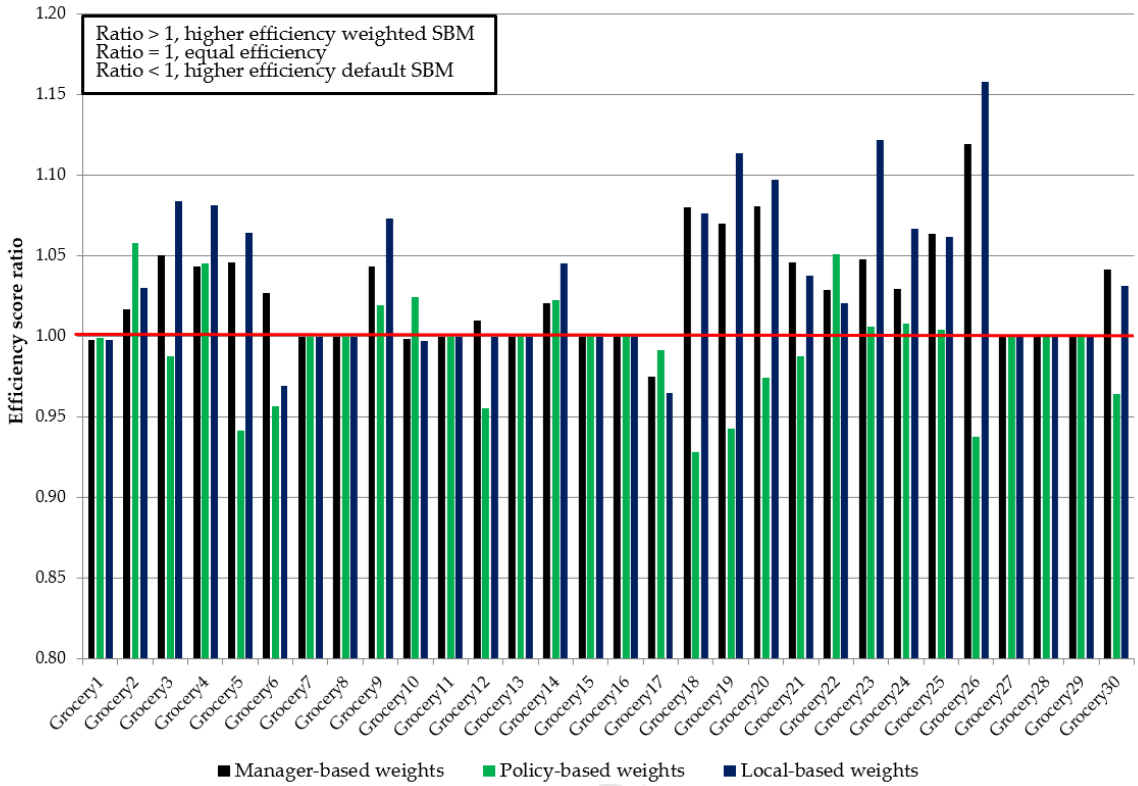

Fig. 2. Ratio of the efficiency scores from the weighted SBM model (weights on operational inputs) to those from the default SBM model.

3.1.2. Influence on target reductions

Fig. 3 shows the average target reductions in the selected DEA inputs for the different approaches to weighting operational inputs. The implementation of decision-makers' weights in the DEA model led to significant differences between the average operational benchmarks, especially regarding electricity and waste. In general, the operational and socio-economic inputs prioritised by the company manager (viz., working hours, electricity, and plastic bags) were found to involve more ambitious targets than in the original study using the default approach (equal weights), which is especially noticeable in the case of electricity.

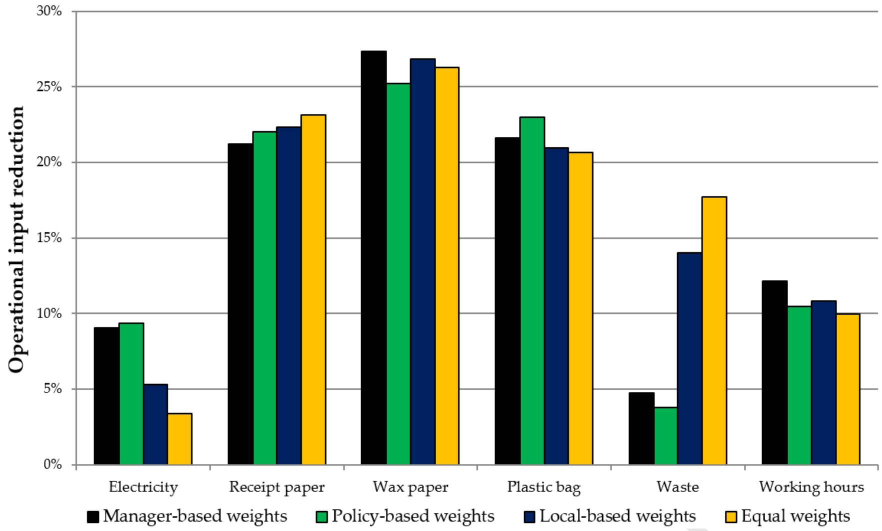

Fig. 3. Average target reductions in DEA inputs applying decision-makers' or equal weights on the operational inputs.

Furthermore, Fig. 4 shows –for the different operation-related weighting approaches– the average environmental benchmarks of the grocery stores, i.e. the average target reductions in the carbon and energy footprints. When compared to the environmental benchmarks from the default approach (equal weights), more ambitious footprint reductions were found when implementing decision-makers' weights. In this regard, average carbon and energy footprint reductions above 10% were targeted regardless of the specific type of decision-maker, with the most ambitious targets found when adopting a company manager or environmental policy-maker standpoint. The rationale behind this trend is closely linked to the operational reduction targets in the electricity input when the decision-makers' weights are implemented in the DEA model: the greater the target reduction in electricity consumption, the greater the target reduction in the carbon and energy footprints. Hence, the incorporation of the operation-related decision-makers' preferences into the analysis of grocery stores was concluded to have a significant influence on the LCA + DEA outcomes, which leads to the general recommendation of taking into account –when feasible– decision-makers' preferences in LCA + DEA studies.

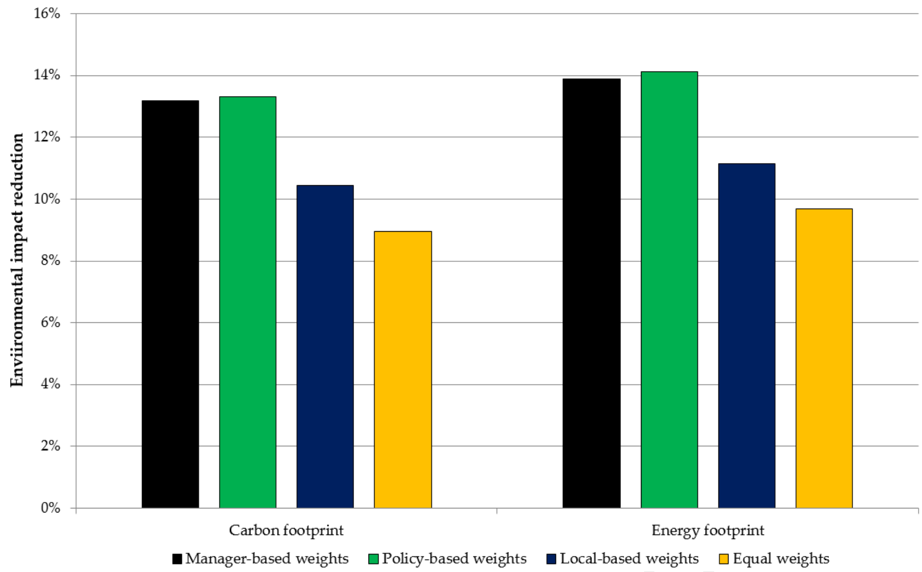

Fig. 4. Average target reductions in carbon and energy footprints applying decision-makers' or equal weights on the operational inputs.

3.2. Sensitivity to weights on time terms

This section analyses the sensitivity of the LCA + DEA results to the manager-based weights on time terms. Only a manager standpoint was followed herein because company managers are expected to be the main actors interested in following a period-oriented assessment of grocery stores. As previously presented in Table 1, three time terms were evaluated: years 2015, 2016 and 2017. A dynamic (unidivisional) SBM model was used (Tone and Tsutsui, 2010) and fed with the DEA matrix directly retrieved from Álvarez-Rodríguez et al. (2019b) and the manager-based weight vector for dynamic DEA reported in Table 4. DEA-Solver Pro was used to computationally solve the optimisation problem (Saitech, 2019).

3.2.1. Influence on efficiency scores

Fig. 5 shows –for each DMU and time term– the ratio of the term-efficiency scores from the weighted dynamic SBM model to those from the default dynamic SBM model (equal weights on terms). Only the term-efficiency scores of five DMUs (viz., grocery stores #3, #4, #12, #14, and #28) were affected by the implementation of the manager's weights on terms in the DEA model. In fact, the influence on this set of affected DMUs was very low, with the inclusion of the manager's preferences leading to a minor increase in the term-efficiency scores for 2015 and to a minor decrease in the term-efficiency scores for 2016. On the other hand, a negligible effect was found on the term-efficiency scores of these DMUs for 2017. Hence, it was concluded that the term-efficiency scores of the sample of grocery stores are hardly sensitive to the assignment of weights on terms. However, this should be understood as a conclusion specific to the case study addressed in this work.

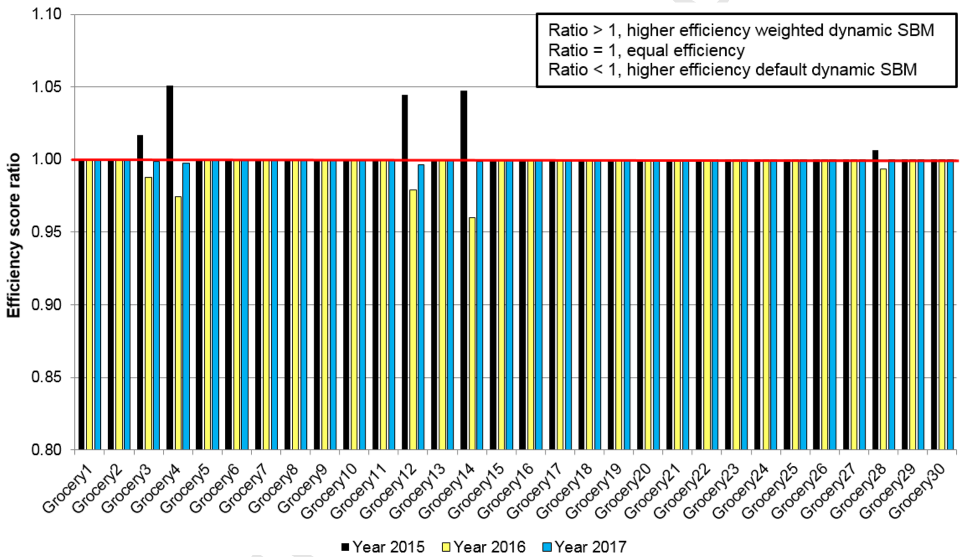

Fig. 5. Ratio of the term-efficiency scores from the weighted dynamic SBM model (manager-based weights on time terms) to those from the default dynamic SBM model (equal weights).

3.2.2. Influence on target reductions

Fig. 6 shows the average target reductions in the selected operational and socio-economic inputs obtained from the weighted dynamic model and those from the default dynamic model (equal weights on terms). As observed in Fig. 6, the assignment of weights to terms was found to involve a slight effect on the operational and socio-economic benchmarks for the terms 2015 and 2016, and a negligible effect on those for 2017. The differences between the average target operational reductions with and without implementing manager's weights on terms in the DEA model were found to be below 1 percentage point for all terms and inputs, except for waste in 2015. The very low influence of the assignment of weights to terms on the operational and socio-economic benchmarks of the sample of grocery stores is closely linked to its very low influence on the term-efficiency scores of the DMUs (as detailed in the previous section), thus confirming the minor role of the weights on terms in the case-specific LCA + DEA results.

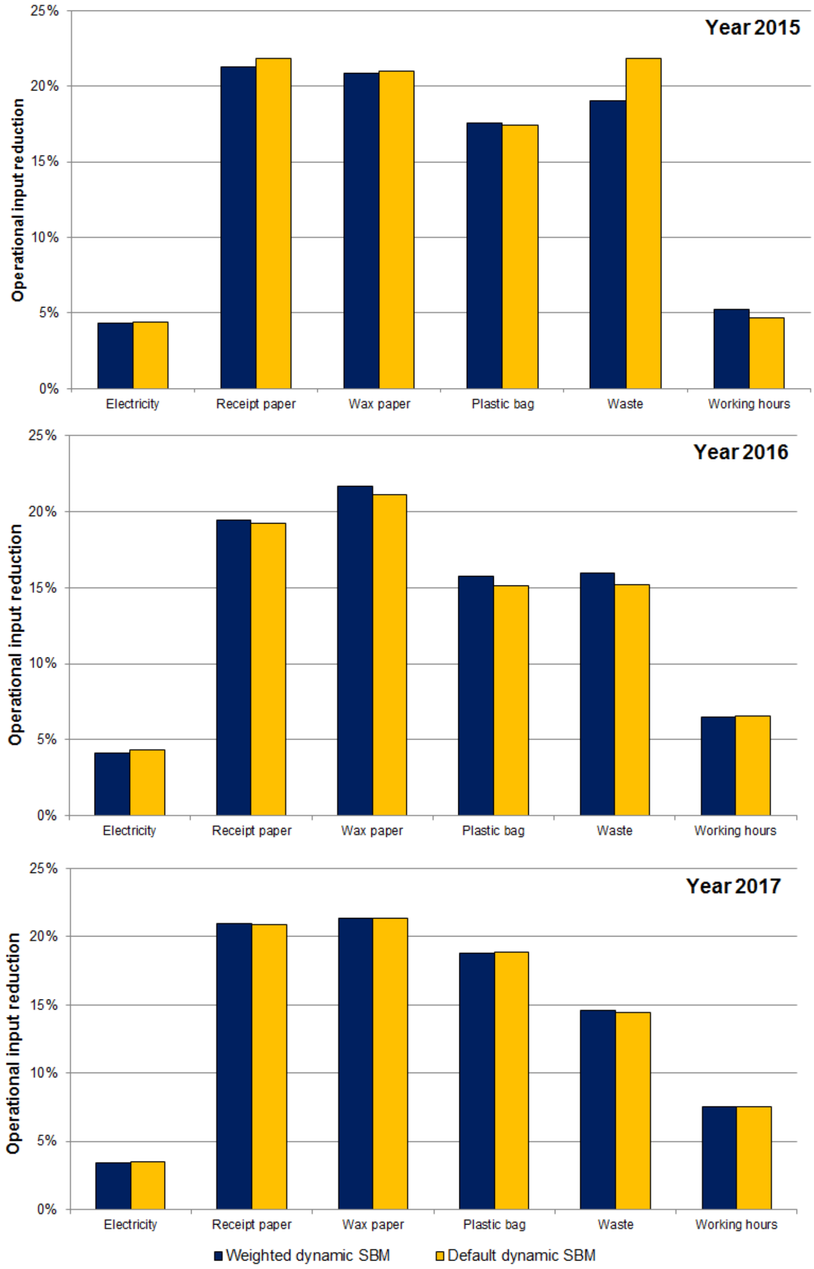

Fig. 6. Average target reductions in DEA inputs applying manager-based or equal weights on time terms.

Furthermore, Fig. 7 and 8 show, respectively, the average target reductions in the carbon and energy footprints of the grocery stores when using manager-based or equal weights on the terms. The average target environmental benchmarks for every term and indicator were found to be practically the same regardless of the implementation of weights on terms in the DEA model. This negligible influence of the assignment of weights to time terms on the environmental benchmarks is a consequence of its very low influence on the operational targets. This finding confirms, for this specific case study of grocery stores, the relatively low influence of the dynamic approach on the LCA + DEA results as highlighted in the original study (Álvarez-Rodríguez et al., 2019b). This is ultimately due to the homogenous practices implemented by the retail company in the stores under its control.

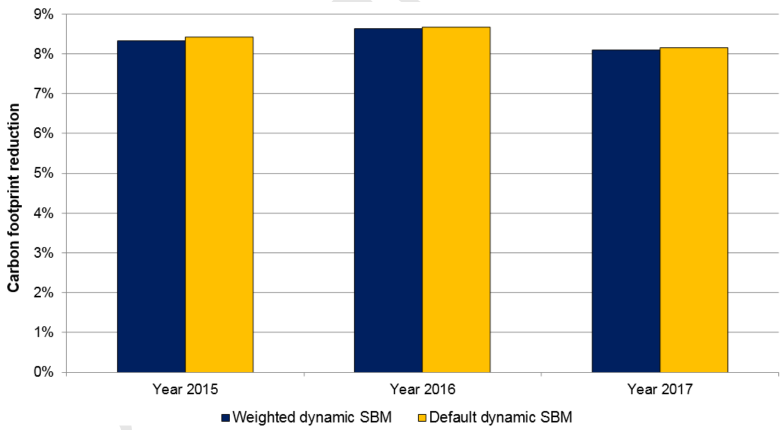

Fig. 7. Average target reductions in carbon footprint applying manager-based or equal weights on time terms.

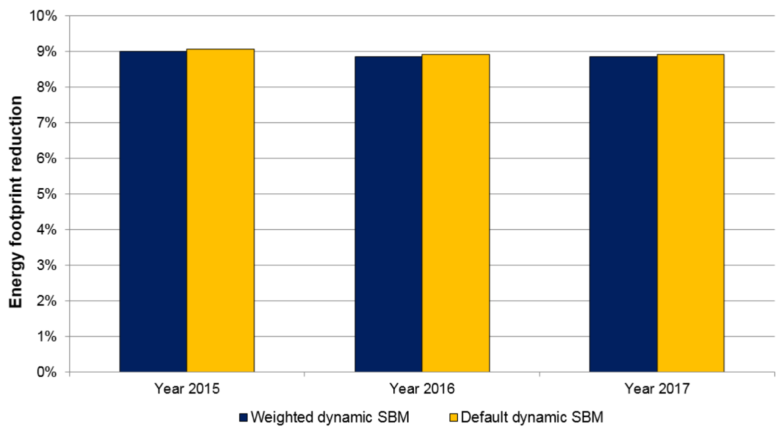

Fig. 8. Average target reductions in energy footprint applying manager-based or equal weights on time terms.

3.3. Sensitivity to weights on divisions

In this section, the sensitivity of the LCA + DEA results to the decision-makers' weights on the DMU divisions was explored. In this case, the boundaries of the DMUs were enlarged to include not only the operation of the grocery stores ("division 2") but also central distribution ("division 1") and home delivery ("division 3"), jointly constituting the RSCs under assessment. A dynamic network SBM model was used (Tone and Tsutsui, 2014) and fed with the DEA matrix retrieved from Álvarez-Rodríguez et al. (2020) and the weight vectors for network DEA reported in Table 4. DEA-Solver Pro was used to solve the optimisation problem (Saitech, 2019).

3.3.1. Influence on efficiency scores

Fig. 9 shows –for each DMU (i.e., RSC) and decision-maker standpoint– the ratio of the divisional efficiency scores from the weighted network model to those from the default network model (equal weights on divisions). As shown in Fig. 9, the divisional efficiency scores of the DMUs were found to be –to a certain extent– influenced by the consideration of decision-makers' weights on the divisions, especially when following an environmental policy-maker or local community standpoint. Within the relatively reduced set of affected DMUs, the divisional efficiency scores for the home delivery division (Div3) were identified as the most affected ones. However, a general trend regarding either an improvement or a penalty in the divisional efficiency scores due to the implementation of the decision-makers' weights on the divisions was not found. Overall, for this case study of RSCs, it was concluded that the divisional efficiency scores show a low or moderate sensitivity to the consideration of weights on the divisions depending on the decision-maker standpoint adopted, which leads to stress again the advisability of enriching conventional LCA + DEA studies by implementing the preferences of the stakeholders effectively involved in the study.

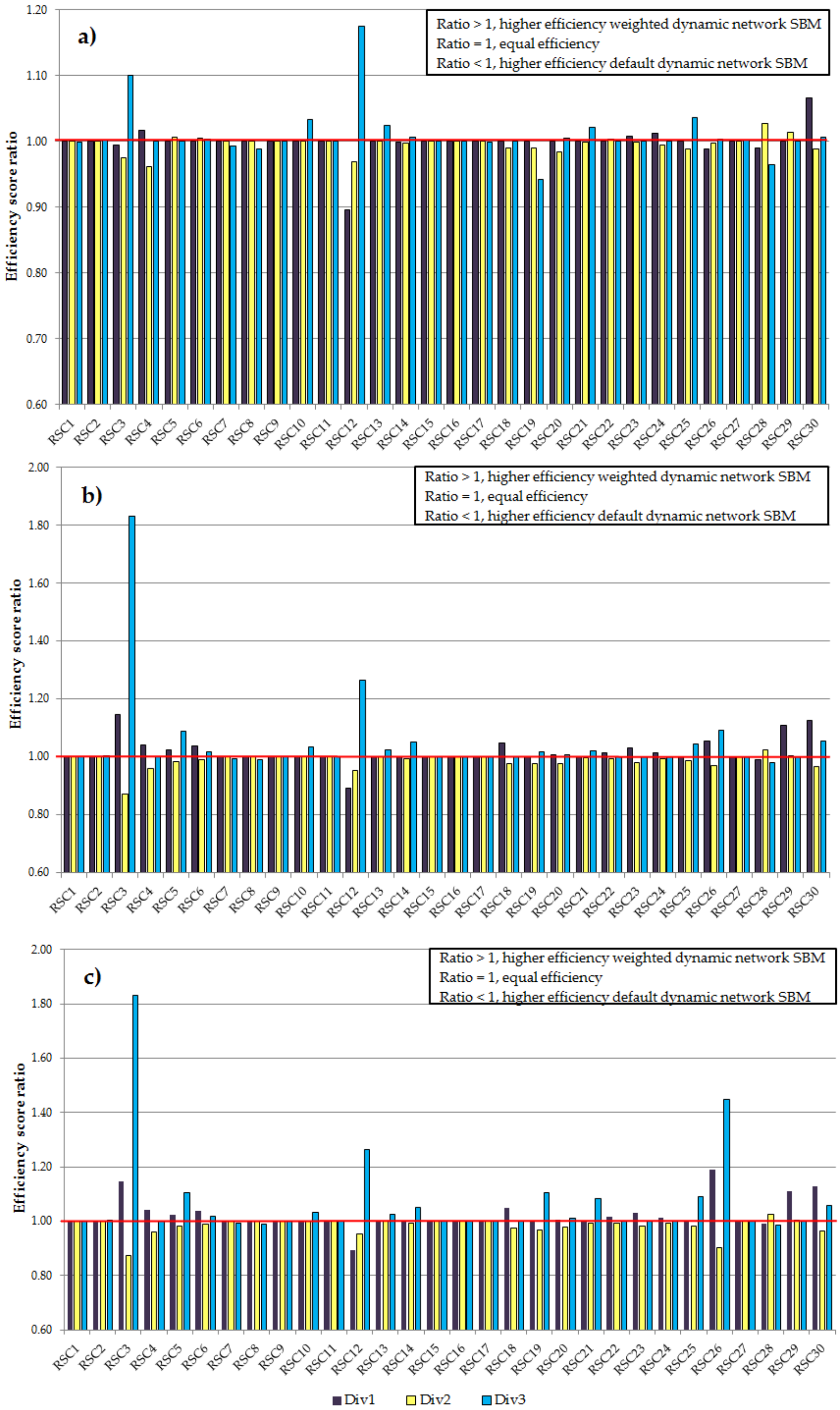

Fig. 9. Divisional efficiency score ratio with respect to the use of equal weights on divisions: influence of weights from (a) company manager, (b) environmental policy-maker, and (c) local community.

3.3.2. Influence on target reductions

Fig. 10 shows the average target operational and socio-economic reductions from the weighted network SBM model and those from the default network model (equal weights on divisions). As in the previous section, the assignment of weights to divisions led to different results depending on the specific decision-maker standpoint. On the one hand, when applying manager-based weights, negligible differences were generally found in the average target operational reductions with respect to those from the original study (Álvarez-Rodríguez et al., 2020). On the other hand, when implementing the preferences of either policy-makers or local community, a moderate influence on the operational benchmarks was observed. In this sense, further prioritising the operation of the stores makes the DEA model pursue higher reductions in the operational levels within Division 2, at the expense of lower reduction targets in the operational elements within Divisions 1 and 3.

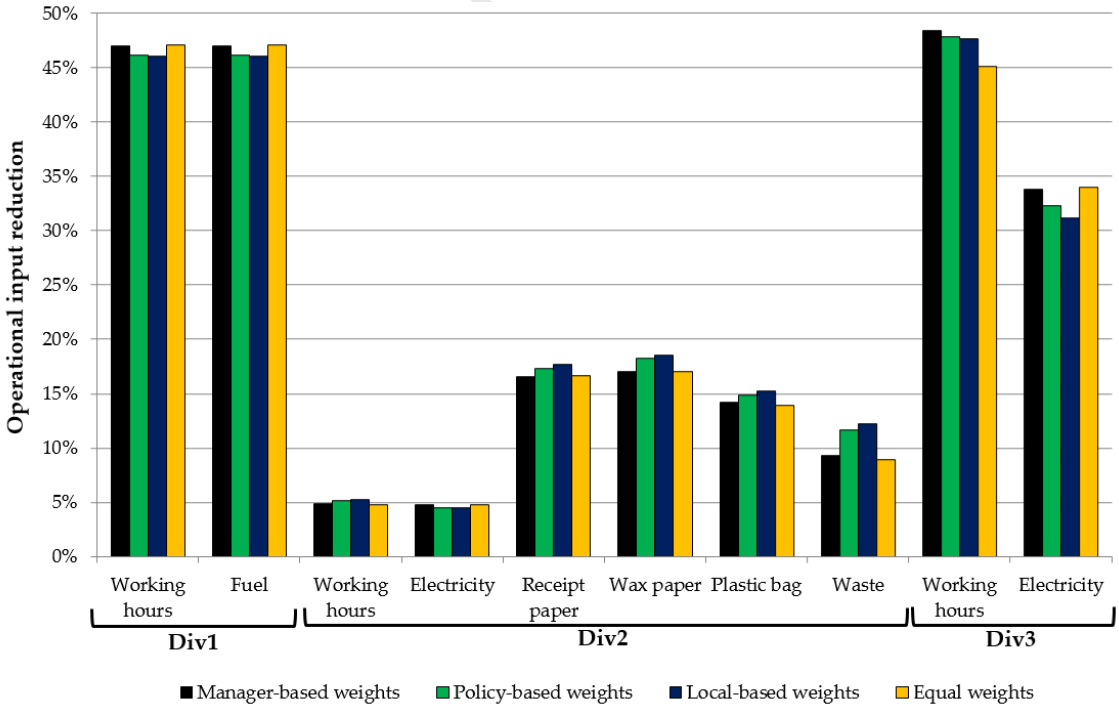

Fig. 10. Average target reductions in DEA inputs applying decision-makers' or equal weights on divisions.

Fig. 11 and 12 show, respectively, the average target reductions in the carbon and energy footprints of the RSCs when using decision-makers' or equal weights on the divisions. For both indicators, the environmental benchmarks computed when implementing the manager-based weights are practically the same as those reported in the original study using equal weights (Álvarez-Rodríguez et al., 2020). On the other hand, a moderate influence on the carbon and energy footprint benchmarks of Divisions 1 and 3 was observed when implementing weights based on policy-makers or local community. According to Álvarez-Rodríguez et al. (2020), the minimisation of diesel demand in Division 1 and electricity demand in Division 2 is crucial to environmentally enhance the management of RSCs. Hence, the similar results in the average electricity reductions (Fig. 10) explain the unaltered carbon and energy footprint benchmarks in Division 2, while the lower operational benchmarks within Divisions 1 and 3 lead to lower environmental benchmarks for these divisions.

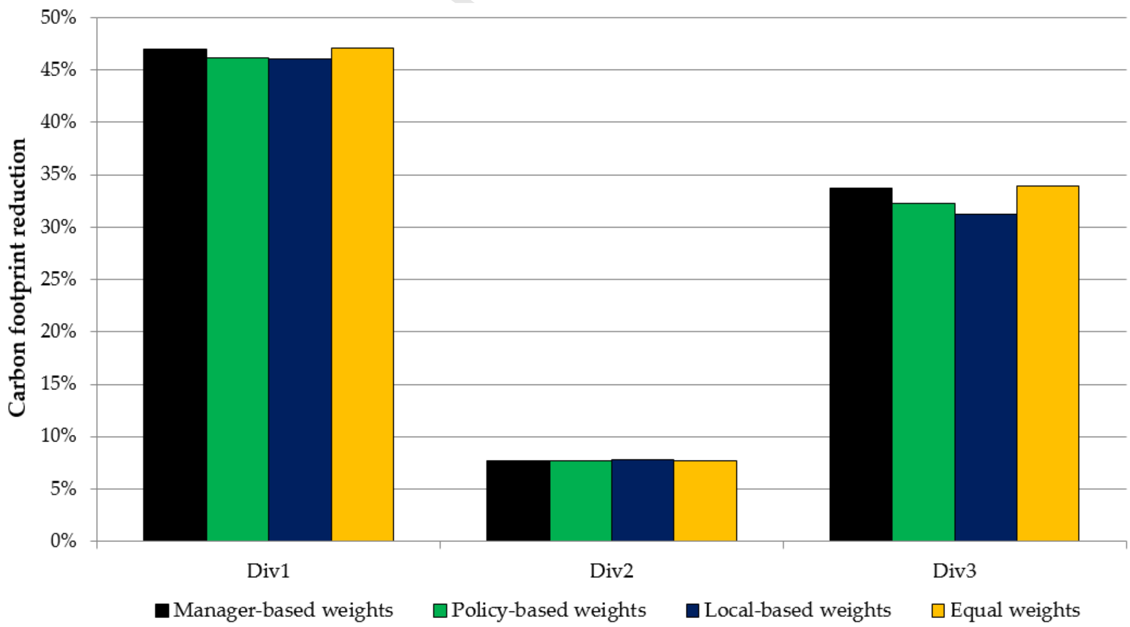

Fig. 11. Average target reductions in carbon footprint applying decision-makers' or equal weights on divisions.

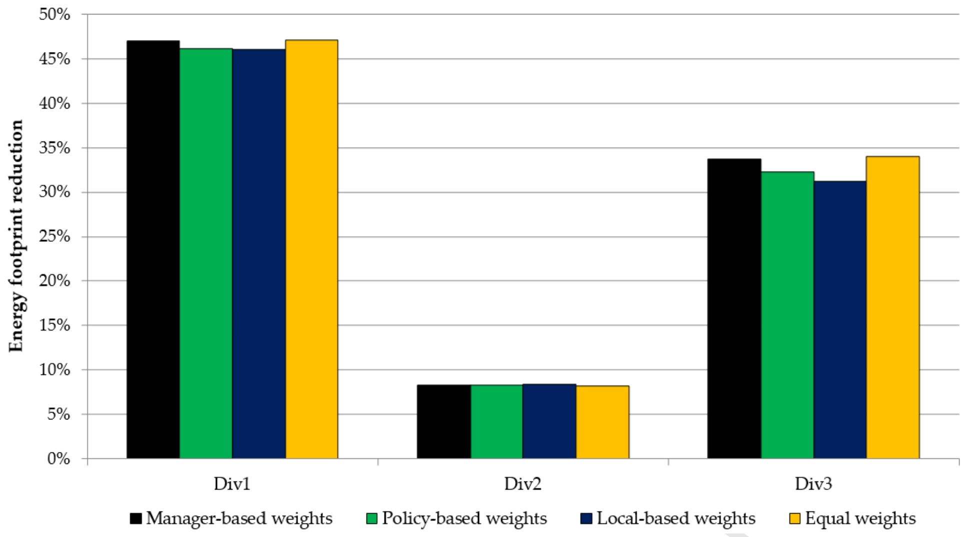

Fig. 12. Average target reductions in energy footprint applying decision-makers' or equal weights on divisions.

3.4. Further discussion

Overall, Table 5 summarises –for the specific case study addressed in this article– the level of influence observed on the LCA + DEA results when implementing alternative decision-makers' preferences for three different types of DEA elements. Such an implementation does affect the LCA + DEA outcomes, especially when assigning weights to the operational elements. Furthermore, the level of influence was also found to be conditioned by the type of stakeholder (decision-maker standpoint). Therefore, the involvement of decision-makers in the LCA + DEA of grocery stores directly affects the benchmarking of managing grocery stores under the umbrella of sustainability. In the light of these findings, the authors highly recommend including the view of decision-makers in LCA + DEA studies (in addition to the default approach based on equal weights) as long as there is a direct involvement of these actors in the evaluation process.

Table 5. Summary of the influence of weights for the case study of grocery stores.

Type of result	**Influence of weights on operational inputs**			**Influence of weights on time terms**			**Influence of weights on divisions**		
Standpoint	*Manager*	*Policy*	*Local*	*Manager*	*Policy*	*Local*	*Manager*	*Policy*	*Local*
Efficiency score	Significant	Significant	Significant	Very low	-	-	Low	Moderate	Moderate
Operational	Significant	Significant	Significant	Very low	-	-	Negligible	Moderate	Moderate

benchmarks									
Environmental benchmarks	Significant	Significant	Significant	Negligible	-	-	Negligible	Moderate	Moderate

Through the revisited case study of retail stores and supply chains, the capability of the combined LCA + DEA concept to foster company action towards the establishment of sustainable production patterns ("produce more with less") was evidenced. The proven feasibility of capturing the view of a certain set of stakeholders within the methodological framework further empowers the LCA + DEA concept to support sound decision-making processes. This is especially achieved by directly influencing the calculation of operational, socio-economic and environmental benchmarks (reduction targets). In particular, the use of LCA + DEA at the company level implementing company managers' preferences arises as an effective way for thorough sustainability management. In this regard, sustainability benchmarks should be used to effectively guide the implementation of improvement actions at the company and DMU levels. Nevertheless, it should be noted that there is no study to date addressing the monitoring of the sustainability performance of DMUs improved on the basis of LCA + DEA outcomes and reference entities. Moreover, delving into the integration of further social aspects into the LCA + DEA framework is still required to consolidate its utility for sustainability-oriented management (Iribarren et al., 2016).

Among the benefits associated with the proposed sustainability management strategy, the enhanced public perception of the company through its alignment with international frameworks such as the United Nations Sustainable Development Goals (in particular, goal 12 on responsible consumption and production) and the European Green Deal is highlighted (Álvarez-Rodríguez et al., 2019a). For instance, the European Green Deal states that companies making green claims should substantiate these against a reference methodology to assess their impact on the environment (European

Commission, 2019). The LCA + DEA methodology could be used to that end, providing companies with reliable, comparable and verifiable information to make sustainability-oriented decisions and reducing the risk of green washing.

4. Conclusions

This work revisited an LCA + DEA case study within the retail sector by applying alternative weighted DEA approaches in order to evaluate the influence of decision-makers' preferences on the final outcomes, thereby filling the knowledge gap in the use of weights in the field of LCA + DEA. Although the results presented in this study are case-specific, they led to the general recommendation of enriching –as far as possible– conventional LCA + DEA studies (which use equal weights by default) by implementing decision-makers' preferences according to the methodological framework proposed in this work. In the specific case study of grocery stores, a significant influence of decision-makers' preferences regarding operational inputs was generally found on efficiency scores and sustainability benchmarks (reduction targets in operational consumption levels and carbon and energy footprints). A moderate influence was also observed on efficiency scores and sustainability benchmarks when adopting a policy-maker or local-community standpoint in weighting DMU divisions. Overall, strengthening the role of decision-makers in LCA + DEA studies paves the way towards an enriched sustainability-oriented management of multiple similar entities. In this regard, the LCA + DEA framework proposed in this study could serve as a starting point for future advances in the field of LCA + DEA for sustainability-oriented management, such as the implementation of further social indicators and the monitoring of improvement actions motivated by the pursuit of sustainability benchmarks.

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Sensitivity of operational and environmental benchmarks of retail stores to decision-makers' preferences through Data Envelopment Analysis

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Conflict of Interest

The authors declare no conflict of interest.

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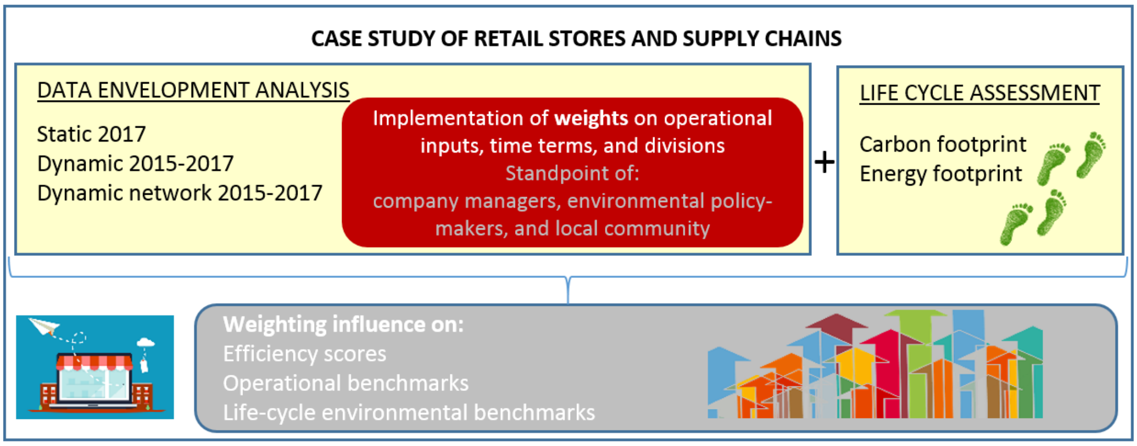
Credit Author Statement

Cristina Álvarez-Rodríguez: conceptualisation; methodology; formal analysis; investigation; writing; visualisation.

Mario Martín-Gamboa: conceptualisation; methodology; formal analysis; writing; supervision.

Diego Iribarren: conceptualisation; methodology; formal analysis; writing; supervision.



Graphical abstract

Sensitivity of operational and environmental benchmarks of retail stores to decision-makers' preferences through Data Envelopment Analysis

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Research highlights

- ✓ Novel use of weights in Data Envelopment Analysis coupled with Life Cycle Assessment
- ✓ Weights on operational inputs, time terms and divisions for retail stores and supply chains
- ✓ Weighting view of company managers, environmental policy-makers and local community
- ✓ Weights influence efficiency scores and operational and environmental benchmarks
- ✓ Recommended inclusion of decision-makers' preferences for sustainability management