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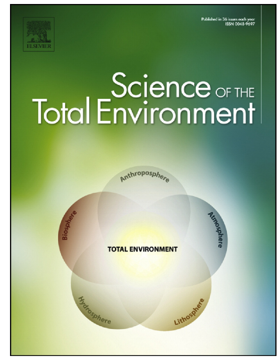

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Sustainability-oriented management of retail stores through the combination of life cycle assessment and dynamic data envelopment analysis

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Abstract

A sound management of retail stores is a crucial aspect in the path towards a sustainable commercial sector, with a lack of research studies in the field of joint efficiency and sustainability assessment within this sector. In this sense, this work delves into the role of operational efficiency in the sustainability-oriented management of retail stores through the case study of 30 groceries in Spain over the period 2015-2017. With this purpose, and given the current knowledge gap in period-oriented sustainability benchmarking for management plans, for the first time a five-step methodological framework based on the combination of Life Cycle Assessment (LCA) and dynamic Data Envelopment Analysis (DEA) was proposed and applied to a case study within the service sector. The overall- and term-efficiency scores calculated through this method led to the general conclusion of a relatively good performance of the set of grocery stores over the evaluated period, which is associated with the centralised management strategy followed by the retail company. Furthermore, operational, socio-economic and environmental benchmarks were calculated as target values that could assist decision-makers at the retail company level in setting the path for a sustainable operation of the company's stores. Overall, the proposed period-oriented LCA + DEA method proved to be a feasible and valuable tool for sustainability management of retail stores, being preferred over the static (i.e., single term) alternative provided that time-series data are available at the company level.

Keywords: data envelopment analysis; efficiency; grocery; life cycle assessment; retail; sustainability management

1. Introduction

Over the past decades, the commercial sector has experienced a great transformation worldwide (Yu and Ramanathan, 2008). The traditional market structure based on single retail units has changed in favour of large-scale supermarkets and firms (Sellers-Rubio and Mas-Ruiz, 2006). According to global statistics, the retail sales worldwide reached 23.45 trillion USD in 2017 (Deloitte, 2018). This rapid development has caused deep social and economic changes not only in the consumption patterns of the population but also in the marketing and distribution systems. One of the results of these changes is an increase in competition, which is expected to lead to an improvement in the efficiency of retail stores (Yu and Ramanathan, 2008).

However, an increase in the competitiveness and efficiency of the retail sector does not necessarily guarantee a sustainable management of retail stores. For instance, in Spain, the commercial sector represents around 5% of the total greenhouse gas (GHG) emissions from all sectors, releasing ca. 11 Mt CO_2 to the atmosphere in 2016 (MAPAMA, 2018). In particular, retail stores are among the building typologies with the highest carbon and energy intensity, the latter typically ranging from 500 to 1000 $kWh \cdot m^{-2} \cdot y^{-1}$ (Ferreira et al., 2018). Hence, the appropriate management of retail stores arises as a crucial aspect to pave the way towards a sustainable commercial sector.

The operational efficiency of each individual retail store is a key aspect of the retailer's productivity since the whole profitability of any retail chain depends on the profitability of its constituent parts. Thus, intra-chain relative efficiency is a measure of paramount importance in this field, as widely addressed in the literature (Yu and Ramanathan, 2008). Previous studies in this area have presented a number of methods to evaluate operational retail efficiency, e.g. data envelopment analysis (DEA), regression, and stochastic frontier analysis. In particular, compared to other options such as parametric regression, DEA emerges as a suitable tool for measuring retail efficiency when assessing a large number of resembling entities without relying on an exogenous definition of a specific production function (Barros and Alves, 2003, 2004; Lozano et al., 2009; Avkiran, 2011). It is a linear programming methodology that quantifies in an empirical manner the comparative productive efficiency of multiple similar entities or decision making units (DMUs) such as –in this case– retail stores within a firm (Cooper et al., 2007). However, the link between operational efficiency and sustainable management of retail stores has been poorly addressed in the literature to date (Ferreira et al., 2018), even though the application of DEA to environmental issues is relatively frequent (Sueyoshi et al., 2017).

In the last decade, the combination of DEA with Life Cycle Assessment (LCA) –a standardised and widely-used methodology to evaluate the performance of a system in terms of environmental indicators (ISO, 2006a, 2006b)– has proven to be a feasible framework for the joint calculation and interpretation of operational efficiencies and sustainability benchmarks of multiple similar entities (Iribarren et al., 2016). In fact, this combined LCA + DEA methodology has been significantly used for case studies within the primary (e.g., agriculture and dairy farming) and secondary (e.g., construction and energy production) sectors (Vázquez-Rowe and Iribarren, 2015; Martín-Gamboa et al., 2017). However, its applicability to case studies within the service sector has just been shown by Álvarez-Rodríguez et al. (2019), who addressed the combined operational and environmental benchmarking of a set of grocery stores using 2017 as the reference year. Nevertheless, it is well-known that this type of study can be significantly affected by the time variability of the system's performance, e.g. on a year-to-year basis (Martín-Gamboa and Iribarren, 2016). Under these circumstances, a period-oriented eco-efficiency assessment would be preferred, which could be addressed through the combination of LCA and dynamic DEA (Tone and Tsutsui, 2010). In this regard, the use of dynamic DEA rather than other period-oriented DEA approaches benefits from the consideration of different types of carry-overs as transition elements that represent the potential variability of DMUs between periods of time (Mariz et al., 2018). Within this context, this article explores –for the first time– the combined use of LCA and dynamic DEA through a case study of the service sector for the sustainability-oriented management of retail stores over an extended period of time.

Hence, this article contributes to filling the current knowledge gap in period-oriented sustainability management and benchmarking. In this sense, two main novel aspects are emphasised: (i) the novel use of a period-oriented approach in an LCA + DEA study within the tertiary sector, and (ii) the novel use of LCA + DEA for period-oriented sustainability benchmarking, regardless of the specific sector under study. Thus, the ultimate objective of this research article is to provide analysts with a well-defined methodological framework for period-oriented sustainability management, proven in –but not limited to– a case study of grocery stores.

2. Material and methods

2.1. LCA + DEA framework

The goal of this study is to prove the applicability of the combined use of LCA and dynamic DEA for the sustainability-oriented management and benchmarking of multiple similar entities, particularly retail stores. With this purpose, the case study of 30 Spanish grocery stores presented in Álvarez-Rodríguez et al. (2019) was used, but extending the assessment to the period 2015-2017 instead of assessing only a reference year (2017). In this regard, another objective of the study consists in exploring the influence of period orientation on the eco-efficiency results of the case study when compared to the individual assessment of a single year.

Regarding the case study, the retail trade plays a relevant role in the Spanish economy, representing 5% of its gross domestic product. In fact, the retail trade accounted for 31% of the turnover and 56% of the personnel occupied in the Spanish commercial sector in 2017 (SEPE, 2018). In particular, within the structure of the Spanish retail trade sector, grocery stores are widely present as central elements of the supply chain of retail companies. In this respect, a single company usually owns tens to hundreds of grocery stores distributed across various locations. These grocery stores typically involve energy-intensive buildings (prolonged heating, cooling, lighting, etc.) with intensive material consumption (paper, plastic, etc.). Thus, Spanish grocery stores constitute a relevant and illustrative case study for enhanced, sustainability-oriented management through the combined use of LCA + DEA. Furthermore, this case study is relevant to a high number of countries with similar features (mainly in terms of retail chain). Besides, LCA + DEA practitioners should understood this case study as an illustrative one that presents –for the first time– the period-oriented sustainability management and benchmarking of multiple similar entities, which makes the study of general interest to analysts and managers regardless of the specific sector under study. In this sense, the step-by-step application of the methodological approach described below is expected to serve as a guide for its application to any case study involving the period-oriented assessment of multiple similar entities for sustainability management plans.

In particular, a five-step, period-oriented LCA + DEA approach was followed (Fig. 1). Vázquez-Rowe et al. (2010) originally established the five steps required for the combined operational and environmental assessment of multiple similar entities. This approach was selected –rather than other LCA + DEA approaches such as the three-step one (Vázquez-Rowe and Iribarren, 2015)– due to its suitability for dealing with operational, environmental, economic and social aspects, thereby providing a joint interpretation under sustainability criteria (Iribarren et al., 2016). However, it should be stressed that, while the original approach in Vázquez-Rowe et al. (2010) corresponds to a static (i.e., single term) perspective, this study constitutes the first time (regardless of the specific sector) that the five-step LCA + DEA method is used with a period-oriented perspective. In this regard, the inclusion of a "dynamic" perspective is required to calculate the operational efficiency and sustainability benchmarks of each grocery store over the selected period of time (2015-2017). It should be noted that, while the period-oriented calculation of efficiency scores constitutes itself a novelty in the field of LCA + DEA in the tertiary sector –as compared with the static approach in Álvarez-Rodríguez et al. (2019)–, the period-oriented sustainability benchmarking constitutes a novelty in LCA + DEA regardless of the sector under study –going beyond the static approaches in Vázquez-Rowe et al. (2010) and Iribarren et al. (2016).

[Fig. 1. Five-step, period-oriented LCA + DEA method applied to the sample of grocery stores]

As shown in Fig. 1, the first step focuses on data collection to prepare the life cycle inventory (LCI) and socio-economic information of each grocery and year. When compared to the study in Álvarez-Rodríguez et al. (2019), the extension of the assessment to a 3-year period significantly increases the need for data. A detailed quantification of the inputs and outputs considered is provided later in Section 2.2. In the second step, the LCIs are used to perform the life cycle impact assessment (LCIA) of each grocery for each year, thereby obtaining their current environmental profiles.

The third step involves the use of a period-oriented DEA model that processes a matrix of operational and socio-economic data into efficiency scores (overall- and term-efficiency scores of each DMU). The dynamic DEA model proposed by Tone and Tsutsui (2010) was used to calculate the efficiency of the groceries as well as the operational and socio-economic benchmarks of the inefficient stores within the selected period of time. Fig. 2 shows the structure of this dynamic DEA study, which involves 30 grocery stores and 3 specific years (2015-2017). For each of these years, every DMU is integrated by a set of DEA elements. In this case, DEA inputs encompass five operational elements (electricity, receipt paper, wax paper, plastic bags, and generated waste) and one socio-economic parameter (working hours), while turnover is the only DEA output. After defining the structure of the dynamic DEA study, key features of the DEA model must be selected: carry-over, metrics, orientation, and display of the production possibility set (Tone and Tsutsui, 2010; Martín-Gamboa and Iribarren, 2016).

When performing dynamic DEA, the use of a link or carry-over is essential in order to connect two consecutive terms and take into account efficiency changes. For the case study of grocery stores, the store inventory at the end of the year (economic stock) was selected as a discretionary (free) carry-over, which is in line with previous studies (Tone and Tsutsui, 2014). In fact, according to Mariz et al. (2018), capital stock is the second type of link most commonly used as carry-over in dynamic DEA studies, which reinforces the choice of this parameter. An input-oriented dynamic slacks-based measure of efficiency model with variable returns to scale (DSBM-I-VRS) was used, as mathematically formulated in Tone and Tsutsui (2010). The choice of non-radial metrics and input orientation is in accordance with previous DEA studies (Martín-Gamboa et al., 2017) and justified by the objective of minimising the operational consumption levels associated with each input while guaranteeing the ability to fulfil at least the same demand (which can also be understood as the ability to generate the same turnover). By means of dynamic DEA, term-efficiency scores are computed for each grocery and year ($\Phi_{i,j}$) along with the overall eco-efficiency score of each store (Φ_i).

These efficiency scores allow distinguishing comparatively efficient grocery stores (Φ = 1) from inefficient ones (Φ < 1). Furthermore, operational benchmarks (i.e., target values) are calculated for each inefficient entity over the period of assessment.

[Fig. 2. Key components of the dynamic DEA study of grocery stores]

The operational benchmarks obtained in the third step involve a modification of the LCIs of the grocery stores. Hence, the fourth step addresses the LCIA of the target DMUs taking into account the modified inventory data, thus providing the environmental benchmarks of each inefficient grocery for each year. Finally, the fifth step tackles the interpretation of the results from the previous steps. For instance, the operational benchmarks can be translated into economic savings, while the socio-economic benchmarks (virtual reduction in working hours) facilitate the identification of useless hours that should be reallocated to different activities within the structure of the groceries (e.g., training) (Iribarren et al., 2013). Moreover, the analysis of operational, socio-economic and environmental benchmarks enables a joint interpretation in terms of sustainability, thus providing the retail company with guidelines for a sustainability-oriented management of its grocery stores.

2.2. Data acquisition

Within the LCA + DEA framework, the data collection step is the source of LCIs as well as of the matrix needed to perform dynamic DEA. Tables 1 and 2 present –for each grocery store and year– the data corresponding to turnover and stock, respectively. These data were retrieved from surveys filled in by the managers of the grocery company, which strengthens the reliability of the study. The average turnover of the sample of grocery stores over the evaluated period was 389,056 €·y^{-1}. As observed in Table 1, the turnover generated by the grocery stores generally experienced a moderate growth during the period 2015-2017, with the highest volume of turnover found for the grocery number 11 in the year 2017 (760 k€·y^{-1}). Regarding the carry-over, the average stocks of the sample were found to range from 2060 €·y^{-1} (year 2017) to 9547 €·y^{-1} (year 2016).

[Table 1. Turnover (€) per grocery and term]

[Table 2. Stock (€) per grocery and term]

Additionally, Table 3 gathers the most relevant input and output annual flows involved in the operation of the grocery stores: electricity, paper for receipts, wax paper, and plastic bags; waste generation; and working hours. These data were also directly provided by the company's managers. The evolution of these annual values generally shows a growth consistent with that of the volume of turnover, with average increases ranging from 7.5% (working hours) to 21% (waste generation).

Overall, the observed variability in the dataset of the sample of grocery stores highlights the convenience of a period-oriented evaluation of their operational performance and the subsequent identification of opportunities (i.e., benchmarks or target values) for their sustainability-oriented management.

[Table 3. Annual operational (electricity [kWh]; receipt paper, wax paper, plastic bags, waste [kg]) and socio-economic (working hours) data for each grocery and year]

The LCIs of the stores were built using the data presented in Table 3 (excluding working hours). Accordingly, the LCA methodology was applied only to the operation of the grocery stores, based on the environmental relevance of this phase (Ferreira et al., 2018). The LCA inputs included all the above-mentioned components of the operational phase of the groceries (electricity, receipt and wax paper, and plastic bags). The LCA output included the generated waste to treatment (mainly organic waste to incineration), and the function of the system was represented by the annual turnover of each store. The use of primary data coming from the company's managers arose as a key aspect determining the reliability of the study. Finally, data for background processes were retrieved from the ecoinvent database (Weidema et al., 2013), which provides the environmental assessment of the operational stage of grocery stores with an actual life-cycle perspective.

3. Results and discussion

This section provides a detailed application of the LCA + DEA methodological framework described in Section 2.1 to the specific case study of grocery stores. Despite the specificity of the results to the case study, this section serves as a general guide for the application of the method to any other case study of multiple similar entities. In this sense, key results such as efficiency scores and sustainability benchmarks are provided with the aim of proving the feasibility of the proposed method for developing sustainability management plans.

3.1. Current environmental characterisation

The LCIs of the grocery stores for each year were translated into life-cycle impacts through their implementation in the software SimaPro (Goedkoop et al., 2016). The life-cycle profile of each grocery was characterised by two environmental impact potentials: global warming (GWP; carbon footprint), and cumulative non-renewable energy demand (CED; energy footprint). GWP was evaluated according to IPCC (2013), while CED was quantified according to the VDI method (VDI, 2012). The choice of GWP and CED was motivated by the fact that they are key life-cycle indicators when evaluating the operational stage of groceries (Iyer et al., 2015; Seebauer et al., 2016). The characterisation results are presented in Tables 4 and 5 for the current carbon and energy footprints, respectively. The values in these tables refer to the annual operation of each grocery.

[Table 4. Current carbon footprint (t CO_2 eq) per grocery and term]

[Table 5. Current energy footprint (GJ) per grocery and term]

On average, the highest carbon and energy footprints were found in the last year of the evaluated period (i.e., 2017), which corresponds to average annual GWP and CED values of 26 t CO_2 eq and 600 GJ, respectively. On the other hand, the lowest average carbon footprint was found for the year 2016 (23 t CO_2 eq), while the lowest average energy footprint was found for the year 2015 (541 GJ). In any case, electricity production was identified as the main process behind the evaluated impacts, with average contributions of 76% and 72% to GWP and CED, respectively (considering the whole sample of grocery stores over the evaluated period). This finding is in agreement with relevant scientific literature which identifies retail stores among the most energy intensive classes of building (Iyer et al., 2015).

3.2. Dynamic DEA

After the characterisation of the grocery stores' environmental performance, the dynamic DEA model (DSBM-I-VRS) was used to calculate their overall efficiency score as well as their term-efficiency scores. This requires the formulation of a DEA matrix made up of the data for the most relevant inputs and outputs of the sample in each year. In this respect, the DEA matrix of this case study involved –for each grocery store within the sample– annual data for (i) turnover as the DEA output (i.e., Table 1), (ii) stock as the carry-over (i.e., Table 2), and (iii) operational and socio-economic data as DEA inputs (i.e., Table 3). Such a DEA matrix was implemented in the optimisation model solved through the software DEA-Solver Pro (Saitech, 2019).

Fig. 3 shows the ranking of the grocery stores according to their overall efficiency scores from dynamic DEA computation. Since overall scores equal to 1 ($\Phi = 1$) denote grocery stores with a comparatively efficient performance, the analysis led to identify

12 (out of 30 DMUs) efficient stores, which corresponds to 40% of the sample. Furthermore, it should be noted that the remaining stores (i.e., the inefficient DMUs) show overall efficiency scores above 0.60. Therefore, the computed overall efficiency scores reveal a relatively good performance of the whole sample over the selected period of time. This finding is associated with the centralised control assumed from the retail company headquarters, with a management policy of homogenous practices in as many grocery stores as possible.

[Fig. 3. Overall efficiency score of each grocery store]

Further results from the dynamic DEA study include the term-efficiency score of each grocery store for each year under evaluation. These term-efficiency scores actually constitute the basis for the calculation of the above-mentioned overall efficiency scores. Table 6 presents the term-efficiency scores obtained for the sample of groceries. Regarding individual periods, the three evaluated years show –on average– similar efficiency scores (around 0.85). Concerning term-efficient entities, the number of strictly efficient grocery stores is the same in 2015 and 2016 (12), while a slight increase was observed in the year 2017 (14). Taking into account the whole set of 90 term-efficiency scores, all values are above 0.59. Approximately 60% of the sample shows term-efficiency scores above 0.80. In fact, more than 45% of the grocery stores present scores above 0.90. Overall, the obtained term-efficiency scores reaffirm the relatively good performance of the sample of grocery stores. In order to discuss the influence of the carry-over and the continuity condition between consecutive periods inherent to the dynamic DEA model (Tone and Tsutsui, 2010) on the results, further analysis was conducted as detailed later in Section 3.5.

[Table 6. Term-efficiency scores (%) of the grocery stores]

Beyond overall- and term-efficiency scores, additional results from the DEA study include operational and socio-economic benchmarks, i.e. target values of the DEA elements that would turn inefficient DMUs into efficient ones. In fact, this article constitutes the first time that the five-step LCA + DEA method was used with a dynamic perspective, thus allowing the calculation of robust operational and socio-economic reduction percentages for the sample of groceries over the selected period of time (Tables 7-9). Overall, the operational and socio-economic benchmarks calculated for the grocery stores show that the inefficient stores present significant room for improvement. Socio-economic benchmarks should be understood as a virtual reduction in working hours, identifying useless hours to be reallocated to activities such as training (Iribarren et al., 2013).

[Table 7. Target operational and socio-economic reduction percentages for the grocery stores in the year 2015]

[Table 8. Target operational and socio-economic reduction percentages for the grocery stores in the year 2016]

[Table 9. Target operational and socio-economic reduction percentages for the grocery stores in the year 2017]

3.3. Target environmental characterisation

The operational benchmarks calculated in the dynamic DEA step involve modifications in the inventory data of each inefficient grocery in each year. The new life-cycle profiles resulting from the modified LCIs can be translated into environmental benchmarks expressed as reduction percentages of the carbon and energy footprints with respect to the current values in Tables 4 and 5. Thus, Tables 10 and 11 present the environmental benchmarks in terms of GWP and CED, respectively. Regarding GWP, the average carbon footprint reduction for the whole sample of inefficient groceries was found to be around 13% in each of the evaluated years, reaching the maximum reductions in the case of the grocery number 23 (33% in the year 2017). Regarding CED, similar average benchmarks (around 14%) were found for the sample of inefficient stores in each of the selected years. The rationale behind the low inter-period variability of the GWP and CED benchmarks is linked to the computed term-efficiency scores, which present similar values for the sample of grocery stores over the evaluated period of time. Additionally, the similarity between GWP and CED benchmarks was already expected according to the high correlation usually found between both life-cycle indicators (Valente et al., 2018).

[Table 10. Target carbon footprint reductions (%) for the grocery stores]

[Table 11. Target energy footprint reductions (%) for the grocery stores]

Given the high contribution of the electricity production to the selected life-cycle indicators, the attainment of the operational benchmarks specific to electricity consumption would play a leading role in achieving the proposed environmental targets. In this regard, for the inefficient groceries, the average operational benchmarks in the electricity consumption are around 7% in each year. For instance, the company could partly address these operational targets by reallocating working hours to training campaigns that raise awareness among employees about good practices in terms of energy efficiency. Overall, the provision of reference values calculated through the LCA + DEA methodology has the potential to support decision-makers in developing robust plans within the environmental management strategy of the company, paving the way for an efficient and cleaner operation of its grocery stores.

3.4. Interpretation

In addition to the calculation of operational, socio-economic and environmental benchmarks, the combined LCA + DEA methodology with a dynamic perspective allows analysts to estimate economic savings for the sample of inefficient groceries over the evaluated period. This potential strengthens the use of this combined LCA + DEA method not only as a tool for environmental management, but also as a valuable tool for sustainability management.

Table 12 presents the potential economic savings associated with the attainment of the operational benchmarks from the dynamic DEA study. These values were calculated for each grocery and year according to the economic prices directly provided by the company's managers. The total annual savings for the whole sample of DMUs were found to range from 67 k€ to 74 k€. Regarding inefficient grocery stores, the average annual savings were found to be around 4 k€, approximately 1% of the average annual turnover.

[Table 12. Economic savings (€) per grocery and term linked to the accomplishment of operational targets]

3.5. Comparison between static and dynamic efficiency assessment

In order to further explore the relevance of the dynamic approach, a comparison between the term-efficiency scores for the year 2017 and those coming from a static DEA study as proposed in Álvarez-Rodríguez et al. (2019) was made in this section. The static efficiency scores and operational and socio-economic benchmarks for the year 2017 were calculated by implementing a DEA matrix specific to this year –readily available in Álvarez-Rodríguez et al. (2019)– in an input-oriented slacks-based measure of efficiency model with variable returns to scale, SBM-I-VRS (Tone et al., 2001). The software DEA-Solver Pro (Saitech, 2019) was used again to solve the optimisation problem.

Fig. 4 shows the comparison between the term-efficiency scores and the static scores referred to the year 2017. As observed, a similar trend was generally found for both sets of efficiency scores. In fact, similar average efficiency scores for the sample of groceries were found: $\Phi = 0.86$ in the dynamic DEA study and $\Phi = 0.83$ in the static one. However, it should be noted that differences above 10 percentage points were identified in 4 entities, which was found to affect the identification of term-efficient grocery stores.

Additionally, Fig. 5 shows –for the year 2017– the comparison of the average target reductions in the selected DEA inputs obtained from the static and the dynamic DEA study. The operational and socio-economic benchmarks from both DEA studies were found to be similar, with differences above 4 percentage points only in the case of wax paper.

Overall, a moderate influence of the dynamic approach on the results was found in comparison with a static approach. However, this finding should be seen as case-specific and should not be generalised to other case studies applying dynamic DEA (Martín-Gamboa and Iribarren, 2016; Martín-Gamboa et al., 2018). In other words, the moderate influence of the dynamic approach in this specific case study was found to be motivated by the relatively homogenous practices implemented by the retail company in the grocery stores under its control, which is a singularity of the case study. In fact, since data availability is not expected to constitute a problem at the company level, the use of a dynamic LCA + DEA approach should be prioritised over the application of a static one.

The main implications of implementing such a dynamic LCA + DEA approach for the sustainability-oriented management of multiple similar entities would be found at the company level, supporting thorough decision-making processes and facilitating the elaboration of management plans for continuous improvement. In this respect, term-efficiency scores would be used for monitoring the entities' performance and the sustainability benchmarks would be used to set improvement targets for future years. Furthermore, regarding policy making, the proposed method could be used to set reference values or targets that underpin the implementation of best practices in a given sector, which is likely to require the creation of a database of a consortium of multiple entities not only from the same company but also from different companies (Iribarren et al., 2016).

[Fig. 4. Comparison of the efficiency scores for the year 2017 from dynamic and static DEA]

[Fig. 5. Comparison of the average target reductions in DEA inputs for the year 2017 from dynamic and static DEA]

4. Conclusions

The proposed period-oriented LCA + DEA methodology proved to be a feasible and valuable tool for sustainability management of retail stores. Through its application to a case study of grocery stores in Spain, operational efficiency scores and sustainability benchmarks were calculated for a sample of 30 groceries over a period of three years. All the assessed entities presented overall efficiency scores above 0.60, and 12 of them were deemed efficient. In addition to overall efficiency scores, the use of dynamic DEA allowed the calculation of term-efficiency scores, which led to the general conclusion of a relatively good performance of the set of grocery stores over the evaluated period. The centralised control assumed from the retail company headquarters was identified as the key factor behind this conclusion.

Regarding the calculation of sustainability benchmarks, inefficient grocery stores should pursue significant reductions in operational consumption leading to average reductions of 13% and 14% in carbon and energy footprints, respectively. Given the leading role of electricity in the life-cycle profile of grocery stores, the attainment of the electricity consumption benchmarks (average target reduction of 7% for the sample of inefficient stores) was identified as a key aspect in achieving the environmental targets, also resulting in relevant economic savings. This could be partly achieved through the reallocation of working hours to activities such as the training of employees, e.g. on energy-efficient practices.

These findings –coming from the joint interpretation of operational, socio-economic and environmental aspects– show the suitability of the proposed methodology for sustainability management and benchmarking of retail stores and, in general, of multiple similar entities. In particular, decision-makers at the retail company level could use sustainability benchmarks as reference values towards a sustainable operation of the company's stores, thereby contributing to developing a cleaner and sustainable commercial sector.

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Table and figure captions

Fig. 1. Five-step, period-oriented LCA + DEA method applied to the sample of grocery stores.

Fig. 2. Key components of the dynamic DEA study of grocery stores.

Fig. 3. Overall efficiency score of each grocery store.

Fig. 4. Comparison of the efficiency scores for the year 2017 from dynamic and static DEA.

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Table 1. Turnover (€) per grocery and term.

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Table 10. Target carbon footprint reductions (%) for the grocery stores.

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Table 12. Economic savings (€) per grocery and term linked to the accomplishment of operational targets.

Table 1. Turnover (€) per grocery and term.

DMU code	Year 2015	Year 2016	Year 2017
Grocery1	153,600	163,000	173,900
Grocery2	318,900	304,000	293,000
Grocery3	309,000	330,000	360,000
Grocery4	361,800	395,000	435,000
Grocery5	532,600	540,000	582,500
Grocery6	321,700	398,000	406,000
Grocery7	228,000	241,300	257,000
Grocery8	356,000	384,000	328,300
Grocery9	360,500	407,000	376,300
Grocery10	591,500	621,200	626,300
Grocery11	649,600	729,900	759,800
Grocery12	382,800	448,000	509,000
Grocery13	193,300	205,000	214,000
Grocery14	332,600	362,200	382,000
Grocery15	522,100	532,000	554,800
Grocery16	566,900	612,000	653,000
Grocery17	598,000	628,000	662,000
Grocery18	383,000	398,000	409,000
Grocery19	479,300	491,000	526,000
Grocery20	450,000	460,000	478,000
Grocery21	541,800	551,000	553,000
Grocery22	279,000	252,400	319,500
Grocery23	198,600	202,600	202,900
Grocery24	186,000	181,400	177,500
Grocery25	371,000	319,800	371,400
Grocery26	344,100	353,400	358,200
Grocery27	154,200	158,900	166,400
Grocery28	214,000	287,000	336,400
Grocery29	341,900	336,400	343,000
Grocery30	388,200	399,700	398,600

Table 2. Stock (€) per grocery and term.

DMU code	Year 2015	Year 2016	Year 2017
Grocery1	2300	1000	4600
Grocery2	5100	8400	1500
Grocery3	4600	8800	1700
Grocery4	5500	10,000	2100
Grocery5	7100	15,200	3600
Grocery6	4800	10,900	1500
Grocery7	1100	5400	1300
Grocery8	5300	10,000	1900
Grocery9	4900	11,400	1900
Grocery10	9600	16,600	2500
Grocery11	9400	19,000	4000
Grocery12	5000	11,500	2400
Grocery13	3100	5300	1100
Grocery14	4900	9300	1800
Grocery15	7800	13,800	2800
Grocery16	9000	15,500	2800
Grocery17	10,400	8800	1700
Grocery18	5400	10,300	1700
Grocery19	7000	10,900	1700
Grocery20	6500	11,500	2500
Grocery21	7500	13,000	2900
Grocery22	4200	6900	1900
Grocery23	3000	5500	1200
Grocery24	2900	3000	1000
Grocery25	5600	9000	1900
Grocery26	4500	9200	1800
Grocery27	2500	4200	600
Grocery28	3100	7200	1700
Grocery29	5100	6800	1800
Grocery30	6100	8000	1900

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Table 3. Annual operational (electricity [kWh]; receipt paper, wax paper, plastic bags, waste [kg]) and socio-economic (working hours) data for each grocery and year.

DMU code	Year 2015						Year 2016						Year 2017					
	Electricity	Receipt paper	Wax paper	Plastic bag	Waste	Working hours	Electricity	Receipt paper	Wax paper	Plastic bag	Waste	Working hours	Electricity	Receipt paper	Wax paper	Plastic bag	Waste	Working hours
Grocery1	32,609	14	884	525	3100	4800	39,286	14	936	534	3720	4800	43,373	18	1040	572	4650	4800
Grocery2	32,609	31	1560	906	8060	5760	35,714	29	1560	895	8060	5760	43,373	27	1560	853	7750	5760
Grocery3	52,174	29	1300	996	8060	5760	58,571	32	1352	1096	9920	5760	65,060	36	1560	1196	10,850	5760
Grocery4	52,935	27	1040	1137	9300	6720	64,286	32	1820	1099	12,090	6720	66,506	37	2080	1146	13,020	6720
Grocery5	71,739	45	2340	1744	17,050	7680	62,857	50	2340	1938	17,980	7680	70,843	54	2600	2325	19,220	7680
Grocery6	58,696	50	1456	1893	9300	5760	50,000	52	1560	1993	12,710	5760	52,048	55	1664	2192	12,710	7680
Grocery7	33,522	22	988	1196	5890	3840	41,000	24	972	1375	7440	3840	43,373	26	1040	1415	8060	3840
Grocery8	62,609	18	1300	598	1560	7680	72,857	23	2080	797	10,850	7680	57,831	20	1560	598	9300	7680
Grocery9	37,826	36	1508	1145	9610	5760	44,286	40	2184	1255	11,780	5760	46,265	36	1820	1145	10,850	5760
Grocery10	53,478	37	2080	1491	15,190	7680	62,857	37	2600	153	18,600	7680	66,506	37	2600	1529	18,600	8640
Grocery11	52,174	36	2288	1841	24,800	9600	58,571	36	2340	1860	24,800	9600	60,000	38	2600	1938	26,350	9600
Grocery12	52,826	27	1300	1163	9920	5760	58,571	32	1456	1356	13,950	5760	61,446	36	1560	1550	15,500	6720
Grocery13	39,130	18	624	687	4030	3840	43,571	20	624	725	4030	3840	45,542	22	624	763	4650	3840
Grocery14	52,174	29	1196	821	8370	5760	58,571	32	1248	835	8990	5760	60,723	36	1300	912	9300	5760
Grocery15	65,870	27	1300	1163	6200	6720	72,857	27	1352	1163	6820	6720	75,181	29	1404	1240	7440	6720
Grocery16	65,217	32	1404	1085	14,570	5760	57,143	34	1456	1163	16,120	6720	59,277	36	1560	1240	18,600	6720
Grocery17	63,913	34	1924	1511	14,570	8640	71,429	36	1976	1550	17,050	8640	75,181	40	2080	1647	18,600	9600
Grocery18	52,174	50	2080	2116	9610	6720	61,429	52	2080	2217	10,230	6720	65,060	54	2080	2418	10,540	6720
Grocery19	65,217	49	1820	1821	12,400	5760	72,857	50	1976	1848	13,020	5760	75,181	54	2080	1938	13,640	6720
Grocery20	65,217	54	2080	1975	11,470	5760	72,857	58	2340	2015	11,780	5760	72,289	63	2600	2116	12,400	7680
Grocery21	50,870	69	3120	2325	13,640	7680	57,857	72	3120	2325	14,260	7680	60,723	72	3120	2325	14,260	8640
Grocery22	52,174	32	1300	1023	7130	5760	57,143	25	1040	930	5580	5760	43,373	36	1560	1116	9920	6720
Grocery23	49,565	25	2080	858	5270	4800	58,571	27	2080	858	5580	4800	62,169	27	2080	858	5580	4800
Grocery24	40,435	22	1040	687	4650	3840	45,714	22	1040	687	4650	3840	46,988	22	1040	687	4650	3840
Grocery25	65,217	45	2080	1478	9610	5760	57,143	36	1560	1326	8370	5760	57,831	45	2080	1516	9920	6720
Grocery26	52,174	52	2808	2277	8370	5760	57,857	54	2860	2286	9920	5760	59,277	54	3120	2325	9920	5760
Grocery27	45,652	17	728	515	3410	3840	50,000	17	728	534	3410	3840	40,482	18	780	572	3720	3840
Grocery28	52,174	31	1560	1302	5580	3840	57,143	39	1820	1488	7440	4800	40,482	45	2080	1860	8680	5760
Grocery29	52,174	27	1092	916	8680	5760	57,857	25	1040	858	8990	6720	43,373	27	1040	954	8990	5760
Grocery30	65,217	44	2028	1787	9920	6720	72,857	45	2080	1860	10,230	7680	54,940	45	2080	1824	10,230	6720

Table 4. Current carbon footprint (t CO_2 eq) per grocery and term.

DMU code	Year 2015	Year 2016	Year 2017
Grocery1	14.28	14.16	18.27
Grocery2	16.40	15.08	19.83
Grocery3	23.12	21.84	28.26
Grocery4	23.30	24.35	29.60
Grocery5	33.71	26.79	34.69
Grocery6	27.64	21.71	26.05
Grocery7	16.30	16.62	20.16
Grocery8	25.74	26.56	24.41
Grocery9	18.73	19.49	22.01
Grocery10	26.18	23.50	31.47
Grocery11	27.16	25.64	30.35
Grocery12	23.77	22.71	27.92
Grocery13	16.56	15.30	18.74
Grocery14	22.59	21.09	25.67
Grocery15	28.27	25.98	31.50
Grocery16	28.37	21.98	26.63
Grocery17	29.65	27.80	33.90
Grocery18	26.82	26.23	31.67
Grocery19	30.53	28.70	34.33
Grocery20	31.24	29.60	34.50
Grocery21	28.67	27.31	31.83
Grocery22	23.14	20.39	20.48
Grocery23	23.07	22.36	27.19
Grocery24	17.73	16.55	19.77
Grocery25	30.12	22.19	27.23
Grocery26	28.30	26.61	31.14
Grocery27	18.66	16.90	16.79
Grocery28	24.09	22.92	21.83
Grocery29	22.63	20.58	19.24
Grocery30	30.69	28.78	26.87

Table 5. Current energy footprint (GJ) per grocery and term.

DMU code	Year 2015	Year 2016	Year 2017
Grocery1	307.76	335.57	404.67
Grocery2	359.50	359.92	443.20
Grocery3	502.07	523.62	634.38
Grocery4	510.94	577.10	657.84
Grocery5	737.85	650.27	799.79
Grocery6	624.91	542.91	617.54
Grocery7	370.56	414.61	471.10
Grocery8	545.70	618.80	532.79
Grocery9	415.22	465.73	496.58
Grocery10	575.81	519.67	704.91
Grocery11	602.30	617.04	689.65
Grocery12	520.22	548.07	635.88
Grocery13	360.58	369.91	423.24
Grocery14	485.36	499.96	571.32
Grocery15	614.84	623.99	708.34
Grocery16	609.60	524.05	596.33
Grocery17	648.93	666.35	763.69
Grocery18	613.39	652.30	745.21
Grocery19	679.04	698.25	785.11
Grocery20	698.66	722.01	792.74
Grocery21	653.07	669.71	738.21
Grocery22	503.94	490.33	464.39
Grocery23	495.11	526.01	600.61
Grocery24	383.03	394.22	440.86
Grocery25	659.44	537.80	620.37
Grocery26	647.67	657.32	725.81
Grocery27	398.06	401.33	374.71
Grocery28	533.04	558.06	515.91
Grocery29	489.63	490.52	435.61
Grocery30	681.94	701.45	622.54

Table 6. Term-efficiency scores (%) of the grocery stores.

DMU code	Year 2015	Year 2016	Year 2017
Grocery1	100.00	100.00	100.00
Grocery2	100.00	100.00	100.00
Grocery3	77.05	75.67	74.64
Grocery4	82.19	75.88	76.15
Grocery5	68.18	70.68	68.45
Grocery6	62.14	75.48	67.80
Grocery7	100.00	100.00	100.00
Grocery8	100.00	100.00	100.00
Grocery9	100.00	99.99	100.00
Grocery10	100.00	100.00	100.00
Grocery11	100.00	100.00	100.00
Grocery12	84.86	86.90	85.48
Grocery13	100.00	100.00	100.00
Grocery14	84.25	89.77	86.94
Grocery15	100.00	100.00	100.00
Grocery16	100.00	100.00	100.00
Grocery17	100.00	100.00	100.00
Grocery18	65.17	63.30	63.15
Grocery19	75.66	99.99	77.62
Grocery20	69.05	68.59	62.31
Grocery21	78.51	72.63	67.28
Grocery22	74.57	79.11	80.06
Grocery23	69.57	69.02	68.94
Grocery24	87.53	91.13	86.98
Grocery25	68.40	70.49	69.72
Grocery26	60.67	59.84	60.24
Grocery27	100.00	100.00	100.00
Grocery28	87.98	81.20	100.00
Grocery29	85.69	100.00	100.00
Grocery30	63.09	62.12	71.13

Table 7. Target operational and socio-economic reduction percentages for the grocery stores in the year 2015.

DMU code	Electricity	Receipt paper	Wax paper	Plastic bag	Waste	Working hours
Grocery1	0.00	0.00	0.00	0.00	0.00	0.00
Grocery2	0.00	0.00	0.00	0.00	0.00	0.00
Grocery3	6.97	26.50	33.70	14.28	40.53	15.74
Grocery4	0.19	16.25	6.69	18.13	44.71	20.89
Grocery5	8.39	37.19	43.40	34.37	52.13	15.43
Grocery6	15.54	57.31	39.01	53.91	47.56	13.81
Grocery7	0.00	0.00	0.00	0.00	0.00	0.00
Grocery8	0.00	0.00	0.00	0.00	0.00	0.00
Grocery9	0.00	0.01	0.00	0.01	0.00	0.00
Grocery10	0.00	0.00	0.00	0.00	0.00	0.00
Grocery11	0.00	0.00	0.00	0.00	0.00	0.00
Grocery12	0.00	10.65	16.69	17.01	43.46	3.06
Grocery13	0.00	0.00	0.00	0.00	0.00	0.00
Grocery14	0.00	26.46	18.47	0.00	44.16	5.42
Grocery15	0.00	0.00	0.00	0.00	0.00	0.00
Grocery16	0.00	0.00	0.00	0.00	0.00	0.00
Grocery17	0.00	0.00	0.00	0.00	0.00	0.00
Grocery18	0.00	51.39	46.61	54.32	40.29	16.39
Grocery19	9.07	43.61	30.51	38.53	24.35	0.00
Grocery20	10.10	51.64	43.87	47.06	33.07	0.00
Grocery21	0.00	47.47	37.21	38.46	0.00	5.81
Grocery22	5.23	42.30	21.34	27.47	55.25	0.97
Grocery23	20.20	34.74	60.11	29.59	37.62	0.32
Grocery24	0.20	20.31	36.61	2.86	14.84	0.00
Grocery25	22.45	46.66	47.42	25.05	39.81	8.19
Grocery26	1.73	57.54	66.59	59.96	39.68	10.48
Grocery27	0.00	0.00	0.00	0.00	0.00	0.00
Grocery28	15.59	17.89	22.87	11.88	3.92	0.00
Grocery29	0.00	19.98	9.68	3.93	46.73	5.55
Grocery30	15.82	47.03	49.33	45.54	46.25	17.50

Table 8. Target operational and socio-economic reduction percentages for the grocery stores in the year 2016.

DMU code	Electricity (%)	Receipt paper	Wax paper	Plastic bag	Waste	Working hours
Grocery1	0.00	0.00	0.00	0.00	0.00	0.00
Grocery2	0.00	0.00	0.00	0.00	0.00	0.00
Grocery3	7.06	29.87	32.14	15.49	46.85	14.53
Grocery4	6.91	24.80	40.60	3.89	49.98	18.56
Grocery5	0.00	40.18	42.13	41.57	36.94	15.11
Grocery6	0.00	48.04	27.15	41.45	20.50	9.98
Grocery7	0.00	0.00	0.00	0.00	0.00	0.00
Grocery8	0.00	0.00	0.00	0.00	0.00	0.00
Grocery9	0.00	0.01	0.02	0.01	0.00	0.00
Grocery10	0.00	0.00	0.00	0.00	0.00	0.00
Grocery11	0.00	0.00	0.00	0.00	0.00	0.00
Grocery12	0.00	15.90	15.46	10.68	35.99	0.54
Grocery13	0.00	0.00	0.00	0.00	0.00	0.00
Grocery14	7.94	22.96	5.34	0.00	15.58	9.57
Grocery15	0.00	0.00	0.00	0.00	0.00	0.00
Grocery16	0.00	0.00	0.00	0.00	0.00	0.00
Grocery17	0.00	0.00	0.00	0.00	0.00	0.00
Grocery18	1.06	54.26	48.34	55.66	44.20	16.71
Grocery19	0.01	0.02	0.02	0.02	0.00	0.00
Grocery20	23.37	51.51	50.54	49.55	13.49	0.00
Grocery21	0.00	54.11	50.65	49.05	0.00	10.42
Grocery22	16.32	17.29	29.85	15.23	20.53	26.09
Grocery23	25.78	26.67	69.30	16.80	28.16	19.15
Grocery24	0.00	9.42	27.63	2.80	13.40	0.00
Grocery25	5.76	37.98	43.62	33.75	40.15	15.78
Grocery26	1.78	57.84	65.67	60.00	46.58	9.08
Grocery27	0.00	0.00	0.00	0.00	0.00	0.00
Grocery28	17.25	37.04	40.68	10.59	0.00	7.22
Grocery29	0.01	0.00	0.00	0.00	0.00	0.01
Grocery30	16.40	48.36	45.47	48.39	44.28	24.40

Table 9. Target operational and socio-economic reduction percentages for the grocery stores in the year 2017.

DMU code	Electricity	Receipt paper	Wax paper	Plastic bag	Waste	Working hours
Grocery1	0.00	0.00	0.00	0.00	0.00	0.00
Grocery2	0.00	0.00	0.00	0.00	0.00	0.00
Grocery3	10.21	32.45	34.24	20.60	45.72	8.91
Grocery4	2.35	30.76	39.26	10.01	50.29	10.41
Grocery5	4.66	41.84	44.00	47.63	37.81	13.34
Grocery6	0.00	49.38	37.81	55.55	17.08	33.38
Grocery7	0.00	0.00	0.00	0.00	0.00	0.00
Grocery8	0.00	0.00	0.00	0.00	0.00	0.00
Grocery9	0.00	0.01	0.01	0.00	0.00	0.00
Grocery10	0.00	0.00	0.00	0.00	0.00	0.00
Grocery11	0.00	0.00	0.00	0.00	0.00	0.00
Grocery12	8.04	16.05	10.35	32.02	12.66	7.97
Grocery13	0.00	0.00	0.00	0.00	0.00	0.00
Grocery14	9.02	31.08	13.11	0.00	17.49	7.68
Grocery15	0.00	0.00	0.00	0.00	0.00	0.00
Grocery16	0.00	0.00	0.00	0.00	0.00	0.00
Grocery17	0.00	0.00	0.00	0.00	0.00	0.00
Grocery18	3.93	52.37	48.54	57.16	40.74	18.34
Grocery19	18.07	42.70	28.51	40.56	4.42	0.00
Grocery20	5.17	57.04	51.98	46.73	44.97	20.28
Grocery21	0.00	56.47	55.13	51.01	6.43	27.26
Grocery22	0.00	28.76	35.48	19.56	17.20	18.63
Grocery23	29.64	29.57	59.68	26.02	27.07	14.36
Grocery24	11.34	12.78	28.50	10.19	15.34	0.00
Grocery25	0.00	46.40	44.05	38.59	36.58	16.09
Grocery26	2.80	56.79	65.12	61.20	43.98	8.64
Grocery27	0.00	0.00	0.00	0.00	0.00	0.00
Grocery28	0.00	0.00	0.00	0.00	0.00	0.00
Grocery29	0.00	0.00	0.00	0.00	0.00	0.00
Grocery30	0.00	43.12	44.59	49.08	16.45	20.00

Table 10. Target carbon footprint reductions (%) for the grocery stores.

DMU code	Year 2015	Year 2016	Year 2017
Grocery1	0.00	0.00	0.00
Grocery2	0.00	0.00	0.00
Grocery3	10.57	11.23	13.86
Grocery4	3.20	11.61	8.08
Grocery5	16.08	13.35	16.28
Grocery6	23.56	11.73	14.15
Grocery7	0.00	0.00	0.00
Grocery8	0.00	0.00	0.00
Grocery9	< 0.01	< 0.01	< 0.01
Grocery10	0.00	0.00	0.00
Grocery11	0.00	0.00	0.00
Grocery12	3.95	3.84	11.14
Grocery13	0.00	0.00	0.00
Grocery14	2.27	7.18	8.85
Grocery15	0.00	0.00	0.00
Grocery16	0.00	0.00	0.00
Grocery17	0.00	0.00	0.00
Grocery18	15.54	17.60	17.78
Grocery19	15.13	0.01	21.59
Grocery20	19.07	30.52	16.93
Grocery21	13.27	18.36	16.89
Grocery22	9.42	17.40	7.04
Grocery23	27.00	31.72	33.15
Grocery24	4.10	3.25	12.77
Grocery25	25.80	14.17	10.60
Grocery26	22.60	24.25	22.75
Grocery27	0.00	0.00	0.00
Grocery28	15.84	19.22	< 0.01
Grocery29	1.82	0.01	< 0.01
Grocery30	23.50	24.60	12.93

Table 11. Target energy footprint reductions (%) for the grocery stores.

DMU code	Year 2015	Year 2016	Year 2017
Grocery1	0.00	0.00	0.00
Grocery2	0.00	0.00	0.00
Grocery3	10.36	10.63	13.71
Grocery4	3.93	9.96	7.22
Grocery5	16.84	14.55	18.50
Grocery6	26.41	14.38	18.56
Grocery7	0.00	0.00	0.00
Grocery8	0.00	0.00	0.00
Grocery9	< 0.01	< 0.01	< 0.01
Grocery10	0.00	0.00	0.00
Grocery11	0.00	0.00	0.00
Grocery12	4.45	3.57	12.79
Grocery13	0.00	0.00	0.00
Grocery14	1.62	6.77	8.25
Grocery15	0.00	0.00	0.00
Grocery16	0.00	0.00	0.00
Grocery17	0.00	0.00	0.00
Grocery18	19.58	20.29	21.32
Grocery19	17.06	0.02	23.18
Grocery20	21.41	31.71	18.68
Grocery21	16.11	20.48	19.67
Grocery22	10.23	17.05	7.41
Grocery23	26.62	29.88	32.39
Grocery24	3.64	2.64	12.44
Grocery25	25.39	14.63	12.02
Grocery26	26.36	26.20	25.68
Grocery27	0.00	0.00	0.00
Grocery28	15.50	18.15	< 0.01
Grocery29	1.47	0.01	< 0.01
Grocery30	25.05	25.74	15.81

Table 12. Economic savings (€) per grocery and term linked to the accomplishment of operational targets.

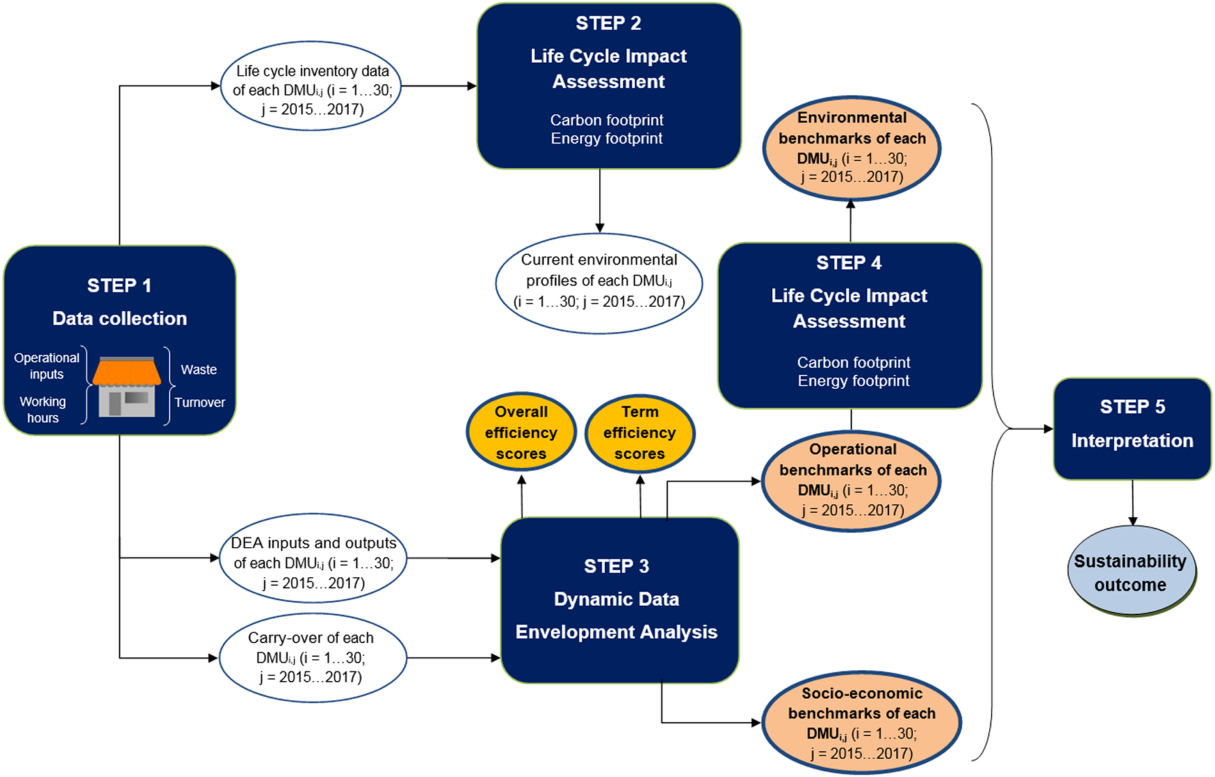
DMU code	Year 2015						Year 2016						Year 2017					
	Electricity	**Receipt paper**	**Wax paper**	**Plastic bag**	**Waste**	**Total savings**	**Electricity**	**Receipt paper**	**Wax paper**	**Plastic bag**	**Waste**	**Total savings**	**Electricity**	**Receipt paper**	**Wax paper**	**Plastic bag**	**Waste**	**Total savings**
Grocery1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Grocery2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Grocery3	668.77	88.86	438.13	515.41	326.64	2037.81	760.85	112.68	434.59	614.99	464.80	2387.90	1169.56	136.01	534.15	892.22	496.10	3228.03
Grocery4	18.69	51.08	69.57	745.63	415.80	1300.77	817.42	93.55	738.86	154.65	604.27	2408.75	275.21	131.49	816.63	415.11	654.80	2293.24
Grocery5	1108.11	194.82	1015.62	2173.56	888.84	5380.95	0.00	235.77	985.93	2920.99	664.13	4806.81	580.97	263.01	1143.88	4016.16	726.68	6730.69
Grocery6	1678.73	336.28	568.02	3696.96	442.26	6722.24	0.00	291.96	423.47	2992.10	260.52	3968.05	0.00	315.57	629.23	4410.91	217.04	5572.75
Grocery7	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Grocery8	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Grocery9	0.00	0.03	0.00	0.41	0.00	0.45	0.00	0.06	0.38	0.45	0.02	0.92	0.00	0.02	0.14	0.00	0.01	0.17
Grocery10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Grocery11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Grocery12	0.00	33.46	216.95	715.82	431.14	1397.37	0.00	59.98	225.14	524.35	502.12	1311.59	869.74	67.27	161.48	1796.64	196.24	3091.36
Grocery13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Grocery14	0.00	88.73	220.95	0.00	369.58	679.26	855.34	86.59	66.64	0.00	140.03	1148.59	964.32	130.24	170.45	0.00	162.67	1427.68
Grocery15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Grocery16	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Grocery17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Grocery18	0.00	301.55	969.47	4172.75	387.22	5830.99	120.05	329.74	1005.40	4479.29	452.12	6386.62	450.50	329.23	1009.70	5018.19	429.36	7236.99
Grocery19	1087.98	251.28	555.23	2544.93	301.95	4741.38	1.93	0.12	0.35	1.34	0.00	3.74	2391.03	268.45	592.94	2850.02	60.32	6162.76
Grocery20	1212.13	324.61	912.41	3374.05	379.31	6202.52	3133.40	345.41	1182.57	3625.08	158.90	8445.36	657.40	418.31	1351.53	3589.71	557.57	6574.52
Grocery21	0.00	379.99	1160.92	3242.95	0.00	4783.86	0.00	453.55	1580.26	4135.90	0.00	6169.71	0.00	473.36	1719.92	4301.16	91.65	6586.09
Grocery22	502.29	159.54	277.41	1,014.79	393.95	2347.98	1716.09	50.72	310.48	511.47	114.56	2703.32	0.00	120.52	553.48	788.27	170.61	1632.87
Grocery23	1842.32	101.93	1250.39	917.64	198.27	4310.55	2778.10	82.73	1441.34	521.00	157.14	4980.30	3243.01	92.96	1241.36	806.93	151.04	5535.31
Grocery24	15.04	53.21	380.72	70.96	69.02	588.95	0.00	23.69	287.33	69.47	62.30	442.80	937.43	32.14	296.37	252.81	71.32	1590.07
Grocery25	2694.20	242.51	986.30	1339.29	382.56	5644.86	605.42	159.17	680.42	1619.36	336.05	3400.43	0.00	243.07	916.20	2116.10	362.86	3638.23
Grocery26	165.86	349.65	1869.75	4950.50	332.13	7667.89	189.68	363.63	1878.21	4974.88	462.06	7868.46	292.24	357.01	2031.86	5160.38	436.30	8277.80
Grocery27	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Grocery28	1496.36	65.59	356.79	558.56	21.87	2499.17	1813.71	169.21	740.45	569.04	0.00	3292.41	0.00	0.02	0.08	0.00	0.00	0.10
Grocery29	0.00	62.79	105.72	130.00	405.65	704.16	0.95	0.01	0.00	0.00	0.04	1.00	0.00	0.00	0.00	0.00	0.00	0.00
Grocery30	1899.00	241.44	1000.40	2937.91	458.76	6537.51	2198.44	253.32	945.82	3249.19	452.97	7099.75	0.00	225.91	927.40	3230.91	168.27	4552.49

Sustainability-oriented management of retail stores through the combination of life cycle assessment and dynamic data envelopment analysis

Cristina Álvarez-Rodríguez, Mario Martín-Gamboa, Diego Iribarren

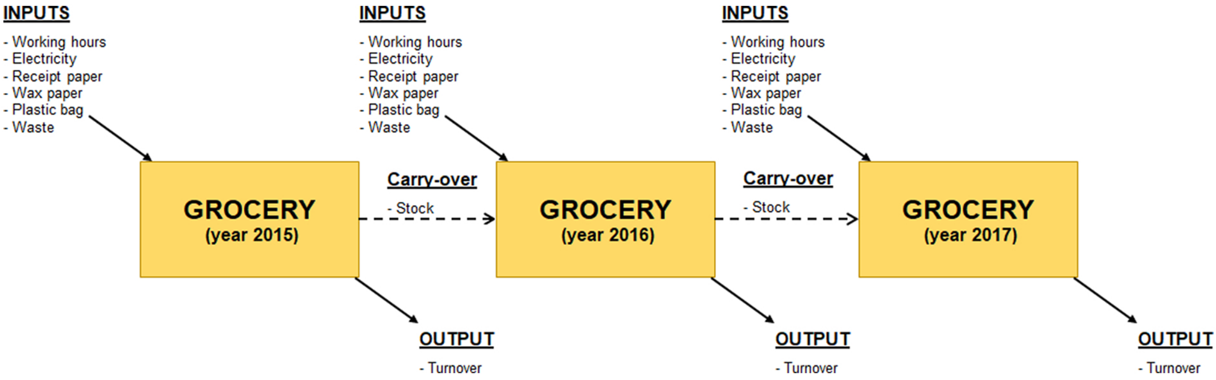
Research highlights

- ✓ Efficiency assessment of 30 grocery stores in Spain over the period 2015-2017
- ✓ Five-step method using life cycle assessment and dynamic data envelopment analysis
- ✓ Relatively good performance of the sample based on overall and term efficiencies
- ✓ Operational, socio-economic and environmental benchmarks for sustainable operation
- ✓ Feasible period-oriented approach for sustainability management of retail stores



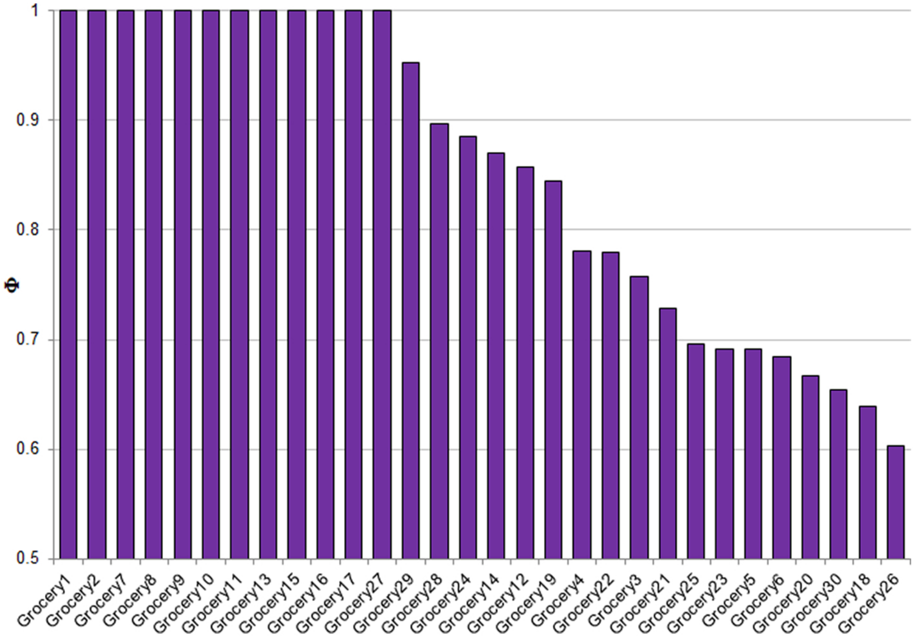
STEP 1
Data collection
Operational inputs
Working hours
Waste
Turnover
Life cycle inventory data of each DMUi,j (i = 1…30; j = 2015…2017)
STEP 2
Life Cycle Impact Assessment
Carbon footprint
Energy footprint
Current environmental profiles of each DMUi,j (i = 1…30; j = 2015…2017)
Environmental benchmarks of each DMUi,j (i = 1…30; j = 2015…2017)
STEP 4
Life Cycle Impact Assessment
Carbon footprint
Energy footprint
Overall efficiency scores
Term efficiency scores
Operational benchmarks of each DMUi,j (i = 1…30; j = 2015…2017)
DEA inputs and outputs of each DMUi,j (i = 1…30; j = 2015…2017)
Carry-over of each DMUi,j (i = 1…30; j = 2015…2017)
STEP 3
Dynamic Data Envelopment Analysis
Socio-economic benchmarks of each DMUi,j (i = 1…30; j = 2015…2017)
STEP 5
Interpretation
Sustainability outcome

Figure 1



INPUTS
- Working hours
- Electricity
- Receipt paper
- Wax paper
- Plastic bag
- Waste
GROCERY
(year 2015)
Carry-over
- Stock
OUTPUT
- Turnover
INPUTS
- Working hours
- Electricity
- Receipt paper
- Wax paper
- Plastic bag
- Waste
GROCERY
(year 2016)
Carry-over
- Stock
OUTPUT
- Turnover
INPUTS
- Working hours
- Electricity
- Receipt paper
- Wax paper
- Plastic bag
- Waste
GROCERY
(year 2017)
OUTPUT
- Turnover

Figure 2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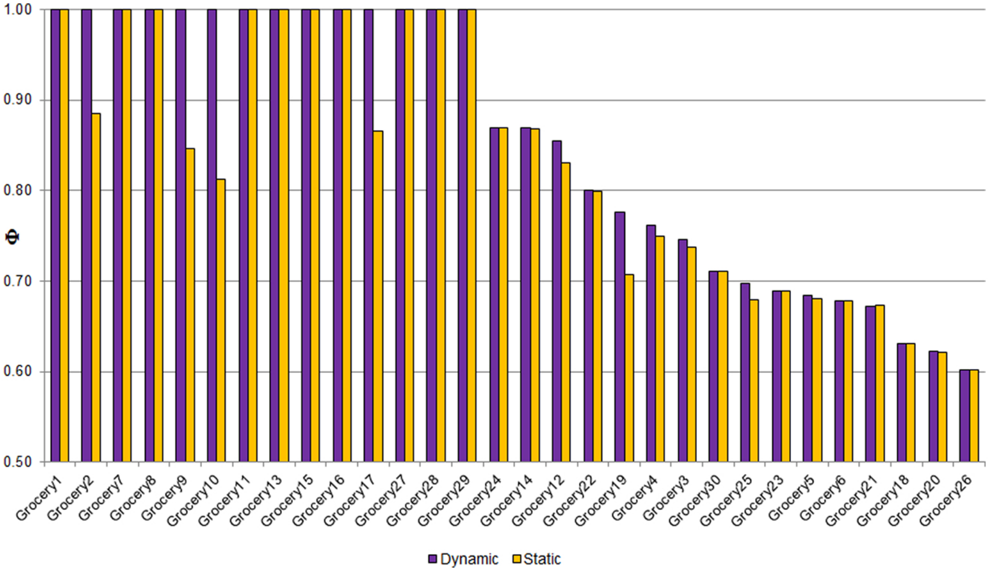
Grocery26

Figure 3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Grocery18
Grocery20
Grocery26
Dynamic
Static

Figure 4

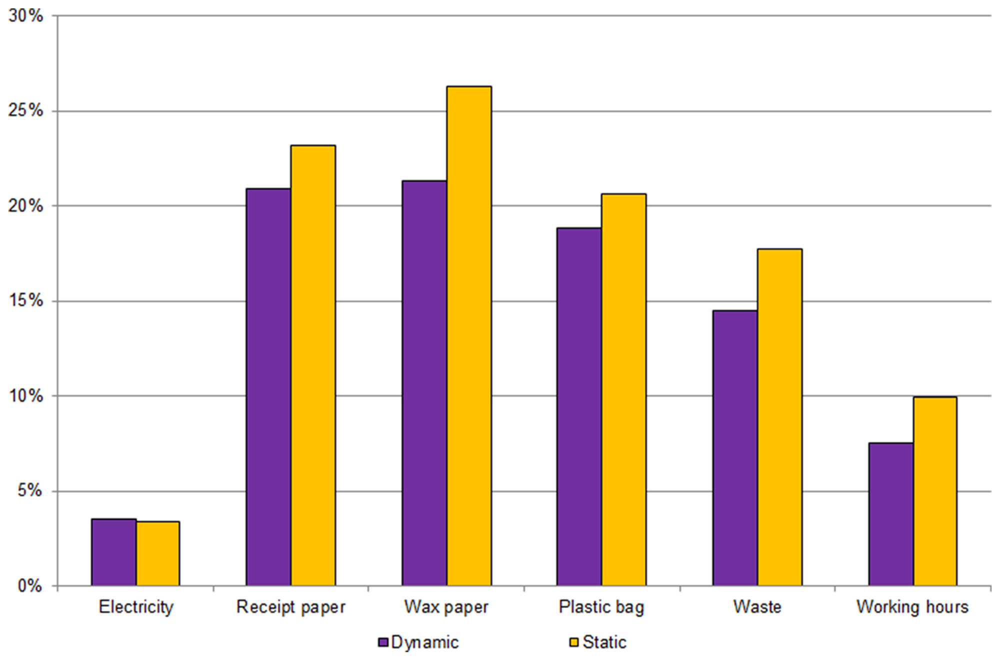
30%
25%
20%
15%
10%
5%
0%
Electricity
Receipt paper
Wax paper
Plastic bag
Waste
Working hours
Dynamic
Static

Figure 5