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Sustainability-oriented efficiency of retail supply chains: A combination of Life Cycle Assessment and dynamic network Data Envelopment Analysis

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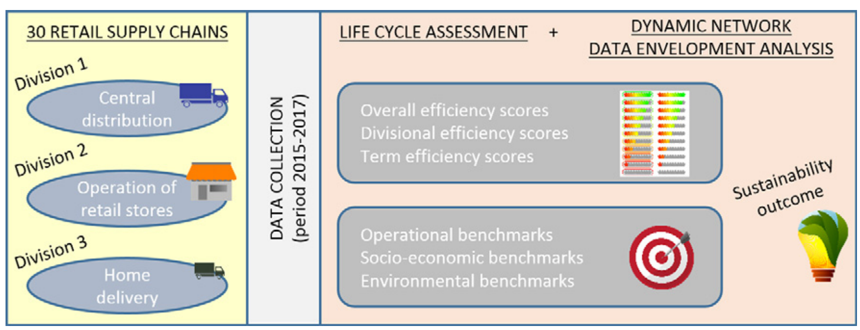
HIGHLIGHTS

- Life Cycle Assessment and dynamic network Data Envelopment Analysis were combined.
- The method was proven through a case study of 30 retail supply chains with 3 divisions.
- Efficiency scores, sustainability benchmarks and economic savings were estimated.
- Unlike store operation, central distribution and home delivery bring inefficiency.
- The network perspective enriches the results from previous unidivisional studies.

GRAPHICAL ABSTRACT



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ABSTRACT

Assessing the efficiency of retail supply chains (RSCs) requires analytical tools that address the different activities involved in these chains. In this sense, dynamic network Data Envelopment Analysis (DEA) arises as a suitable method to evaluate the operational performance of RSCs over a period of time. However, its use for sustainability-oriented efficiency assessment constitutes a knowledge gap that limits its applicability for thorough decision-making processes, *e.g.* at the retail company level. This article fills this gap through the combination of Life Cycle Assessment (LCA) and dynamic network DEA. A novel five-step LCA + DEA approach is proposed and applied to a case study of 30 RSCs in Spain for the period 2015–2017. In this case, the supply chain structure involves three divisions: central distribution, operation of retail stores, and home delivery. Both overall- and term-efficiency scores were found to widely range from 0.38 to 1.00, with only 1 RSC deemed efficient. Regarding divisional efficiency, store operation was found to generally show significantly higher efficiency scores than the distribution divisions. The link between long distribution distances and low efficiency stresses the relevance of integrating a network perspective into the efficiency assessment. In addition to efficiency scores, the LCA + DEA approach enriches the assessment by providing environmental, operational and socio-economic benchmarks to further support the management of RSCs from a sustainability perspective.

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1. Introduction

The retail sector has experienced a profound transformation from traditional and small owner-managed stores to large-scale retail firm structures (Yu and Ramanathan, 2009). This transformation has noticeably increased the total retail sales of consumer goods worldwide, reaching high rates at present (Deloitte, 2018). Regarding this high supply and demand of products, customers increasingly pay attention to the ethical and sustainability aspects behind the goods they purchase. Overall, the transformation of the retail sector and the increasing consumer awareness have promoted competitiveness within the sector (Shen et al., 2013). Within this context, the measure of inter-efficiency (between retail firms) and/or intra-efficiency (between stores within the same firm) has become a key matter of interest to retail companies (Yu and Ramanathan, 2009).

Despite the increased competitiveness observed in retail companies, a suitable balance between environmental impacts and economic growth is still an issue in this sector. In fact, achieving sustainable consumption and production patterns is a key goal in regions such as the European Union (EU). In the last years, CO_2 emissions from the retail sector accounted for around 3–4% of the total emissions in most of the EU countries (Eurostat, 2019). These emissions are closely linked to the high energy intensity of retail stores, usually within the range 500–1000 kWh m^{-2} y^{-1} (Ferreira et al., 2018). When enlarging the scope from the store to the whole retail supply chain (RSC), additional concerns arise mainly from the energy consumption and the corresponding emissions associated with the distribution stages. Assessing and benchmarking the sustainability performance of RSCs is needed. The evaluation of RSC efficiency can serve as an instrument for sustainability assessment, pursuing the delivery of competitively priced goods and services that satisfy human needs while reducing the use of resources and the environmental impacts from a life-cycle perspective.

Among the analytical tools available for efficiency assessment, Data Envelopment Analysis (DEA) has been extensively applied to the service sector (Avkiran, 2011), including the assessment of retail stores (Barros and Alves, 2003, 2004). It is a linear programming methodology that quantifies in an empirical manner the relative efficiency of multiple similar entities, called decision making units (DMUs) (Cooper et al., 2007). Classical DEA models treat each individual DMU as a “black box”, making no assumptions on its internal operations (Chen and Yan, 2011). Within the service sector, this perspective is suitable to evaluate the performance of retail stores (Álvarez-Rodríguez et al., 2019a), but it is insufficient when focusing the analysis on the performance of RSCs.

In order to appropriately measure the efficiency of complex structures such as RSCs, several authors have proposed extensions of the “black box” DEA concept. For instance, Färe and Grosskopf (2000) introduced the network DEA model, which was further developed by Tone and Tsutsui (2009, 2014) under a slacks-based measure approach. In particular, the dynamic network slacks-based measure of efficiency (DNSBM) model proposed by Tone and Tsutsui (2014) enables comprehensive analyses measuring intertemporal efficiency changes in complex network systems. It has been significantly used to evaluate operational performance within the service sector, *e.g.* in banking (Avkiran, 2015; Fukuyama and Weber, 2015) and shipping (Chao et al., 2018). However, although the call for incorporating economic, social and environmental aspects into the assessment of supply chain operations has increased in recent years (Ghadimi et al., 2019), the use of dynamic network DEA for the sustainability-oriented efficiency assessment of RSCs remains unexplored (Kalantary and Saen, 2019).

In the last years, advances in the combined use of Life Cycle Assessment (LCA) – a standardised methodology for the evaluation of the environmental performance of a system (ISO, 2006a, 2006b) – and DEA have allowed analysts to measure the efficiency and benchmark the performance of multiple similar entities from a sustainability perspective (Vázquez-Rowe and Iribarren, 2015; Martín-Gamboa et al., 2017). Some of these advances have recently been proven in the tertiary sector for the sustainability-oriented management of retail stores, with a focus on their operation (Álvarez-Rodríguez et al., 2019a, 2019b). Within this context, this article aims to fill the gap in the LCA + DEA field concerning sustainability-oriented efficiency assessment in complex supply chains. To the best of our knowledge, this article constitutes the first time that LCA and dynamic network DEA are combined for efficiency calculation and benchmarking of RSCs from a sustainability perspective, looking for a synergistic effect that enhances the capability of both LCA and DEA to support thorough decision-making processes, especially at the retail company level.

2. Material and methods

2.1. LCA + dynamic network DEA framework

The goal of this study is to prove the feasibility of the combination of LCA and dynamic network DEA for the sustainability-oriented efficiency assessment of RSCs. To this end, the case study of grocery stores presented in Álvarez-Rodríguez et al. (2019b) was enlarged through the inclusion of two additional divisions other than the grocery stores themselves. In other words, the DMU under assessment was redefined from the retail store itself to a three-division RSC. As in Álvarez-Rodríguez et al. (2019b), 30 DMUs (one per grocery store, located in the northwest of Spain) and three time terms (years 2015, 2016, and 2017) were used. The RSCs under study include not only the internal operation of each grocery but also two additional divisions involving distribution stages: (i) transport of groceries from the common distribution centre to each retail store by means of diesel-fuelled lorries, and (ii) distribution of purchased goods from retail stores to households by electric vans (home delivery service). The three divisions that constitute each RSC are under the control of the same firm, and refer exclusively to the butcher's section of the grocery stores.

In order to calculate the efficiency and sustainability benchmarks of each RSC, a novel five-step LCA + DEA approach with a dynamic network structure was formulated as shown in Fig. 1. The dynamic network structure is the key novelty in comparison with the five-step LCA + DEA method originally introduced by Vázquez-Rowe et al. (2010) for the combined operational and environmental assessment of multiple similar entities. When compared to other LCA + DEA approaches such as the three-step method (Lozano et al., 2010), five-step methods are typically associated with enhanced robustness for dealing with operational, environmental, economic and social aspects, providing a joint interpretation under the umbrella of sustainability (Martín-Gamboa et al., 2017). In response to the complex structure of the entities under evaluation (RSCs), this study constitutes the first time that the five-step LCA + DEA method is applied with a dynamic network perspective, at the same time as the knowledge gap concerning the use of dynamic network DEA for sustainability-oriented efficiency assessment is filled. In this sense, the ultimate goal is to enhance the potential of the LCA + DEA concept for thorough decision-making processes. While this was pursued herein through the case study of grocery RSCs, it should be noted that the applicability of the novel methodological framework developed in this article is not limited to this case study, but it is relevant to the sustainability assessment and benchmarking of multidivisional DMUs in general.

As shown in Fig. 1, the first step of the methodological framework focuses on data collection with the aim of building the life cycle inventory (LCI) of each RSC for each year, also retrieving socio-economic information. A time-intensive task of data collection was carried out in this study in order to quantify the inputs and outputs of each division (*i.e.*, the two distribution stages and the operation of grocery stores). A detailed quantification of the inputs and outputs considered (mass and energy flows and socio-economic aspects) is provided later in Section 2.2.

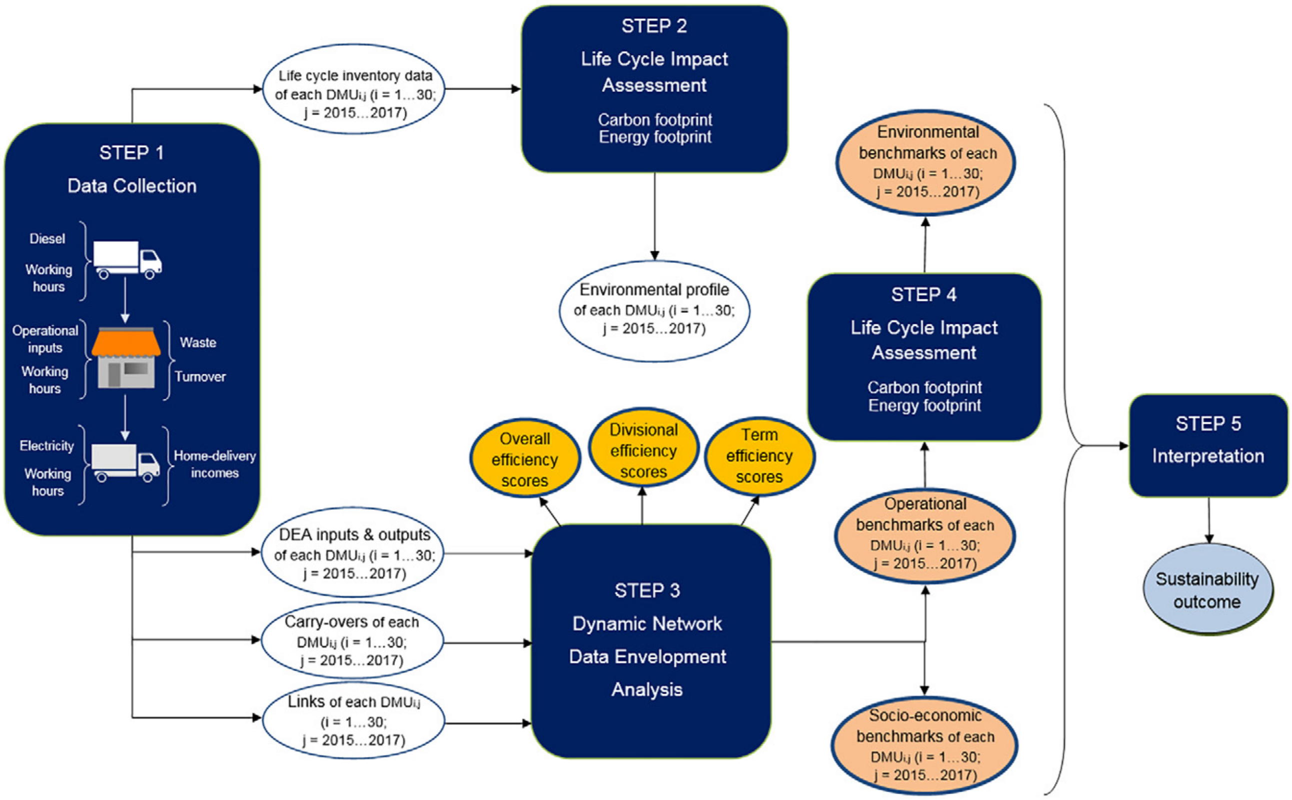

Fig. 1. Five-step LCA + dynamic network DEA method for retail supply chains.

In the second step, the LCIs of the RSCs were used to perform the life cycle impact assessment (LCIA) of each RSC for each year, thereby obtaining their current environmental profiles. Given the RSC definition, this step also allows analysts to identify the divisions with the most unfavourable environmental performance, thus enriching the outcomes of the assessment.

The third step entails the application of the dynamic network DEA model proposed by Tone and Tsutsui (2014) to calculate the

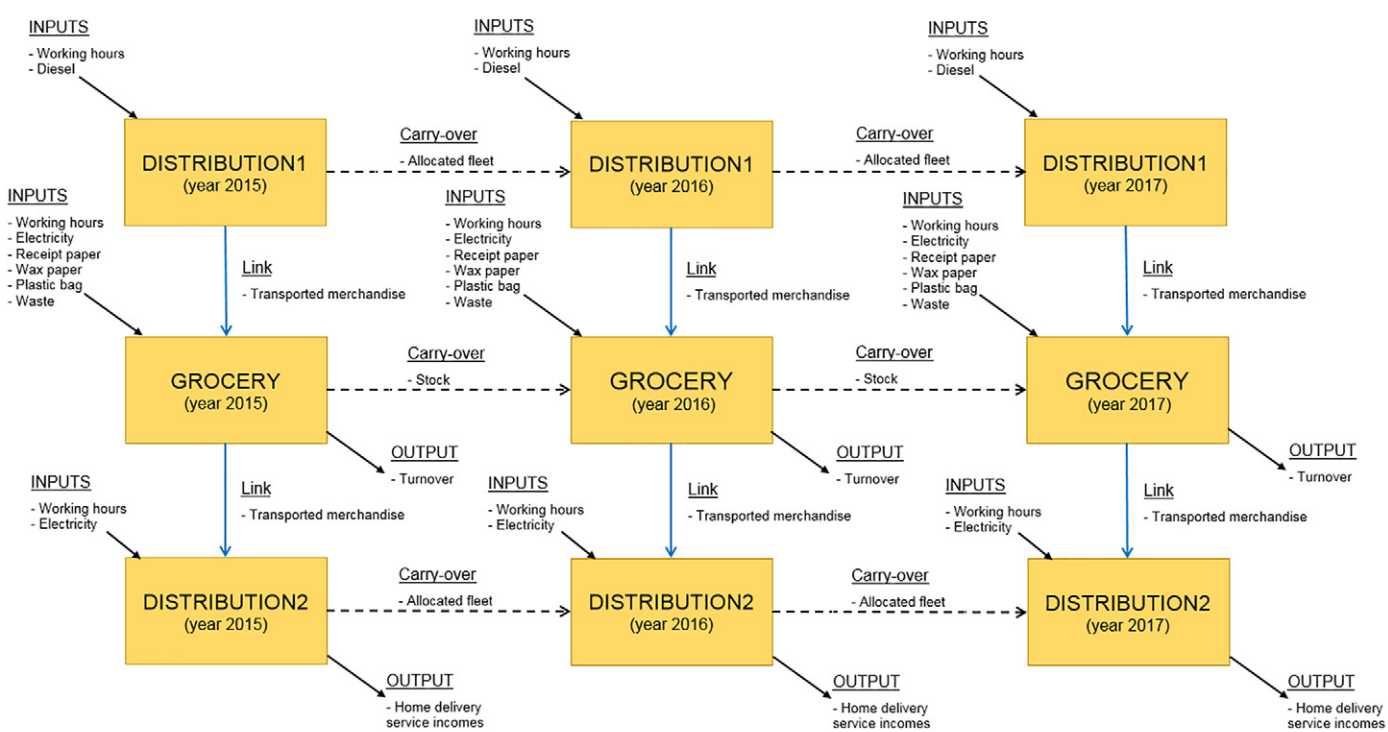

Fig. 2. Key components of the dynamic network DEA study of retail supply chains.

efficiency scores of the RSCs as well as their operational and socio-economic benchmarks over the period 2015–2017. To this end, a matrix of selected data (key operational and socio-economic data) was processed to relative efficiency scores. In addition to the overall efficiency score of each RSC, the efficiency of the internal activities within the complex DMU structure (*i.e.*, divisional efficiency scores) and intertemporal efficiency (*i.e.*, term-efficiency scores) were measured.

Fig. 2 shows the structure of the dynamic network DEA study of RSCs. Each DMU (*i.e.*, RSC) involves three divisions (central distribution, operation of grocery stores, and home delivery) and three specific years (2015–2017). For each of these years, every DMU is integrated by a set of DEA elements belonging to the different divisions. The DEA inputs selected for each division include: (i) diesel for division 1 (central distribution), (ii) electricity, receipt paper, wax paper, plastic bags and waste for division 2 (store operation), and (iii) electricity for division 3 (home delivery). Additionally, one socio-economic parameter (working hours) was included as a DEA input in the three divisions under evaluation. Regarding the DEA outputs, turnover and home delivery service income were selected for divisions 2 and 3, respectively. These outputs represent the economic nature of the RSCs.

As also shown in Fig. 2, within the dynamic network DEA framework, divisions are connected by "links", while time terms are connected by "carry-overs" (Tone and Tsutsui, 2014). The use of these elements is essential when measuring divisional and intertemporal efficiency. In this case study of RSCs, the transported merchandise was used as a discretionary (free) link to connect the three divisions. Regarding the choice of discretionary (free) carry-overs, the fleet allocated to the butcher's section was used for divisions 1 and 3, while the annual capital stock was used for division 2. The choice of these elements conforms to the nature of the key activities within the DMU and are further supported by the available DEA literature (Tone and Tsutsui, 2014; Mariz et al., 2018).

The specific DEA model used is an input-oriented dynamic network slacks-based measure of efficiency model with variable returns to scale (DNSBM-I-VRS) as formulated by Tone and Tsutsui (2014). The choice of non-radial metrics and input orientation conforms to the objective of minimising each DEA input while maintaining at least the same output levels, in line with previous studies (Martín-Gamboa et al., 2017). The overall-, term- and divisional-efficiency scores (Φ) obtained for each RSC allow distinguishing between comparatively efficient ($\Phi = 1$) and inefficient ($\Phi < 1$) DMUs. For those RSCs deemed inefficient, the DEA study also provides target values (*i.e.*, operational and socio-economic benchmarks) that would turn inefficient DMUs into efficient ones.

The operational benchmarks calculated in the third step for each inefficient RSC and year involve a modification of the LCIs of the RSCs. The fourth step of the methodological framework consists in the LCIA of the target DMUs according to the new LCIs. This step results in the target environmental profile (*i.e.*, environmental benchmarks) of each inefficient RSC.

The final step addresses the joint interpretation of the results from the previous steps, completing the sustainability-oriented efficiency assessment of RSCs. For instance, the comparison between the environmental results from steps 2 and 4 leads to quantitatively verify the eco-efficiency concept, *i.e.* proving that minimising resource intensity leads to environmental impact reductions while performing the same service (Iribarren et al., 2011). Moreover, the operational benchmarks obtained in the third step can be translated into economic savings for each entity under assessment. Finally, the socio-economic benchmarks (virtual reductions of working hours) from the third step facilitate the identification of useless hours that should be reallocated to different activities within the structure of the RSCs, as recommended in Álvarez-Rodríguez et al. (2019b). Overall, the joint analysis of the operational, socio-economic and environmental benchmarks enables a comprehensive interpretation of the results from a sustainability perspective.

Table 1
Turnover (€) and home delivery service income (€) by retail supply chain and year.

DMU code	Division 2			Division 3		
	Year 2015	Year 2016	Year 2017	Year 2015	Year 2016	Year 2017
RSC1	153,600	163,000	173,900	10,752	13,040	17,390
RSC2	318,900	304,000	293,000	19,134	15,200	14,650
RSC3	309,000	330,000	360,000	6180	13,200	10,800
RSC4	361,800	395,000	435,000	54,270	63,200	87,000
RSC5	532,600	540,000	582,500	69,238	86,400	116,500
RSC6	321,700	398,000	406,000	12,868	27,860	32,480
RSC7	228,000	241,300	257,000	11,400	16,891	20,560
RSC8	356,000	384,000	328,300	56,960	103,680	72,226
RSC9	360,500	407,000	376,300	21,630	40,700	26,341
RSC10	591,500	621,200	626,300	65,065	80,756	125,260
RSC11	649,600	729,900	759,800	71,456	94,887	113,970
RSC12	382,800	448,000	509,000	11,484	17,920	25,450
RSC13	193,300	205,000	214,000	5799	6150	6420
RSC14	332,600	362,200	382,000	23,282	36,200	45,840
RSC15	522,100	532,000	554,800	10,4420	117,040	138,700
RSC16	566,900	612,000	653,000	85,035	116,280	143,660
RSC17	598,000	628,000	662,000	41,860	62,800	66,200
RSC18	383,000	398,000	409,000	38,300	47,760	61,350
RSC19	479,300	491,000	526,000	19,172	34,370	52,660
RSC20	450,000	460,000	478,000	76,500	92,000	105,160
RSC21	541,800	551,000	553,000	10,836	11,020	16,590
RSC22	279,000	252,400	319,500	0	0	0
RSC23	198,600	202,600	202,900	5958	6078	6087
RSC24	186,000	181,400	177,500	0	0	0
RSC25	371,000	319,800	371,400	14,840	22,386	37,140
RSC26	344,100	353,400	358,200	13,764	14,136	17,910
RSC27	154,200	158,900	166,400	7710	7945	8320
RSC28	214,000	287,000	336,400	10,700	20,090	33,640
RSC29	341,900	336,400	343,000	34,190	37,004	44,590
RSC30	388,200	399,700	398,600	42,702	55,958	51,818

Table 2
Allocated fleet by retail supply chain and year.

DMU code	Division 1			Division 3		
	Year 2015	Year 2016	Year 2017	Year 2015	Year 2016	Year 2017
RSC1	0.03	0.03	0.04	0.70	0.70	0.70
RSC2	0.03	0.03	0.05	0.56	0.56	0.56
RSC3	0.04	0.04	0.06	1.46	1.46	1.46
RSC4	0.08	0.08	0.11	0.34	0.34	0.34
RSC5	0.06	0.06	0.09	1.39	1.39	1.39
RSC6	0.03	0.03	0.05	0.42	0.42	0.42
RSC7	0.08	0.08	0.11	2.37	2.37	2.37
RSC8	0.03	0.03	0.04	0.70	0.70	0.70
RSC9	0.07	0.07	0.11	0.34	0.34	0.34
RSC10	0.13	0.13	0.19	1.57	1.57	1.57
RSC11	0.09	0.09	0.13	3.20	3.20	3.20
RSC12	0.13	0.13	0.19	1.18	1.18	1.18
RSC13	0.10	0.10	0.15	1.39	1.39	1.39
RSC14	0.18	0.18	0.26	2.25	2.25	2.25
RSC15	0.06	0.06	0.09	0.79	0.79	0.79
RSC16	0.10	0.10	0.15	1.12	1.12	1.12
RSC17	0.15	0.15	0.23	2.02	2.02	2.02
RSC18	0.02	0.02	0.03	0.42	0.42	0.42
RSC19	0.08	0.08	0.11	1.67	1.67	1.67
RSC20	0.02	0.02	0.03	0.70	0.70	0.70
RSC21	0.06	0.06	0.09	0.90	0.90	0.90
RSC22	0.02	0.02	0.03	0.00	0.00	0.00
RSC23	0.03	0.03	0.04	0.42	0.42	0.42
RSC24	0.03	0.03	0.04	0.00	0.00	0.00
RSC25	0.02	0.02	0.03	1.39	1.39	1.39
RSC26	0.08	0.08	0.11	0.70	0.70	0.70
RSC27	0.09	0.09	0.13	0.47	0.47	0.47
RSC28	0.07	0.07	0.11	0.78	0.78	0.78
RSC29	0.06	0.06	0.09	0.34	0.34	0.34
RSC30	0.08	0.08	0.11	0.45	0.45	0.45

Table 3
Transported merchandise (kg) by retail supply chain and year.

DMU code	Division 1 ➔ Division 2			Division 2 ➔ Division 3		
	Year 2015	Year 2016	Year 2017	Year 2015	Year 2016	Year 2017
RSC1	31,000	31,000	37,200	2170	2480	3720
RSC2	82,150	80,600	77,500	4960	4030	3720
RSC3	79,670	103,850	108,500	1550	4030	3255
RSC4	93,000	120,900	124,000	13,950	19,220	24,800
RSC5	170,500	179,800	186,000	22,010	28,520	37,200
RSC6	93,000	123,690	124,000	3720	8370	9920
RSC7	58,900	71,300	77,500	2790	4960	6200
RSC8	91,760	108,500	93,000	14,570	29,140	20,460
RSC9	93,000	117,800	111,600	5580	11,780	7750
RSC10	152,830	186,000	186,000	16,740	26,040	37,200
RSC11	248,000	251,100	260,400	29,760	32,550	39,060
RSC12	98,890	142,600	155,000	2790	5580	7750
RSC13	39,990	40,300	44,020	1240	1240	1240
RSC14	83,700	89,590	93,000	5890	8990	11,160
RSC15	62,000	68,200	71,300	12,400	14,880	17,670
RSC16	146,320	158,100	186,000	22,010	29,760	40,920
RSC17	154,380	178,250	186,000	10,850	17,670	18,600
RSC18	98,890	103,850	105,400	9920	12,400	15,810
RSC19	124,000	128,960	135,780	4960	8990	13,640
RSC20	116,250	118,730	123,380	19,840	23,746	27,280
RSC21	139,810	142,600	142,600	2790	3100	4030
RSC22	71,920	52,080	93,000	0	0	0
RSC23	51,460	52,080	52,080	1550	1550	1550
RSC24	48,050	45,880	45,570	0	0	0
RSC25	95,790	82,150	96,100	4030	5890	9610
RSC26	88,600	91,450	92,380	3410	3720	4650
RSC27	34,100	34,100	37,200	1705	1705	1860
RSC28	55,180	74,090	86,800	2790	5270	8680
RSC29	88,040	86,800	88,350	8680	9300	11,470
RSC30	100,130	103,230	102,920	10,850	14,570	13,330

2.2. Data acquisition

A specific survey was prepared to collect the required data directly from the managers of the company. The use of primary data reduces the uncertainty associated with the results and increases the reliability of the study. All the tables presented in this section refer to a sample size of 30 DMUs and 3 different years, and they focus on the information that cannot be directly retrieved from the previous unidivisional analyses in Álvarez-Rodríguez et al. (2019a, 2019b). Table 1 presents the data collected for the DEA outputs of the divisions 2 (store operation) and 3 (home delivery). A slight growth of the stores' turnover was observed over the period 2015–2017, with an average value of 389 k€ y^{-1} and a maximum turnover of 760 k€ y^{-1} (RSC11 in the year 2017). A similar trend was found for home delivery service incomes, with an average of 41 k€ y^{-1} and generally reaching the highest values in the last year.

The data collected for the carry-over of divisions 1 and 3 (allocated fleet) are presented in Table 2, while the carry-over of division 2 (stock) is readily available in Álvarez-Rodríguez et al. (2019b). The values in Table 2 represent the size of the fleet assigned to the distribution of the groceries corresponding to the butcher's section. The allocated fleet of the set of DMUs remains generally constant over the selected period of time for both divisions, with a minor increase in the year 2017 for division 1. This stability over time supports the choice of the allocated fleet as the carry-over for the dynamic network DEA of RSCs (Tone and Tsutsui, 2014). Regarding the carry-over of the second division, the average stock of the sample is 5.7 k€ y^1. It should be noted that capital stock is among the most common categories of carry-over in dynamic DEA studies according to Mariz et al. (2018).

Table 3 presents the data corresponding to the transported merchandise, used as link between divisions. The annual average values found for the sample are 104 t (for the link between divisions 1 and 2) and 11 t (for the link between divisions 2 and 3). Transported merchandise is a common intermediate product within the structure of a

Table 4
Operational (diesel [l] and electricity [kWh]) and socio-economic (h) inputs for divisions 1 and 3 over the period 2015–2017.

DMU code	Division 1						Division 3					
	Year 2015		Year 2016		Year 2017		Year 2015		Year 2016		Year 2017	
	Diesel	Working hours	Diesel	Working hours	Diesel	Working hours	Electricity	Working hours	Electricity	Working hours	Electricity	Working hours
RSC1	1320	48.06	1320	48.06	1320	72.09	10.99	1335.65	12.57	1335.65	18.85	1335.65
RSC2	1716	62.48	1716	62.48	1716	93.72	20.10	1068.52	16.33	1068.52	15.08	1068.52
RSC3	1980	72.09	1980	72.09	1980	108.14	20.42	2804.49	53.09	2804.49	42.88	2804.49
RSC4	3960	144.18	3960	144.18	3960	216.27	42.41	647.19	58.43	647.19	75.39	647.19
RSC5	3300	120.15	3300	120.15	3300	180.23	223.03	2671.30	289.00	2671.30	376.96	2671.30
RSC6	1584	57.67	1584	57.67	1584	86.51	11.31	801.39	25.44	801.39	30.16	801.39
RSC7	3960	144.18	3960	144.18	3960	216.27	48.06	4541.22	85.44	4541.22	106.81	4541.22
RSC8	1452	52.87	1452	52.87	1452	79.30	73.82	1335.65	147.64	1335.65	103.66	1335.65
RSC9	3696	134.57	3696	134.57	3696	201.85	16.96	647.19	35.81	647.19	23.56	647.19
RSC10	6600	240.30	6600	240.30	6600	360.45	339.26	3011.76	527.74	3011.76	753.92	3011.76
RSC11	4620	168.21	4620	168.21	4620	252.32	693.61	6144.00	758.63	6144.00	910.36	6144.00
RSC12	6600	240.30	6600	240.30	6600	360.45	42.41	2258.82	84.82	2258.82	117.80	2258.82
RSC13	5280	192.24	5280	192.24	5280	288.36	12.57	2671.30	12.57	2671.30	12.57	2671.30
RSC14	9240	336.42	9240	336.42	9240	504.63	119.37	4314.61	182.20	4314.61	226.18	4314.61
RSC15	3300	120.15	3300	120.15	3300	180.23	87.96	1510.11	105.55	1510.11	125.34	1510.11
RSC16	5280	192.24	5280	192.24	5280	288.36	223.03	2157.30	301.57	2157.30	414.66	2157.30
RSC17	7920	288.36	7920	288.36	7920	432.54	197.90	3883.15	322.30	3883.15	339.26	3883.15
RSC18	1056	38.45	1056	38.45	1056	57.67	30.16	801.39	37.70	801.39	48.06	801.39
RSC19	3960	144.18	3960	144.18	3960	216.27	60.31	3205.57	109.32	3205.57	165.86	3205.57
RSC20	1188	43.25	1188	43.25	1188	64.88	100.52	1335.65	120.31	1335.65	138.22	1335.65
RSC21	3300	120.15	3300	120.15	3300	180.23	22.62	1725.84	25.13	1725.84	32.67	1725.84
RSC22	1056	38.45	1056	38.45	1056	57.67	0.00	0.00	0.00	0.00	0.00	0.00
RSC23	1320	48.06	1320	48.06	1320	72.09	4.71	801.39	4.71	801.39	4.71	801.39
RSC24	1320	48.06	1320	48.06	1320	72.09	0.00	0.00	0.00	0.00	0.00	0.00
RSC25	924	33.64	924	33.64	924	50.46	40.84	2671.30	59.69	2671.30	97.38	2671.30
RSC26	3960	144.18	3960	144.18	3960	216.27	17.28	1335.65	18.85	1335.65	23.56	1335.65
RSC27	4620	168.21	4620	168.21	4620	252.32	10.37	903.53	10.37	903.53	11.31	903.53
RSC28	3696	134.57	3696	134.57	3696	201.85	28.27	1505.88	53.40	1505.88	87.96	1505.88
RSC29	3300	120.15	3300	120.15	3300	180.23	26.39	647.19	28.27	647.19	34.87	647.19
RSC30	3960	144.18	3960	144.18	3960	216.27	43.98	1121.80	59.06	1121.80	54.03	1121.80

supply chain, typically being an appropriate choice as link in dynamic network DEA studies (Tone and Tsutsui, 2014).

Regarding the DEA inputs, Table 4 includes the operational (diesel and electricity) and socio-economic (working hours) inputs selected for divisions 1 and 3, while the inputs selected for division 2 are readily available in Álvarez-Rodríguez et al. (2019b). Diesel consumption in division 1 (central distribution) remains constant over the period 2015–2017 because the route from the distribution centre to the stores is not modified during this period. On the other hand, the electricity consumption associated with the third division shows higher variability due to changes in home delivery routes. Regarding the operation of the stores, the evolution of the working hours and the operational flows is generally in accordance with the turnover volume (Álvarez-Rodríguez et al., 2019b).

The collected operational data were used to build the LCIs of the RSCs for the LCA study. In this regard, the system's boundaries of the LCA study were expanded in comparison with those set in Álvarez-Rodríguez et al. (2019a, 2019b), assessing the three divisions of the RSCs rather than only store operation. The LCA outputs include the direct emissions from diesel combustion and the end-of-life flow “waste to treatment” (mainly based on animal waste to incineration), while the system's function was set to be represented by the annual economic output of each RSC. Finally, data for background processes were retrieved from the ecoinvent database (Weidema et al., 2013).

3. Results and discussion

3.1. Current environmental characterisation

The life-cycle environmental profile of the RSCs was calculated through the implementation of their LCIs in the software SimaPro 9 (Goedkoop et al., 2016). As done in Álvarez-Rodríguez et al. (2019b),

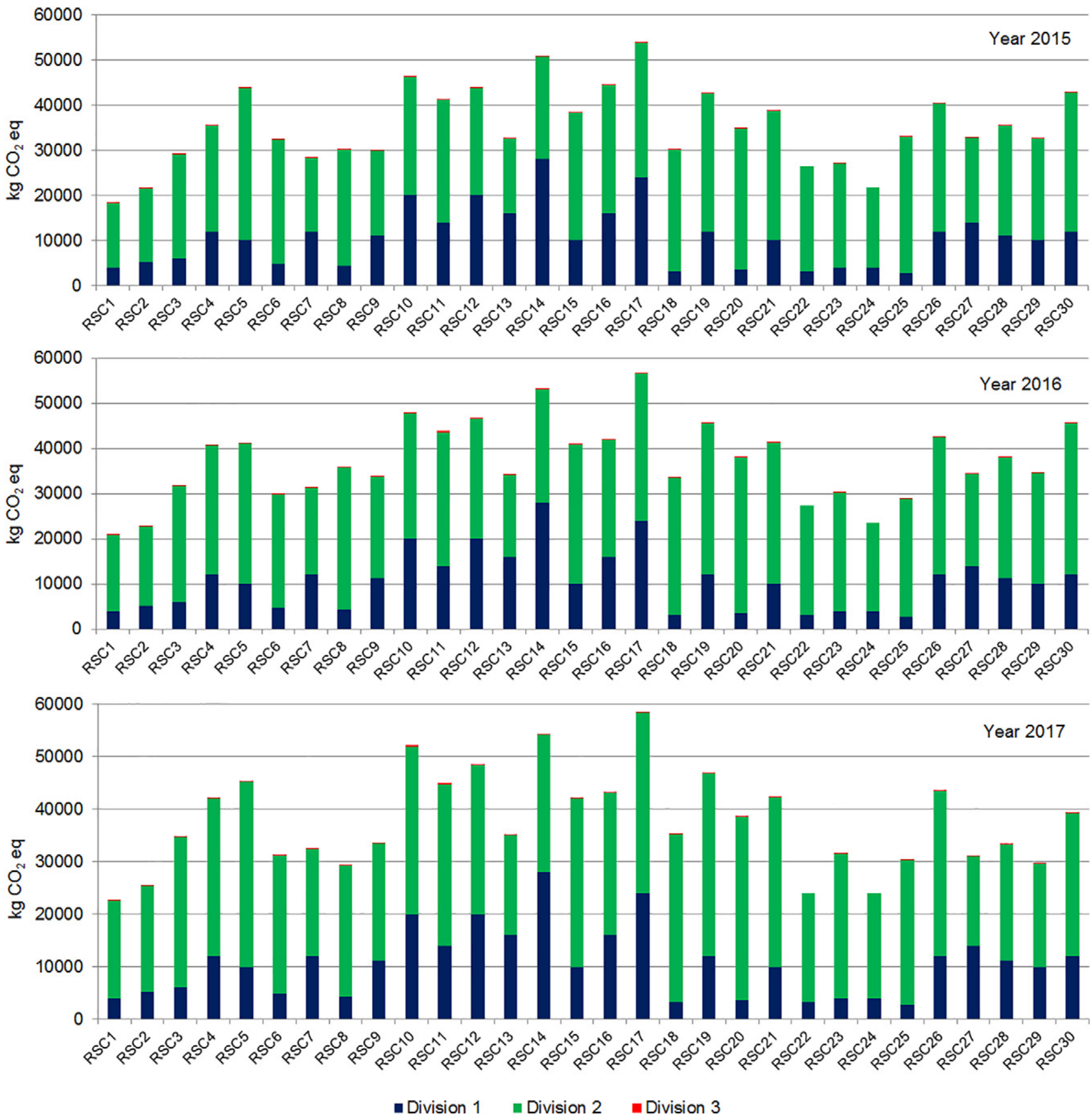

Fig. 3. Annual carbon footprint of each retail supply chain by division and year.

the life-cycle profile of the RSCs was characterised by two indicators: (i) the carbon footprint (*i.e.*, global warming impact potential, GWP) evaluated according to IPCC (2013), and (ii) the energy footprint (*i.e.*, cumulative non-renewable [fossil and nuclear] energy demand, CED) evaluated according to VDI (2012). The relevance of these indicators is supported by the scientific literature on environmental assessment of RSCs in general (Rizet et al., 2012; Seebauer et al., 2016) and of food-related supply chains in particular (Tidy et al., 2016).

Figs. 3 and 4 show the current carbon and energy footprints of the retail supply chains under study, respectively. A similar behaviour was found for both indicators due to their typically high correlation (Valente et al., 2018). Based on the LCA results, divisions 2 (store operation) and 1 (central distribution) dominate GWP and CED, whereas division 3 (home delivery) plays a minor role. In particular, the average contribution of division 2 to the selected indicators is above 70% in all the evaluated years. Among the operational aspects within this division, the electricity demanded by the retail stores was found to be the main contributor to GWP and CED, which is in line with the common identification of retail stores among the most energy intensive classes of buildings (Iyer et al., 2015).

Finally, it should be noted that the highest environmental impacts of each RSC were generally found in the last year of the period (*i.e.*, 2017). This observation could be linked to the economic growth of the sample of RSCs, involving higher operational consumption to meet the increased demand.

3.2. DEA results

A dynamic network DEA model (*viz.*, DNSBM-I-VRS) was applied to estimate the overall-, divisional- and term-efficiency scores of each RSC.

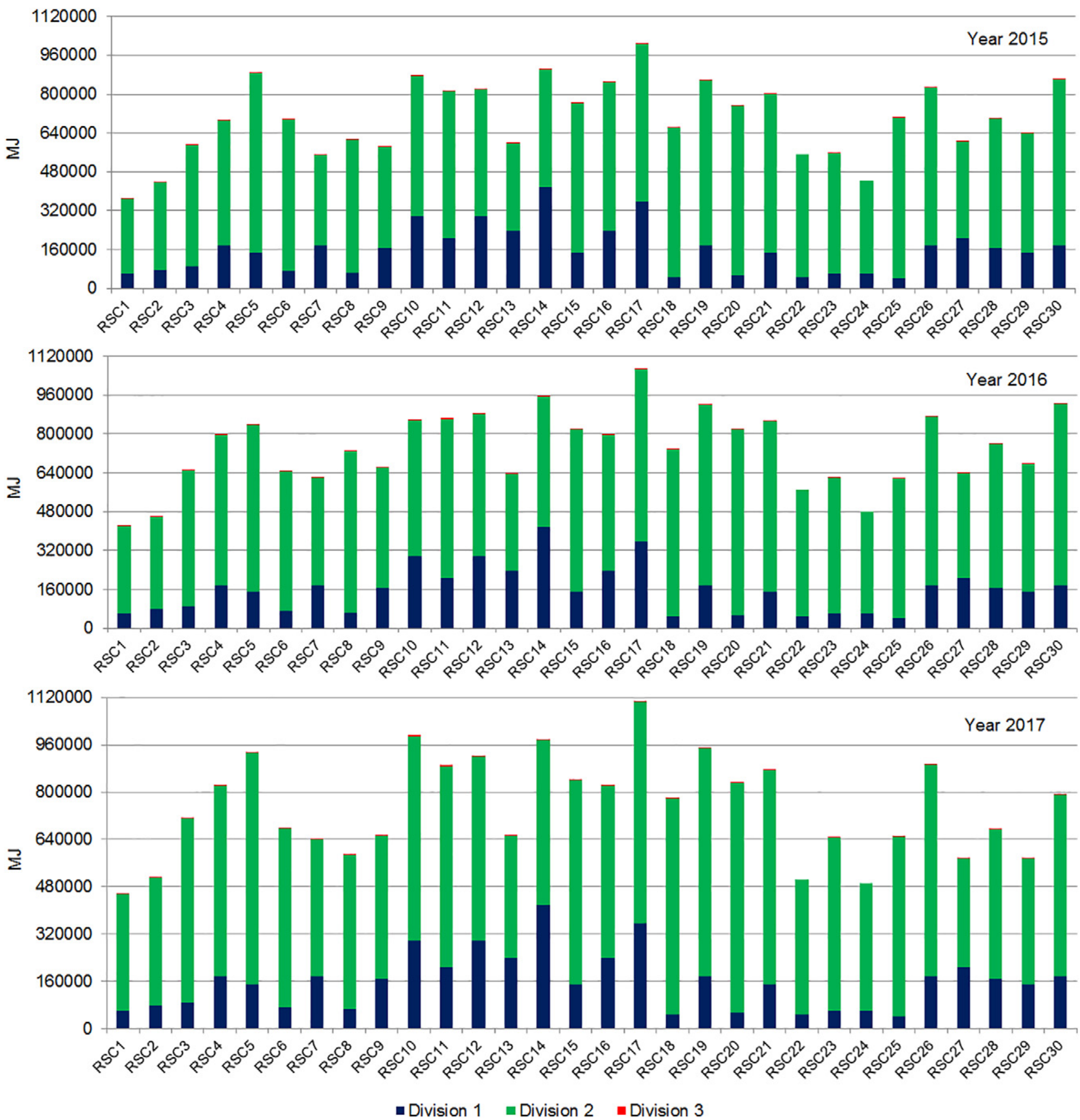

Fig. 4. Annual energy footprint of each retail supply chain by division and year.

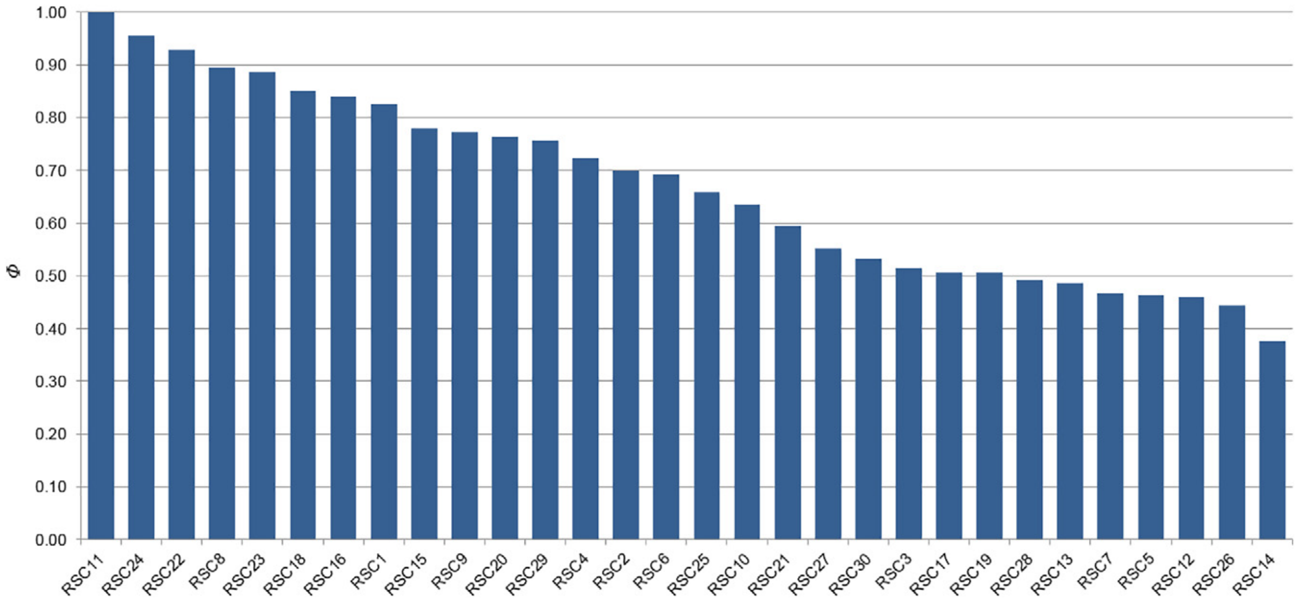

Fig. 5. Overall efficiency of the retail supply chains.

A DEA matrix including the most relevant elements of the DMUs according to the managers' standpoint (*i.e.*, the elements shown in Fig. 2) was implemented in the optimisation model solved through the software DEA-Solver Pro (Saitech, 2019).

Fig. 5 shows the overall efficiency scores calculated for the RSCs under evaluation. Only RSCs with an overall efficiency score equal to 1 ($\Phi = 1$) qualify as efficient. In this case study, the computation of DEA led to identify RSC11 as the only efficient DMU. As observed in Fig. 5, a wide range of scores was obtained for the inefficient entities, ranging from 0.37 (RSC14) to 0.96 (RSC24). The average overall efficiency score of the sample is 0.67, which suggests a relatively unfavourable performance. In order to further explore this behaviour, the efficiency scores were also analysed at the level of division and year.

The main novelty of this study lies in the combination of dynamic network DEA and LCA for the sustainability-oriented efficiency assessment of RSCs. As a result of this network structure, Table 5 presents the divisional efficiency scores calculated for the sample of 30 RSCs. Store operation (division 2) was found to be the division with the highest number of divisionally-efficient entities (12), ahead of home delivery (division 3; 9 divisionally-efficient entities) and central distribution (division 1; 3 divisionally-efficient entities). Furthermore, division 2 presents the highest average divisional efficiency score (0.89), while divisions 3 and 1 show significantly lower average divisional efficiency scores (0.59 and 0.53, respectively). All the divisional efficiency scores for division 2 were found to be >0.67. These findings indicate a relatively good performance of the retail stores, which is in agreement with previous studies (Álvarez-Rodríguez et al., 2019a, 2019b). In contrast, the divisional efficiency scores for divisions 1 and 3 show high variability, and minimum scores around 0.11.

Another relevant outcome of the dynamic network DEA study is the calculation of the term-efficiency scores associated with each year under evaluation. Table 6 presents the term-efficiency scores calculated for the sample of 30 RSCs. The three evaluated years present similar average term-efficiency scores (around 0.67) and only one term-efficient entity. Furthermore, a low variability of the term-efficiency scores was observed at the DMU level. As also observed for the overall efficiency scores, the term-efficiency scores of the inefficient entities within a year show a wide range of values. The joint interpretation of the three types of efficiency scores presented in this section highlights the role of divisions 1 and 3 as sources of relative inefficiency for the sample of RSCs.

In addition to the set of efficiency scores, the operational and socio-economic benchmarks for the sample of 30 RSCs –broken down by division– are presented in Tables 7–9 for the years 2015, 2016 and 2017, respectively. These benchmarks are expressed as reduction percentages with respect to the current values. Similar benchmarks were generally found for a given DMU in the different years, especially regarding the distribution-related divisions (*i.e.*, divisions 1 and 3). Overall, the target operational reductions in Tables 7–9 suggest a significant room for improvement of the inefficient DMUs. Finally, it should be

Table 5
Divisional efficiency scores (%) of the retail supply chains.

DMU code	Division 1	Division 2	Division 3
RSC1	100.00	100.00	47.97
RSC2	61.13	100.00	48.80
RSC3	51.13	86.97	16.62
RSC4	28.72	88.34	100.00
RSC5	32.26	70.75	35.73
RSC6	64.03	78.60	65.26
RSC7	28.79	100.00	11.05
RSC8	75.57	100.00	92.90
RSC9	31.92	100.00	99.99
RSC10	44.43	100.00	46.46
RSC11	100.00	100.00	100.00
RSC12	18.00	90.50	29.39
RSC13	24.13	100.00	22.01
RSC14	11.49	87.36	14.25
RSC15	33.94	100.00	100.00
RSC16	52.21	100.00	100.00
RSC17	34.80	100.00	17.11
RSC18	87.50	67.57	100.00
RSC19	36.70	88.14	26.98
RSC20	86.64	67.38	74.80
RSC21	54.69	99.59	23.96
RSC22	98.52	80.20	100.00
RSC23	94.58	71.45	100.00
RSC24	97.92	88.95	100.00
RSC25	100.00	76.98	20.88
RSC26	24.67	70.06	38.50
RSC27	28.57	100.00	37.12
RSC28	31.83	89.73	26.14
RSC29	29.59	97.36	100.00
RSC30	24.06	69.76	65.76

Table 6
Term-efficiency scores (%) of the retail supply chains.

DMU code	Year 2015	Year 2016	Year 2017
RSC1	82.24	83.61	82.12
RSC2	69.84	70.02	70.07
RSC3	53.19	49.85	51.67
RSC4	76.24	70.72	70.09
RSC5	45.55	46.68	46.51
RSC6	67.04	72.46	68.38
RSC7	46.68	46.63	46.53
RSC8	89.31	91.86	87.30
RSC9	77.30	77.30	77.30
RSC10	62.51	62.79	65.59
RSC11	100.00	100.00	100.00
RSC12	46.23	45.63	46.02
RSC13	48.16	48.74	49.24
RSC14	37.72	37.86	37.52
RSC15	77.98	77.98	77.98
RSC16	84.07	84.07	84.07
RSC17	50.56	50.78	50.56
RSC18	86.03	84.36	84.68
RSC19	52.11	52.52	47.18
RSC20	76.37	77.43	75.02
RSC21	59.14	59.30	59.80
RSC22	92.38	93.48	92.85
RSC23	88.52	87.94	89.57
RSC24	95.15	95.53	96.19
RSC25	65.98	66.37	65.51
RSC26	44.23	45.22	43.78
RSC27	54.73	56.08	54.88
RSC28	47.96	47.23	52.51
RSC29	73.88	76.53	76.53
RSC30	51.70	54.06	53.82

noted that socio-economic benchmarks should not be understood as a real reduction in working hours, but as a reallocation of useless hours to activities such as training (Álvarez-Rodríguez et al., 2019b).

3.3. Target environmental characterisation

The operational benchmarks from the third step of the LCA + DEA method result in a modification of the LCIs of the inefficient DMUs, thus leading to target environmental profiles of these entities after LCIA. In particular, Table 10 presents the carbon footprint benchmarks (*i.e.*, impact reductions) of the 30 RSCs broken down by division and year. On the other hand, the energy footprint benchmarks are not tabulated since they involve the same target reduction percentages as the carbon footprint benchmarks for the divisions 1 and 3, which is due to the fact that these divisions involve only one operational item. The energy footprint benchmarks for division 2 (which involves five operational items) do vary with respect to the corresponding carbon footprint benchmarks, but this variation is slight due to the high correlation between GWP and CED (Valente et al., 2018; Álvarez-Rodríguez et al., 2019a, 2019b). It should be noted that RSC11 involves 0% impact reductions in every division and year since identical target and current operating points is an intrinsic feature of currently efficient DMUs (Vázquez-Rowe et al., 2010).

The average carbon and energy footprint reductions for the whole sample of entities are 22% and 19%, respectively, for each of the evaluated years. Most of this reduction could be achieved if the operational benchmarks calculated for divisions 1 and 2 were attained. In particular, the minimisation of diesel demand in division 1 and electricity demand in division 2 was identified as a central objective. For instance, improvement measures in terms of business logistics, fossil diesel substitution (*e.g. via* increased biofuel blending ratio) and energy efficiency (*e.g.* through training campaigns for employees) could significantly contribute to effectively reducing the carbon and energy footprints of the RSCs under evaluation.

3.4. Interpretation

Following the traditional eco-efficiency concept, reductions in resource consumption should lead to environmental impact reductions.

Table 7
Operational and socio-economic reductions (%) for the retail supply chains (year 2015).

DMU code	Division 1		Division 2						Division 3	
	Diesel	Working hours	Electricity	Receipt paper	Wax paper	Plastic bag	Waste	Working hours	Electricity	Working hours
RSC1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	21.42	85.11
RSC2	38.87	38.87	0.00	0.00	0.00	0.00	0.00	0.00	24.81	78.44
RSC3	48.87	48.87	7.66	12.11	7.50	1.24	1.44	12.50	73.79	95.17
RSC4	71.28	71.28	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
RSC5	67.74	67.74	9.43	38.20	40.91	30.25	55.25	9.31	72.76	57.34
RSC6	35.97	35.97	16.88	48.82	19.75	47.82	16.89	4.60	11.80	62.41
RSC7	71.21	71.21	0.00	0.00	0.00	0.00	0.00	0.00	81.36	96.12
RSC8	24.43	24.43	0.00	0.00	0.00	0.00	0.00	0.00	15.29	0.00
RSC9	68.08	68.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02
RSC10	55.57	55.57	0.00	0.00	0.00	0.00	0.00	0.00	73.83	39.94
RSC11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
RSC12	82.00	82.00	0.00	8.86	13.88	14.15	36.16	2.54	51.16	82.23
RSC13	75.87	75.87	0.00	0.00	0.00	0.00	0.00	0.00	62.92	96.38
RSC14	88.51	88.51	0.00	26.01	12.99	0.00	39.18	0.43	79.75	90.69
RSC15	66.06	66.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
RSC16	47.79	47.79	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
RSC17	65.20	65.20	0.00	0.00	0.00	0.00	0.00	0.00	83.33	82.88
RSC18	12.50	12.50	0.00	49.21	47.51	54.88	0.99	23.91	0.00	0.00
RSC19	63.30	63.30	5.65	27.20	19.03	24.03	15.19	0.00	45.90	84.47
RSC20	13.36	13.36	11.26	51.31	42.44	44.54	33.19	0.00	37.13	16.99
RSC21	45.31	45.31	0.00	0.08	0.06	0.07	0.00	0.01	62.03	92.43
RSC22	1.48	1.48	6.50	39.93	17.60	21.05	43.15	0.00	0.00	0.00
RSC23	5.42	5.42	20.75	27.67	68.40	16.82	22.00	18.51	0.00	0.00
RSC24	2.08	2.08	0.20	20.31	36.61	2.86	14.84	0.00	0.00	0.00
RSC25	0.00	0.00	22.08	40.56	39.30	21.29	0.09	4.56	71.85	89.65
RSC26	75.33	75.33	3.35	52.99	58.74	54.96	2.45	3.91	37.48	87.68
RSC27	71.43	71.43	0.00	0.00	0.00	0.00	0.00	0.00	40.30	88.46
RSC28	68.17	68.17	15.34	17.60	22.51	11.69	3.86	0.00	70.17	82.04
RSC29	70.41	70.41	0.00	16.41	0.00	6.72	21.93	2.54	0.00	0.00
RSC30	75.94	75.94	9.91	49.06	37.69	52.09	45.32	0.00	24.31	48.91

Table 8
Operational and socio-economic reductions (%) for the retail supply chains (year 2016).

DMU code	Division 1		Division 2						Division 3	
	Diesel	Working hours	Electricity	Receipt paper	Wax paper	Plastic bag	Waste	Working hours	Electricity	Working hours
RSC1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	13.26	85.11
RSC2	38.87	38.87	0.00	0.00	0.00	0.00	0.00	0.00	23.73	78.44
RSC3	48.87	48.87	11.45	21.01	23.65	6.81	14.77	15.55	76.92	95.17
RSC4	71.28	71.28	11.32	20.37	25.96	15.23	13.29	13.15	0.00	0.00
RSC5	67.74	67.74	0.00	40.44	39.56	41.42	41.02	13.79	68.38	57.34
RSC6	35.97	35.97	0.00	35.60	0.00	34.06	23.07	0.00	0.00	62.41
RSC7	71.21	71.21	0.00	0.00	0.00	0.00	0.00	0.00	81.69	96.12
RSC8	24.43	24.43	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
RSC9	68.08	68.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02
RSC10	55.57	55.57	0.00	0.00	0.00	0.00	0.00	0.00	72.19	39.94
RSC11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
RSC12	82.00	82.00	0.28	7.35	9.26	10.75	15.86	0.00	65.50	82.23
RSC13	75.87	75.87	0.00	0.00	0.00	0.00	0.00	0.00	59.44	96.38
RSC14	88.51	88.51	6.48	24.19	9.01	0.00	21.10	9.35	81.76	90.69
RSC15	66.06	66.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
RSC16	47.79	47.79	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
RSC17	65.20	65.20	0.00	0.00	0.00	0.00	0.00	0.00	82.04	82.88
RSC18	12.50	12.50	11.42	50.94	49.12	56.69	18.99	19.30	0.00	0.00
RSC19	63.30	63.30	0.00	0.00	0.00	0.00	0.00	0.00	73.79	84.47
RSC20	13.36	13.36	22.72	51.42	49.19	46.17	14.21	0.00	30.49	16.99
RSC21	45.31	45.31	0.00	0.33	0.31	0.31	0.05	0.10	60.79	92.43
RSC22	1.48	1.48	20.38	14.17	23.72	23.62	0.00	26.51	0.00	0.00
RSC23	5.42	5.42	26.10	28.18	67.58	18.08	28.03	16.64	0.00	0.00
RSC24	2.08	2.08	0.00	12.03	35.28	3.56	17.10	0.00	0.00	0.00
RSC25	0.00	0.00	13.05	31.11	29.26	44.15	2.64	15.16	67.01	89.65
RSC26	75.33	75.33	9.87	41.66	54.76	48.59	9.78	8.37	32.68	87.68
RSC27	71.43	71.43	0.00	0.00	0.00	0.00	0.00	0.00	32.19	88.46
RSC28	68.17	68.17	16.49	37.73	41.90	10.48	0.00	7.21	60.31	82.04
RSC29	70.41	70.41	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
RSC30	75.94	75.94	19.47	46.11	35.63	52.59	13.02	20.54	12.39	48.91

The use of the LCA + DEA methodology to quantitatively verify this hypothesis has been widely addressed in the scientific literature in the last years (Martín-Gamboa et al., 2017). For the case study of RSCs, average operational reductions range from 4% to 47% and lead to average carbon and energy footprint reductions of 22% and 19%, respectively, thus proving the eco-efficiency concept in a quantitative way.

An additional outcome of the LCA + DEA study is the estimation of the economic savings associated with the operational reductions for

Table 9
Operational and socio-economic reductions (%) for the retail supply chains (year 2017).

DMU code	Division 1		Division 2						Division 3	
	Diesel	Working hours	Electricity	Receipt paper	Wax paper	Plastic bag	Waste	Working hours	Electricity	Working hours
RSC1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	22.16	85.11
RSC2	38.87	38.87	0.00	0.00	0.00	0.00	0.00	0.00	23.39	78.44
RSC3	48.87	48.87	16.76	21.92	31.57	5.98	13.55	9.10	64.07	95.17
RSC4	71.28	71.28	17.44	27.28	32.13	22.22	7.23	4.29	0.00	0.00
RSC5	67.74	67.74	0.00	42.55	37.51	41.21	40.99	4.71	72.44	57.34
RSC6	35.97	35.97	0.00	42.30	11.20	47.16	16.89	20.24	9.43	62.41
RSC7	71.21	71.21	0.00	0.00	0.00	0.00	0.00	0.00	82.30	96.12
RSC8	24.43	24.43	0.00	0.00	0.00	0.00	0.00	0.00	27.35	0.00
RSC9	68.08	68.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02
RSC10	55.57	55.57	0.00	0.00	0.00	0.00	0.00	0.00	55.38	39.94
RSC11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
RSC12	82.00	82.00	0.00	10.81	6.77	14.83	19.53	0.00	60.31	82.23
RSC13	75.87	75.87	0.00	0.00	0.00	0.00	0.00	0.00	56.42	96.38
RSC14	88.51	88.51	9.09	31.06	13.30	0.00	17.50	7.84	80.91	90.69
RSC15	66.06	66.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
RSC16	47.79	47.79	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
RSC17	65.20	65.20	0.00	0.00	0.00	0.00	0.00	0.00	83.33	82.88
RSC18	12.50	12.50	15.97	48.76	48.90	58.08	7.21	21.75	0.00	0.00
RSC19	63.30	63.30	13.62	41.10	27.67	28.86	11.16	0.00	65.03	84.47
RSC20	13.36	13.36	10.51	56.62	50.45	48.85	33.35	20.95	32.62	16.99
RSC21	45.31	45.31	0.00	2.17	1.80	1.54	0.00	0.60	56.11	92.43
RSC22	1.48	1.48	0.00	28.80	35.47	19.69	17.05	18.75	0.00	0.00
RSC23	5.42	5.42	27.71	21.74	61.14	15.61	12.12	16.84	0.00	0.00
RSC24	2.08	2.08	7.38	6.67	34.00	0.00	8.00	0.00	0.00	0.00
RSC25	0.00	0.00	8.31	38.56	49.50	31.99	1.60	21.15	66.90	89.65
RSC26	75.33	75.33	8.92	48.01	65.91	51.75	5.54	9.36	35.81	87.68
RSC27	71.43	71.43	0.00	0.00	0.00	0.00	0.00	0.00	39.42	88.46
RSC28	68.17	68.17	0.00	0.00	0.00	0.00	0.00	0.00	66.56	82.04
RSC29	70.41	70.41	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
RSC30	75.94	75.94	0.00	39.04	49.37	43.98	8.52	22.07	21.99	48.91

Table 10
Target carbon footprint reductions (%) by retail supply chain, division and year.

DMU code	Year 2015			Year 2016			Year 2017		
	Div1	Div2	Div3	Div1	Div2	Div3	Div1	Div2	Div3
RSC1	0.00	0.00	21.42	0.00	0.00	13.26	0.00	0.00	22.16
RSC2	38.87	0.00	24.81	38.87	0.00	23.73	38.87	0.00	23.39
RSC3	48.87	6.99	73.79	48.87	12.15	76.92	48.87	17.11	64.07
RSC4	71.28	0.00	0.00	71.28	13.20	0.00	71.28	19.33	0.00
RSC5	67.74	16.20	72.76	67.74	11.29	68.38	67.74	11.19	72.44
RSC6	35.97	21.61	11.80	35.97	6.19	0.00	35.97	9.75	9.43
RSC7	71.21	0.00	81.36	71.21	0.00	81.69	71.21	0.00	82.30
RSC8	24.43	0.00	15.29	24.43	0.00	0.00	24.43	0.00	27.35
RSC9	68.08	0.00	0.00	68.08	0.00	0.00	68.08	0.00	0.00
RSC10	55.57	0.00	73.83	55.57	0.00	72.19	55.57	0.00	55.38
RSC11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
RSC12	82.00	3.28	51.16	82.00	2.53	65.50	82.00	2.74	60.31
RSC13	75.87	0.00	62.92	75.87	0.00	59.44	75.87	0.00	56.42
RSC14	88.51	1.73	79.75	88.51	6.46	81.76	88.51	8.92	80.91
RSC15	66.06	0.00	0.00	66.06	0.00	0.00	66.06	0.00	0.00
RSC16	47.79	0.00	0.00	47.79	0.00	0.00	47.79	0.00	0.00
RSC17	65.20	0.00	83.33	65.20	0.00	82.04	65.20	0.00	83.33
RSC18	12.50	15.19	0.00	12.50	22.73	0.00	12.50	26.04	0.00
RSC19	63.30	9.44	45.90	63.30	0.00	73.79	63.30	16.78	65.03
RSC20	13.36	19.44	37.13	13.36	28.47	30.49	13.36	20.63	32.62
RSC21	45.31	0.02	62.03	45.31	0.10	60.79	45.31	0.52	56.11
RSC22	1.48	9.35	0.00	1.48	20.68	0.00	1.48	6.95	0.00
RSC23	5.42	27.51	0.00	5.42	30.95	0.00	5.42	30.93	0.00
RSC24	2.08	4.09	0.00	2.08	3.50	0.00	2.08	9.12	0.00
RSC25	0.00	23.71	71.85	0.00	17.85	67.01	0.00	16.08	0.00
RSC26	75.33	21.12	37.48	75.33	22.90	32.68	75.33	24.80	35.81
RSC27	71.43	0.00	40.30	71.43	0.00	32.19	71.43	0.00	39.42
RSC28	68.17	15.59	70.17	68.17	18.48	60.31	68.17	0.00	66.56
RSC29	70.41	0.91	0.00	70.41	0.00	0.00	70.41	0.00	0.00
RSC30	75.94	18.55	24.31	75.94	24.89	12.39	75.94	12.53	21.99

the sample of RSCs. For this calculation, the economic prices of the operational elements were directly provided by the managers of the company. Table 11 presents the potential economic savings disaggregated by division and year for each of the 30 RSCs. The total annual savings calculated for the whole sample of RSCs amount to >123 k€ every year. The highest annual economic savings at the division level were found for division 1 (>60 k€ for the whole sample of RSCs) followed by division 2 (>55 k€). Overall, the joint interpretation of the (overall, divisional and term) efficiency scores, (operational, socio-economic and environmental) benchmarks and potential economic savings from the proposed LCA + DEA method arose as a useful strategy to strengthen the management of RSCs from a sustainability perspective. This advancement is in line with the need for sustainability assessment of service supply chains, which is usually identified as a challenge in supply chain modelling and analysis (Ghadimi et al., 2019). It also confirms the usefulness of operational research tools in service supply chain management (Wang et al., 2015), especially regarding the use of DEA for sustainability assessment of supply chains (Kalantary and Saen, 2019).

3.5. Influence of enlarging the boundaries of the DMU

This section explores whether expanding the limits of the DMU – from retail store to RSC– affects the results of the efficiency assessment. This was done by comparing the term-efficiency scores for the year 2017 presented in Section 3.2 (network DEA) with those reported in Álvarez-Rodríguez et al. (2019a) for a static unidivisional efficiency assessment of retail stores (using the input-oriented slacks-based measure of efficiency model with variable returns to scale proposed by Tone (2001)). Therefore, two different DMU structures (3-divisional *vs.* unidivisional DMU) were used herein since the goal of this section is to analyse the influence of including the distribution phases in the efficiency assessment.

Fig. 6 shows the ratio between the network (*i.e.*, three-divisional) and the unidivisional (*i.e.*, store-limited) term-efficiency scores of each DMU for the year 2017. Values above 1 mean a higher efficiency score of the network DMU (RSC), while values below 1 denote a higher efficiency score of the unidivisional DMU (retail store). Values equal to 1 imply the same efficiency score of both the network and the

Table 11
Economic savings (€) by retail supply chain, division and year.

DMU code	Year 2015				Year 2016				Year 2017			
	Division 1	Division 2	Division 3	Total savings	Division 1	Division 2	Division 3	Total savings	Division 1	Division 2	Division 3	Total savings
RSC1	0.00	0.00	0.43	0.44	0.00	0.00	0.29	0.30	0.00	0.01	0.73	0.75
RSC2	740.31	0.00	0.92	741.23	676.95	0.00	0.68	677.64	733.64	0.01	0.62	734.27
RSC3	1074.16	929.49	2.77	2006.42	982.23	1996.13	7.19	2985.55	1064.49	2910.13	4.84	3979.45
RSC4	3133.38	0.00	0.00	3133.39	2865.21	2596.05	0.00	5461.26	3105.16	3841.92	0.00	6947.08
RSC5	2481.25	5256.86	29.86	7767.96	2268.89	4811.03	34.78	7114.69	2458.89	5505.41	48.06	8012.36
RSC6	632.41	5833.25	0.25	6465.90	578.28	2968.24	0.00	3546.52	626.71	4416.09	0.50	5043.30
RSC7	3130.20	0.00	7.20	3137.40	2862.30	0.00	12.29	2874.59	3102.00	0.00	15.47	3117.48
RSC8	393.77	0.00	2.08	395.85	360.07	0.03	0.00	360.10	390.23	0.00	4.99	395.22
RSC9	2793.04	0.00	0.00	2793.04	2553.99	0.00	0.00	2554.00	2767.88	0.00	0.00	2767.88
RSC10	4071.33	0.00	46.09	4117.42	3722.89	0.00	67.05	3789.94	4034.66	0.01	73.49	4108.15
RSC11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
RSC12	6007.32	1162.53	3.99	7173.84	5493.18	940.84	9.78	6443.80	5953.20	1285.74	12.50	7251.44
RSC13	4446.50	0.00	1.45	4447.96	4065.94	0.01	1.31	4067.26	4406.44	0.01	1.25	4407.69
RSC14	9078.38	570.57	17.52	9666.47	8301.41	1061.29	26.22	9388.91	8996.60	1437.18	32.21	10,465.99
RSC15	2419.80	0.00	0.00	2419.80	2212.70	0.00	0.00	2212.70	2398.00	0.00	0.00	2398.00
RSC16	2801.12	0.00	0.00	2801.12	2561.38	0.00	0.00	2561.38	2775.88	0.00	0.00	2775.88
RSC17	5731.52	0.00	30.35	5761.87	5240.99	0.01	46.54	5287.53	5679.89	0.00	49.76	5729.65
RSC18	146.52	5502.18	0.00	5648.70	133.98	7321.78	0.00	7455.76	145.20	8326.94	0.00	8472.14
RSC19	2782.51	2957.12	5.09	5744.72	2544.37	0.23	14.20	2558.80	2757.44	4815.75	18.98	7592.17
RSC20	176.19	6130.90	6.87	6313.96	161.12	7954.43	6.46	8122.00	174.61	7230.18	7.94	7412.73
RSC21	1659.61	8.53	2.58	1670.73	1517.58	39.41	2.69	1559.67	1644.66	204.14	3.23	1852.03
RSC22	17.36	2088.44	0.00	2105.81	15.88	3130.68	0.00	3146.56	17.21	1636.58	0.00	1653.78
RSC23	79.40	4034.06	0.00	4113.45	72.60	4900.71	0.00	4973.31	78.68	4924.02	0.00	5002.70
RSC24	30.54	588.76	0.00	619.30	27.93	564.97	0.00	592.90	30.27	1018.27	0.00	1048.53
RSC25	0.00	4817.21	5.40	4822.61	0.00	4039.90	7.04	4046.94	0.00	3847.81	11.47	3859.28
RSC26	3311.33	6851.32	1.19	10,163.84	3027.93	6959.16	1.08	9988.17	3281.50	7707.34	1.48	10,990.32
RSC27	3663.00	0.01	0.77	3663.78	3349.50	0.01	0.59	3350.10	3630.00	0.01	0.78	3630.79
RSC28	2796.85	2459.77	3.65	5260.26	2557.48	3156.46	5.67	5719.61	2771.65	0.01	10.30	2781.96
RSC29	2579.26	464.23	0.00	3043.49	2358.51	0.04	0.00	2358.55	2556.02	0.00	0.00	2556.02
RSC30	3337.96	6015.61	1.97	9355.53	3052.27	7143.41	1.29	10,196.97	3307.88	4213.82	2.09	7523.80

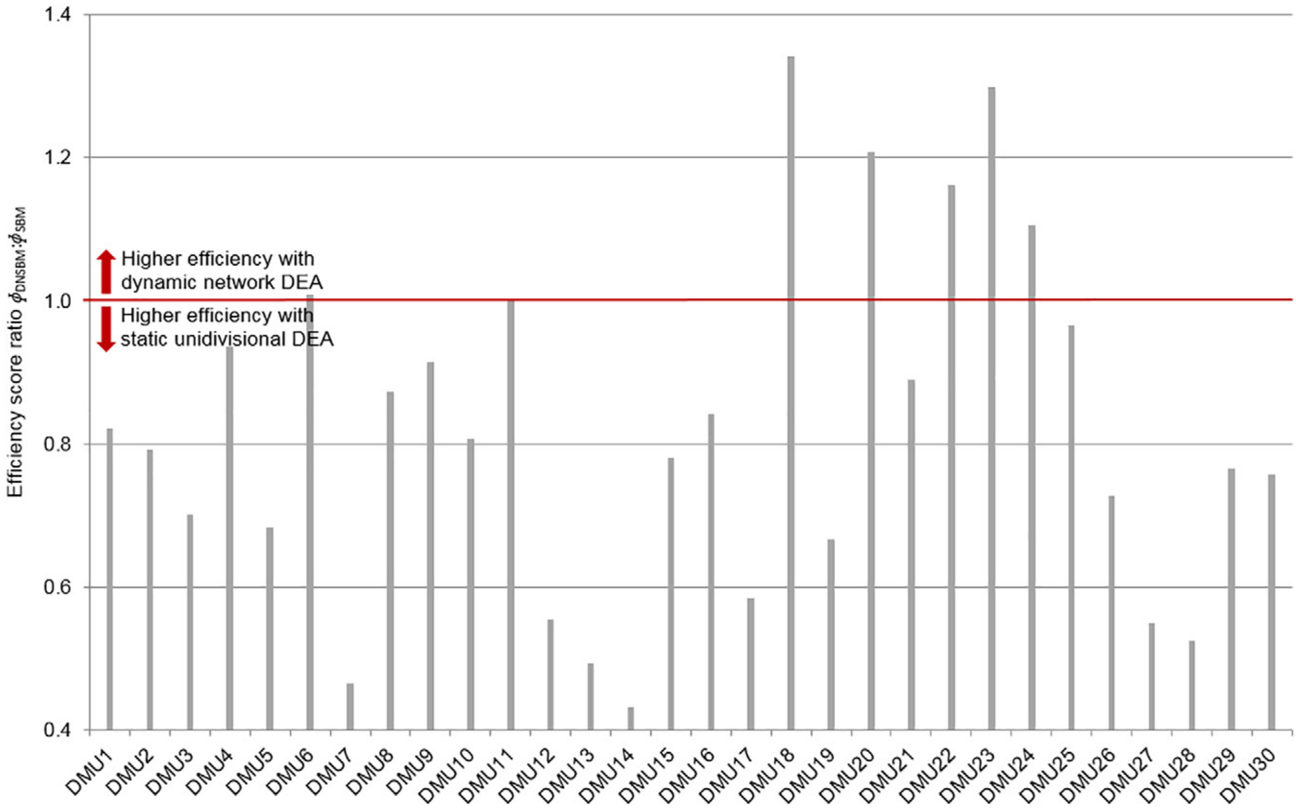

Fig. 6. Ratio between the efficiency scores from dynamic network DEA and static unidivisional DEA (year 2017).

unidivisional DMU. As observed, only DMU11 involves the same efficiency score at both the store level and the supply-chain level. When the efficiency assessment addresses not only store operation but also the distribution divisions, only 6 DMUs were found to increase their efficiency scores with respect to the unidivisional scores. For the remaining entities, extending the boundaries of the DMU was found to lead to efficiency penalties. In fact, a link between long distribution distances and low divisional efficiency was identified, especially for division 1. Nevertheless, short distribution distances are not necessarily linked to high efficiency.

Taking into account the moderate relevance of the dynamic component of the study (Álvarez-Rodríguez et al., 2019b), it is concluded that the inclusion of the distribution divisions significantly affects the outcomes of the efficiency assessment. In other words, the enlarged scope of the DMU and the network perspective significantly change the efficiency outcomes of the previous unidivisional –*i.e.* store-limited– static (Álvarez-Rodríguez et al., 2019a) and dynamic (Álvarez-Rodríguez et al., 2019b) studies. This finding highlights the suitability of enriching the efficiency study with a network structure when the unit of assessment can be extended from a unidivisional one to a multidivisional one (*i.e.*, a supply chain) (Kalantary and Saen, 2019). In this study, further enrichment was attained through the additional use of LCA to provide the efficiency assessment of supply chains with a sustainability perspective (Ghadimi et al., 2019).

4. Conclusions

The LCA + DEA methodology with a dynamic and network perspective proved to be a feasible tool for the calculation of efficiency scores and sustainability benchmarks of RSCs. Being the first time that a network model has been used in the field of LCA + DEA, this study not only proves the feasibility of the novel methodological framework, but it also leads to the general recommendation of enriching LCA + DEA studies by moving from unidivisional DMUs to multidivisional ones as far as possible. It should be noted that this recommendation aims at LCA + DEA practitioners in general, not being limited to the case study presented in this article. For the evaluated sample of 30 RSCs, unlike store operation (division 2), central distribution (division 1) and home delivery (division 3) arose as key sources of inefficiency. In fact, only 1 out of 30 RSCs was found to be efficient. Furthermore, average carbon and energy footprint reductions of 22% and 19%, respectively, were benchmarked. These reduction targets could be achieved mainly by minimising the consumption of diesel in division 1 and electricity in division 2. Additionally, total annual savings above 123 k€ were estimated for the whole sample of RSCs, with the highest potential savings associated with division 1 and, to a lesser extent, division 2.

This work also proved the potentially high influence of enlarging the scope of the DMU on the efficiency assessment of entities within the retail sector. In the case study developed in this article, extending the boundaries of the retail stores by including two distribution stages generally led to significant efficiency penalties when compared to unidivisional (store-limited) efficiency scores. Overall, the enhancement of the LCA + DEA methodology with a dynamic network perspective shows high potential for the sustainability-oriented efficiency assessment of retail supply chains and –in general– of multidivisional entities.

Declaration of competing interest

The authors declare no conflict of interest.

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