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Life cycle assessment of energy flow and packaging use in food purchasing

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A B S T R A C T

The aim of this project is to obtain quantitative data on the metabolic flows (energy consumption, not only by the establishment but also in the transportation of workers and customers, and packaging use) and their resulting environmental impacts of a standard shopping basket purchase in five city center municipal markets and a hypermarket in a suburban retail park in the province of Barcelona (Catalonia, Spain). The main results show that a standard shopping basket purchased in a retail park requires 20 times more energy than one purchased in a municipal market (11.1 kWh and 0.57 kWh, respectively). Customer transportation represents 83.2% of energy consumption in a retail park, while the greatest impacts in a municipal market stem from the establishment itself (49.5%) and worker transportation (40.4%). Secondly, the packaging use inventory is higher in a hypermarket (253 g) than in a municipal market (102 g). However, the overall environmental impact associated with a standard shopping basket is 10 times higher on average in a hypermarket than in a municipal market, and the carbon footprints of the hypermarket and the municipal market are 3.8 and 0.4 kg of CO_2 eq., respectively. According to the sensitivity analysis, current policies for reducing the amount of plastic bag packaging have little repercussion in a retail park because its relative weight in terms of total packaging use is only 7%. Nevertheless, they have notable effects in municipal markets where plastic bags represent 25% of the packaging use. Finally, if customers selected the least packaged products available in hypermarkets, each shopping basket could reduce up to 47.2% of its used packaging weight and between 15.4 and 59.0% of its associated environmental impact.

1. Introduction

The service sector carries the greatest economic weight in Western countries, representing approximately 70% of GDP (World Bank, 2008). Until now, the metabolic flows of this sector have not been thoroughly studied as they were assumed to be similar across types of services and of little importance to agricultural and industrial activities (Graedel, 1997). As a result, there has been environmental concern in these latter sectors, especially in the industrial area, and policies were generated in response, focusing mainly on air emissions and waste disposal (Graedel, 1997). This trend is justified as the dominant types of service-related activities have appeared to require less energy and materials than industry and agriculture (Heiskanen and Jalas, 2000), and this disconnection of economic growth from natural resource use, referred to as decoupling, has been associated with a lower environmental impact (Ayres and Ayres, 2001).

Furthermore, tertiarization in recent decades has increased energy and materials consumption of the service sector as well as their associated impacts. Nevertheless, these flows vary depending on the type of services (transport, tourism, catering, etc.), and a quantitative characterization of these flows can provide a qualitative view of the impacts associated with each type. According to the European Environmental Agency (2010), the service sector (excluding transport) represented 11.2% of the final energy consumption of the EU-27 in 2007 and 8.7% of greenhouse gas (GHG) emissions.

Furthermore, the service sector has nearly the same energy intensity as the industrial sector (6.9 TJ compared with 8.4 TJ, taking in account the equivalent of 1 million Euros of GDP), according to Jespersen (1994), who analyzed the energetic intensity

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of more than 100 economic sectors (including heavy industry and the service sector) through input–output tables.

Finally, industrial ecology offers a different point of view to this kind of studies, given that the metabolic perspective considers the service sector from the point of view of traditional ecology and considers the service system as a system integrated in the biosphere (Erkman, 1997). Moreover, industrial ecology can study aspects of the service sector in depth, including factors that have not been taken into account in recent improvements that have been applied to the sector, such as the potential synergies among different parts of the system that is significant for services polygon formats (Farreny et al., 2009).

On the other hand, the food trade is one of the most important commercial branches of the service sector because it represents an essential service for a basic human need (Jones, 2002). Traditionally, there were municipal markets and small businesses that provided food services, but in recent decades, department stores and retail parks that provide food services have also appeared, extending a concept forged in North America in the 1930s and associated with the spread of car-based transportation in the 1960s to other continents (Escudero, 2008). Western European estimates for 2006 suggested there were almost 1400 hypermarkets selling food and several thousand selling non-food products concentrated in 700 retail parks (Guy, 2006).

According to Guy (1994), a retail park is a group of various retail outlets on one floor that typically includes a range of shopping chains (generally supermarkets as well as clothing, footwear, electrical and do-it-yourself material retailers) with large parking lots and proximity to major transport routes.

A municipal market can be defined as commercial equipment located in public spaces within the urban network where food can be purchased in stalls or small specialized shops of independent merchants.

In terms of income, commercial formats are distributed in the province of Barcelona (Generalitat de Catalunya, 2010a) among supermarkets (400–2500 m^2) (59%), super-services (150–400 m^2) (12.7%), hypermarkets (12%), boutiques (11.2%), stores (4%) and self-service (1.2%). The commercial formats that are compared in this analysis concentrate on 23.2% of sector income and play a significant role. In addition, municipal trade facilities like municipal markets are associated with some other key roles in cities (Morales, 2009). First, markets are places that contribute to the quality of life and sociability of neighborhoods; second, public markets maintain a close relationship with urban planning; third, they also contribute to economic and social development; and, finally and most importantly for our purposes here, they play a role in addressing environmental concerns.

Food products have been the focus of several studies in recent decades. The food industry is one of the world's largest industrial sectors, and it uses a great amount of energy. Agricultural production has been indicated as a hotspot in the life cycle of food products (Poritosh et al., 2009). Using the life cycle assessment methodology, the production stage has been analyzed for industrial food products, including: tomato ketchup (Andersson et al., 1998) and dairy and meat production (Berlin et al., 2007), and agricultural products, such as tomatoes (Antón et al., 2005). Moreover, the research on agricultural production has also focused on raw materials and waste management (Martínez-Blanco et al., 2009, 2011; Muñoz et al., 2004), as well as on cultivation methodologies to improve the environmental profile of crops, such as organic farming (Cederberg and Mattsson, 2000; Meisterling et al., 2009). Besides, the introduction of good practices in food industry were also analyzed, highlighting waste minimization (Henningsson et al., 2004; Hyde et al., 2001) and food waste management (Lundie and Peters, 2005).

Recently, the packaging of food products has been studied as a product (taking into account their production, materials and waste) (Ross and Evans, 2003; Zabaniotou and Kassidi, 2003) and as part of the food product cycle, such as beer (Koroneos et al., 2005).

Regarding the distribution stage, some studies have quantified the energy consumption and environmental impact related to the overall food supply chain (Jones, 2002) as well as the differences between local and imported products (Milà I Canals et al., 2007).

Although retail has been included in the life cycle of food products in some studies when defined as food consumption (Jungbluth et al., 2000), it only includes customer transportation and food preparation and cooking. Several significant factors have been omitted, and these omissions highlight the need for including the food retail facility and its workers in an environmental performance analysis of a food purchase.

In this context, the aim of this study is to quantify the overall environmental impact associated with energy consumption and packaging use of a standard purchase in two types of commercial facilities. Moreover, quantitative data can support the decision-making process in food retail, not only from the customers' point of view but also from the manager's one.

2. Methodology

This paper focuses its analysis on those food product life cycle stages that are related to retail. More specifically, the study focuses on the energy consumption and on the packaging use vectors (Fig. 1), excluding food transportation to retail and other minor vectors such as water consumption. The study works in two phases: the quantification of vector flows on the basis of a Material and Energy Flow Analysis (MEFA) (Haberl et al., 2004) and the quantification of associated impact by means of a Life Cycle Assessment (LCA) (ISO 14040, 2006).

2.1. Study system

The analysis was performed in two typologies of food retail stores representative of the sector and with different social and environmental characteristics. The study area is the province of Barcelona, Catalonia, in northeastern Spain.

For the municipal market typology, five markets were chosen and the average data was used. They are representative of different types of municipal markets as they present differences in the pattern of energy consumption (heating, ventilation and air conditioning systems) and in the availability of free parking areas, which conditions motorized access. No quantitative studies had been performed previously in these markets (Table 1).

For the hypermarket typology, a hypermarket in a retail park was chosen. This is located outside compact urban areas and closely linked to a motorway, being representative of this type of commercial format in Europe. It has free parking for 4000 private vehicles and includes nine single-floored buildings, of which the largest and most representative includes the hypermarket (Farreny et al., 2008) (Table 1).

2.2. Functional unit

For comparative purposes, a standard shopping basket was defined as the functional unit. For the goal of this study, the standard shopping basket contains: 150 g lean meat, 400 g minced meat, 125 g boiled ham, 125 g cheese, 6 eggs, 250 g sliced cod, 500 g clams, 4 apples, 3 courgettes, 300 g green beans, 1 kg potatoes and 90 g almonds.

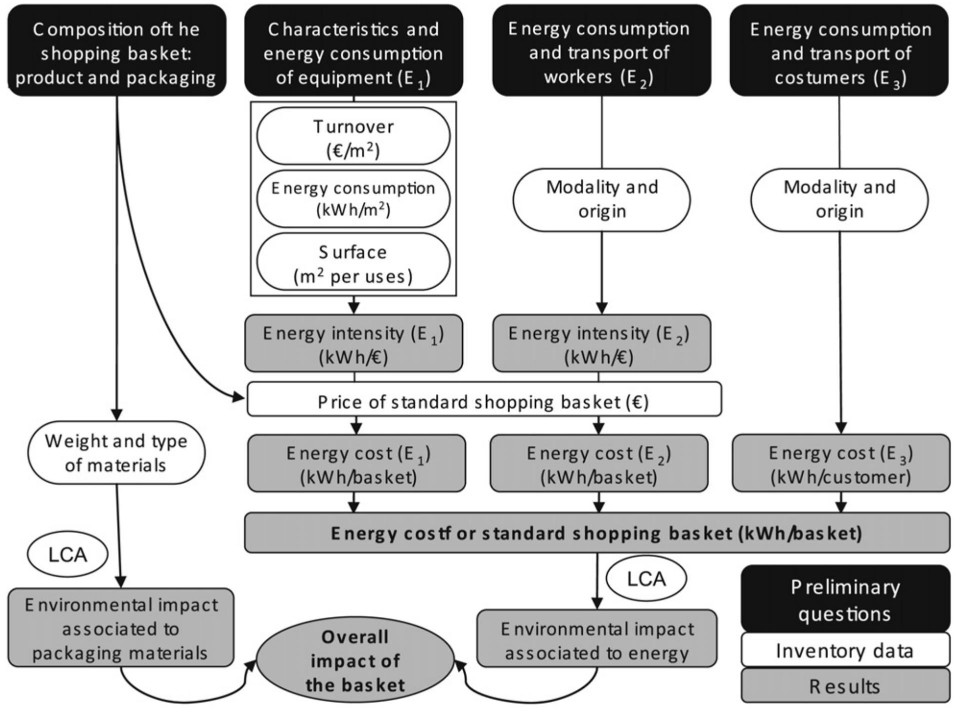

Fig. 1. Methodological structure followed in the paper.

This basket was determined on the basis of the Consumer Price Index (CPI) of the Spanish National Statistics Institute (INE) and on the Continuous Survey of Family Budgets (ECPF). Moreover, the product quantity was determined according to a balanced 2300 kcal diet as established in Pinto and Carvajal (2003), and specific product quantities were chosen to avoid those only available in packs of certain units or quantities in a retail park.

2.3. Material and energy flow analysis

2.3.1. Energy consumption

The energy cost of the standard shopping basket (kWh/basket) was quantified in three stages: the energetic consumption of the establishment, worker transportation and customer transportation. For the establishment and the worker transportation consumption, data was quantified in turnover terms (kWh/€) and extrapolated for the price of the standard shopping basket (€). For customer transport, the energy cost is the energy consumption by one customer, as each purchase is made for one group of customers (Fig. 1).

Given that municipal market systems are aggregations of small stalls, each with its own data, the data collection procedure for these systems was complex due to data atomization. This fact makes it difficult to collect accurate data of energy consumption and annual turnover; thus, this paper estimated some data using surveys.

2.3.1.1. Establishment. Establishment energy intensity (kWh/€) was obtained from the electrical invoice for the hypermarket. Data source for the hypermarket was the establishment itself, including the proportion of electrical energy consumption (kWh) over turnover (€) for 2006. In economic terms, energy intensity (1) for the municipal market system was estimated using the installed power and the establishment weekly schedule (Diputació de Barcelona, 2009).

Table 1
City population, store characteristics, turnover and shopping basket price for the different stores analyzed.

	Hypermarket	Municipal markets				
	Sant Boi del Llobregat	Sant Boi del Llobregat	Olesa	Castellar	Cerdanyola	
					Serraparera	Fontetes
Population[a]	82,411	82,411	23,646	23,129	58,407	
Total surface (m^2)	300,000	7276.32	3290	1690	3527.67	2344.68
Retail surface (m^2)	26,000	1922.32	660	160	166.16	829.02
Workers	600	64	83	29	60	40
Ratio (Worker/100 m^2)	2.3	3.33	12.58	10.51	6.02	4.83
Work schedule (h/week)	72	57	52	46.5	42.5	42.5
Turnover (€/m^2)[b]	5570.80	2464.40	2189.70	1797.80	2380.50	3830.80
Shopping basket cost (€)[c]	27.02			33.57		

[a] IDESCAT (2001).
[b] Estimation based on the data of annual average turnover per surface of shop (m^2) by kind of shop, from Diputació de Barcelona (2007), and the surface of each municipal market, available in Generalitat de Catalunya (2010b).
[c] Field work data.

$$\text{Establishment energy intensity}(\text{kWh}/€) = \frac{\text{Installed potential}^{1}(\text{kW/m}^2) \times \text{Week schedule (h/week)} \times 52\ (\text{week/year})}{\text{Turnover intensity}^{2}(€/\text{m}^2)} \quad (1)$$

[1]8 W/m^2 is considered from Diputació de Barcelona (2009), where calculations were done for municipal markets with an installed potential between 6 to 10 W m^{-2}.

[2]Estimation based on the data of annual average turnover per surface of shop (m^2) by kind of store from Diputació de Barcelona (2007) and the surface of each municipal market (Generalitat de Catalunya, 2010b).

2.3.1.2. Transport. Transport of workers and customers was measured using the methodology shown in Farreny et al. (2008) with some adjustments. Calculations were made by estimating the total distance covered using the work movement pattern and trip distance (Table 2). For the fuel consumption estimation, the average motorized distance (D_m) (2) was obtained using 276 working days per year, the total number of workers (T) and the trips taken in the same municipality (X_w), including the walking modality ($\%_w$). Finally, the transportation consumption for workers (3) and customers (4) were calculated using the distribution of the fleet of vehicles by fuel type (INE, 2009), the occupancy for private and public vehicles, the efficiency for transport and fuel typology and the TOE conversion (GHG Protocol Initiative, 2005) (Table 3).

$$D_m = 276 \cdot T \cdot 2 \cdot (X - \%_w \cdot X_w) \quad (2)$$

$$\text{Energy intensity of workers transport (kWh/€)} = \frac{(\text{Public transport consumption} + \text{Private transport consumption})(\text{TOE}) \times 11,620(\text{kWh/TOE})}{\text{Establishment surface } (\text{m}^2) \times \text{Turnover}^2 (€/\text{m}^2)} \quad (3)$$

$$\text{Energy intensity of customer transport (kWh/customer)} = (\text{Public transport consumption} + \text{Private transport consumption})(\text{TOE}) \times 11,620\ (\text{kWh/TOE}) \quad (4)$$

Where:

$$\text{Public transport consumption (TOE)} = \frac{D_m \cdot \%_{pu}(\text{km})}{o_2 \cdot e_3(\text{km/L}) \cdot c_3(\text{L/TOE})}$$

$$\text{Private transport consumption(TOE)} = \frac{D_m \cdot \%_{pr}(\text{km})}{o_2} \cdot \left(\frac{\%_{diesel}}{e_1(\text{km/L}) \times c_1(L/\text{TOE})} + \frac{\%_{gasoline}}{e_2(\text{km/L}) \times c_2(L/\text{TOE})}\right)$$

2.3.2. Packaging vector

The quantity and type of packaging materials of the standard purchase were quantified, sorting the primary product packaging and plastic bags used by customers to transport the basket home. The shopping basket designed was done in a municipal market and in a hypermarket of the study area. The purchase was done in the same city to avoid geographic cost differences. The packaging of each product was sorted, weighted using analytical scales and categorized by type of material for each type of commercial establishment to perform the environmental impact analysis.

2.4. Sensitivity analysis

The study includes a sensitivity analysis for the packaging vector (A and B) and for the energy vector (C):

- Scenario A: the removing of LDPE bags was evaluated assuming that they are replaced by a shopping trolley;
- Scenario B: the least packed options for hypermarket products are accounted; and
- Scenario C: the quantification of sustainable mobility policies for hypermarket customers was done assuming the same modality as the municipal market users (80% public transport and 20% private vehicle).

2.5. Environmental tools: life cycle assessment (LCA) and data quality

Once the energy and packaging flows were quantified, the LCA methodology (ISO 14040, 2006) was applied to classify and characterize the environmental impacts for different categories. Classification enabled each environmental load to be sorted into one or more impact categories, and characterization allowed the

Table 2
Average distance and modality for workers and customers transport, by food store type.

	Workers[a]		Customers[b]	
	Average distance (km)	Modality	Average distance (km)	Modality
Retail park	5 km	Walking ($\%_w$) = 21% Private vehicle ($\%_{pr}$) = 65% Public transport ($\%_{pu}$) = 14%	7.3 km	Walking ($\%_w$) = 0% Private vehicle ($\%_{pr}$) = 99% Public transport ($\%_{pu}$) = 1%
Municipal markets	4.3 km	Walking ($\%_w$) = 58% Private vehicle ($\%_{pr}$) = 21% Public transport ($\%_{pu}$) = 21%	1 km	Walking ($\%_w$) = 90% Private vehicle ($\%_{pr}$) = 2% Public transport ($\%_{pu}$) = 8%

[a] IDESCAT, 2001 – Labor mobility statistics, by municipality.
[b] Market study for retail park data, and municipal market managers for municipal markets.

Table 3
Summary of vehicle energy efficiencies, conversion factors, distribution by type of fuel in the Spanish private vehicle park and occupancy.

Vehicle	Efficiency[a] (km/L)	Conversion to TOE[a] (L/TOE)	National private vehicle park[b]		Occupancy[c]
			Number	%	
Diesel auto	10.20 (e_1)	1150 (c_1)	1,902,138	57%	1.56 (o_1)
Gasoline auto	9.34 (e_2)	1250 (c_2)	1,430,386	43%	1.56 (o_1)
Diesel bus	2.85 (e_3)	1150 (e_3)	–		20 (o_2)

[a] The average efficiency used is for typical vehicles based on averages from US EPA 2001 Guide (GHG Protocol Initiative, 2005).
[b] INE, 2009.
[c] Farreny et al., 2008.

calculation of the overall impact by multiplying each load by a factor associated with each impact category. The classification and characterization stages observed the CML 2 Baseline (Guinée et al., 2001) methodology. The selected midpoint impact potentials and their units are abiotic depletion (kg Sb eq.), acidification (kg SO_2-eq.), eutrophication (kg PO_4^{3-}-eq.), global warming (kg CO_2 eq.), ozone layer depletion (kg CFC-11-eq.) and human toxicity (kg 1.4-DB-eq.).

Background data for the inventory was obtained from the Ecoinvent 2.0 database for the energy production of energy flows (electric and fossil fuels) (Dones et al., 2007) and the materials of the inventoried packaging flow (Hischier, 2007). For the packaging vector, the life cycle stages taken into account in the LCA were the extraction of the raw materials, the transportation and its processing; other stages, such as waste management, were excluded in the analysis. Foreground data includes the amount and typology of materials for the packaging use and the energy consumption (electricity and fuel) for the establishment and the transportation of workers and customers.

3. Results and discussion

3.1. Energy consumption

The energy consumption of a standard shopping basket (Table 4) is higher for a food purchase in a hypermarket (11.10 kWh) than in a municipal market (0.57 kWh) with a ratio of 20–1. Customer transportation is the main contribution to it for the retail park, with a higher motorized distance and a motorized share. The customer transport ratio between the two establishments is 160–1 and indicates the greatest divergence between the two systems. If this stage was excluded from the analysis, the ratio would be reduced to 5–1. This result agrees with Morales (2009), which states that municipal markets play a role in addressing environmental concerns as they reduce distance traveled by vehicles. Due to a lower ratio of workers per surface in municipal markets, worker transportation is the only stage that has a higher energy cost for municipal markets than for the hypermarket (Table 4). Thus, by analyzing the characteristics of each stage of consumption, the inequalities between the types of establishment are observed (Table 5).

According to the energy consumption patterns observed, the customers distance and the establishment consumption are the key points. For one site, municipal markets are situated in city centers and the avoided customer transport is an environmental benefit compared to retail parks. However, municipal markets showed that environmental strategies should focused on the establishment's energy efficiency.

Table 4
Inventory results for energy vector.

	Energy consumption (kWh/basket)			
	Facility	Worker transportation	Customer transportation	Total
Hypermarket in a retail park (RP)	1.68	0.18	9.23	11.1
Municipal market (M)	0.28	0.23	0.06	0.57
RP/M ratio	6	0.8	160	19.5

3.2. Packaging vector

Packaging use is also higher in a retail park (253 g) than in a municipal market (102 g). However, the distribution between primary packaging and plastic bags and the type of materials used are different in each establishment (Table 6).

Primary packaging is more relevant (93%) in hypermarkets, where product positioning promotes easy and rapid acquisition by customers and means that products tend to be overpackaged. In contrast, plastic bags have a greater role in municipal markets (25% by weight) as a consequence of their lower optimization because one is given per stall.

The materials used in the manufacture of trays (PS, PP, HDPE), multilayer packaging (PET) and casing for other packaging (cardboard) is not generated, or these materials are generated in much smaller quantities at a municipal market because this kind of packaging is not characteristic of such establishments.

Table 5
Characteristics of each establishment, by consumption stage.

	Establishment	Transport of workers	Transport of customers
Hypermarket in a retail park	Greater number of high power equipment installed (air conditioning, refrigeration)	Higher average distance (5 km) Motorization: 79% Higher economic intensity (€/m^2) and lower ratio of workers per m^2, which reduces unitary consumption (kWh/€)	Supramunicipal influence Higher establishment-home distance (7.3 km) Motorization: 100% Lower use of public transport (1%)
Municipal market	Lower number of high power equipment installed	Lower average distance (3.4 km) Motorization: 42% Higher cost of basket, which leads to higher total consumption (kWh/basket)	Municipal influence Lower average distance (0.8 km) Motorization: 10% Greater use of public transport (8%)

Table 6
Inventory data for packaging vector, by system, material and typology of packaging.

		Hypermarket in a retail park (RP)	Municipal market (M)	RP/M ratio
Primary packaging		235.0 g	76.6 g	3.0
Plastics	Low Density Polyethylene (LDPE)	16.7 g	22.2 g	
	Polystyrene (PS)	92.7 g	3.8 g	
	Polypropylene (PP)	14.6 g	10 g	
	Ethylene Propylene Diene Monomer rubber (EPDM)	0.4 g	0.7 g	
	High density Polystyrene (HDPE)	59.1 g	0	
	Polyethylene terephthalate (PET)	21.6 g	0	
Others	Waxed paper	0	20.2 g	
	Recycled cardboard	0	19.9 g	
	Cardboard	29.9 g	0	
Plastic bags	Low Density Polyethylene (*LDPE*)	17.9 g	25.5 g	0.7
Total		252.9 g	102.1 g	2.5

Regarding the shopping basket components, packaging for meat products and for vegetables were different for both retails. However, products in the hypermarket showed a higher material intensity due to their overpacking. Therefore, even with changes in the shopping basket, a less packaging amount is obtained in purchases done in municipal markets as the bulk shopping represents a monomaterial and light packaging for food products.

3.3. Environmental impact

The environmental impact associated to a standard shopping basket is higher for a hypermarket in a retail park than for a municipal market by a ratio of 7–18 to 1, depending on the different categories. The environmental impact associated with the transport of customers is more divergent, between 75 and 233 times higher in a retail park depending on the category analyzed (Table 7).

The impact associated with packaging use is lower for a municipal market, representing between 22% and 48% of the impact in hypermarkets, depending on the impact category (Table 7). The use of packaging (in weight) in hypermarkets is 2.5 times greater than that of municipal markets, and materials with a greater impact per kg (PS, PET and cardboard) are found in much higher quantities in hypermarkets.

The overall impact of the shopping basket (Table 5) is between 6 and 18 times higher in a hypermarket, depending on the category analyzed. Differentiating between the two vectors of the study, between 70 and 95% of the overall impact in a hypermarket in a retail park is associated with energy consumption, while the distribution between vectors is more even in municipal markets where the packaging vector represents between 25 and 62%.

The environmental profile shows that the impact categories have the same pattern, except for Ozone Layer Depletion Potential (ODP). However, in the context of global environmental awareness and particularly with regard to GHG emissions, Global Warming Potential (GWP) requires more attention.

In the systems defined in this study, the GWP related to energy consumption and packaging of a standard shopping basket is 3.80 kg CO_2 eq. for a retail park and 0.47 kg CO_2 eq. for a municipal market. This impact category points to differences observed between the weights of each vector depending on the type of establishment: the energy vector represents 81% in a retail park versus 55% in a municipal market.

The results showed that the environmental policies in food retail depend on the store type. Municipal markets should focus on the energy consumption of the establishment and to be energy efficient. Moreover, bulk shopping showed less environmental impact for packaging, but common bags for the overall market (and not one by store) could optimize the secondary packaging use.

On the other hand, the distance between city centers and retails parks represent the hotspot in the environmental impact associated to a shopping basket done in a hypermarket. Establishments nearer the city center and public transport for customers would be effective environmental policies.

3.4. Sensitivity analysis

3.4.1. Scenario A: LDPE bag removal in both systems

In terms of weight, there was a 7% reduction of the packaging use in the hypermarket and 25% in municipal markets when LDPE bags were removed from each system. Accordingly, the environmental impact decrease for the packaging vector shows the same

Table 7
Environmental impact of one standard shopping basket by impact category, commercial establishment and vector.

	Abiotic depletion	Acidification	Eutrophication	Global warming potential	Ozone layer depletion	Human toxicity
	(kg Sb eq)	(kg SO_2-eq)	(kg PO_4^{3-}eq)	(kg CO_2 eq)	(kg CFC-11-eq)	(kg 1,4-DB-eq)
Retail park (RP)						
Energy	2.05E−02	1.34E−02	1.26E−03	3.07E+00	3.65E−07	7.39E−01
Packaging	8.92E−03	2.37E−03	3.21E−04	7.27E−01	1.14E−08	1.14E−01
Total	2.94E−02	1.58E−02	1.58E−03	3.80E+00	3.76E−07	8.53E−01
Municipal market (M)						
Energy	1.73E−03	1.91E−03	1.38E−04	2.46E−01	2.02E−08	6.51E−02
Packaging	2.50E−03	7.43E−04	9.25E−05	2.20E−01	5.29E−09	2.80E−02
Total	4.23E−03	2.53E−03	2.08E−04	4.46E−01	2.08E−08	8.73E−02
RP/M Ratio						
Energy	11.9	7.0	9.1	12.5	18.2	11.4
Packaging	3.6	3.2	3.5	3.3	2.2	4.1
Total	7.3	6.2	7.6	8.8	18.1	9.8

Note: eq = equivalents, Sb = antimony, SO_2 = sulfur dioxide, PO_4^{3-} = phosphate, CO_2 = carbon dioxide, CFC-11 = chlorofluorocarbons, 1,4-DB = 1,4-dibutyl. Source: Authors of SimaPro V.7.2 and CML 2000 Methodology.

trend; for a hypermarket, the impact was 0.04%–6.6% lower in this scenario for the different categories, and for the municipal market, the reduction of 0.1%–33.9% shows higher impacts (Tables 5 and 6).

This sensitivity analysis indicates that this proposal has a higher effect in municipal markets than in hypermarkets due to the fact that consumer packaging represents a higher percentage of all packaging in the municipal market system.

As a result, the potential impact for the packaging use in hypermarkets remains higher than the municipal market system by a ratio of 2.1–5 to 1.

3.4.2. Scenario B: Primary packaging reduction in the hypermarket shopping basket

The total amount of packaging was reduced to 47% of weight (170 g) by choosing products with less packaging, an attribute that also varies the material composition.

This primary packaging for the hypermarket saved 15.4%–59% in the different categories of environmental impact, excluding ODP, which increased by 4.4% compared to the baseline scenario (Table 8).

Unless this scenario shows an improvement of the environmental profile, the potential impact of the packaging vector for the hypermarket remains higher than for the municipal market system in all of the categories analyzed at a rate of 1.5–3.5 to 1 across the different categories (Table 8).

3.4.3. Scenario C: sustainable policies for customer transport to and from the retail park

Using the same customer transportation modality distribution for the retail parks as for the municipal markets, the scenario showed a significant reduction (49%) of the energy consumption associated with the standard food purchase from 11.1 to 5.8 kWh. This decrease represents a 49% reduction for the environmental impact related to the energy vector, but it remains higher for a retail park than for a municipal market (Table 9) due to the distance of customer travel.

4. Conclusions and improvement proposals

4.1. Hypermarket in a retail park

The transport of customers represents 83.2% of energy consumption and produces the greatest difference in the energy vector for the two systems of analysis. With this in mind, the managers of such establishments may choose to distribute sustainable mobility policies to their customers to decrease the share of trips in private vehicles and increase the use of public transport. Such a policy could reach a reduction of 49% of energy consumption and environmental impact per basket. Although these indicators would be still higher for a retail park, the energy vector ratio for retail park to municipal market could be reduced from 20–1 to 10–1 for energy consumption and from 11.7–1 to 6–1, on average, for the other environmental impact categories analyzed.

According to the sensitivity scenarios, current policies for reducing the amount of packaging are focused on consumer packaging, such as the elimination of plastic bags (LDPE), and thus, they result in little positive environmental impact, as relative weight in the total amount of packaging is only 7%. In this sense, waste management policies have to focus more on reducing primary packaging, where the main materials are HDPE and PS, with a 64.6% of the total weight and the promotion of bulk purchases. The elimination or reduction of materials with greater negative environmental impact, such as polystyrene and PET, also fall under the scope of better waste management practices.

Finally, the environmental impact of energy consumption contributes most to the overall environmental impact, representing 69.7–97.1% across the different categories. For the retail park hypermarket, the packaging vector has less relevance than energy consumption.

4.2. Municipal market

The energy consumption associated to a purchase done in a municipal market is mainly done in the establishment itself (49.5%) and in the transportation of workers (40.4%). Improvement activities must focus on the market's energy efficiency, amortizing its consumption by increasing commercial surface occupancy and promoting shared use of private vehicles by workers.

At the same time, policies for eliminating plastic bags are relevant to the packaging vector because they represent 25% of the total packaging weight. Nevertheless, the reduction or elimination of materials, such as polystyrene, with high impact potential on any of the categories analyzed would reduce the impact associated with the vector. The main materials (LDPE, recycled cardboard and plastic paper) have a low impact potential and represent 81.2% of primary packaging weight.

In a municipal market the environmental impact is shared more equally by the two vectors analyzed, where the packaging vector represents between the 25–60% of impacts across categories and the energy vector the 40–75%.

Table 8
Environmental impacts of one standard shopping basket related to the packaging vector for scenarios 0, A and B, by category of impact, commercial establishment and environmental vector.

	Abiotic depletion (kg Sb eq)	Acidification (kg SO_2-eq)	Eutrophication (kg PO_4^{3-} eq)	Global warming potential (kg CO_2 eq)	Ozone layer depletion (kg CFC-11-eq)	Human toxicity (kg 1,4-DB eq)
Scenario 0						
Retail park	8.92E−03	2.37E−03	3.21E−04	7.27E−01	1.14E−08	1.14E−01
Municipal market	2.50E−03	7.43E−04	9.25E−05	2.20E−01	5.29E−09	2.80E−02
RP/M Ratio	3.6	3.2	3.5	3.3	1.9	4.1
Scenario A						
Retail park	8.32E−03	2.23E−03	3.09E−04	6.90E−01	1.14E−08	1.12E−01
Municipal market	1.65E−03	5.40E−04	7.66E−05	1.67E−01	5.28E−09	2.54E−02
RP/M Ratio	5.0	4.1	4.0	4.1	2.2	4.4
Scenario B						
Retail park	3.66E−03	1.36E−03	2.38E−04	4.03E−01	1.19E−08	9.64E−02
Municipal market	2.50E−03	7.43E−04	9.25E−05	2.20E−01	5.29E−09	2.80E−02
RP/M Ratio	1.5	1.8	2.6	1.8	2.3	3.4

Note: eq = equivalents, Sb = antimony, SO_2 = sulfur dioxide, PO_4^{3-} = phosphate, CO_2 = carbon dioxide, CFC-11 = chlorofluorocarbons, 1,4-DB = 1,4-dibutyl. Source: Authors from SimaPro V.7.2 and CML 2000 Methodology.

Table 9
Environmental impacts of one standard shopping basket related to the packaging vector for scenarios 0 and C, by category of impact, commercial establishment and environmental vector.

	Energy consumption (kWh/basket)	Abiotic depletion (kg Sb eq)	Acidification (kg SO_2-eq)	Eutrophication (kg PO_3^{4-} eq)	Global warming potential (kg CO_2 eq)	Ozone layer depletion (kg CFC-11-eq)	Human toxicity (kg 1.4-DB eq)
Scenario 0							
Retail park	11.1	2.05E−02	1.34E−02	1.26E−03	3.07E+00	3.65E−07	7.39E−01
Municipal market	0.57	1.73E−03	1.91E−03	1.38E−04	2.46E−01	2.02E−08	6.51E−02
RP/M Ratio	19.5	11.9	7.0	9.1	12.5	18.2	11.4
Scenario C							
Retail park	5.79	1.07E−02	6.83E−02	6.43E−04	1.57E+00	1.86E−07	3.77E−01
Municipal market	0.57	1.73E−03	1.91E−03	1.38E−04	2.46E−01	2.02E−08	6.51E−02
RP/M Ratio	10.2	6.2	3.6	4.7	6.4	9.2	5.8

Note: eq = equivalents, Sb = antimony, SO_2 = sulfur dioxide, PO_4^{3-} = phosphate, CO_2 = carbon dioxide, CFC-11 = chlorofluorocarbons, 1,4-DB = 1,4-dibutyl. Source: Authors from SimaPro V.7.2 and CML 2000 Methodology.

4.3. Comparison of food retail typologies

The environmental comparison determines that municipal markets are environmentally better than hypermarkets in retail parks. For the functional unit, the environmental impact is, on average, 10 times higher in a retail park than in a municipal market. In the retail park hypermarket, the related indicators showed energy consumption as 20 times higher and packaging use as 2.5 times higher. Concerning GHG emissions, the associated CO_2 equivalent emissions for a standard shopping basket in a retail park are 3.80 kg, or 8 times higher than the emissions rate of a municipal market (0.47 kg).

In the food retail sector, measures to reduce environmental impact need to focus on energy consumption, which contributes 40–75% in a municipal market and 70–97% in a retail park hypermarket.

These differences showed that bulk shopping and distances from urban areas are the main differences between the food retail stores analyzed. Therefore, these would be the key points for environmental policies, focusing in the energy efficiency of the buildings, the reduction of distances between the store and the urban areas, and minimizing the packaging amount not only for primary packaging but also for secondary ones. Finally, municipalities' environmental policies should protect the traditional commercial stores situated in the city center as they showed a better environmental performance than the new type of commercial, like retail parks.

5. Further research lines

Future research should focus on applying the concepts of industrial ecology to the service sector and food retail establishments to quantify the flows and better understand the metabolism of the different types of facilities. This kind of analysis would allow the comparison between retail food establishments analyzed here and other facilities in the service sector.

The approach used in this study could be broadened by incorporating the water vector in the metabolism and by designing a different kind of standard shopping basket to determine the main characteristics of different products. This methodology could also be applied in different places in a territorial study that could compare the differences within the same country or between specific countries.

Finally, further research may study the overall stages of the life cycle of agricultural products, from the production stage to waste management and including the distribution stage to develop the relationship between local production and environmental performance.

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