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Monitoring the carbon footprint of products: a methodological proposal

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ABSTRACT

The management of greenhouse gas (GHG) emissions at the product level is a key issue for many companies. The scientific community has produced numerous references which help in determining the impact that products have on climate change, but none of these models contain detailed rules that can help organizations with the monitoring and management of single-product GHG emissions over time.

Based on an analysis of the published ISO standards for GHG emissions this article offers a model with which the management and monitoring of emissions over time at the level of the individual product can be facilitated. Results show that by integrating the main ISO standards for GHG emissions, the model supports the establishment of enterprises and the management of emissions related to products throughout their life cycle.

1. Introduction

Climate change is a key issue that is being debated at the international level (UN, 1992; UNFCC, 1997, 2010). The commitments made and actions taken by major industrialised countries to limit the causes and consequences of this phenomenon increasingly impact consumer choices and business enterprises (EC, 2003; Golly and Homburg, 2009; Nyborg et al., 2006; Solomon et al., 2007; UNFCC, 2010; Berners-Lee et al., 2010).

The carbon footprint concept emerged to measure the impact (measured in CO2-equivalent) that a product, service or organisation has on climate change (Finkbeiner, 2009; Boguski, 2010; Musanighe, 2010). Examples of models that support companies in calculating their carbon footprints include the following:

- At the product level, the Life Cycle Assessment (LCA) model, described in ISO 14040 and Framework PAS 2050 is the most significant (ISO, 2006a, 2006b; BSI, 2008; SETAC, 2008; Petersen and Solberg, 2002; Iribarren et al., 2010a; Johnson, 2009a; Kenny and Gray, 2009). Currently, for the purposes of calculating the carbon footprint of a product, the ISO is developing a specific standard, ISO 14067 (Finkbeiner, 2009), and the World Business Council for Sustainable Development (WBCSD), along with the World Resources Institute (WRI), within the GHG Protocol project, have supported the publication of footprint-specific guidelines (WRI and WBCSD, 2011a).
- At the organisational level, ISO 14064-1, the GHG Protocol and the Emission Trading Directive are the most salient references (ISO, 2006c; WRI and WBCSD, 2004; EC, 2004). Currently, the ISO is developing an accompanying report for ISO 14064, ISO/PDTR 14069 (ISO, 2010), and the WBCSD has supported the publishing of guidelines on the selection of the processes to be included in scope 3 ('other indirect emissions') of the protocol (WRI and WBCSD, 2011b). Another relevant initiative at the Corporate level is the Carbon Disclosure Project (CDP) (CDP, 2011).

Environmental Management Accounting emphasizes the importance of measuring and calculating the carbon footprint and environmental impacts of products (Burritt et al., 2011a; McKinnon, 2010 Wackernagel and Rees, 1996; Schmidt and Schwegler, 2008; Seuring and Müller, 2008).

The ISO 14040 family of standards is commonly used to determine the GHG emissions of a product during its life cycle (Johnson, 2009b). However, these standards do not provide clear and precise rules for the ongoing monitoring and management of these impacts (Edwards-Jones et al., 2009; Finnveden et al., 2009; Scipioni et al., 2010). ISO 14040 does not contain prescriptions concerning the monitoring of emissions over time. BSI PAS 2050, the other major reference for the analysis of the carbon footprints of products, has similar limitations (Iribarren et al., 2010b).

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To monitor and manage GHG emissions comprehensively, standards designed to be applied at the organisational level should also be considered (Edwards-Jones et al., 2009; Finnveden et al., 2009; Scipioni et al., 2010; Lee, 2011).

ISO 14064 outlines a process for monitoring, managing and reporting CO2-equivalent (CO2-eq) emissions at the organisational level. This standard allows companies to monitor both the direct and indirect emissions from processes under their control. The standard also calls for reporting on actions taken to reduce GHG emissions.

Interest in the development of tools for managing the environmental impacts of products has been widely expressed in literature (Van Berke et al., 1999; Ammenberg and Sundin, 2003; Burritt and Saka, 2006; Burritt et al., 2011b; Jasch, 2006; Lohmann, 2009). However, there is no research of product impact carbon footprinting. Some studies have used a product perspective to implement GHG management tools across the supply chain (Scipioni et al., 2010; Lee, 2011; Sundarakani et al., 2010; Burritt and Saka, 2006; Burritt et al., 2011b) but not for implementing GHG monitoring and management at the product level.

Other tools focus on more comprehensive environmental impact assessment. This is the case of the ecological footprint (Wackernagel and Rees, 1996). This method is now well-known, though not without its critics (Fiala, 2008).

This research, therefore, has some of the following objectives:

- to determine if ISO 14040 can be integrated with ISO 14064 Part 1 to ensure implementation of the monitoring and management of emissions at the product level;
- to determine if ISO 14064 allows the reporting of GHG emissions at the product level; and
- to determine if ISO 14064, when adapted to the product level, allows the monitoring of GHG emissions over time.

The research presented in this paper is a follow-up to previous work which focused on GHG emission monitoring at the organisational level (Scipioni et al., 2010). The differences are that:

- the focus of the former study was on the organisation, while the object of the present study is the product level;
- the previous study used the life cycle approach to determine other indirect emissions under the control of the organisation (ISO, 2006c), while the research described in this paper focused on monitoring the life cycle of the GHG emissions of products.

2. Methodological framework

The model was developed according to ISO 14064 which outlines a process for quantifying and reporting GHG emissions and for internally managing the quality of the results. The process outlined in this standard was aligned with the ISO 14040 standards which govern life cycle assessment studies. Therefore, this study integrated the life cycle approach of the ISO 14040 standards with ISO 14064 to model the management and monitoring of emissions and to develop an inventory of GHG emissions for products. The model is shown in Fig. 1.

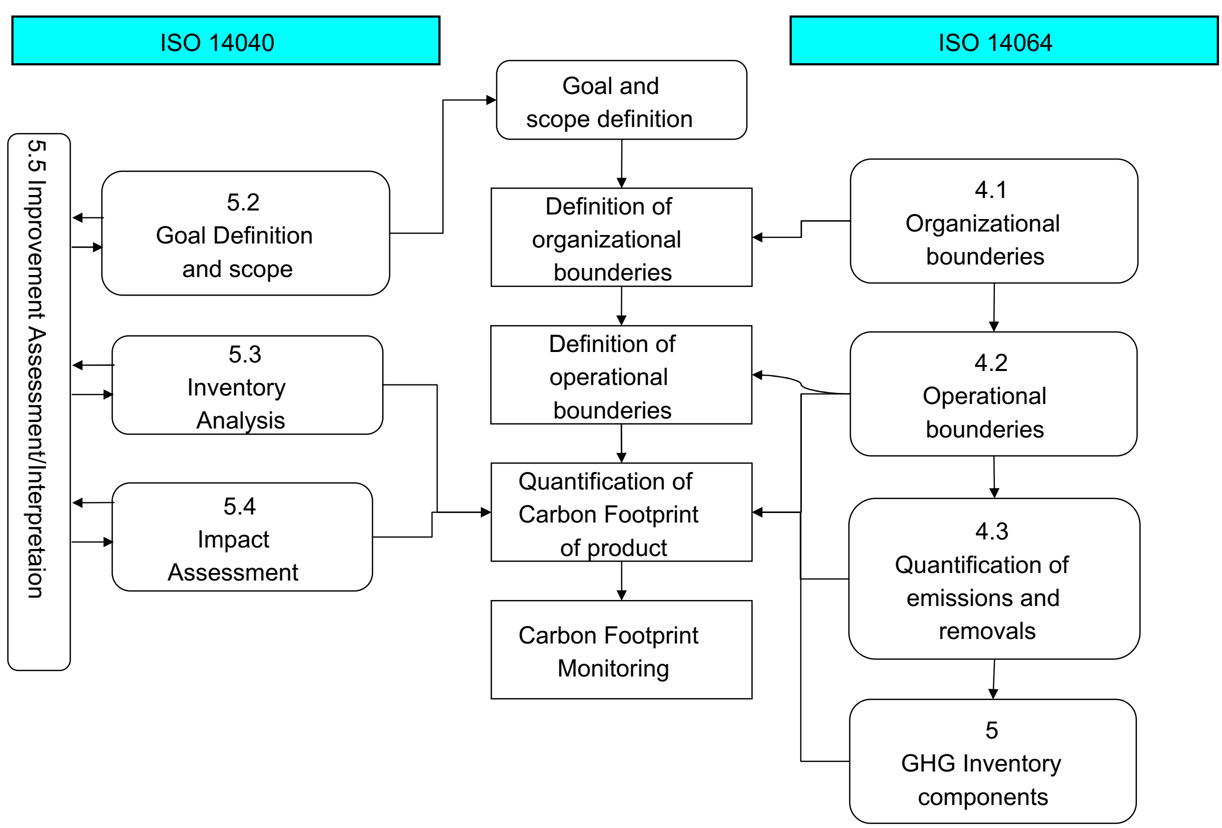

Fig. 1. Model for monitoring GHG emissions at the product level.

The methodology used in the study (Fig. 1) can be represented in five stages.

- Stage1 Objective of the research. The requirements of ISO 14044 are used as a reference to determine the research objective, the use of the study, the target audience and the willingness of the organisation to use the research outcomes. This step is required by ISO 14040 for the study of the life cycle of products, but it is not required by ISO 14064.
- Stage 2 Organisational boundary definition. The facilities and the level of aggregation of GHG emissions are identified. To determine the organisational boundary, two approaches can be used: control or equity share (ISO, 2006c). According to the first approach, the organisation shall monitor GHG emissions and/or removals of the activities over which it has financial or operational control. According to the second approach, the organisation should account for its GHG emissions and/or removals from its respective facilities. The objective is to determine the responsibility of the organisation for the GHGs emitted by the facilities responsible for the production of the selected products. This step is required by ISO 14064 Part 1, but it is not included in ISO 14040.
- Stage 3 Operational boundary definition. All processes to be included in the monitoring of GHG emissions are identified. This stage is required by ISO 14064 Part 1. All processes involved in the life cycle of the product (including the function, functional unit, product system and system boundaries) are also identified. These activities are required by ISO 14040. Operational boundaries, defined according to ISO 14064, enable the identification of relevant GHG sources. These sources include the following:
  - direct atmospheric emissions from the operation of the facilities included within organisational boundaries (mandatory according to ISO 14064 Part 1);
  - indirect emissions from the energy and heat consumption of the facilities which fall within organisational boundaries (mandatory according to ISO 14064 Part 1); and
  - other indirect emissions. The life cycles of the product are considered when determining operations that create other indirect emissions, so the ISO 14040 standards are considered. This approach captures emissions from organisations and activities located outside the physical boundaries of the organisation (this includes direct interactions with the suppliers, customers and institutions involved in the life cycle of the products).

The Greenhouse gas protocol has also addressed these scopes (WRI and WBCSD, 2011b).

- Stage 4 Quantification of the product's carbon footprint. At this stage the quantification method is selected, necessary data are collected and CO2-eq emissions are quantified. A key issue is the selection and establishment of a historical base year for GHG emissions and removals for comparative purposes. These steps are required by ISO 14064. Inventory analysis and impact assessment are required by ISO 14040. First, according to ISO 14064, a methodology to quantify GHG emissions is selected. For example, one of the methodologies uses emission factors and activity data. Emission factors quantify the emissions of individual processes (expressed as CO2-eq) and account for the variable contributions of different GHGs (Eggleston et al., 2006). Emission factors are calculated using the following equation:

$$\text{emission\_factor}_i = \sum \text{GWP}_{100,x} {}^* g_x \quad (1)$$

where GWP100 is Global Warming Potential, as specified by the Intergovernmental Panel on Climate Change (IPCC) (Solomon et al., 2007), and g_x is the amount of GHGs produced by process x.

GHG emissions for each process are then calculated from the product of the organisation's activity data and the relevant emission factors. Emission factors should be expressed in the units of measurement used for the activity data. This GHG impact assessment methodology is in compliance with ISO 14044 requirements.

Specifically, in accordance with the scope and objective of the study, only the Climate Change category (which represents impacts in units of grams of CO2-eq) is considered. The radiative forcing of different GHGs is considered, and as recommended by the IPCC, the GWP100 characterisation model is used.

After selecting the quantification method, all the relevant data are collected. The data are collected according to ISO 14040 inventory analysis requirements. The environmental input–output (EIO) approach can be used for data collection (Wiedmann and Minx, 2008). This is a top-down approach in which an input–output economic account of all economic activities at the mesa (sector) level is combined with reliable environmental account data (Wiedmann and Minx, 2008).

- Stage 5 Carbon footprint monitoring. Monitoring starts with a review of the organisational and operational boundary, a review of the base year, the quantification methodology and the inventory. Activity data are then collected and the carbon footprint of the product is quantified.

To implement the model, the current authors began by identifying the requirements and objectives common to both standards: the definition of study boundaries, the choice of processes representative of the product's life cycle and the choice of an impact assessment methodology (Scipioni et al., 2010).

This research was quantitative, had a confirmative purpose and used a single case study (Corbetta, 1999).

3. Study design and data

The organisation selected for this study was Tetra Pak Italy of the Tetra Pak Group, a leader in the packaging sector. This company, which has a GHG emissions monitoring system at the organisational level that is in compliance with ISO 14064 (Scipioni et al., 2010), demonstrated an interest in developing a model to monitor GHG emissions at the product level. Their objective was to assess and monitor how GHG reduction strategies would affect the climate change performance of their products.

The Tetra Brick 200 (TBA200) and the Tetra Brick 100 with a polyethylene cap (TBA1000), with volumes of 200 and 1000 ml respectively, were selected for this study. These products are manufactured in Italy at the Tetra Pak Carta (TPC) facility and are sold by the Tetra Pak Italiana (TPI) facility.

The two products were selected for the following reasons:

- to test the applicability of the model on different products manufactured by the same organisation;
- to compare the GHG emissions of different products manufactured by the same organisation.

The study covered the data, operations and activities of Tetra Pak's Italian facilities. The base year for emission reporting was 2006 because the most complete and reliable data was available for this year. Changes in emissions over time and company progress towards reducing emissions were monitored in 2008.

3.1. Stage 1: objective of the study

At this stage, the reason for the study, the intended application and audience, and a comparative assertion declaration were determined. Table 1 shows the responses made in this case study to the requirements of stage 1: "Objective of the study".

3.2. Stage 2: organizational boundary definition

At this stage, the organisation shall determine its responsibilities for GHG emissions and/or removals that come from the facilities where the products (the objects of the study) are manufactured.

In this case study, the organisational boundaries were defined according to the organisation's ability to control operations; only emissions for processes controlled by the organisation were considered. This approach was chosen because Tetra Pak Italy has control over 100% of the operations of its facilities.

Therefore, TPC and TPI are responsible for the GHG emissions of TBA 200 and TBA 1000.

Table 2 shows the sources of emissions considered per organisation.

3.3. Stage 3: operational boundary definition

The function and functional units for TBA 200 and TBA 1000 were defined as being the ability to hold 200 ml and 1000 ml of fruit juice, respectively.

The life cycle approach was used to determine the activities, operations and processes to be considered in the study of the two products.

Fig. 2 shows the Life Cycle of the selected products. Green and red indicate included and excluded processes, respectively. Some processes were excluded because data on the secondary distribution network and the use of the products by consumers were limited and unreliable.

The product-related GHG emissions were then classified as being direct, indirect and other indirect emissions at the organisational level (Table 3). These operations refer to both TBA 200 and TBA1000.

3.4. Stage 4: GHG emissions quantification

The methodology used to quantify GHG emissions is described in Chapter 2. According to this methodology, the organisation shall collect activity data and specific emissions factors.

Table 1
The objective of the study.

Requirement	Decisions
Reason for the study	The objective of the study was to implement a Carbon Footprint monitoring system for TBA 200 and TBA 1000. These products are made by TPC and sold on the Italian market by TPI.
Intended application	The intended application was to improve the environmental performance of Tetra Pak and to reduce carbon footprints.
Intended audience	The results were used internally to assess Tetra Pak's ability to reduce emissions and to evaluate the impact that choices made at the organisational level have on the carbon footprint of products.
Comparative assertion	The company did not choose to use these results for comparative purposes.

Table 2
Organisational boundaries.

Organization	Source of GHG emissions
TPC	Raw and auxiliary materials
	Transporting raw and auxiliary materials
	Packaging material production
TPI	Marketing
	Transporting products to the consumer
	Filling
	End of life (post-consumer)

No GHG removals or sinks were identified for TPC and TPI.

For this case study, activity data were available directly from the organisation. Data from 2006 served as the base year against which GHG emissions were monitored. Assumptions were necessary to model the end of life stage. In this case, activity data from COMIECO (Italian National Organisation for Separate Collection of Paper Waste) were used to determine the destination of the beverage cartons (incineration, recycling or landfill). Moreover, only the paper component was considered for recycling.

The emission factors were determined using life cycle assessment databases and in consideration of all the relevant GHG emissions of the selected operations.

Table 4 details the databases used to determine the emission factors of the operations considered for TPC and TPI. These data refer to both TBA 200 and TBA1000.

By applying Eq. (1) to the processes within the system boundaries of the two products and summing the results, the impacts of the two products during their life cycles were quantified.

3.5. Stage 5: carbon footprint monitoring

After quantifying the GHG emissions of the two products in 2006, the monitoring process began. This process consisted of a review of organisational and operational boundaries, the quantification method and the inventory. The review process confirmed the validity of the choices made in 2006 and 2008. Then, all the relevant activity data for the year 2008 and the emission factors were collected using the same criteria and sources for 2006. It was finally possible to quantify the GHG emissions of the two products in 2008.

4. Results and discussion

At the product level, the overall results were expressed in grams of CO2-eq (not in tons of CO2-eq as required by ISO 14064). In 2006, TBA 200 produced 23.30 g of CO2-eq (Fig. 3) and TBA 1000 produced 104.42 g of CO2-eq (Fig. 4).

The results for the two products in 2006 show that 94–97% of the total emissions were classified as being other indirect emissions. The remaining 3–6% were direct emissions from energy consumption (Table 5). Direct emissions were close to 0%.

Based on these results, it is proposed that the organisation should work with suppliers and consumers to reduce GHG emissions from the two products.

In 2006, the largest sources of overall CO2-eq emissions for TBA 200 were derived from raw and auxiliary materials, end of life (post-consumer) management and the pack material production processes.

TBA 1000 showed similar results, but because this product had a polyethylene cap, filling was also a significant source of emissions. The production and end of life management of the caps were responsible for approximately 13.8% of total emissions (14.4 g of CO2-eq). All these emissions are other indirect emissions.

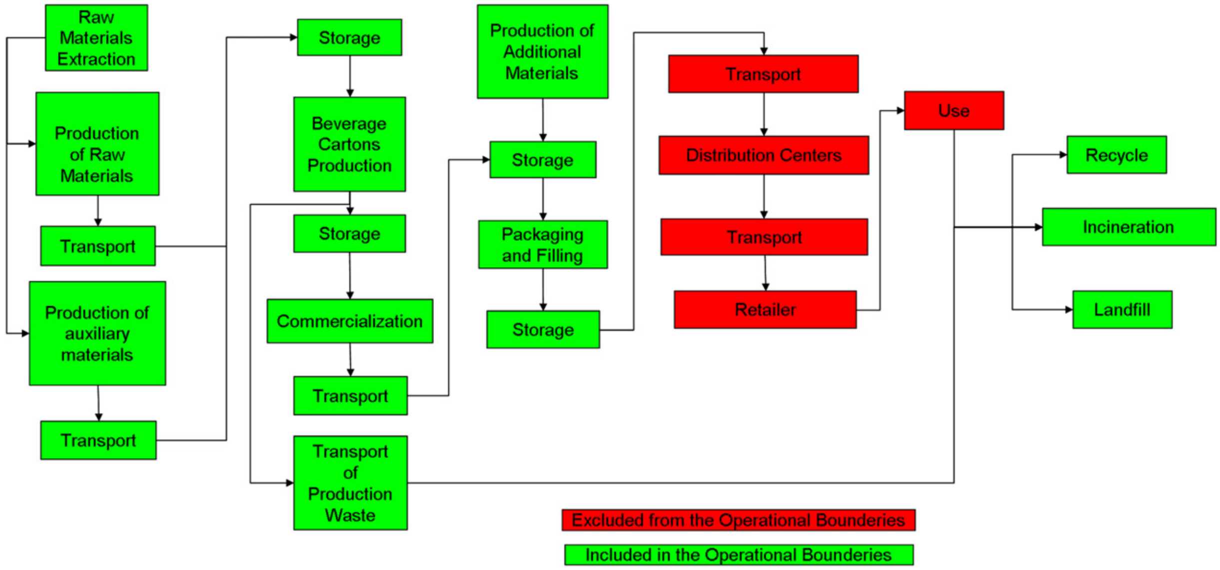

Fig. 2. Operational boundaries.

To reduce climate change impacts, the organisation should adopt the following GHG emission reduction strategies:

- support the development of separate collection and recycling systems for beverage cartons in Italy;
- increase the efficiency of production and filling machinery, reduce waste, limit the use of raw and auxiliary materials and limit the consumption of electricity; and
- use electricity from renewable sources.

Table 3
Classification of GHG emissions and operations considered in the study.

Organization	Emissions category	Operations	Source of GHG emissions
TPC	Direct	Cooling and heating; methane used in the production process	Pack material production
	Indirect (energy consumption)	Electric energy consumption	Pack material production
	Other indirect	Raw material and auxiliary material consumption	Raw and auxiliary materials
		Production wastes	Pack material production
		Transportation of raw and auxiliary material from different suppliers	Transportation of raw and auxiliary materials
		Transportation of production wastes to treatment sites	Pack material production
TPI	Direct	Cooling and heating	Marketing
	Indirect (energy consumption)	Consumption of electricity	Marketing
	Other indirect	Transportation of end product to clients	Transportation to consumer
		Packaging (at Tetra Pak's customers' production sites): energy consumption, consumption of additional materials, technical materials, waste generation	Filling
		End of life treatment (post-consumer)	End of life

To reduce the consumption of raw materials, the company should investigate its product designs. Currently, this solution is constrained by technological limitations associated with aluminium rolling.

In 2008, production of a single TBA 200 produced 21.60 g of CO2-eq (Fig. 3) and a TBA1000 produced 100.79 g of CO2-eq (Fig. 4). Changes in the sources of emissions over time were observed.

Direct emissions from energy consumption were considerably lower in 2008 than 2006 (Table 6). In 2008, TPC and TPI used only energy from hydroelectric plants. This type of energy has minimal impact compared with fossil fuels. Table 6 shows the equivalent emissions aggregated at the TPI and TPC levels for each product studied and year of monitoring.

Table 4
Databases used to determine GHG emission factors.

Organization	Operations	Database
TPC	Cooling and heating; methane used in the production process	Ecoinvent v.2.2 (2010)
	Electric energy consumption	Ecoinvent v.2.2 (2010)
	Raw material and auxiliary material consumption	BUWAL 250 (2004), Dutch Input-Output Database (2004), Industry data (2010)
	Production wastes	Ecoinvent v.2.2. (2010)
	Transportation of raw and auxiliary material from different suppliers	Ecoinvent v.2.2. (2010)
	Transportation of production wastes to treatment sites	Ecoinvent v.2.2. (2010)
TPI	Cooling and heating	Ecoinvent v.2.2. (2010)
	Consumption of electricity	Ecoinvent v.2.2. (2010)
	Transportation of end product to clients	Ecoinvent v.2.2. (2010)
	Packaging (at Tetra Pak's customers' production sites): energy consumption, consumption of additional materials, technical materials, waste generation	Ecoinvent v.2.2. (2010), Boustead (2006), BUWAL 250 (2004), Dutch Input-Output Database (2004), Industry data v.2 (2010)
	End of life treatment (post-consumer)	Ecoinvent v.2.2. (2010)

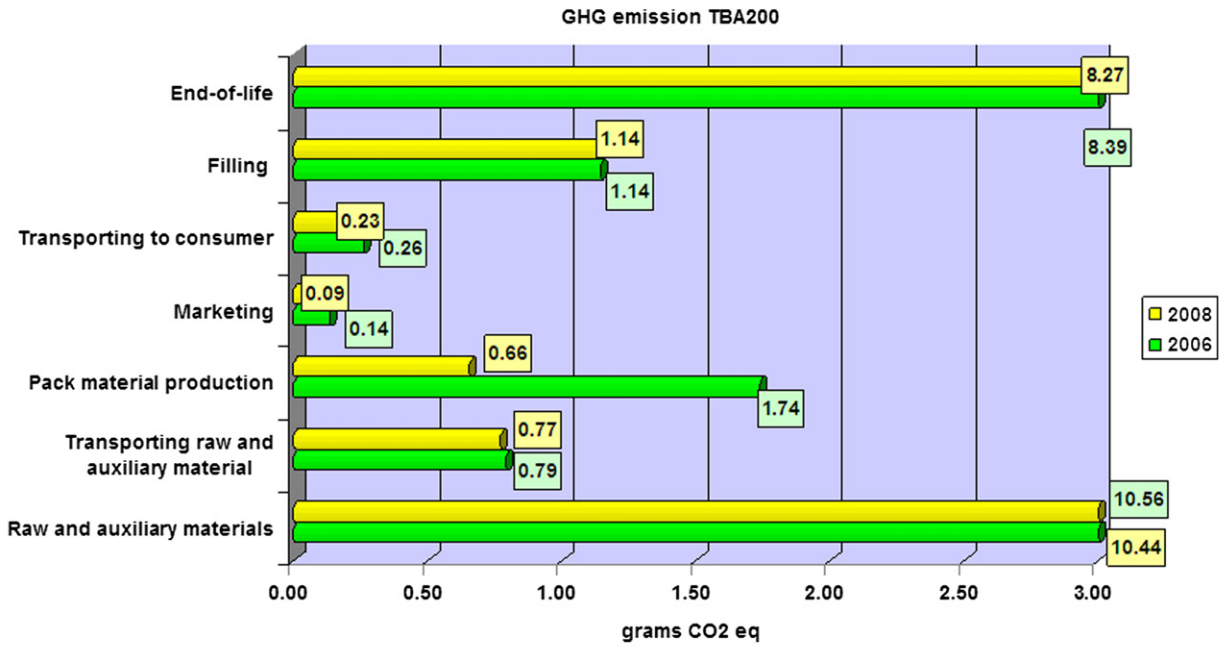

Fig. 3. GHG emissions of TBA 200 in 2006 and 2008.

In 2008 (Fig. 3), production of TBA 200 generated fewer emissions at every source than in 2006, resulting in a decrease of 1.43 g of CO2-eq, or 6.2% of the overall emissions. The emissions for raw and auxiliary material consumption, end of life management and production processes decreased by 1.19%, 1.36% and 62.19%, respectively. The reduction for the end of life phase was a result of the increased proportion of beverage cartons recycled (from 12.66% to 17.10%). This placed a reduced burden on the amount landfilled (from 49.72% to 44.6%). The remaining percentage were attributed to incineration with energy recovery.

The reduction of emissions from the consumption of raw materials and auxiliary production was attributed to the use of new machinery and the use of electricity derived from hydroelectric sources. The increased efficiency of the machines resulted in lower production of manufacturing waste, affecting the volumes of both raw material inputs and wastes. The impacts of energy

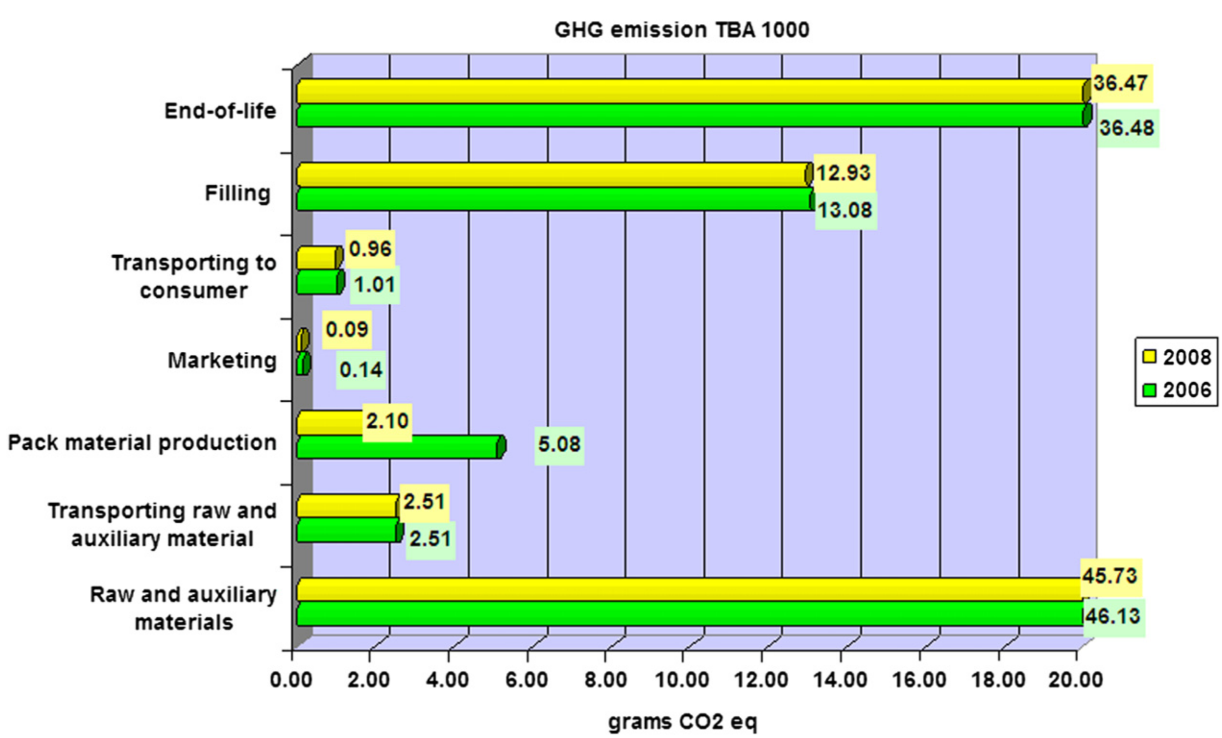

Fig. 4. GHG emissions of TBA 1000 in 2006 and 2008.

Table 5
GHG emissions per emission category.

Emission categories	gCO2-eq/TBA 200 year 2006	gCO2-eq/TBA 200 year 2008	gCO2-eq/TBA 1000 year 2006	gCO2-eq/TBA 1000 year 2008
Direct	0.06	0.02	0.17	0.06
Indirect (energy consumption)	1.31	0.29	3.41	0.64
Other indirect	21.65	21.28	100.84	100.22

Table 6
GHG emissions for the specified facilities.

Facility	gCO2-eq/TBA 200 year 2006	gCO2-eq/TBA 200 year 2008	gCO2-eq/TBA 1000 year 2006	gCO2-eq/TBA 1000 year 2008
TPC	13.09	11.86	53.71	50.34
TPI	9.93	9.73	50.70	50.44

consumption decreased considerably because of the use of certified hydropower.

In 2008 (Fig. 4), TBA 1000 created fewer emissions at every source than in 2006. Emissions for raw and auxiliary material consumption, end of life management, and filling and production processes decreased by 0.86%, 0.03%, 1.15% and 58.68%, respectively. These improvements were attributable to the same factors as those for TBA 200. The improvement in the filling phase was due to the higher efficiency of the filling machines and the production of less cap-related waste, which significantly contributed to overall emissions. These processes are not involved in the production of TBA 200.

Based on these results, to further reduce CO2-eq emissions at the product level for TBA 200 and TBA 1000, the company should address the issues of transportation of raw and auxiliary materials and the sources that were identified as being significant in 2006.

5. Conclusions

This research, conducted between 2007 and 2009, had the following objectives:

- to integrate ISO 14040 with ISO 14064 Part 1 for the monitoring and management of emissions at the product level;
- to determine if ISO 14064 allows the reporting of GHG emissions at the product level; and
- to verify if ISO 14064 applied to the product level enables the monitoring of GHG emissions over time.

To achieve the objectives, a new methodological framework was created (Fig. 1) that included the following steps: 1) identify the objective of the study; 2) define organisational boundaries; 3) define operational boundaries; 4) quantify the carbon footprint; and 5) monitor the carbon footprint.

The study applied the model to two different beverage cartons with volumes of 200 and 1000 ml.

To monitor and report the GHG emissions of the products, data were only collected for the Climate Change impact category. Activity data relevant to processes in the life cycles of the two products were collected at the product level. The aggregated data were physically allocated among the processes according to ISO 14040 standards. The total GHG emissions were expressed in grams of CO2-eq and not in tons of CO2-eq, as required by ISO 14064. All inputs and outputs were classified in the climate change category, and normalisation was not performed.

The monitoring of emissions over time (with a base year of 2006, and 2008 being the first screening year) enabled an evaluation of the effectiveness of the strategies implemented to reduce emissions. For both products, emissions were reduced by the use of hydroelectric power at the manufacturing plant. ISO 14064 also highlights the role of the direct and indirect emissions which occur during a product's life cycle. The results from the two years of monitoring suggest that the company should invest into reducing the emissions which occur upstream and downstream of its processes.

This model, based on a life cycle approach, has the same limitations as life cycle assessment studies: there is an element of subjectivity in defining the operational boundaries and the selection of data sources, and the necessary data may not always be accessible. These factors influence the reliability of the data and the quality of the final results (Hermann et al., 2007; Rebitzer, 2005). Moreover this methodology focuses only on the climate change impact category and does not account for other environmental impacts. Other limitations apply to the integration of the life cycle assessment approach and management systems. The main ones include the complexity of the procedure, the time required and the cost of the process (all of which are much higher in the first year of monitoring and assessment) (Finnveden et al., 2009; Lewandowska et al., 2011). Furthermore, the use of basic inventory data to determine emissions factors is not without problems (Schaltegger, 1997; Reap at al, 2008). Inventory data are not always representative of specific conditions or processes under study and the consistent quality of data is not always guaranteed; this can affect the reliability and quality of the results.

The results obtained in this study demonstrate how ISO 14064 and ISO 14040 can be integrated and how ISO 14064 can be used to monitor and to report GHG emissions at the product level.

Thanks to this approach, an organisation can determine over time how decisions taken at the organisational level affect the product's carbon footprint. Moreover, the organisation is able to understand its direct contribution to the product's carbon footprint and to determine where to intervene in the supply chain to reduce it. Therefore, this information supports the drafting of management strategies that investigate the impacts a product has on climate change. Thanks to the management and environmental impact assessment aspects considered in the proposed methodology, organisations can better manage their operations and supply chains and reduce their impacts on climate change. This approach results in better environmental sustainability performance, both at the product and organisational levels.

Organisations can use the methodological framework presented in this study to determine suitable strategies to reduce their environmental (climate change) impacts.

The results of this study indicate new directions for future research.

The model should be compared with the PAS 2050 standards (BSI, 2008; Plassmann et al., 2010), which were not used in this study. Such a comparison would provide insight into the definition of system boundaries, the treatment of biogenic CO2, the use of weighted average impacts for emissions from the use and final disposal phases and the use of weighted average impacts for carbon storage in products.

The applicability of this model to other contexts should also be evaluated (Iribarren et al., 2010a,b).

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