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PACKAGING SYSTEMS

The sustainability of communicative packaging concepts in the food supply chain. A case study: part 1. Life cycle assessment

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Abstract
Purpose In recent years, a new perspective for food packaging has emerged as a result of several issues like quality, safety, competitive prices or providing of useful information to consumers. This new perspective is called communicative packaging. Communicative packaging may influence consumers/companies on purchasing decisions. Since the environmental evaluation of such systems has not yet been performed, this paper is focused on the environmental evaluation of a flexible best-before-date (FBBD) communicative device on a packaging consumer unit and its implications on reducing environmental impacts related to fresh products. This consumer unit consists of a nanoclay-based polylactic acid tray filled with pork chops.
Methods The environmental assessment of the consumer unit was made through life cycle assessment (LCA) using a cradle-to-gate approach. Environmental impacts were assessed according to the Eco-Indicator 99 v 2.1 methodology in Individualist (I) perspective.
Results and discussion Several results were obtained from the LCA. With regard to environmental impacts of the FBBD, most of them were due to the paper substrate used for the manufacture of this communicative packaging concept as well as to the transports for delivering the components of the FBBD communicative device. On the other hand, when environmental impacts of packaging system with and without FBBD were compared, a large environmental load was detected for the system that has the communicative device affixed as a result of the higher weight of the package. However, the environmental load caused by the use of the FBBD was minimal in comparison with the total environmental load of the whole packaging system. On the contrary, the consumer unit that has the communicative device affixed showed less environmental burden than the consumer unit that has not affixed the device. This was due to the environmental benefits that the communicative device provides by reducing the amount of out-of-date packaged products at retailer outlets.
Conclusions The use of a FBBD contributes to minimize environmental burdens related to the production, packaging and delivery of pork chops since it facilitates a dynamic control of out-of-date products even though the consumer unit with FBBD weighs 1 g more than the consumer unit that does not use the communicative device.
Recommendations The results presented in this paper are estimated results of a specific case study for a prototype of communicative packaging device. Consequently, these

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results must be considered as a first approach according to future developments on communicative packaging.

Keywords Communicative packaging · Life cycle assessment · Packaging · Sustainability

1 Introduction

One of the main challenges for the European Union is to reach a sustainable development (Eurostat 2009). The sustainability concept is wide and covers lots of aspects in our daily life. Each individual consumes hundreds of different products and services everyday (cars, electricity, clothes, food, water, internet, etc.). In the case of food products, most of them are packaged in order to protect, content and preserve the food and their quality/properties. On the other hand, consumption patterns for food are changing, and consequently, packaged products are preferred (European Environmental Agency 2005). Additionally, consumers also want better information about what they are going to eat. In fact, specific information on composition or quality is highly appreciated (European Commission 2006). Furthermore, aspects like safety and shelf life are also important for consumers. Therefore, an interest on packages with extra features is noticed. These extra features can be incorporated into conventional packages. Depending on their level of sophistication, these new packages can be classified into three categories: active packaging, intelligent packaging and smart packaging. Active packages are those capable to react to various stimuli (oxygen scavengers (NanoMarkets 2006), carbon dioxide absorbers (NanoMarkets 2006), etc.). Intelligent packages are those where the packaging structure changes in order to improve their functionality (NanoMarkets 2006). Smart packages are those that the use of technology adds extra features to the packaging (information about shelf life, identification about the type/origin of the product, those that catch the eye of the potential buyer, provide protection against counterfeiting, etc.) (Kreft et al. 2005). A specific concept in smart packaging is the communicative packaging, where the challenge can be achieved by the combination of both packaging technology and communicative signals (e.g. changing colours, diagrams, displays, etc.).

On the other hand, a growing amount of packaging waste is generated in the European Union area (European Environmental Agency 2009). At the same time, recent developments on packaging systems could be a challenge to improve their environmental behaviour. There are a wide range of strategies that can be used to minimize their environmental impacts: design of improvements, the use of new materials, use of active packaging systems or communicative devices to reduce the amount of product losses and to improve product traceability. Besides environmental improvements of these new developments (that could be assessed by life cycle assessment studies), other issues such as economy and society should be analysed.

In that sense, SustainPack Integrated Project offered a sound framework to carry out a comprehensive research over communicative packaging concepts as well as many others.[1] The SustainPack project was a 4-year research programme with a budget of 36 million euros. The European Union VI Framework Research Programme provided 19 million euros for this project. The SustainPack team was comprised of a consortium of 35 partners from 13 countries, representing research associations, academia and industry, and coordinated by Innventia (formerly STFI Packforsk). Several communicative devices were developed within this project, but one of them turned out of interest for consumers and retailers: the flexible best-before-date (FBBD) communicative device that allows minimizing the amount of food losses at retailer outlets since it facilitates a dynamic control of out-of-date products. This device is essentially a combination of a data logger with a moving image display working together at the same time. On the one hand, the data logger records the temperature of the packaged product. This data logger is loaded with the quality decay model and the expected initial quality of the product; therefore, actual product quality can be determined (van der Heijden et al. 2007). On the other hand, the moving display allows modifying the expiry date and/or price of the product, based on triggers from the data logger (van der Heijden et al. 2007). Consequently, expiry date, as well as price, changes as function of temperature record, providing a lower price in case of a short expiry date of the product. Alternatively, this communicative packaging concept can also show a fixed price with a flexible expiry date based on Dynamic Expiry Date (DED) model (Kreft et al. 2006), as it was assumed in this life cycle assessment (LCA) study. Furthermore, all possible improvements derived from the use of the FBBD were allocated at retailer level. Therefore, it was assumed that the use of the FBBD did not affect the production and delivery chain, except from possible longer shelf lives in the supermarket. Moreover, the performance of the supply chain towards the supermarket did not change, and the gain in expiry date might not be used for extra storage or longer transport times in the chain itself (van der Heijden et al. 2007). An example of a FBBD is shown in Fig. 1.

This type of communicative device was also combined with a nanoclay-based polylactic acid (PLA) tray sealed with SiO_x-coated PLA film that contains pork chops. The main goal of this research was to assess the sustainability of the new packaging concept already described. Due to the extension of this research, it was decided to split the results in two papers. The first one shows the results achieved on

[1] Use of nanoparticles on packaging, biodegradable materials or development of communicative packaging concepts among others.

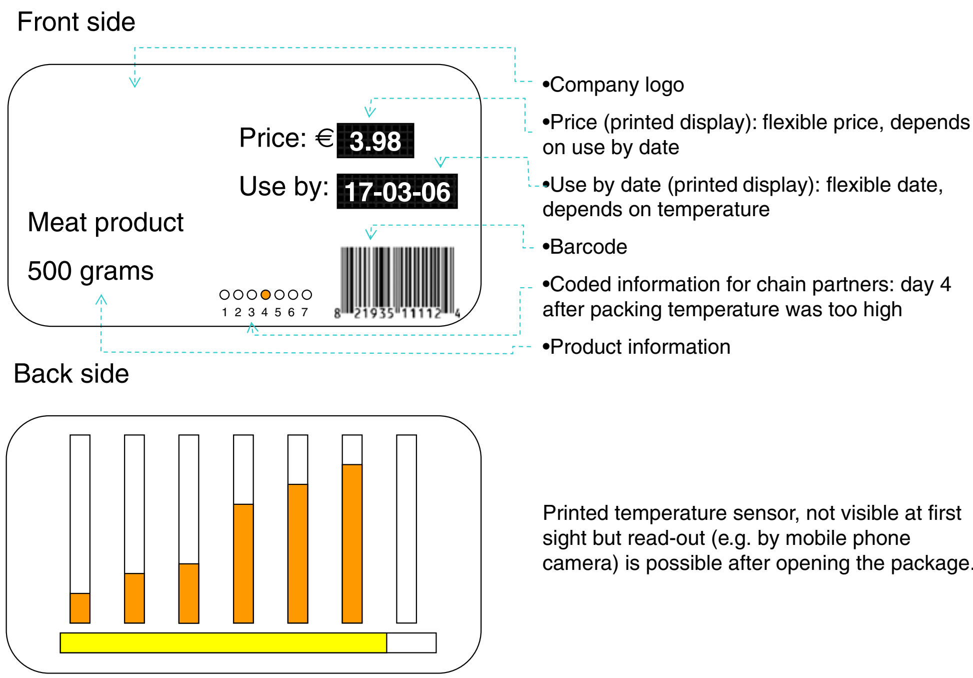

Fig. 1 Example of a FBBD indicator (Source: DTI)

the life cycle assessment for a consumer unit consisting of pork chops packaged into a nanoclay-based PLA tray with or without a FBBD. These LCA results are in this paper. In a second paper is described the sustainability assessment of the new packaging concept, where the life cycle assessment, life cycle costing and contingent valuation results were combined using the sustainability methodology proposed by Bovea et al. (2004).

2 Methods

2.1 Goal of the LCA study

The main purpose of the life cycle assessment was the evaluation of the environmental impact caused and/or saved by the use of a new communicative device in packaging. In particular, a packaging system consisting of a nanoclay-based PLA tray sealed with SiO_x-coated PLA film with or without a FBBD communicative device stuck was considered in the whole study.

It was also assumed that this packaging system was filled with pork chops. The combination of tray/sealing film, pork chops and FBBD (if any) was named consumer unit. The components of a consumer unit are described in Table 1.

Two different scenarios were considered in the LCA:

1. Scenario 1: A consumer unit consisting of 340 g of pork chops packaged in a nanoclay-based PLA package with a FBBD communicative device affixed.
2. Scenario 2: A consumer unit consisting of 340 g of pork chops packaged in a nanoclay-based PLA

Table 1 Product system to be studied

	Tray[a]	Sealing film (for closure)	FBBD device[b]
Materials	PLA	PLA coated with SiO_x	Compound 1[c]
	Nanoclay		Compound 2[c]
	PEG[d]		Paper
Weight (g)	11.2	2.81	1
Dimensions (mm)	188×134×50	188×134	85×55
Product content (g)	340 g of pork chops		

[a] No polyacrylate absorber is considered in the bottom of the tray

[b] If considered

[c] Since the communicative packaging devices are still under the first stage of development, most of the information used to develop the LCA model is under confidential agreements.

[d] Poly (ethylene glycol)

package without a FBBD communicative device affixed.

In accordance with these scenarios and components of the product system, the following goals were achieved as a result of LCA development:

1. To identify the environmental impacts related to FBBD communicative device life cycle.
2. To make a comparison between the environmental impacts related to packaging system with or without a FBBD communicative device.
3. To carry out a comparison between environmental impacts related to consumer unit with or without a FBBD communicative device.

It should be noted that this study was just a comparison between different situations, being not affected by any third party, since no trademark or comparison among specific materials was intended as a goal of this research project. Therefore, no critical review was carried out. Consequently, the results of this research were intended to be a way to provide better knowledge in communicative and sustainable packaging concepts.

2.2 Scope of the study

2.2.1 Functional unit

The functional unit considered in this study was the production, packaging and delivery to the point of sale of 1,000 kg of pork chops in The Netherlands using nanoclay-based PLA packages having affixed or not a FBBD communicative device. Considering this functional unit and the concept of consumer unit (as stated in Section 2.1) as well, a reference flow to deliver such amount of pork chops with the packaging system was calculated: 3,029 consumer units when the FBBD is not used and 2,941 consumer units when the FBBD is stuck in the package.

Therefore, the functional unit considered the package life cycle, the life cycle of pork chops (from farmer to meat processor) as well as the life cycle for the logistic supply chain for consumer units. One of the purposes of this study was the evaluation of environmental savings achieved by the avoided food losses. This issue could only be addressed if the life cycle of the pork chops and life cycle for the logistic supply chain for consumer units are within the system boundaries. Therefore, the whole consumer unit (product plus package) was considered.

2.2.2 Life cycle description

As stated above, four different life cycles were identified to carry out the environmental assessment intended within this study: (1) pork chops life cycle, (2) package life cycle, (3) FBBD life cycle, and (4) life cycle for the logistic supply chain of consumer units.

Although FBBD communicative device was one of the constituents of the packaging system, its life cycle was dealt with separately in order to assess the relative contribution to environmental impacts due to only FBBD communicative device.

All life cycles considered within this study are described as follows:

- Pork chops life cycle. The life cycle for pork chops started at the farmer level when pigs were fattened. When pigs were fat enough, they were carried to the slaughterhouse where pigs were slaughtered. Finally, pork carcasses were delivered to the meat processor where pork carcasses were cut in order to obtain several types of meat products (chops, steaky bacon, ham, etc.). Pork chops were then packed in situ using a thermoforming–fill–seal machine. Farming, fattening, transport and slaughtering took place in The Netherlands (NL).
- Package life cycle (nanoclay-based PLA tray+SiO_x-coated sealing film). Package life cycle started with the raw material extraction for each component defined in Table 1. PLA and nanoclay were extracted and produced in The United States (US). Afterwards were shipped to The Netherlands where a nanoclay-based PLA sheet manufacturer was located. Moreover, PLA pellets were delivered from The Netherlands to Switzerland (CH) where a sealing film manufacturer was located. Such material was converted on each component of the package and then delivered to the meat processor. Here, the meat was filled into the package (nanoclay-based PLA tray) and then sealed with SiO_x-coated PLA sealing film.
- FBBD communicative device life cycle. This life cycle started with raw material extraction of each component of the FBBD (inks and printing substrate). FBBD components were manufactured in Sweden (S). The inks and the substrate were then delivered to the meat processor where the communicative device was printed over a paper substrate and stuck to the package depending on the scenario considered.
- Life cycle for the logistic supply chain of consumer units. The life cycle for the logistic supply chain started at meat processor when consumer units were packed into corrugated box, palletised and delivered to the retailer distribution centre in The Netherlands. The consumer units were stored for one night and finally delivered to the retailer outlet in an urban area in The Netherlands. Afterwards, consumer units were sold and carried to the households where they were put into

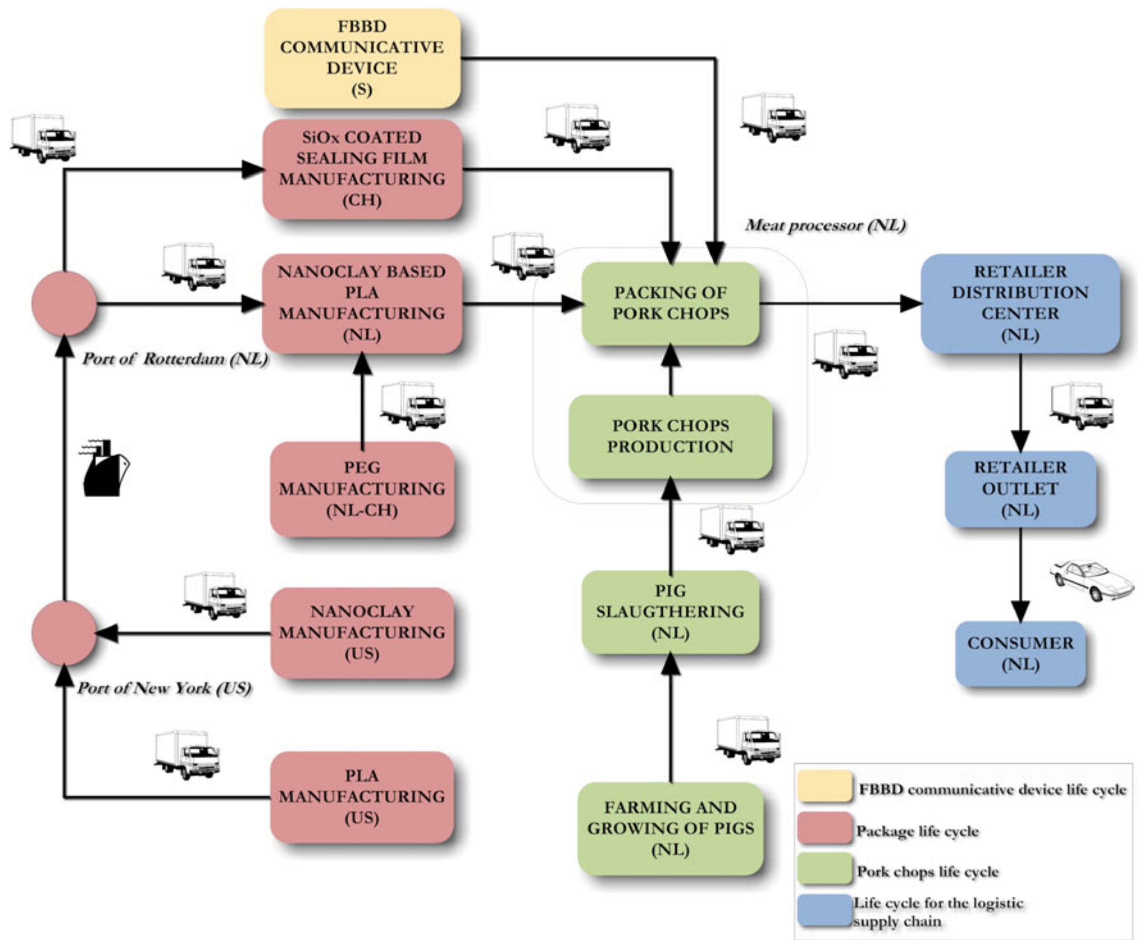

Fig. 2 Life cycle considered in this study

fridges until the product is consumed. A daily demand of 15 consumer units at retailer outlets was assumed. The consumer units were ordered to the meat processor in a fixed amount of 30 consumer units per day (van der Heijden et al. 2007). In accordance to van der Heijden research (van der Heijden et al. 2007), a specific scenario related to the consumer behaviour at supermarket level was selected: 60% of consumers took the longest expiry date whereas the remaining 40% took the first available product that had the shortest expiry date.

The whole life cycle scheme is shown in Fig. 2.

2.2.3 System boundaries

As shown in Fig. 2, a "cradle-to-gate" perspective was taken into account in this study: from raw material extraction for each package component (tray, sealing film and FBBD) and pork chops (including the logistic supply chain) until delivery to the point of sale at retailer stores. Therefore, the following assumptions were considered with regard to the life cycle system boundaries:

- Use phase[2] was excluded from the system boundaries since it was assumed that household storage/consumption is shorter (only a few days) compared to the longer times in the supply chain to the distribution centres and supermarkets.
- End-of-life phase was also excluded from the system boundaries as a result of the uncertainties of the end-of-life treatment of new components like FBBD devices. The FBBD devices are still under development, and there were no data available about the end-of-life behaviour at the time of this research. Consequently, higher uncertainties on the end-of-life results are expected for the consumer units with FBBD. Moreover, a wide range of end-of-life scenarios for

[2] Use phase of the package starts when a consumer purchases the pork chops at the supermarket until the disposal of the package, when the customer consumes the meat.

Table 2 Breakdown of food losses for each scenario (per consumer unit)

Component	Type	Amount (g)	
		Scenario 1 (0.5% of food losses)	Scenario 2 (3.5% of food losses)
Meat waste	Food losses	1.7	11.9
Packaging waste	Nanoclay-based PLA tray losses	0.056	0.392
	SiO_x-coated PLA sealing film losses	0.01405	0.09835
	FBBD losses	0.005	0
Total weight loss		1.77505	12.39035

the packaging and wasted meat can be considered even if the study is focused in the Dutch market. Therefore, it was difficult to find a representative scenario for the waste management system of consumer units.

- Food losses were only evaluated at retailer level. As stated in Section 1, it was assumed that the use of the FBBD did not affect the production and delivery chain, except from possible longer shelf lives in the supermarket. Therefore, food losses at household level were not considered. This is sound with the assumption made to exclude the use phase from the system boundaries. In fact, a brief calculation during the research carried out in the project delivered more than 98 scenarios at household level considering just the family members, fridge energy classification and consumer behaviour (either the consumers take the longest expiry date or the shortest expiry date). In contrast, the distribution channels (retailer distribution centres and retailer outlets) operate in a similar way, and fewer scenarios were observed. Furthermore, the amount of food losses at retailer outlets can be quantified easily than at household level. In fact, estimation of food losses at household level implies "considerable uncertainties in calculation of the resource demand and environmental impact of food" (Schneider 2007), and a variety of factors including household size, income, and food safety concerns, may influence the type and quantity of food losses at household level (Kantor et al. 1997).
- For distribution phases, a specific scenario for the delivery from the slaughterhouse facility to the meat processor (packer) and subsequently to the retailer distribution centre and retailer outlets was defined. This approach is sound since several logistic chains can be found, as well as transport distances between producers–packers–distributors–retailers.
- Environmental impacts coming from building and dismantling of industrial equipment (like machinery) at every life cycle stage were excluded from the system boundaries.
- Land use for the growing of crops used as raw material for polylactic acid production was considered within the system boundaries. This is an important issue since PLA is a polymeric material manufactured from industrial crops like corn (Wink et al. 2007).
- Package components that had not exceeded mass (<1% of total inputs), energy or environmental cut-off rules were excluded from system boundaries.

2.2.4 Key assumptions

Some key assumptions were taken into account to carry out the LCA of the consumer unit. Most of them were related to the nanoclay-based PLA package and the FBBD since both elements are still in their early stage of development. All assumptions in the LCA are described below:

Key assumptions on package life cycle

- A certain percentage of nanoclay dispersed into the PLA matrix for the tray was taken into account. Nanoclays would decrease oxygen transmission rate (Shina Ray et al. 2003) (Maiti et al. 2002). Consequently, less oxygen in the system results in minimization of undesirable effects on meat products like oxidation of lipids, loss of exudates, loss of texture and development of liver-like flavours (Ahvenainen 2003).
- A SiO_x-coated PLA film lid for protecting the meat was assumed in the packaging system.

Key assumptions on flexible best-before-date communicative device

- The FBBD was directly printed over a paper substrate stuck to the SiO_x-coated PLA sealing film.

Key assumptions on logistic supply chain of consumer units

- Pork chops were packed in a modified atmosphere (van der Heijden et al. 2007).
- A certain percentage of food losses at retailer outlet was assumed in both scenarios for the consumer unit in accordance with van der Heijden research (van der Heijden et al. 2007). In scenario 1 (consumer unit with FBBD), a 0.5% of food losses was assumed. This

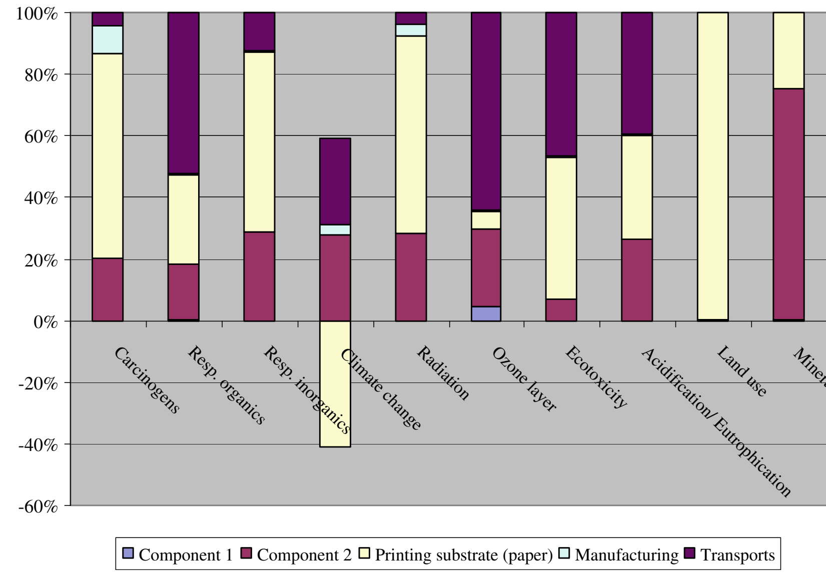

Fig. 3 Environmental impacts related to FBBD communicative device life cycle

percentage rises up to 3.5% for scenario 2 (consumer unit without FBBD).

2.3 Life cycle inventory

Life cycle inventory (LCI) was obtained considering a component-by-component approach for each of the four life cycles identified in Section 2.2.

- Life cycle inventory of pork chops
- Life cycle inventory of the packaging
- Life cycle inventory of FBBD communicative device
- Life cycle inventory for the logistic supply chain of consumer units

LCI data were taken from several sources. Data related to the packaging system and the FBBD device were provided by SustainPack partners. These data were complemented with specific LCI data related to the raw materials used in the packaging: PLA (Wink et al. 2007), SiOx-coated (Vetter 2007) and nanoclay (Roes et al. 2007). The life cycle data for pork chops were based on the research from Nielsen et al. (2003). Data on the logistic supply chain of consumer units were obtained from van der Heijden et al. work (2007). Additionally, some other literature references, patents, as well as commercial databases were also considered to complete the LCI. All LCI data were carefully analysed and crosschecked.

As stated above, two different scenarios were considered in the LCA, depending on whether the FBBD was used or not. The use of the FBBD affects the LCI of the logistic supply chain of consumer units considering the percentage of food losses and the amount of meat and packaging waste generated at retailer outlets[3] in each case.

Shrinkage of meat product might reduce from 3.5% to 0.5% (van der Heijden et al. 2007) by the use of FBBD. Therefore, up to 3% of the food losses at retailer level can be saved by the use of FBBD communicative device. Consequently, 0.5% and 3.5% of food losses for scenarios 1 and 2 were assumed, respectively. The breakdown of food losses for each scenario is shown in Table 2.

3 Results and discussion

Based on the information of LCI for each component (packaging system, FBBD, pork chops and logistic supply chain of consumer units), environmental impacts were evaluated according to Eco-Indicator 99 v 2.1 in Individualist (I) perspective (PRé Consultants & Ministerie von Wolkshuisvesting 2001).

According to the goals of this LCA study (already described in Section 2.1), the results were divided into three categories:

1. Identification of the environmental impacts related to the FBBD communicative device life cycle.
2. Comparison between the environmental impacts related to packaging system with or without a FBBD.
3. Comparison between environmental impacts related to consumer unit with or without a FBBD communicative device affixed.

[3] As stated in Section 2.2 where system boundaries were described; since food losses at households are excluded, food losses at retailer outlets have only been considered.

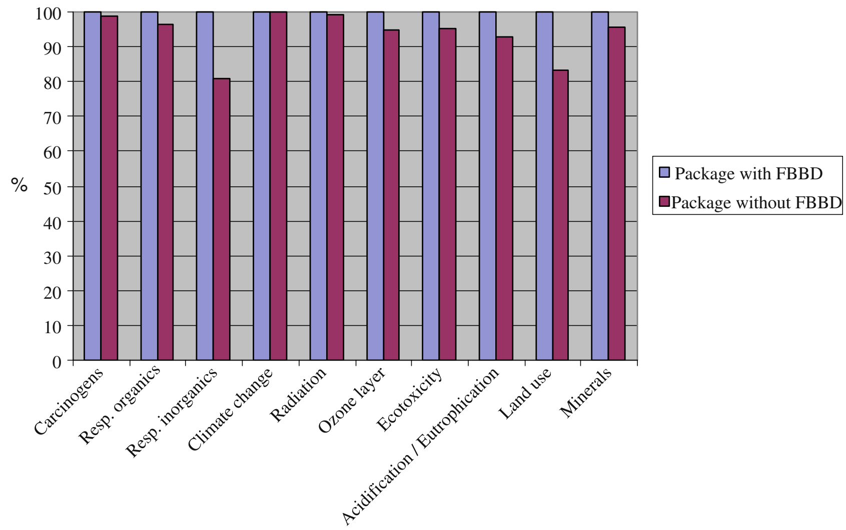

Fig. 4 Comparison of life cycle impact assessment results for the packaging system depending on the scenario considered

3.1 Identification of the environmental impacts related to FBBD communicative device life cycle

Figure 3 shows the relative contribution to environmental impacts for each phase of FBBD communicative device life cycle (from raw material extraction to FBBD communicative device manufacturing).

An interesting result from Fig. 3 is that a great part of the environmental impact of the FBBD in most of the impact categories is due to the paper substrate used for the manufacture of the communicative packaging device. However, a remarkable minimization of the environmental impact was observed for printing substrate on climate change category. This fact is due to the CO_2 drain effect produced by trees used for paper production.

On the other hand, it should be noted that the manufacturing of the FBBD has a small effect over the results whereas transport of inks and substrate has a higher impact. This fact is due to transport distances since these products are delivered from Sweden to the meat processor, which is located in The Netherlands.

3.2 Comparison between the environmental impacts related to packaging system with or without FBBD communicative device affixed

Figure 4 shows a comparison of life cycle impact assessment results for the packaging system when the FBBD was used (scenario 1) or not (scenario 2). This analysis allows assessing the influence of FBBD communicative device over the whole packaging system. Therefore, environmental impacts were obtained considering only the life cycles of the packaging (nanoclay-PLA tray+SiO_x-coated sealing film) and the FBBD communicative device (if any). LCA results revealed that a packaging system with a FBBD communicative device affixed has a large relative contribution to environmental impact. This fact is due to the large weight of the package when a FBBD is used[4] (scenario 1) as well as the use of specialty chemicals and electricity for its manufacturing. However, the environmental load caused by the use of the FBBD is minimal in comparison with the environmental load of the packaging system.

3.3 Comparison between environmental impacts related to consumer unit with or without FBBD communicative device affixed

Figure 5 shows a comparison of life cycle impact assessment results for the consumer unit when a FBBD is used (scenario 1) or not (scenario 2). As stated above, a consumer unit consists of a packaging system, pork chops and FBBD (if any), considering the subsequent logistic supply chain as well.

In that case, the results of the environmental behaviour of a consumer unit were just the opposite than those already observed for the packaging system: the relative contributions to environmental impact are lower for the consumer unit with FBBD (scenario 1) and larger for the consumer unit without a FBBD device (scenario 2). This fact is due to the environmental benefits that can be achieved by the use of the FBBD communicative device, since a reduction by 3% of food losses was considered even the consumer unit with FBBD weighs 1 g more than the consumer unit that does not use this communicative device. Differences between 0.72% and 3.79% were observed as function of the impact category. The largest difference was observed in

[4] 15.01 g (scenario 1) in front of 14.01 g (scenario 2).

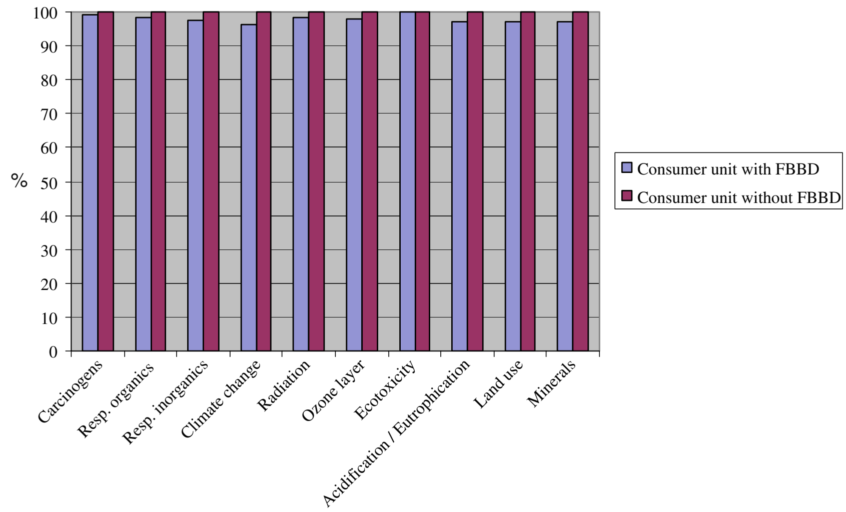

Fig. 5 Comparison of life cycle impact assessment results for the consumer unit depending on the scenario considered

climate change category (3.79%) since less food and packaging losses were produced when the FBBD is used, reducing GWP emissions.

4 Conclusions

LCA results show that the use of a FBBD communicative device contributes to minimize environmental burdens associated to the production, packaging and delivery to the point of sale of pork chops since it facilitates a dynamic control of out-of-date products. The results obtained showed that the consumer unit with the FBBD device had lower impacts for most of the impact categories studied. Even though the packaging system with FBBD weighs 1 g more than the packaging system without FBBD, the environmental burden of a consumer unit[5] that uses the FBBD is lower than the consumer unit which does not use it. This is due to the benefits of reducing food losses with the FBBD device.

On the other hand, the environmental load caused by the use of the FBBD was minimal in comparison with the environmental load of the packaging system. The main environmental impacts for the FBBD communicative device are due to the paper used, printing substrates and transport of such materials for in situ printing at meat processor facilities.

5 Recommendations

The results presented in this study are estimated results of a specific case study, using a cradle-to-gate approach as well as prototype of communicative packaging device. Therefore, these results are not intended to be used as assertive comparisons between products. Furthermore, future improvements on packaging communicative device and technology are expected. Consequently, these results must be considered as a first approach according to communicative packaging future developments.

Therefore, some important issues must be considered for future studies since further research on development of communicative devices is expected. First of all, a specific product must be considered as a function of the scenario considered. Production of poultry meat, beef or deli products do not have the same environmental burdens. Therefore, different results will be obtained as soon as different products will be studied. On the other hand, similar considerations must be considered as function of the intended use of the packaging communicative device (anticounterfeiting, freshness, etc.).

An enlargement of the LCA approach (from cradle-to-gate approach to cradle-to-grave approach) might give more specific results. In such a case, particular scenarios must be defined basically to widen the range of possibilities at use phase by households and end-of-life. As a result of the simulation of different scenarios, several alternatives to give benefits to consumers and suitable end-of-life treatment for communicative devices could be identified.

[5] Consumer unit is the combination of packaging system, pork chops, and FBBD (if any)

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