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# Food losses, shelf life extension and environmental impact of a packaged cheesecake: a life cycle assessment

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ABSTRACT

Packaging is associated with a high environmental impact. This is also the case in the food industry despite packaging being necessary for maintaining food quality, safety assurance and preventing food waste. The aim of the present study was to identify improvements in food packaging solutions able to minimize environmental externalities while maximizing the economic sustainability. To this end, the life cycle assessment (LCA) methodology was applied to evaluate the environmental performance of new packaging solutions. The environmental impact of packaging and food losses and the balance between the two were examined in relation to a cheesecake that is normally packaged in low density polyethylene film and has a limited shelf life due to microbial growth. A shelf life extension was sought via application of the well-established modified atmosphere packaging (MAP) technique. Samples for MAP ($N_2/CO_2$: 70/30) were placed inside multilayer gas barrier trays, which were then wrapped with a multilayer gas and water barrier film (i.e. AerPack packaging); control batches were packaged in gas barrier recycled polyethylene terephthalate (XrPet) trays and wrapped with a XrPet film. Samples were then stored at 20°C and inspected at regular intervals for chemical-physical, microbiological and sensory parameters. Results show that the new packaging solution could considerably extend the shelf life of cheesecakes, thereby reducing food waste and decreasing the overall environmental impact. Moreover, the new packaging allows one to minimize transport costs and to generate economies of scale in manufacturing.

*Keywords*: Life cycle assessment, modified atmosphere packaging, environmental impacts, shelf life



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## 1. Introduction

According to the European Commission (European Commission, 2010), food waste in the EU accounts for around 89 million tons of waste per year and, if the current trends persist, this figure is expected to increase to 126 million tons by 2020. In fact, the food/drink manufacturing and retail/wholesale supply chain produces the largest share of EU food waste (58%), followed in second place by household waste (44%). In addition to ethical and economic concerns, food waste has negative consequences on natural resources. In fact, as pointed out by Manfredi, Fantin, Vignali & Gavara (2015), food waste is socially and ethically unacceptable because of the persistent high number of malnourished people and also because of the number of consequences on the environment such as emissions into air, water and soil in the phases of production and supply chain. Moreover, as noted by WRAP (2009) in the case of the United Kingdom, reducing the considerable amount of household food and drink waste would save households money, whilst reducing the environmental impact.

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Thus, each step of the entire food chain (farmers, food manufacturers, retailers, consumers) has the capacity to play a significant role in preventing and reducing food waste. However, it is worth noticing that most of the loss in retail occurs in relation to baked goods, meat, seafood and ready-to-eat foods due to their high level of perishability (Gunders, 2012). As highlighted by Gunders (2012), several drivers influence in-store retail losses, such as expectations of aesthetic perfection and expired “sell by” or “best before” dates. In fact, market research has shown that many customers select their preferred stores based on the quality of perishable goods; thus retailers are highly motivated to display products of the perfect shape, size, and colour. Furthermore, products are generally discarded just before they reach their sell by or best before dates.

In this context, packaging is well-known to play an active role in preventing food waste by preserving food quality and, in turn, guaranteeing safety, even though it is itself associated with a high environmental impact that may even be higher than that associated with the production/loss of some food products. However, quantifying environmental impact is difficult, also due to differences in local practices regarding waste treatment, thus the available evidence is rather sparse and inconclusive. The Directive 94/62/EC, nevertheless, has imposed to EU countries, targets for the recycling rates of packaging waste, but the complex situation where the industry is responsible for an activity that is carried out by local authority poses potential conflicts (Ferreira da Cruz et al., 2014a). These problems concern the recycling system structure, the account for the cost of managing packaging waste, and the environmental impacts from conservation of raw materials and diversion of waste from landfills (Ferreira da Cruz et al., 2014b). WRAP (2011) emphasizes the role of the food industry in food waste prevention that can act by influencing behaviour and facilitating behaviour change through the way the industry packages and presents products to the consumer.

Innovations in packaging could represent a tool for increasing the global sustainability of food production and reducing food loss and waste achieved through extending shelf life – defined as the time span during which the quality of the food product is satisfactory.

The present study aims to contribute to the literature by identifying potential packaging improvements that in addition to extending the product shelf life also minimize environmental externalities and thereby maximize the economic outcome and thus incentivize their application. As far as we are aware, no previous study has analyzed these issues from the perspective of the food industry. A cheesecake was chosen as the food model as it has a short shelf life that is mainly limited by mould growth. This product is normally packaged in cardboard trays wrapped with Low Density Polyethylene (LDPE) film and shows a maximum mould-free shelf life of 1 week. To extend the shelf life, a Modified

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Atmosphere Packaging (MAP) approach was applied and sensory, textural and other chemical-physical parameters were assessed, being the primary factors affecting the shelf life of a food product. The results will enable decision-makers to understand the performance, economic and environmental trade-offs that need to be made between the alternative packaging systems in order to make the most appropriate packaging choices in a sustainable perspective.

The paper is organized as follows: after this introduction, a short literature review on the LCA of food packaging and its importance for the limitation of food waste is presented in the second section. The description of the methodological approach adopted is provided in the third section. The fourth section contains the results and their discussion while concluding remarks are presented in the fifth and final section.

## 2. LCA of food packaging and its importance for the limitation of food waste

The Life Cycle Assessment (LCA) approach allows one to account for the environmental aspects (European Commission, 2012). This methodology is mainly applied to industrial products and processes, and it is the subject of increasing interest due to for its application in evaluating the environmental impacts of products, processes or activities. Indeed, it is often employed for assessing the equilibrium between technological innovation and environmental protection (Siracusa, Ingrao, Lo Giudice, Mbohwa, & Dalla Rosa, 2014; Manfredi & Vignali, 2015). As far as food packaging and LCA are concerned, a number of studies have applied this methodology over recent years (Williams & Wilkström, 2011; Siracusa et al., 2014; Silvenius, Grönman, Katajajuuri, Soukka, Koivupuro, & Virtanen, 2014; Wikström, Williams, Verghese, & Clune, 2014; Manfredi, Fantin, Vignali & Gavara, 2015; Zhang, Hortal, Dobon, Bermudez, & Lara-Lledo, 2015). One strand of research analyses the relationship between the environmental impacts of food waste and packaging alternatives. For instance, Williams & Wilkström (2011) examined the environmental impact of

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packaging and food losses and the balance between the two for 5 different food items (cheese, bread, milk, ketchup and beef). Their results show that packaging that reduces food waste can provide an important tool for reducing the total environmental impact; even if the impact associated with the packaging itself is greater than the impact associated with the food loss. As highlighted by the authors, this is particularly relevant in the case of cheese and bread. To investigate these findings further, Wilkström, et al., (2014) analyzed the consequences of omitting food waste from the LCA of packaging systems. The paper shows the packaging attributes that influence food waste; the goal being to demonstrate how packaging attributes may affect consumer behaviour and food waste, and thus influence the outcome of a LCA study on packaging. Additionally, the authors highlight that a reduction in food waste may often incentivize a packaging format with a higher climate impact. Silvenius et al. (2014) examined the environmental impacts of food waste and how packaging choices can even constitute a factor that causes food waste. The paper presents the results of three LCA case studies of packaged food products (ham, dark bread and yogurt drink) with different assumptions about the packaging sizes and alternative materials. According to their results, packaging solutions that minimize waste generation in households as well as in the distribution and retail processes will minimize the environmental impacts of the entire product-packaging chain.

Furthermore, Manfredi, Fantin, Vignali & Gavara (2015) apply LCA to compare the environmental performance of a traditional packaging system with the performance of packaging coated with an active layer for fresh milk packaged in Tetra Top® beverage containers. The final aim is to study the influence of the packaging on the amount of milk waste. The findings show that there is a reduction in milk waste by employing the second solution and a consequent reduction of environmental impacts due to milk saving. Similarly, with the aim to assess the overall environmental performance of the food and packaging system considering the effect of food loss reduction by using active packaging Zhang,

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Hortal, Dobon, Bermudez & Lara-Lledo (2015) perform a LCA to evaluate an essential oil component-enabled packaging for fresh beef. Their findings show that the active packaging solutions could reduce beef losses at the retail of the EU market.

In a recent study, Conte and colleagues (2015) employed LCA to evaluate a new packaging design concept and their aim was to provide an eco-indicator able to measure the environmental effect of packaging alternatives. Their study focused on an Italian cheese product and considered shelf life and food loss probability. The findings highlighted that in order to minimize environmental implications, it is fundamental that the capacity of packaging to reduce food loss is considered, in addition to the impact of the packaging production and disposal phases.

This thought is in line also with the study of Manfredi and colleagues (2015) that demonstrates the importance of including food waste in the analysis of packaging systems by employing LCA. As they pointed out, it is a central issue the evaluation of the relationship between packaging design and food waste for the environmental sustainability of packaging solutions. In fact, a preliminary LCA analysis on the food and its shelf life connected with the packaging allows one to assess several aspect of a product environmental impacts and has the potential to help evaluations to minimise the food waste.

It is also important to note that from the retailer's point of view, the package should protect the product and deliver it undamaged to the final consumer. Therefore, its role must also be considered from an environmental perspective when comparing different packaging solutions, especially for highly perishable products with a short shelf life. Albrecht, Brandstetter, Beck, Fullana-i-Palmer, Grönman, Baitz, Deimling, et al.,( 2013) show the preferable environmental performance for three transport packaging systems, but especially indicate the necessary relevance to merging economic and social aspects into a LCA. Merging economic aspects will be one of the study goals. LCA is particularly relevant in this kind of analysis since it involves a simplified procedure that allows one to identify particular

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characteristics but also key issues associated with a product in order to improve its sustainability. In fact, as reported in Ferreira at al. (2016) LCA can serves several purposes that, however, have in common the assessment of the environmental dimension.

## 3. Methods

### 3.1 Goal and scope, the product and the system

The objective of this study was to compare the environmental impacts and the economic aspects associated with different food preservation methods as a way to potentially improve a business's overall performance. Specifically, the research project is aimed at validating new packaging solutions in the food market in order to extend product shelf life. To this purpose, screening LCAs were performed on existing products in order to evaluate the environmental performance of alternative packaging solutions. Screening LCAs entail a simplified procedure that allows one to identify particular characteristic or key issue associated with the analysis that will normally be the subject of further, more intensive study (Christiansen et al. 1997). The simplification may involve exclusion of certain life cycle stages, system inputs or outputs, or impact categories, or the use of generic data modules rather than data specific to the system under study. Moreover, reducing the complexity of the LCA implies reducing the cost, time and effort required to run it.

The product under consideration is a typical cheesecake produced in Sardinia (Italy), composed of a wheat-based pastry crust and a cheese filling. The cheesecake is prepared as follows: wheat flour (70%) is mixed with animal fat (15%) for 20 minutes; water (15%) is then added and mixed until the shortcrust pastry develops. The shortcrust pastry is laminated and cut to obtain pastry circles of 12 cm in diameter. The filling is made up by mixing freshly grated ewe's cheese (75%), sugar (11%), semolina (4%), egg yolks (4%), dry raisins (4%) and grated orange rind as flavouring (2%).



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MAP ($N_2/CO_2$ – 70/30) samples were packaged in multilayer ethylene vinyl alcohol/polystyrene/polyethylene (EVOH/PS/PE) gas barrier trays (AerPack B5-30, Coopbox Italia, Reggio Emilia, Italy) and wrapped with a multilayer (EVOH/OPET/PE) gas and water barrier film (54 µm, EOM 360B, Sealed Air, USA). Ambient atmosphere samples (acting as control samples) were packaged in gas barrier recycled polyethylene terephthalate (XrPet) trays and wrapped with an XrPet film (Coopbox Italia, Reggio Emilia, Italy). Samples were subsequently stored at 20°C. The functional unit (F.U.) considered for the analysis corresponds to a tray containing two cheesecakes, with a total weight of approximately 300 gr. In the case of XrPet the F.U. has a shelf life (SL) of 7 days, whether in the case of the AerPack the SL is of 28 days.

The boundaries of the system are provided in Figure 1 and are defined in such a way to be as realistic as possible. The LCA was performed from a cradle to gate perspective, meaning that all phases from raw material extraction to the retail gate (i.e. supermarket) are included. As such, the involved phases were: 1) production of the raw materials employed in food and packaging production; 2) food and packaging manufacture that leads to the 3) packaging of a tray containing two cheesecakes; 4) logistics system; 5) transport to retail and 6) disposal of food and packaging.

This study considers the role of packaging in preserving food quality and safety as well as the influence of packaging on food spoilage and loss and therefore on cheesecake shelf life and finally, the waste disposal. As far as the disposal phase is concerned, the food waste is treated as bio waste and then collected by the municipal waste service that provide for the incineration, a treatment method that involves combustion of waste material. This method treats waste to reduce its volume and hazard and destroys potentially harmful substances. In the case of bio-waste, there is almost no residue from incineration (JRC, 2011). The plastic waste is sent to a mechanical recycling following the work by Perugini et al. (2005). The authors collected data about material and energy flows related to the production of recycled

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PET and polyethylene from plastic waste. We just consider data related to the production of 1 kg of mechanically recycled polyethylene.

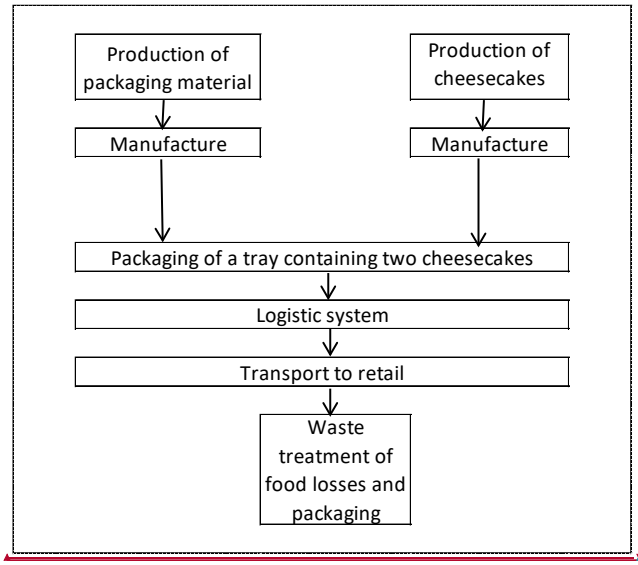



Figure 1. System boundaries.

### 3.2 *Inventory analysis*

The inventory data related to the most important aspects of the study are primary data, that are defined as information measured and gathered in-person and on-site. In fact, these data were collected through a detailed questionnaire completed through face-to-face interviews, or by telephone, with 6% of the representative bakery-manufacturing companies located in the north-west of Sardinia in 2015. According to ATECO 2007[1], these companies are classified as "producers of baked food", code 10.7. According to the 2011 industry and services census data (ISTAT, 2011), a total of 244 companies belonging to this classification

[1] ATECO is the classification adopted by the Italian National Statistics Institute (ISTAT) for the classification of economic activities.



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are present in the area. Ninety-nine point seven percent of them are classified as either small (1–2 employees) or medium (3–49 employees) sized businesses.

All processes carried out within the companies relate to "gate to gate" processes. The questionnaire asked for information on the origin of the inputs, the relative quantities and costs for 1 kg of final product, the major energy flows for each stage of production as well as for information about the derivation of the packaging and its disposal options. All products were distributed within Italy only.

Secondary data, that are data that has been derived from averages, statistical projections, and spot-checked primary sources, are used for the "upstream" or "downstream" processes of cheesecake production. We employed the ecoinvent v.3.1 database (Ecoinvent, Zurich, Switzerland) for the packaging material and packaging manufacturing (i.e. thermoforming and extrusion), and we referred to the Agri Footprint v.1.0 database for the agricultural phases of food production (Agri Footprint, Gouda, The Netherlands), both embedded in the software SimaPro, version 8.05.13. These databases contain almost all processes needed for the consumption of resources, materials and energy, as well as the use of transport means. The fabrication of production equipment (i.e. capital goods) was excluded from the analysis due to the assumed low attribution of these phases to a single packaged cheesecake and it is also in line with ISO 14044 requirements for LCAs (Frischknecht et al. 2007).

A brief summary of the principal processes and input data for the production and processing stage are shown in Table 1 and Table 2. Primary data related to electricity consumption were collected from the business premises directly, while data used to describe the processes related to electricity production (i.e. voltage level) were obtained from the Italian national energy system. Electricity is the primary power input employed in the cheesecake production phase and in the packaging phase. It is used for the mixing phase of ingredients, both of the pastry and of the filling, for the lamination of the shortcrust pastry and for the cooking phase and for the MAP packaging solution. Inventory data regarding electricity are extrapolated



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from the dataset ecoinvent v. 3.1 that describes the electricity available on the medium voltage level in Italy. This is done by showing the transmission of 1 kwh electricity at medium voltage. Specifically, it includes: the electricity inputs produced and from imports and transformed to medium voltage, the transmission network, the direct emissions to air (SF6 from the insulation gas in the high voltage level switchgear are allocated to the electricity demand on medium voltage) and the electricity losses during transmission. The average technology used to transmit and distribute electricity includes underground and overhead lines, as well as air-, vacuum- and SF6-insulated high-to-medium voltage switching stations.

To gather detail about the packaging materials we employ the producer company technical data sheets and the corresponding thermoforming and extrusion processes were identified in the ecoinvent v. 3.1 database. The functional unit (FU), that is a tray of cheesecake, the finished product, was assumed to be delivered to the final retailer by road transport (light commercial vehicle, ecoinvent v. 3.1). Based upon the data provided by the bakery-manufacturing companies a distance of approximately 60 km was appraised to product delivering. The data were estimated by consulting relevant resources (i.e. specialised articles) and own assumptions.

The modelling of the end of life scenario was based upon the primary data and combined with the available data in ecoinvent v. 3.1. The functional unit is treated for the food part (i.e. the cheesecakes) as waste disposal of bio-waste in a municipal solid waste incinerator and the packaging materials are assumed to be collected by the municipal waste collection service.

Table 1. Inventory data for the cheesecake production

| Input | Unit | Amount per 1 kg of final product | Amount per F.U. (300 gr) | Source |
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|---|---|---|---|---|
| Wheat flour | g | 300 | 84 | Agrifootprint v.1.0 |
| Animal fat | g | 100 | 28 | Agrifootprint v.1.0 |
| Grated ewe's cheese | g | 500 | 140 | Ecoinvent v. 3.1 |
| Sugar | g | 100 | 28 | Agrifootprint v.1.0 |
| Semolina | g | 30 | 8.4 | Agrifootprint v.1.0 |
| Egg yolks | p | 2 | 0.56 | Agrifootprint v.1.0 |
| Electricity-*Phase of production* | | | | |
| Mixing | kWh | 0.138 | 0.018 | Ecoinvent v. 3.1 |
| Lamination | kWh | 0.063 | 0.039 | Ecoinvent v. 3.1 |
| Cooking | kWh | 0.625 | 0.175 | Ecoinvent v. 3.1 |

Table 2. Weight of packaging materials and electricity employed per F.U.

| **Material** | **Unit** | **AerPack** | **XrPet** | **Source** |
|---|---|---|---|---|
| Tray | | | | |
| EVOH/PS/PE | g | 11.25 | | Ecoinvent v. 3.1 |
| XrPet | g | | 16 | Ecoinvent v. 3.1 |
| Film | | | | |
| EVOH/OPET/PE | g | 2.25 | | Ecoinvent v. 3.1 |
| XrPet | g | | 1.45 | Ecoinvent v. 3.1 |
| Gas mixture-MAP | | | | |
| (N2/CO2) | g | 0.035 | - | Ecoinvent v. 3.1 |
| Electricity- MAP | kWh | 0.017 | - | Ecoinvent v. 3.1 |

### 3.3 *Key assumptions*

The purpose of this study is to evaluate the effects of an extension in a food product's shelf life from both the environmental and an economic points of view. In order to explore these aspects together, we needed to consider all the producer's activities in the market place: the producer delivers its goods according to a consignment agreement, bears all goods' transport costs and the waste management burden of unsold goods. The bakery manufacturing companies adopt a "just in time" delivery system. This condition restricts or eliminates storage time span as a result of the short shelf life of cheesecakes. Conversely, other



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agricultural products, such as tomato-based manufactured, can benefit from a more efficient logistics due their seasonality and much longer storage times (Bottani et al. 2014). Moreover, we needed to understand the minimum gross operating profit (GOP) that allows the company to stay in the market and therefore the minimum amount of consigned product that must be sold. The unsold share allows one to proxy the food loss and therefore the waste scenario.

In order to evaluate these aspects, the average variable cost (AVC) to produce one unit (1 kilogram) of product must be calculated, equal to the sum of the costs for each production input:

$$AVC = \sum_{i=1}^{I} avc \quad (1)$$

As highlighted above, bakery/cookie manufacturing companies belong to the category of small- or medium-sized businesses and are characterized by increasing returns to scale, constants and equal average and marginal costs for all output, as suggested by standard industrial organization theory (Nguyen and Reznek, 1991).

Specifically, the total variable cost of production ($VC$) for a bakery/cookie manufacturing company is given by $VC = AVC * Q_C$, where $Q_C$ is the quantity of product produced and delivered according to the consignment agreement. The total revenue ($TR$) is given by $TR = P * Q_S$, where $Q_S$ is the quantity sold and $P$ is the price paid to the manufacturing company. The GOP is therefore given by $GOP = TR - VC$.

Here, we calculated the minimum amount ($Q_s^{min}$) of the product delivered on consignment that must be sold as:

$$Q_s^{min} = \frac{VC - (VC * \frac{P - AVC}{P})}{AVC} \quad (2)$$

Thus $Q_s^{min}$ is the ratio of the variable cost of the quantity sold and the average variable cost of the quantity $Q_c$ actually delivered. When $Q_S$ is the same as $Q_s^{min}$ then the GOP is equal to 0, i.e. no net profit is made, that is the minimum gross operating profit.

Following this framework, using the *AVC* of 1 kg of cheesecake for the two different packaging alternatives (including energy costs) and the price *P*, we calculated $Q_s^{min}$ and *VC*. Table 3 presents the food loss considered in the waste management model for the two packaging alternatives: XrPet, with a shelf life (SL) of 7 days, and the AerPack with a SL of 28 days. If the input and output relative prices do not change, both packaging solutions have the same $Q_s^{min}$ amount and we can consider the maximum waste impact due to economic grounds $(Q_C - Q_s^{min})$. In fact, it would not be rational for the businesses to operate when $(Q_C - Q_s^{min})$ or when the GOP < 0.

Table 3. Economic figures for the two packaging solutions

| Plastic film | SL* | AVC (€) | P (€) | Qc | $Q^{min}$ | VC (€) | GOP (€) | FL |
|---|---|---|---|---|---|---|---|---|
| XrPet | 7 | 4.626 | 13.878 | 100 | 33.333 | 462.597 | 0.0 | 67 |
| AerPack | 28 | 4.643 | 13.928 | 100 | 33.333 | 464.266 | 0.0 | 67 |

*SL, shelf life in days; AVC, average variable cost in euros; P, price in euros; Qc, quantity produced and given on consignment in percentage terms, $Q^{min}$ quantity produced and given on consignment in percentage terms; VC, variable costs of production in euros; GOP, minimum gross operating profit in euros; FL, food losses in percentage terms.

All other things being equal (i.e. the shelf life), when the quantity sold corresponds to $Q_s^{min}$ the food losses (FL) correspond to 67% of the product.

Accounting for the shelf life, considering an equal amount of product delivered, AerPack sales are greater. This is due to the fact that the product maintains its aesthetic quality and is available for purchase for longer; it therefore comes into contact with a higher number of potential buyers. Moreover, the consumer is more likely to consider buying the product because he sees that the product is not yet close to its best before date. This reduces the

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amount of unsold product by the time of its expiration date, reducing transport and waste disposal costs.

The distribution of sales also depends on consumer buying habits and the length of the shelf life. In this regard, the entrepreneur should deliver a quantity that minimizes the $Q_c - Q_s$ difference. However, shelf life and commercial life may be different, especially for food goods. A food may indeed have ended its business or commercial life, but not its shelf life. This situation arises when the buyer decides he cannot consume the packaged product before its best before date. It is not a coincidence that retailers often reduce prices to encourage the sale of foods close to the expiry date.

Given a stock of goods, a longer shelf life is associated with higher sales compared with a shorter shelf life. XrPet and AerPack packaging solutions have different shelf life durations. Assuming that the distribution of sales is described by the following exponential function , $Q_t = (w - t)^x$which measures the quantity sold on each day of the week, for the XrPet packaging solution the cumulative quantity of product sold can be given as follows:

$$\bar{Q}_t = (w - t)^x + \sum_{t-1}^{1} Q_t \quad (3)$$

such that

$$Q_s^{min} \leq \bar{Q}_t$$

and SL = 7; *t-day* = 2, … ,6; *w* = 7.

For the AerPack packaging solution, the cumulative quantity of product sold is given by:

$$\bar{Q}_t = (w - t)^x + \sum_{t-1}^{1} Q_t + \left[\left(Q_c^w * \frac{1}{w}\right) * (SL - w)\right] \quad (4)$$

such that

$$Q_s^{min} \leq \bar{Q}_t$$

and SL = 28, *t*-day = 2, … ,6; *w* = 7.

The amount $Q_t$ is a function of time *t* that elapses between the moment when the last weekly product is available for sale and the end of its shelf life. Considering the time spanning (*SL* –

*w*), the producer delivers its goods ( $Q_c^w$ ) on consignment each week and all goods delivered are sold. In the last week, the *x* exponent defines the temporal distribution of products sold. For example, for *x* = 2 and AerPack packaging, $\bar{Q}_t$ = 391 defines the quantity sold and FL = 9 the quantity of food losses. Use of the AerPack packaging is therefore associated with a greater weekly amount sold, thus reducing the relative food losses.

Therefore, taking into account a time span of 28 days, the FL is equal to 36% of the product in the case of the XrPet packaging solution and to 9% in the case of AerPack packaging. From the viewpoint of economic sustainability, the AerPack would seem to be the most advantageous solution for the firm, despite the AVC of production being slightly higher. In fact, this solution allows for transport costs to be minimized and for economies of scale in manufacturing due to its ability to keep the product fresh for longer. The cost differences between the XrPet and AerPack packaging solutions are thus rendered negligible.

### 3.4 *Life cycle impact assessment*

LCA is a powerful method for measuring the impact of human activities on the environment. SimaPro (version 8.05.13) was used with the ReCiPe endpoint method, developed by Goedkoop et al. (2009), which characterizes life cycle inventory data according to both 'problem oriented' and 'damage oriented' approaches. The primary objective of the ReCiPe method, is to transform the long list of Life Cycle Inventory results into a limited number of indicator scores. ReCiPe defines indicators at the midpoint or endpoint level. At the midpoint level seventeen indicators are calculated, whereas three damage categories are computed for the endpoint; damage to human health; damage to ecosystems; or damage to resource availability. Endpoint indicators are easier to interpret than the large number of midpoint indicators, partially because there are fewer of them and partially because their interpretation

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is more tangible. Therefore, several impact categories could be considered in an environmental impact assessment**,** however, resource use, human health and ecological consequences (assessed according to endpoint levels) are the three main impact categories taken into account in this study due to their greater ease of interpretation.

## 4**.** Results and discussion

### *4.1 Baseline impact assessment*

The results attained for the XrPet and AerPack packaging solutions are reported in Table 4 for quantities sold corresponding to $Q_s^{min}$ and a corresponding food loss of 67% of product. The results were calculated per unit of food sold, the functional unit, corresponding to a tray containing two cheesecakes, with a total weight of approximately 300 gr. In this part of the analysis, no reference to time (i.e. shelf life) is made.

Table 4. Impact categories of the product and its loss.

| Impact category | Unit | XrPet | AerPack | Impact variation[d] |
|---|---|---|---|---|
| Climate change human health | DALY[a] | 1.22E-05 | 1.21E-05 | -1% |
| Ozone depletion | DALY | 1.10E-09 | 1.09E-09 | -1% |
| Human toxicity | DALY | 1.78E-05 | 1.72E-05 | -3% |
| Photochemical oxidant formation | DALY | 3.87E-10 | 3.82E-10 | -1% |
| Particulate matter formation | DALY | 1.97E-06 | 1.95E-06 | -1% |
| Ionising radiation | DALY | 7.63E-09 | 7.50E-09 | -2% |
| Climate change ecosystems | species.yr[b] | 6.48E-08 | 6.42E-08 | -1% |
| Terrestrial acidification | species.yr | 5.59E-10 | 5.55E-10 | -1% |

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|---|---|---|---|---|
| Freshwater eutrophication | species.yr | 3.08E-11 | 3.00E-11 | -2% |
| Terrestrial ecotoxicity | species.yr | 2.04E-09 | 2.03E-09 | -1% |
| Freshwater ecotoxicity | species.yr | 2.96E-11 | 2.88E-11 | -3% |
| Marine ecotoxicity | species.yr | 4.01E-09 | 3.88E-09 | -3% |
| Agricultural land occupation | species.yr | 3.47E-08 | 3.45E-08 | -1% |
| Urban land occupation | species.yr | 6.39E-10 | 6.27E-10 | -2% |
| Natural land transformation | species.yr | 2.89E-08 | 2.85E-08 | -2% |
| Metal depletion | $[c] | 8.99E-03 | 8.67E-03 | -4% |
| Fossil depletion | $ | 1.57E-01 | 1.55E-01 | -1% |

[a]DALY (Disability-Adjusted Life Year): a measure of the overall severity of a disease, expressed as the number of years lost due to illness, disability or premature death. [b]Species.yr: a measure of the extinction rate that is the loss of species during a year. [c]$: a measure of surplus costs of future resource production over an infinitive timeframe, considering a 3% discount rate. The unit is 2000US$. [d]Impact variation: (AerPack score-XrPet measure score)/(AerPack score)

Overall, the XrPet solution shows a slightly higher environmental impact for each of the impact categories considered. The difference between the two solutions is rather marginal, however the impact category that varies the most relates to a high environmental impact of packaging, namely metal depletion, followed by human toxicity, freshwater ecotoxicity and marine ecotoxicity. Human toxicity concerns the effects of toxic substances on the human environment, whereas health risks of exposure in the working environment are not included. Freshwater and marine ecotoxicity refer to the impact on fresh water ecosystems as a result of emissions of toxic substances into the air, water and soil and to the impact of toxic substances on marine ecosystems, respectively. A review by Pimentel et al. (1993) linked pesticide use with negative effects on a wide range of environmental and ecosystem functions (see also Pimentel & Burgess, 2014). Pesticides have also been linked to negative

impacts on human health. Mostafalou & Abdollahi (2013) reviewed the literature on the correlation between pesticides and human chronic diseases and concluded that a huge body of evidence exists on the connection between pesticide exposure and different disease conditions. Therefore, these impact categories are mainly related with the agricultural phase of raw material production.

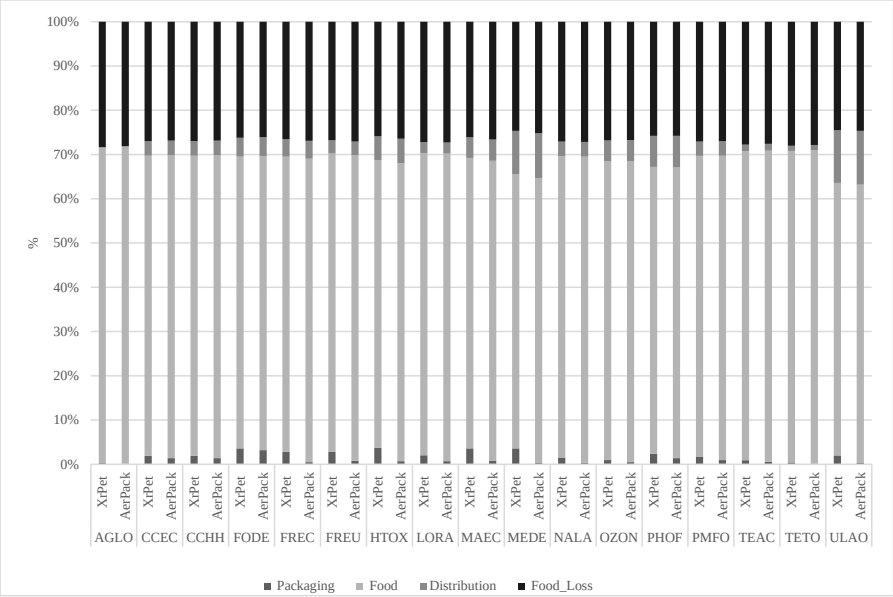



Figure 2. Impact assessment of cheesecake packaging alternatives; contribution analysis in percentage terms

AGLO: agricultural land occupation; CCEC: climate change ecosystems; CCHH: climate change human health; FODE: fossil depletion; FREC: freshwater ecotoxicity; FREU: freshwater eutrophication; HTOX: human toxicity; LORA: ionising radiation; MAEC: marine ecotoxicity; MEDE: metal depletion; NALA: natural land transformation; OZON: ozone depletion; PHOF: photochemical oxidant formation; PMFO: particulate matter formation; TEAC: terrestrial acidification; TETO: terrestrial ecotoxicity; ULAO: urban land occupation.

Figure 2 reports the contribution of the different aspects of the life cycle stages, such that the processes making the biggest environmental impact can be identified: *packaging* refers to

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packaging production and use (AerPack and XrPet); *food*, in this case, refers to cheesecake production, starting from the raw materials; *distribution* includes transportation from producer to retailers; and the *food loss* accounts for the fraction of food that cannot be sold due to spoilage because of the reaching of the expiry date.

The contribution of the packaging varies between 0% (agricultural land occupation, terrestrial ecotoxicity) and 4% (human toxicity, marine ecotoxicity). On average, the higher impacts are found in relation to the XrPet packaging solution. On the other hand, food contributions vary between 62% (urban land occupation, metal depletion) and 72% (agricultural land occupation) and are mainly referable to the agricultural phase of the life cycle. Distribution and food loss show the same impacts in percentage terms for both packaging solutions, meaning that, in this first step of the analysis, the two phases have a similar environmental impact. Overall, the contribution of food loss is greater and varies between 25% (urban land occupation, metal depletion) and 28% (terrestrial acidification).

The ReCiPe method allows us to determine indicator scores at two levels: the previously discussed seventeen midpoint indicators and three, easier to understand, damage categories indicators, being: damage to human health; damage to ecosystems; and damage to resource availability (Goedkoop et al., 2008). The scope to present results at the endpoint level is that they are generally considered more understandable to the decision makers and may facilitate more structured and informed weighting. Moreover, they allow science-based aggregation across categories in terms of common parameters. The endpoint indicator scores obtained for the two packaging solutions under consideration with the relative measurement unit are presented in Table 5. At first glance, the XrPet solution would appear to have higher overall scores than the AerPack solution in relation to the packaging and the food loss phases.

Table 5. Results for the damage categories indicators, ReCiPe.

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| Damage category | Alternative | Unit | Packaging | Food | Distribution | Food Loss |
|---|---|---|---|---|---|---|
| Human Health | XrPet | DALY[a] | 9.21E-07 | 2.12E-05 | 1.42E-06 | 8.43E-06 |
| | AerPack | | 3.08E-07 | 2.12E-05 | 1.42E-06 | 8.32E-06 |
| Ecosystems | XrPet | species.yr[b] | 1.94E-09 | 9.33E-08 | 3.41E-09 | 3.71E-08 |
| | AerPack | | 1.06E-09 | 9.33E-08 | 3.41E-09 | 3.66E-08 |
| Resources | XrPet | $[c] | 5.96E-03 | 1.09E-01 | 7.53E-03 | 4.33E-02 |
| | AerPack | | 4.98E-03 | 1.09E-01 | 7.53E-03 | 4.27E-02 |

[a]DALY (Disability-Adjusted Life Year): a measure of the overall severity of a disease, expressed as the number of years lost due to illness, disability or premature death. [b]Specie.yr: a measure of the extinction rate that is the loss of species during a year. [c]$: a measure of surplus costs of future resource production over an infinitive timeframe, considering a 3% discount rate. The unit is 2000US$.

However, in order to provide a clearer indication of the magnitude of each impact and to compare the overall impact of the two products better using a multi-impact assessment method, Figure 3 reports the same results normalized to the European average reference values. The single scores are obtained by dividing the impact indicators by the score of the reference situation, that is one person's share of all emission and resource use in the world during one year. In relation to both packaging solutions, the human health category is the most affected, followed by resources. However, the overall impact of XrPet is higher. It is also evident that the impact of food preparation and the distribution phase is the same for the two packaging solutions. The biggest difference relates to packaging and to food loss. The ReCiPe normalized results confirm that the AerPack has a lower environmental impact than the XrPet (Figure 3).

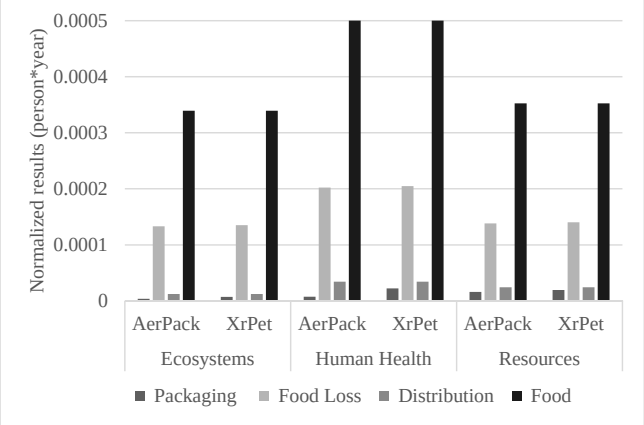



Figure 3. Normalized results.

*4.2 Accounting for the shelf life*

In order to account for the shelf life and the technology of the packaging better, the life cycle assessment was also computed according to the different amounts of food loss associated with the two packaging solutions over a 28 day time span, as discussed in section 2.3. The characterization results (Table 6) show that the impact variation associated with the two solutions is significantly higher compared with the previous case when no reference to time was made (Table 4). This result is mainly due to the savings in food loss and in the distribution process associated with the AerPack packaging solution. The category showing the highest variation is urban land occupation followed by metal depletion. In fact, as urban land is a finite resource, its occupation makes it unavailable for alternative uses or for use by future generations.

Table 6. Impact categories of the product and its loss.

| Impact category | Unit | XrPet | AerPack | Impact variation[a] |
|---|---|---|---|---|

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**Eliminato:** Figure 4 presents the weighted results of the analysis. They were obtained by multiplying the normalized results of each of the impact categories by a weighting factor that expresses the relative importance of the impact category. They have the same unit and can be added up to create one single score for the environmental impact of the products (Total).¶

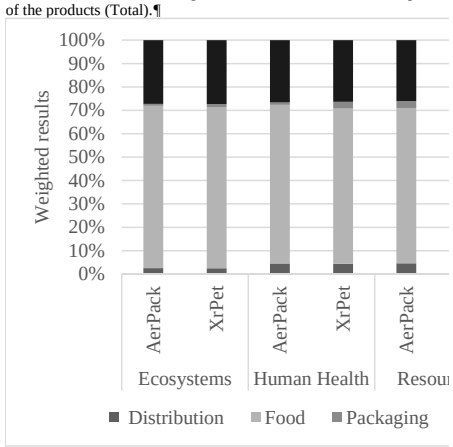



Figure 4. Weighting results, showing results for multiple impact categories for XrPet and AerPack.¶

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|---|---|---|---|---|
| Climate change human health | DALY[b] | 1.22E-05 | 9.48E-06 | -29% |
| Ozone depletion | DALY | 1.16E-09 | 8.61E-10 | -34% |
| Human toxicity | DALY | 1.91E-05 | 1.36E-05 | -40% |
| Photochemical oxidant formation | DALY | 4.35E-10 | 3.04E-10 | -43% |
| Particulate matter formation | DALY | 1.98E-06 | 1.53E-06 | -29% |
| Ionising radiation | DALY | 7.49E-09 | 5.87E-09 | -27% |
| Climate change ecosystems | species.yr[c] | 6.53E-08 | 5.05E-08 | -29% |
| Terrestrial acidification | species.yr | 5.32E-10 | 4.33E-10 | -23% |
| Freshwater eutrophication | species.yr | 3.07E-11 | 2.36E-11 | -30% |
| Terrestrial ecotoxicity | species.yr | 1.92E-09 | 1.58E-09 | -22% |
| Freshwater ecotoxicity | species.yr | 3.04E-11 | 2.27E-11 | -34% |
| Marine ecotoxicity | species.yr | 4.22E-09 | 3.06E-09 | -38% |
| Agricultural land occupation | species.yr | 3.14E-08 | 2.68E-08 | -17% |
| Urban land occupation | species.yr | 8.15E-10 | 5.04E-10 | -62% |
| Natural land transformation | species.yr | 2.91E-08 | 2.23E-08 | -30% |
| Metal depletion | $[d] | 1.09E-02 | 6.93E-03 | -57% |
| Fossil depletion | $ | 1.63E-01 | 1.23E-01 | -32% |

[a]Impact variation: (AerPack score-XrPet measure score)/(AerPack score). [b]DALY (Disability-Adjusted Life Year): a measure of the overall severity of a disease, expressed as the number of years lost due to illness, disability or premature death. cSpecie.yr: a measure of the extinction rate that is the loss of species during a year. [d]$: a measure of surplus costs of future resource production over an infinitive timeframe, considering a 3% discount rate. The unit is 2000US$.

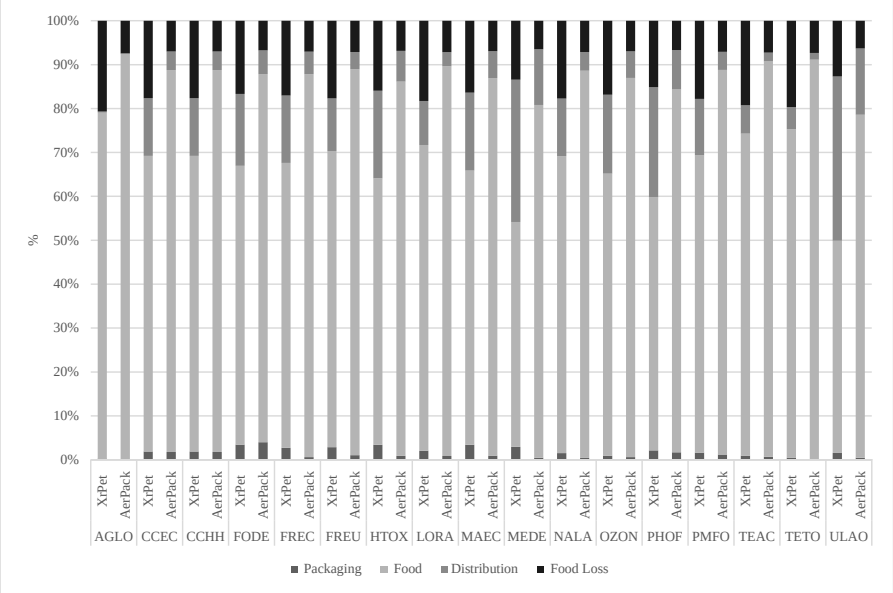



Figure 5. Characterization results in percentage.

AGLO: agricultural land occupation; CCEC: climate change ecosystems; CCHH: climate change human health; FODE: fossil depletion; FREC: freshwater ecotoxicity; FREU: freshwater eutrophication; HTOX: human toxicity; LORA: ionising radiation; MAEC: marine ecotoxicity; MEDE: metal depletion; NALA: natural land transformation; OZON: ozone depletion; PHOF: photochemical oxidant formation; PMFO: particulate matter formation; TEAC: terrestrial acidification; TETO: terrestrial ecotoxicity; ULAO: urban land occupation.

The contribution of XrPet packaging, in percentage terms, to the score of each endpoint indicator does not vary very much; figure 5 shows that the impact of packaging varies between 0% (terrestrial ecotoxicity, agricultural land occupation) and 3% (metal depletion, fossil depletion). Overall, the contribution of food ingredients and processing is the highest in both solutions. The distribution phase results provide a very clear picture: the producer makes more trips to deliver the XrPet product in the 28 day time span than for the AerPack product. Thus the environmental impact of distribution is greater in the XrPet. The impact of food loss is significant less in both solutions when shelf life is taken into consideration

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compared with the XrPet case in which shelf life is not considered (Figure 2). However, the AerPack packaging solution, with its longer shelf life, performs the best overall, leading to a set of smaller environmental indicator scores.

In order to simplify the interpretation of this product comparison, the indicator scores for the damage categories, taking into consideration shelf life, are also presented (Table 7). A higher general environmental impact is observed for the XrPet solution in the packaging and food loss phases.

Table 7. Damage categories accounting for the different shelf life durations, ReCiPe

| Damage category | Alternative | Unit | Packaging | Food | Distribution | Food_Loss | |
|---|---|---|---|---|---|---|---|
| Human Health | XrPet | DALY[a] | 9.21E-07 | 2.12E-05 | 5.67E-06 | 5.56E-06 | 3.34E-05 |
| | AerPack | | 3.08E-07 | 2.12E-05 | 1.42E-06 | 1.71E-06 | 2.46E-05 |
| Ecosystems | XrPet | species.yr[b] | 1.94E-09 | 9.33E-08 | 1.36E-08 | 2.45E-08 | 1.33E-07 |
| | AerPack | | 1.06E-09 | 9.33E-08 | 3.41E-09 | 7.53E-09 | 1.05E-07 |
| Resources | XrPet | $[c] | 5.96E-03 | 1.09E-01 | 3.01E-02 | 2.85E-02 | 1.74E-01 |
| | AerPack | | 4.98E-03 | 1.09E-01 | 7.53E-03 | 8.78E-03 | 1.30E-01 |

[a]DALY (Disability-Adjusted Life Year): a measure of the overall severity of a disease, expressed as the number of years lost due to illness, disability or premature death. [b]Specie.yr: a measure of the extinction rate that is the loss of species during a year. [c]$: a measure of surplus costs of future resource production over an infinitive timeframe, considering a 3% discount rate. The unit is 2000US$.

Figure 6 reports the normalized results with respect to the European average. For both packaging solutions, the human health category is the most affected followed by resources, although the overall impact of XrPet is again confirmed to be higher. Once again, the greatest differences are observed in relation to packaging and food loss. Also in this case, the ReCiPe normalized results confirm that the AerPack solution has a lower environmental impact than the XrPet.



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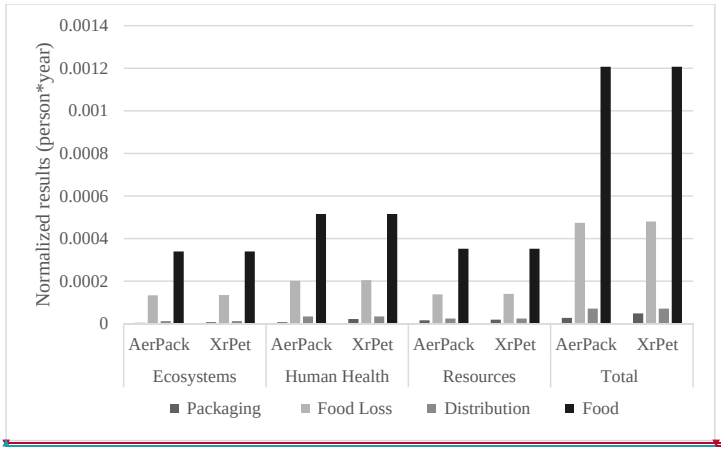



Figure 6. Normalized results

## 6. Conclusions

This paper applies LCA to help understand how an extension in shelf life associated with a different food packaging technology can improve the economic and environmental sustainability of a typical cheesecake. As far as economic sustainability is concerned, a change in the packaging technology allows the cheesecake producer to minimize transport costs and generate economies of scale in manufacturing due to the ability to keep the product fresh longer. The decrease in average costs indeed is due to the decrease in average variable costs and to shelf life change. This result also reduces the minimal efficient scale of production and is particularly relevant for companies belonging to the small or medium sized businesses. The downsizing minimal scale of production indeed allow wider profit margin, as well as the resilience in the market.

According to the LCA results, the extended shelf life associated with the AerPack packaging solution also has positive consequences on environmental sustainability. Unlike Conte et al., (2015), which provide an eco-indicator able to quantify the environmental indirect effects related to the different choices in the food packaging, we utilized, in order to define the



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The weighted results (Figure 7) confirm that the AerPack solution is more sustainable from an environmental point of view. The improvements achieved through use of the AerPack solution would favour a more sustainable production and sale of cheesecakes.¶

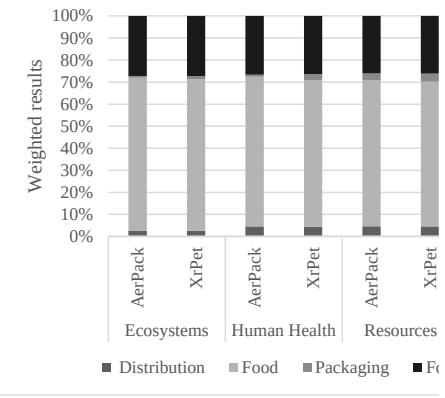



Figure 7. Weighted results for the multiple impact categories taking into account the different shelf life durations of the XrPet and AerPack packaging solutions.¶

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impact of shelf life on food losses, an economic model that considers the minimum amount of product delivered on consignment that must to be sold. The shelf life and the food losses of products associated with XrPet and AerPack packaging were then assessed according to consumers buying habits. One possible selling distribution is considered to hypothetically verify the advantages caused by the extended shelf life. In this sense, the analyses applied in the present work were able to help us understand the ecological and economic impact of different packaging solutions and thus provide a guide for food producers on decision-making processes over packaging choices, such that the right balance between food losses and environmental impact can be identified.

**Acknowledgements**

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**References**

Albrecht, S., Brandstetter, P., Beck, T., Fullana-i-Palmer, P., Grönman, K., Baitz, M., Deimling, S., Sandilands, J., & Fischer, M. (2013). An extended life cycle analysis of packaging systems for fruit and vegetable transport in Europe. *International Journal of Life Cycle Assessment*, 18, 1549–1567.

Bottani, E., Rizzi, A. & Vignali, G. (2015). Improving logistics efficiency of the industrial districts: a framework and case study in the food sector. *International Journal of Logistics: Research and Applications*. 18, (5), 402-423.

Spostato (inserimento) [1]

Conte, A., Cappelletti, G.M., Nicoletti, G.M., Russo, C., & Del Nobile, M.A. (2015). Environmental implications of food loss probability in packaging design. *Food Research International*, 78, 11-17.

Christiansen, K., de Beaufort-Langeveld, A. van den Berg, N., Haydock M., ten Houten, R., Kotaji, S., Oerlemans, E., W. P., Schmidt, W.P., A., Weidenhaupt, A., & White R., (1997). *Simplifying LCA: Just a cut?* Final report from LCA screening and streamlining working group. SETAC-Europe, Brussels.

European Commission (2012). *Life cycle indicators framework: development of life cycle based macro-level monitoring indicators for resources, products and waste for the EU-27*. European Commission, Joint Research Centre, Institute for Environment and Sustainability.

European Commission (2010). *Final Report: Preparatory Study on Food Waste Across EU 27*. European Commission, Joint Research Centre, Institute for Environment and Sustainability.

Ferreira, S., M. Cabral, N.F. da Cruz, P. Simões, and R.C. Marques (2016). The costs and Benefits of packaging waste management systems in Europe: The perspective of local authorities. Journal of Environmental Planning and Management. Routledge. ISSN: 0964-0568. (Forthcoming).

Ferreira da Cruz, N. Ferreira, S., Cabral, M., Simoes, P., & Cunha Marques, P. (2014a). Packaging waste recycling in Europe: is the industry paying for it?. *Waste Management*, 34, 298-308.

Ferreira da Cruz, N., Simoes, P., & Cunha Marques, P. (2014b). Costs and Benefits of packaging waste recycling systems. *Resource, Conservation and Recycling*, 85, 1-4.

Frischknecht, R., Althaus, H.J., Bauer, C., Doka, G., Heck, T., Jungbluth, N., Kellenberger, D., & Nemecek, T. (2007). The Environmental Relevance of Capital Goods in Life Cycle Assessments of Products and Services. *The International Journal of Life Cycle Assessment*.



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Goedkoop, M.J., Heijungs, R., Huijbregts, M., De Schryver, A., Struijs, J., &Van Zelm, R. (2009). *ReCiPe 2008, A life cycle impact assessment method which comprises harmonised category indicators at the midpoint and the endpoint level*; First edition Report I: Characterisation; available at http://www.lcia-recipe.net

Gunders, D. (2012). *Wasted: how America is losing up to 40 percent of its food from farm to fork to landfill*. NRDC, Issue Paper. http://www.nrdc.org/food/wasted-food.asp.

Istat (2011). *Industries and services census data, year 2011*. Available at http://dati-censimentoindustriaeservizi.istat.it/

JRC (2011), Supporting Environmentally Sound Decisions for Bio-Waste Management. A practical guide to Life Cycle Thinking (LCT) and Life Cycle Assessment (LCA) ISBN 978-92-79-21019-8

Manfredi, M., Fantin, V., Vignali, G. & Gavara, R. (2015). Environmental assessment of antimicrobial coatings for packaged fresh milk. *Journal of Cleaner Production* 95, 291-300.

Manfredi, M., & Vignali, G. (2014). LCA of A Packaged Tomato Puree: A Comparison of Environmental Impacts Produced by Different Life Cycle Phases. *Journal of Cleaner Production* 73, 275–284.

Mostafalou, S. & Abdollahi, M. (2013). Pesticides and human chronic diseases: Evidences, mechanisms, and perspectives. *Toxicology and Applied Pharmacology* 268 (2), 157-177.

Nguyen, S. V. & Reznek, A. P. (1991), Returns to Scale in Small and Large U.S. Manufacturing Establishments, *Small Business Economics* 1, 29-46. Reprinted in Small Firms and Economic Growth, J. Acs; (ed.), The International Library of Critical Writings in Economics Series, No. 61, 1996.

Perugini, F., Mastellone, M.L., & Arena, U. (2005) A Life Cycle Assessment of Mechanical and Feedstock Recycling Options for Management of Plastic Packaging Wastes, Environmental Progress, 24, 2, 137-154.



**Codice campo modificato**

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**Formattato:** Inglese (Regno Unito)

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Pimentel, D.; Acquay, H.; Biltonen, M.; Rice, P.; Silva, M.; Nelson, J.; Lipner, V.; Giordano, S., Horowitz A. & D'amore, M. (1993). *Assessment of environmental and economic impacts of pesticide use*. In The pesticide question: environment, economics, and ethics; Pimentel, D.; Lehman, H.; Eds.; Chapman & Hall: New York and London, pp 47-84.

Pimentel, D. & Burgess, M. (2014). *Environmental and economic costs of the application of pesticides primarily in the United States.* In Integrated Pest Management. Pimentel D, Peshin R, editors. New York, Heidelberg, Dordrecht, London: Springer Science + Business Media Dordrecht, 47–71.

Silvenius, F, Grönman, K., Katajajuuri, J., Soukka, R., Koivupuro, H., & Virtanen, Y. (2014). The role of household food waste in comparing environmental impacts of packaging alternatives. *Packaging Technology and Science*, 27, 277–292.

Siracusa, V., Ingrao, C., Lo Giudice, A., Mbohwa, C., & Dalla Rosa, M. (2014). Environmental assessment of a multilayer polymer bag for food packaging and preservation: An LCA approach. *Food Research International*, 62, 151–161.

Wikström, F., H. Williams, K. Verghese, & Clune, S. (2014). The influence of packaging attributes on consumer behaviour in food-packaging life cycle assessment studies – a neglected topic. *Journal of Cleaner Production*, 73, 100–108.

Williams H., & Wikström F. (2011). Environmental impact of packaging and food losses in a life cycle perspective: a comparative analysis of five food items. *Journal of Cleaner Production*, 19, 43–48.

WRAP (2009). Household Food and Drink Waste in the UK. Report prepared by Wastes & Resources Action Programme. Banbury. ISBN: 1-84405-430-6. http://www.wrap.org.uk/.

WRAP (2011).Packaging design to reduce household meat waste. Report prepared by Wastes & Resources Action Programme and Giraffe Innovation Ltd. www.wrap.org.uk/retail.



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Codice campo modificato

Zhang, H., Hortal, M., Dobon, A., Bermudez, J.M. & Lara-Lledo, M. (2015). The Effect of Active Packaging on Minimizing Food Losses: Life Cycle Assessment (LCA) of Essential Oil Component-enabled Packaging for Fresh Beef. *Packaging Technology and Science*, 28, 761–774.

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