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NOTA TÉCNICA

Design of a sustainable, intelligent and interconnected food container following Cradle to the Cradle principles and using Life Cycle Analysis for the evaluation of environmental impacts

Diseño de un envase para alimentos sostenible, inteligente e interconectado siguiendo los principios de la cuna a la cuna y utilizando el Análisis del Ciclo de Vida para la evaluación de impactos ambientales

Projeto de um contêiner de alimentos sustentável, inteligente e interconectado, seguindo os princípios do berço ao berço e usando a Análise do Ciclo de Vida para avaliar os impactos ambientais

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RESUMEN

El objetivo principal de este trabajo es ayudar a combatir las pérdidas de alimentos en la cadena productiva, uno de los principales problemas de la industria alimentaria actual, incorporando conceptos de sostenibilidad. Según la FDA, cada año se arrojan alrededor de 1.300 millones de toneladas de alimentos. Los alimentos se desperdician principalmente a nivel de los hogares, por lo que se elige el diseño sostenible de un envase inteligente interconectado para uso doméstico. Para lograr esto, se exploran diferentes tecnologías, materiales, metodologías y marcos innovadores. En cuanto a los materiales, se estudiaron plásticos biodegradables, reciclados, reciclables y bioplásticos y se investigó la tecnología inteligente a utilizar, en este

caso sensores. Respecto a las metodologías, se hace un estudio del Análisis del Ciclo de Vida (ACV) y la filosofía Cradle to Cradle (C2C). Los sistemas inteligentes de envasado son una opción para contribuir a minimizar el desperdicio de alimentos. El uso correcto de herramientas como el ACV, junto con los principios del C2C y la investigación sobre materiales y tecnologías pueden ayudar a los diseñadores a alcanzar una solución óptima que minimice los impactos ambientales.
PALABRAS CLAVE: Economía circular, impacto ambiental, ecodiseño, envases inteligentes, industria alimentaria.

ABSTRACT

The main objective of this work is to help combat food losses in the production chain, which is one of the main problems of the food industry today, incorporating also sustainability concepts. According to the FDA each year about 1,300 million tons of food are thrown. Food is wasted mainly at household levels, which is why the choice of the sustainable design of an intelligent interconnected packaging for domestic use is made. To achieve this, the exploration of different technologies, materials, methodologies and innovative frameworks is carried out. Regarding materials, the possibility of using biodegradable, recycled, recyclable and bioplastics was studied, along with the research of the intelligent technology to use, which ended up being sensors. As to methodologies, Life Cycle Analysis (LCA) and Cradle to Cradle philosophy (C2C) are studied. Intelligent packaging systems are an option to contribute to minimization of food waste. The correct use of tools such as the LCA, along with the principles of the C2C, and the research on materials and technologies to be used can help designers to reach an optimal solution, minimizing environmental impacts.
KEYWORDS: Circular economy, environmental impact, ecodesign, smart packaging, food industry.

RESUMO

O principal objetivo deste trabalho é ajudar a combater as perdas de alimentos na cadeia produtiva, um dos principais problemas da atual indústria de alimentos, incorporando também conceitos de sustentabilidade. De acordo com a FDA, cerca de 1,3 bilhões de toneladas de alimentos são lançadas a cada ano. Os alimentos são desperdiçados principalmente no nível doméstico, por isso foi escolhido o design sustentável de um contêiner inteligente interconectado para uso doméstico. Para isso, diferentes tecnologias, materiais, metodologias e estruturas inovadoras são exploradas.

Com relação aos materiais, foram estudados plásticos biodegradáveis, reciclados, recicláveis e bioplásticos e investigada a tecnologia inteligente a ser utilizada, neste caso sensores. Com relação às metodologias, foi realizado um estudo da filosofia do Ciclo de Vida (ACV) e da filosofia Cradle to Cradle (C2C).

Sistemas de embalagem inteligentes são uma opção para ajudar a minimizar o desperdício de alimentos. O uso correto de ferramentas como a ACV, juntamente com os princípios do C2C e a pesquisa de materiais e tecnologias pode ajudar os projetistas a alcançar uma solução ideal que minimiza os impactos ambientais.
PALAVRAS-CHAVE: Economia circular, impacto ambiental, design ecológico, embalagens inteligentes, indústria de alimentos.

INTRODUCTION

The problem of food waste

According to Food and Agriculture Organization, "food waste" can be defined as food that is appropriate for human consumption but is discarded before it is spoiled, as a result of negligence or conscious decision to throw away food (Heising, et al., 2017).

Expert advisors to the United Nations estimate that, around the world today, about 30% of the food grown is lost due to deterioration (Russell, 2014). Others are encouraged to say that even 40% of all food intended for human consumption in developed countries ends up being a waste (Heising, et al., 2017). In tons, according to the 2011 FDA report, about 1.3 billion tons of food is thrown away every year (Dobrucka and Cierpiszewski, 2014).

Food waste quantification by category of food in households has been studied by Williams and Wikström (2010), who showed that fruits and vegetables, prepared foods and dairy products are the ones that contribute the most to waste when expressed based on weight (Heising, et al., 2017).

Prevention of avoidable food waste generation along the supply chain represents the most advantageous option within the food waste hierarchy (Heising, et al., 2017) and optimal packaging for each food can help reduce all these numbers.

Promptly in middle and high income countries, food is wasted mainly at retail and consumption levels (Russell, 2014), and this is the reason why this research work is aimed at smart packaging at the domestic level.

The entire value chain has a responsibility to explain that sustainability is not synonymous of recycling, recyclability, recycled content, biodegradability and other buzzwords, but that main efficiency of supply chain resources should be the top priority (Russell, 2014).

Sustainability and packaging

Improving sustainability requires knowledge of complete value chains; focus on one section is insufficient since solving a problem in one place can result in the creation of a different problem in another (Russell, 2014). Specially in terms of packaging, since, due to their inherent dependencies, life cycles of the product/packaging combinations are more complex than the individual life cycles for the products (Abramovici, 2013), as can be seen in Figure 1.

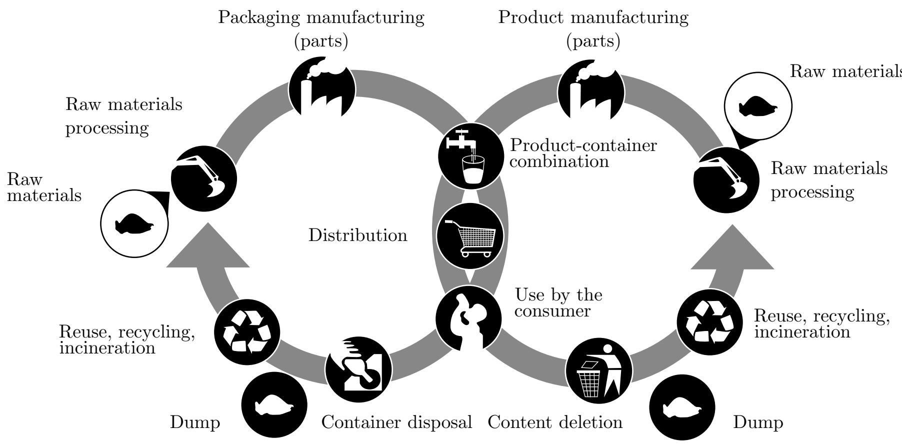

Figure 1. Life cycles of the product, the container and their superposition.

There are many attributes that can contribute to a more sustainable food package, such as it being produced from recycled material, or that it minimizes the use of water, generates zero waste in landfills, has the potential to be reused, is made using renewable energy, does not generate air pollution, does not generate greenhouse gas emissions, protects human health, etcetera. In fact, all these attributes can be valid and valuable, however, no solution meets all sustainability criteria at the same time (Russell, 2014).

The main criterion with which it must comply is to offer, first and foremost, its content to the consumer in good condition (Russell, 2014) because by containing, protecting and preserving its contents, packaging contributes to important social aspects of sustainability, such as health and the need for food (Abramovici, 2013).

For example, when the shelf life of a cucumber can be extended from three days to more than two weeks simply by wrapping it in 1,5 g of packaging, the food supply chain becomes much more sustainable and means that the small amount of polyethylene used is a good candidate to be called ‘sustainable packaging’ (Russell, 2014).

A more comprehensive and integrated approach, which encompasses economic, social and environmental considerations, along with more efficient packaging designs that save materials and are recyclable, is the key to sustainable packaging (Lee and Xu, 2005).

In this context, Life Cycle Assessment (LCA) can be applied as a design support tool to highlight criticisms regarding environmental aspects and improvement solutions in the life cycle of packages, thus promoting the use of greener products (Siracusa, et al., 2014).

For decades, the dominant environmental problems in the packaging area have been optimization of materials and possibilities of recycling, and not the reduction of food losses. However, for all the above, it is concluded that the principle of avoiding food losses should be included in the packaging design if the overall environmental impact of the food packaging system aims to be reduced.

The ideal is to find new packaging solutions that not only reduce the impact of the packaging itself, but also reduce the losses of the food it contains. However, it should be borne in mind that, in some cases, it may be necessary to increase the environmental impact of the new packaging to reduce food losses.

It is important to analyze whether there is a risk that food losses increase when the design of the package changes, for example, when it is sought to reduce the amount of packaging material. The total environmental impact will surely increase if this decision implies an increase in food losses, even if the impact of the packaging decreases.

Environmental impact is generally higher for products of animal origin such as meat and milk than for vegetable products.

Regarding the environmental impact of the food/environmental impact of the container, the following comparison can be made: a refined food product with an animal origin such as cheese has a high environmental impact per kilogram. The polyethylene cheese package has a relatively low environmental impact per kilogram of cheese. This means that large increases in cheese packaging could be justified for a new package that reduces the losses of this product. The F/T ratio (environmental impact of the food/environmental impact of the container) is much lower for ketchup, a refined article with vegetable origin, for which the packaging solution has a high environmental impact. The low F/T ratio indicates that it is probably as important to find packaging systems with less environmental impact than to develop packages that reduce ketchup losses (Williams and Wikström, 2010).

Moreover, consumer behavior has probably the greatest potential to reduce food losses, and packaging can influence their behavior through the provision of information and/or technical solutions. Printed information on how to store the contents, how to improve interpretation of expiration dates, etcetera, may affect this parameter, so it is important to carry out research on the extent to which losses can be influenced by the communication power of the packaging.

Smart packaging in the food industry

New packaging solutions allows to improve the economic aspect of food waste and the interest in active and intelligent packaging is increasing. This is reflected in the number of patent applications and patents granted in recent years (Barska and Wyrwa, 2017).

One of the major causes of waste is fixed expiration dates, since consumer's willingness to pay for a food product generally decreases if there are fewer days left before the expiration date. This means that as soon as a new batch of product with a longer shelf life enters the supermarket, consumers will probably buy these new products instead of the older ones, and after the expiration date the supermarket will have to discard those products (Heising, et al., 2017).

Therefore, there are studies that propose the establishment of a dynamic expiration date, with a potentially dynamic price, that is, lowering the price as the expiration date approaches. In this system, the price of the food is automatically adapted from an electronic signal of a quality sensor, depending on the expected remaining useful life, influencing the purchase decision of consumers and, as an expected result, should have a lower number of expired products before sale and consumption, thus reducing avoidable food waste (Heising, et al., 2017). This is possible with smart packaging. Deterioration of the intrinsic quality attributes of food products must be studied in depth to determine which smart packaging concept is the most useful for implementing and monitoring or ensuring good product quality.

Smart containers are systems used to detect, perceive and record any changes within the package (Mohebi and Marquez, 2015) during their life cycle and communicate this information related to the quality or safety of the packaged product (Heising, et al., 2017) in order to improve safety and quality as well as to warn about possible problems during transport and storage of food (Mohebi and Marquez, 2015). These use properties or components of the food or some material of the container as indicators of the history and quality of the product. Unlike active packaging, smart ones do not intend to release components into the food (Biji, et al., 2015).

These containers are based on two systems. The first one is based on the measurement of the conditions outside the packaging, while the second one measures directly the quality of the food products inside the packaging and can come into direct contact with the food, therefore, additional safety and quality controls are required (Barska and Wyrwa, 2017).

The appearance of intelligent packaging systems has contributed to a significant change in the existing perception of packaging, since they transform traditional functions of communication into intelligent communications (Barska and Wyrwa, 2017), thus forming an extension of the function of communication of traditional packaging (Biji, et al., 2015).

If this technology were combined with low impact packaging systems, there would be an increase in the environmental sustainability of the food packaging and preservation solution. In addition to this, if the food contained were produced using processes and products with low environmental impact, all packaged food would be more sustainable (Siracusa, et al., 2014).

Objective

The objective of this research work is the design of an intelligent interconnected container of rigid plastic, whose main specification is the storage of climacteric fruits in the refrigerator of a standard household and monitor the ethylene content. At the same time, it aims to inform consumers, through Bluetooth connection, that the fruit it contains is at its optimal date of consumption, thus avoiding food waste.

This package is designed in a way that can be transported from home to the supermarket every time a purchase is made, which means savings in disposable plastic containers used in the packaging of this type of products. It is made of plastic in order to adapt, since it is in this material that most of the innovations for packaging are made. Its resistance property is prioritized, as it is key to achieving the desired useful life.

Sensors will be the chosen technology for the intelligent part of the package, since they are the most successful technology for the detection of volatile compounds such as ethylene. Compared to indicators, sensors are faster, more precise and reliable, and they also provide necessary information on the quality of food in real time. The chosen sensors are called MOSFET and it is of special relevance that the reaction with ethylene has reversibility, since the container will be reused.

For its design, Cradle to Cradle principles are considered and after the container is designed, Life Cycle Analysis is performed in order to look for the process optimization points.

MATERIALS AND METHODS

Materials

Evaluation of materials to use

Bioplastics and biodegradable plastics

To declare that a product is more sustainable it is not enough to know what raw material is used for its manufacture, it is also necessary to understand where and how that raw material is produced. Then there are confusing terms like 'bioplastic'. This may mean what is best described as 'bio-based' plastic produced from renewable raw material sources or it may mean 'biodegradable' plastic. The former refers only to the origin of the raw materials from which plastics are manufactured, while the latter is about its end of life. The key point is that biologically-based plastics may not be biodegradable (for example, biologically based polyethylene) and a biodegradable plastic may not be biologically based (for example, fossil-based aliphatic-aromatic copolyesters that are used to make biodegradable films) The main challenge for raw materials of biological origin is that conversions are required to move from biological raw materials to useful molecules. Usually, that requires energy (about twice the energy for polyethylene obtained from sugarcane than for synthetic polyethylene), and if that energy is supplied by fossil fuels, which it usually is, then emissions from CO_2 can be increased instead of decreased (Russell, 2014).

In addition, the environmental advantages of the new biological materials are sometimes less than the expected due to comparatively high energy consumption in one or more of the production stages. This is also due in part to the fact that these materials have a less favorable barrier and mechanical properties, resulting in greater material inputs (Hermann, et al., 2010).

As for biodegradable plastics, although the biodegradability that supports compostability according to national standards such as UNE-EN 13432 (Asociación Española de Normalización y Certificación, 2001) is a useful property for specific applications in locations where industrial composting facilities exist, it is not a universal solution for the sustainable management of packaging waste or a viable solution to problems such as garbage, which is a problem of social behavior and should be addressed as such (Russell, 2014).

Recycled raw material and recyclable containers

If recycled polymers were used, impacts due to the production phase would decrease proportionally. On the other hand, if packages are produced to be recyclable after disposal, impacts due to the end of life would be reduced (Siracusa, et al., 2014).

Collecting and recycling used containers helps preserve the financial and energy inputs that came in to create the material and reduce environmental burdens by not requiring the creation of new packaging material, but only to the point where collection, classification, cleaning and reprocessing is cheaper, requires less energy and causes less unwanted emissions than virgin packaging production. In addition, the more dispersed or contaminated the packaging material is, the less sustainable its mechanical recycling will be (Russell, 2014).

When considering a Life Cycle Analysis, it is clear that single-layer packaging is more desirable from an environmental point of view, since, in principle, it uses less material and energy in its manufacture. But we must also consider that multilayer packaging is having a great impact on the market because it provides the product a longer shelf life and therefore needs less energy for its conservation and distribution (Lee and Xu, 2005). This is what will be prioritized in this study.

In addition, it is essential to obtain containers and films with good gas barrier properties for the packaging of perishable products such as food and beverages, and for this the need to manufacture this type of packaging is often imperative.

A bilaminar plastic container was then chosen, with PET in the outer layer and HDPE in the inner layer. As an adhesive that joins both layers, the commercially known copolymer Surlyn is used since a correct behavior was observed in the research work carried out by Guerrero and Arroyo (2003).

The chosen criteria were costs, availability and properties (high hardness, washability, aptitude for food contact, low oxygen permeability and low water vapor permeability).

Methods

Cradle to Cradle (C2C)

Cradle to Cradle (C2C) is an innovation framework used since the 1990s in order to design products and services that are beneficial in economic, health and environmental terms to achieve a sustainable world (Ankrah, et al., 2015).

Conceived by architect William McDonough and chemist Michael Braungart, it proposes to replace eco-efficiency with eco-efficacy and has as its mother premise that a closed cycle system does not need to be eco-efficient (reduce the use of resources and waste) because the more waste is generated, more nutrients are available to produce new products (Kausch and Klosterhaus, 2016).

A comparison between eco-efficiency with eco-efficacy can be seen in Figure 2.

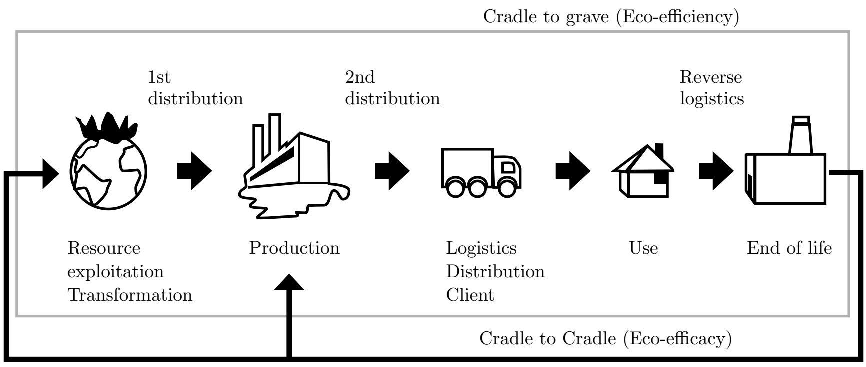

Figure 2. Comparison between eco-efficiency (Cradle to grave) and eco-efficacy (Cradle to Cradle).

It is proposed that eco-efficiency is a reactionary approach that does not address the need for a fundamental redesign of industrial material flows and is primarily a strategy for damage management and the reduction of guilt. Cradle to Cradle is based on the premise that making small changes in a system that is fundamentally incorrect and can never achieve anything 'good', it will only reduce the 'bad things' just a little (Hesselbach and Herrmann, 2011).

In C2C the assumption that industry inevitably destroys the natural environment is rejected, recognizing the potential within the economy of abundance, the power of ingenuity, creativity and prudence, imagining systems that, together with their technical functionality, purify water, the atmosphere and the soil, helping nature create environmental value (Peralta-Álvarez, et al., 2011).

The two cycles of C2C

C2C states that, for the flows generated by the industry, two possible metabolic pathways associated with a technosphere and a naturesphere are established and must be considered in the design of industrial products and systems (Peralta-Álvarez, et al., 2011).

Biological nutrients are metabolized and regenerated by the naturesphere (Peralta-Álvarez, et al., 2011) and are defined as: "A material used by living organisms or cells to carry out vital processes such as growth, cell division, carbohydrate synthesis and other complex functions. They are materials that can be biodegraded safely" (Hesselbach and Herrmann, 2011).

Technical nutrients, which make up the technosphere, are defined as: "A material that remains in a closed cycle manufacturing, reuse and recovery system called technical metabolism, maintaining its value through infinite product life cycles." (Hesselbach and Herrmann, 2011)

Metabolisms in C2C

Three metabolisms are recognized for the products.

The first is infra-recycling (or downcycling), where the materials and the product lose quality and the only thing that is achieved is to postpone its disposal or its arrival to landfills, slowing down its destructive cycle. It reveals a poor design of life cycle and material flow (Peralta-Álvarez, et al., 2011).

The second metabolism is supra-recycling (or upcycling), where it is possible to transform materials or an unused product, destined to be waste, into another of equal or greater utility or value, since they are designed to close cycles and maintain its status as a source. These routes give rise to more valuable materials becoming privileged for the ecodesign of products and industrial ecology (Peralta-Álvarez, et al., 2011). This is what the Cradle to Cradle philosophy points to, where mere recycling is not enough (Toxopeus, et al., 2015).

The last metabolism that arises is the cascade model, where the materials are kept within a technical cycle for a certain amount of iterations, while losing the properties before returning to the biological cycle (Toxopeus, et al., 2015). Paper recycling is a typical example of the waterfall model within the Cradle to Cradle design paradigm.

It must be decided at an early stage whether a material will be used in a technical context or in a biological context (NL Agency, 2011) and biological and technical nutrients should not be mixed. Otherwise, the product created does not fit the biological nor technical metabolism. Such a product can never be truly recycled, but simply degraded to a product of lower quality and value (Hesselbach and Herrmann, 2011).

Non-renewable materials should flow to industrial systems to act as nutrients in the manufacture of new products (Toxopeus, et al., 2015).

C2C Principles

The Cradle to Cradle paradigm is based on three fundamental principles.

The first is about conception of garbage as food; instead of the eco-efficient approach of trying to reduce the amount of waste, the approach should be to design systems with products that other processes can take as nutrients (Hesselbach and Herrmann, 2011).

The products and components should be designed to facilitate the disassembly of the material and the materials should be intelligently combined keeping their integrity intact after their useful life (Ankrah, et al., 2015).

This principle also incorporates the issue of toxicity of the material, with the aim of ensuring that the materials used in the production of components are not less toxic but directly non-toxic and non-hazardous and, when it is impossible, to obtain non-toxic replacements, measures must be taken to keep toxic materials in a continuous closed circuit (Ankrah, et al., 2015).

The second principle is the use of sustainable energy; the energy demanded from industrial activity should be obtained from renewable sources preferably, such as energy from the sun or other forms of renewable energy that are mainly driven by the sun's radiation: wind, geothermal, hydroelectric and bioenergetic (Ankrah, et al., 2015).

Within the design paradigm, it is assumed that these renewable energy sources are widely and abundantly available without practical restrictions (Toxopeus, et al., 2015).

The third principle is based on celebrating diversity and its objective is to avoid uniform solutions (one-size-fits-all) and, instead, to design products and systems with local environments, economies and cultures in mind, under the premise: "Industries that respect diversity are related to local flows of materials and energy, and to local social, cultural and economic forces, rather than seeing themselves as autonomous entities, disconnected from the culture or landscape that gives them surrounds" (Hesselbach and Herrmann, 2011).

To improve the resistance of a system, diversity is necessary. Focusing on a criterion could cause instability and imbalance in a broader context (Toxopeus, et al., 2015).

Life Cycle Analysis (LCA)

LCA is a methodology developed in the 1970's to measure the impact of a product, service or process throughout its life cycle (from when raw materials are obtained until their end of life and subsequent management). It is based on the collection and analysis of the inputs and outputs of the system (natural resources, emissions, waste and by-products) to obtain quantitative data of its potential impacts on the environment, in order to determine strategies for minimization or reduction (Guzmán Vargas and Gutiérrez Fernández, 2016). The LCA considers inputs (raw materials and energy) and products (emissions to air, soil and water) in each phase of the life cycle of the product and states that all the stages involved in the life cycle of a product/activity have a responsibility for its environmental consequences. At the same time, LCA does not result in a rating of what is "more sustainable", but offers a platform to compare alternatives (NL Agency, 2011).

Once a project has been completed, the value of an LCA lies in the opportunity to assess the environmental impact of the finished design and integrate this knowledge into new or follow-up projects. In fact, one of the purposes of LCA in ecological design is the identification of critical environmental points. This analysis helps product developers prioritize areas for improvement after the LCA (NL Agency, 2011).

To the extent that by the application of LCA opportunities for improvement are identified and effectively implemented in the product, an improvement in the environmental performance of that product will also have been achieved (Romero Rodríguez, 2010).

LCA phases

LCA develops in four phases.

The first phase is the definition of the objectives and scope, covering the overall objectives of the LCA, its purpose, the product involved, the scope or magnitude of the analysis (system limits), the functional unit, the necessary data and the type of critical review to be performed (Sanz, et al., 2008). In the case study, the objective is defined as the identification and quantification of the different environmental impacts throughout the life cycle of the container to contribute to achieve an ecodesign. The functional unit is a smart plastic interconnected bilayer PET/HDPE container of 5000 cm^3 volume for (mainly climacteric) fruit packaging in the refrigerator. As for the materials, 2148,91 g of PET, 987,71 g of HDPE and 235,24 g of Surlyn per container will be used.

Regarding the scope of the study, it includes the extrusion of PET and HDPE granules, the coextrusion of the laminates obtained, the thermoforming of the final container, coupling of the sensors in the container, distribution of the containers in the Spanish territory, use of the container, and its disposal at the end of its useful life.

Phase two is the inventory analysis. It involves the elaboration of a quantified list of all the incoming and outgoing flows of the system throughout its useful life, which are extracted from the natural environment or emitted to it, calculating the energy and material requirements of the system and the energy efficiency of its components, as well as the emissions produced in each of the processes and systems (Sanz, et al., 2008).

A very important factor is the quality of the data, which in general is collected from various sources. Usually, the favorite source for researchers is the one that involves people who work in the sector and their respective registries (Cappelletti, et al., 2010).

In the case of this article, as it constitutes a theoretical study, SimaPro software of the Pre consultants (Netherlands) was used as the main source for the life cycle inventory.

The third phase consists of the impact assessment. According to the inventory list, a classification and evaluation of the inventory results is made, and its results are related to observable environmental effects (Sanz, et al., 2008).

In the evaluation phase, the results of the inventory (inflows and outflows of flows to the environment) are classified according to the category(ies) of environmental impact to which they contribute. The characterization includes three main aspects: the consumption of natural resources, human health and the quality of the ecosystem (Rivela, et al., 2013). Ecoindicator 99 is used, so the scope of this LCA also covers the following impacts: climate change, depletion of the ozone layer, acidification / eutrophication (combined), carcinogenesis, respiratory organic compounds, inorganic respiratory compounds, radiation ionizing, ecotoxicity, land use, mineral resources and fossil resources.

Subsequently, models are applied to obtain an environmental indicator in each impact category, unifying to a single reference unit all the substances classified within each category through the use of equivalence factors (Rivela, et al., 2013).

The last phase of LCA is the interpretation of results.

The LCA method is dynamic, and the four stages in which it is performed are related to each other, so that as results are obtained, data, hypotheses, system limits or objectives can be modified or improved, which requires a recalculation of the study (Sanz, et al., 2008).

RESULTS AND DISCUSSION

Application of C2C to the case study

To comply with principle 1, where any output from one system must be the input of another, since the material cannot be recycled because it is a bilayer container, and as the study is carried out in Spain, incineration with energy recovery will be sought, so that that energy constitutes an input for another or the same process. As for the sensors, the considered option is to keep them in a closed cycle agreed with the producer.

In addition, materials used in production should not be toxic or dangerous. This is a compromise for the present package since, after the LCA was performed, high values were observed in that aspect. It is emphasized that electronic components comply with Directive 2002/95/EC (European Union, 2003) on restrictions on the use of certain hazardous substances in electrical and electronic equipment.

A meticulous analysis could also be made regarding the chosen plastics and the adhesive selected to bond them, in order to zero any potential dangerous or toxic substance that may appear in the system.

It is highlighted that, as part of the eco-design (fundamental pillar of the C2C methodology), the packaging in question is dismantlable, which will facilitate its disposal at the end of the useful life.

In order to comply with the use of sustainable energy, it is proposed that renewable energy could be used to meet the energy requirements of most processes in the life cycle of the packaging system, thus reducing global warming and the use of fossil fuels (Siracusa, et al., 2014).

SimaPro Software does not contemplate the use of renewable energies so, for the phase of use of the container, an electric energy mix obtained from non-renewable sources corresponding to the Spanish territory was considered. For the extrusion, co-extrusion and thermoforming phases, the corresponding options are available in the Software.

A study can be done on how the values obtained would change if wind, water or solar energy were used instead of electric energy obtained from non-renewable sources, for example. At this point it is relevant to discuss the use of “renewable energy credits”, which can be purchased by any company, also by packaging producers. In addition, these credits are more likely to be purchased by companies at the converter level of plastic (producers, for example, of PET containers from granules), and less by large-scale producers of petrochemical materials (for example, PET granules), since the former, being closer to final consumers, have a greater potential interest in improving the environmental profile of their packaging (Hermann, et al., 2010).

Regarding the technology used, it is important not to ignore that at the moment investigations of design and manufacture of different gas sensors that can work without power supply are being carried out, especially coupled to RFID tags, although none of them are yet in the market.

In terms of energy efficiency, the activity time of the sensors could be managed, trying to minimize it either by optimizing the operation of the chosen sensors, or by choosing sensors that operate for a shorter time. A meticulous study could also be done on the consumption of available sensors in order to choose the one that consumes the least by providing the same functions. In this work, sensors that have a saving mode were used, which greatly relieves the electric consumption load that falls on the sensor. At this point the option of using conductive polymers is suggested, since their operating temperature is low (<122°F), so, in principle, they would spend less than the chosen sensors. Likewise, this is presented as an idea since there is no research on this type of sensors for the measurement of ethylene in fruits and at the same time the same low operating temperatures make them extremely sensitive to moisture.

The third principle, celebrating diversity, has as its main objective to avoid uniform solutions (one-size-fits-all). In the case study, the package was designed for climacteric fruits, contemplating their behavior and compounds emitted during ripening, so it is not a solution for all types of fruit.

Also, it was considered that all raw material suppliers are Spanish, so that it contributes to the increase of local employment, in addition to the fact that if the production plant were installed it would be installed in Spain, since the study was done assuming this, generating training and employment opportunities.

LCA Results

After performing the LCA, a great impact on the "resources" category of used plastics is observed, which was previously suspected because, as specific physicochemical properties are looked for in the container, bioplastic materials could not be used for this type of packaging.

A high impact of electronic components in general and especially in the category of human health is also observed, which in turn is the second category with the greatest impact of the product. This high contribution is probably due to the composition of the elements, which is why the electronic sector is urged to focus its research and development towards that area, in order to create components that are less harmful to the environment.

PET is seen as the element with the greatest global impact, which reinforces the idea of orienting the selection of plastics for the packaging towards a more environmental and not so economic profile, in order to contribute in this area.

Unlike other Life Cycle Analysis observed in literature referring to non-intelligent packaging, the transport phase does not imply a high environmental impact. This shows that when an intelligent system is added to the packaging, the environmental load is relocated, going from transport to intelligent system. In this observation lies the main contribution of the present research, since the vast majority of LCAs observed in literature are referred to non-intelligent packaging, as for example the one carried out in Madival et al., 2009.

These assessments are shown in Figure 3.

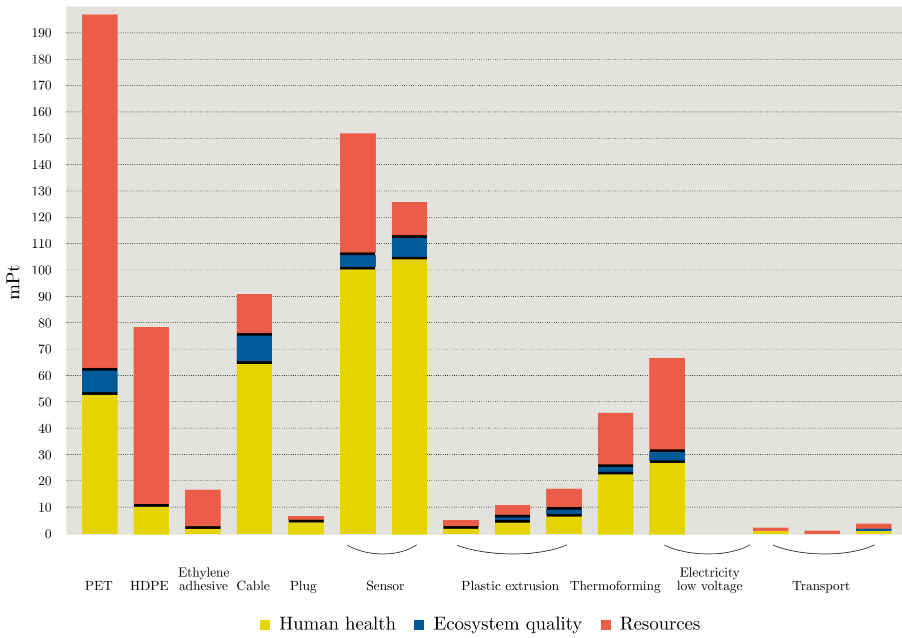

Figure 3. Standardized impacts per component for the different components of the interconnected smart container using SimaPro software.

CONCLUSIONS

Intelligent packaging systems are an option to contribute to the minimization of food waste, which is one of the main problems in the food industry today. Tools to assess sustainability such as Life Cycle Analysis can help evaluate environmental impact of the proposed solution.

In addition, this work seeks to encourage product designers to do so in a more sustainable way, following eco-design criteria when launching projects. The necessary tools are provided, and special emphasis is placed on tracking the product 'from cradle to cradle'.

It is observed that the choice of intelligent packaging technology and the characteristics of the package in general (chosen material, thickness, dimensions) intrinsically depend on the food to be controlled, whose properties and behavior must be studied meticulously in order to find the optimal packaging solution for each food.

In the case study, the greatest environmental impact is found in the production of PET, and then on the electronic components.

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