SUSTAINABILITY ASSESSMENT IN PRODUCT DEVELOPMENT PROJECTS

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ABSTRACT
Sustainable product development initiatives have been evolving for some time to support companies improve the efficiency of current production and the design of new products and services through supply chain management. The development of an Eco-design approach focused on reducing the environmental impacts of products was carried out in the last decades. Nevertheless, sustainability rather consists of the three dimensions: environmental, economy and social well-being.
This work aims at effectively integrating sustainability in product development projects at the same time that traditional product criteria are fulfilled. The project of an isotherm container for the transport and storage of food was addressed. According to LCA evaluation methods, an approach based on the analysis of the flows exchanged by the industrial installation throughout the production step was developed. A set of engineering metrics and indicators were considered useful to comparatively assess the sustainability performance of different product designs.

Keywords: Sustainability, product design, production system, indicators assessment.

1 INTRODUCTION

Product eco-design is based on the fundamental concept of considering the whole product system life cycle, which includes from natural resource production to the disposal of the product at the end of its life ('from the cradle to the grave'). This methodology of design, focused on reducing the environmental impacts of products, is inspired by the concurrent engineering and integrated design, which imply the incorporation of downstream factors, such as manufacturing, assembly, maintenance and end-of-life at the very beginning of the design project [1, 2].
Specific tools for eco-design can be classified in environmental assessment of products and environmental improvement tools [3]. Environmental assessment tools are generally based on a life cycle assessment (LCA) method, which can inform production and consumption choices because it assesses the environmental performance of a product through accounting all the energy and material inputs and the associated emissions and waste outputs at each stage of its life cycle. A life cycle inventory requires many data so that a number of databases were developed in the last decades, based mostly on average data representing average production and supply conditions for goods and services.
Environmental improvement tools, on the other hand, provide guidelines and rules for helping designers to identify potential actions to improve the environmental performance of products, for instance Eco-design Pilot [4] and the Design for Sustainability (D4S) guide [5].
Nevertheless, sustainability does not only consist of the environmental impact, it consists of the three dimensions: environmental (planet), economy (profit) and social well-being (people) [6]. In order to evaluate sustainability in this triple bottom line, a new perspective is being introduced through the life cycle sustainability assessment (LCSA) framework [7-9]. LCSA evaluate all environmental, social and economic negative impacts and benefits in decision-making processes towards more sustainable products and provide guiding principles to achieve sustainable production while stimulating innovation by identifying weakness and enabling further improvements over the product life cycle.
While using Life Cycle Assessment (LCA) to measure the environmental dimension of sustainability is widespread, similar approaches for the economic (LCC) and the social (S-LCA) dimensions of sustainability still have limited application worldwide and there is need for consistent and robust methods and indicators. Life cycle costing is a compilation and assessment of all costs associated with

the life cycle of a product that are directly covered by any or more of the actors in the product life cycle [10]. Usually, the economic evaluation is done by considering manufacturing costs, from a business perspective, and life cycle costs, from the customer' perspective. Whereas, S-LCA provides information on social aspects in order to improve performance of organizations and ultimately the well-being of stakeholders. According to UNEP's guidelines [11], the socio-economic impacts, associated with the product' life, are captured in five suggested stakeholder categories: workers, local community, society, consumers and value chain actors. Many social issues are not easy to quantify, so a number of social indicators contain qualitative standards of systems and activities of the organization.

In order to apply the principles of sustainable development in practice there is a need to measure the individual sustainability dimensions and to achieving a comprehensive presentation of the results. A set of indicators for identification of more sustainable practices in different sectors of society [12] and for industry in particular [13] can be used. Regarding the environmental dimension Andriankaja et al. [3], suggested that two classes of indicators should be represented in order to compliant with other engineering tasks in product design: environmental impact indicators based on LCA evaluation methods and environmental engineering metrics. The last category seems closer to the current industry practice.

The indicators should be developed at the appropriate level of detail to ensure proper assessment of the situation with regard to each particular challenge. Simplified indicators, able to aggregate results and weigh the most important impact categories into easily understandable and user-friendly units, are particularly useful for designers because facilitate the communication of sustainability results to the decision-makers. A total environmental impact can be expressed by means a single score denominated Eco-indicator 99 [14]. This initiative was also addressed from the perspective of economic and societal impacts [15]. In this work, different metrics and indicators are used to assess the three dimensions of sustainability in product development projects. Methodology applied and results obtained for a case study are shown in the following sections.

2 METHODOLOGY

Sustainability evaluation is focused on the production step of the product life cycle. As shows Figure 1, the development of a more sustainable product can be achieved through a sequence of phases organized as follows: 1) Identification of inputs and outputs associated to the production process; 2) Assessment of engineering metrics and indicators for the three dimensions of sustainability; 3) Product redesign integrating sustainability criteria. Next, a new production inventory and sustainability assessment should be carried out for the redesigned product. Finally, the comparative presentation of the sustainability performance of both initial and redesigned product can be performed to detect if product was improved.

2.1 Production inventory

All existent flows associated to the production system are valued in this phase. One manufactured product is the functional unit considered within a high volume manufacturing process. The elementary flows exchanged by the industrial installation include inputs (raw materials and other components supply, energy consumption, consumables, revenues,…) and outputs (products, waste, energy costs, salaries,…).

In addition, manufacturing operations are analyzed in detail to value material transformations and resource consumptions for each part or component of the product. Particularly, the calculation of material removed, time required and power supply is carried out for each productive operation to project the manufacturing process of the redesigned product. In this work, data of the production process for the initial product were provided by the manufacturing company.

2.2 Sustainability assessment

A number of engineering metrics and indicators are obtained in this phase. Metrics considered useful to assess the production activity are the mass and volume of the manufactured product, the total energy consumption, the waste percentage, the costs of raw materials and the annual production volume. To note that these metrics allow obtaining practical information for process designers and are needed to assess sustainability indicators at the production and distribution stages in the product life cycle.

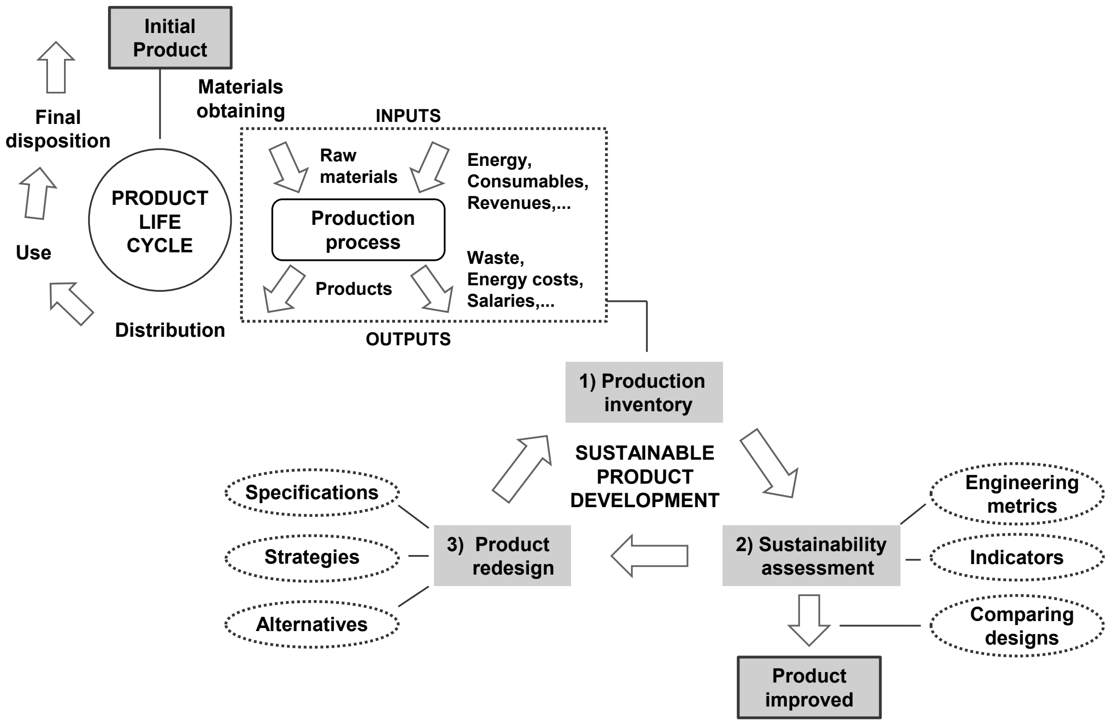

Figure 1. Phases for a sustainable product development

Different indicators are proposed in this work to assess each of the three dimensions of sustainability. Global warming (GW) that represents total emissions of the greenhouse gases and eco-indicator 99 (E99) [16] that weighs different impact categories into a single score, are the indicators proposed to assess the environmental dimension. Midpoint categories and characterization factors from Probas [18] and MEEuP [19] databases are used in the calculus process. Moreover, the reuse-recycling potential at the final disposition phase of product life cycle is taken into account. For the economic dimension, the value added (VA) and the eco-efficiency (EE) are the indicators proposed. The value added [15] expresses the net operating profit of the company and is obtained as the difference between sales revenues and production costs. The eco-efficiency combines and quantifies the economic and the environmental aspects because it is evaluated by the ratio of the value added and the eco-indicator E99. Finally, the indicators selected to assess the social dimension are the working hours and the hourly wage, which are associated to the category of company workers.
Metrics and indicators are expressed by manufactured product unit.

2.3 Product redesign

Product design activities usually begin with an analytical phase where the product requirements and specifications and the diverse parameters of the problem are studied along with the anticipated market demands. Since the goal/specification phase is the most crucial as far as product performance and properties are concerned, this is where the sustainability issues are considered.
Taking into account that each product consists of different parts or components and each of its components fulfils a function, the specifications of individual components should be analyzed. For each individual component, redesign alternatives, which involve the application of sustainability strategies, can be proposed. According to the LiDS wheel [4], the selection of low-impact materials, the reduction of materials and the optimization of production techniques are considered appropriate strategies to improve environmentally a product at the production stage.

3 CASE STUDY

Previous methodology was implemented in the redesign of an isothermal container for the transport and storage of fresh or frozen foods. The main components and characteristics of this product are shown in Figure 2. A low thermal transfer coefficient ensures the preservation of the cold chain of the products transported and the container structure, reinforced with galvanized steel, allows the stacking and optimization of the vehicle space.

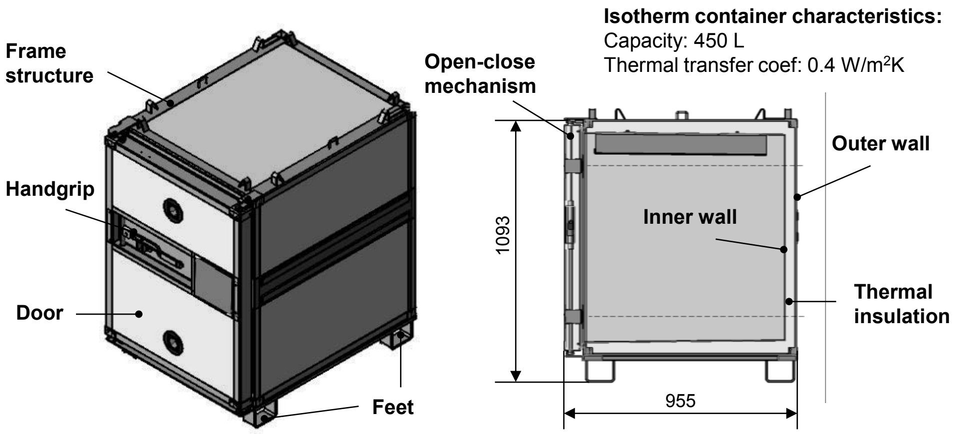

Figure 2. Isothermal container. Components and characteristics

A scheme of the container production process is shown in Figure 3. Raw materials involved are galvanized steel that is used to the container structure manufacturing, high impact polystyrene (HIPS) used in the outer wall, composite (polystyrene and fibreglass) used in the inner wall, isocyanate and polyol, used to obtain the polyurethane (PU) thermal insulation, as well as rubber, polyvinyl chloride (PVC) and polystyrene (PS), which are used in all other components. Material inputs and outputs associated to the production process as well as the main manufacturing operations, times required by operation and energy consumptions to manufacture one product unit are shown in Figure 3. Assembly is the operation that requires more time in production. Laser cutting and welding of sheets and structural profiles of galvanized steel are the operations with the highest energy consumptions.

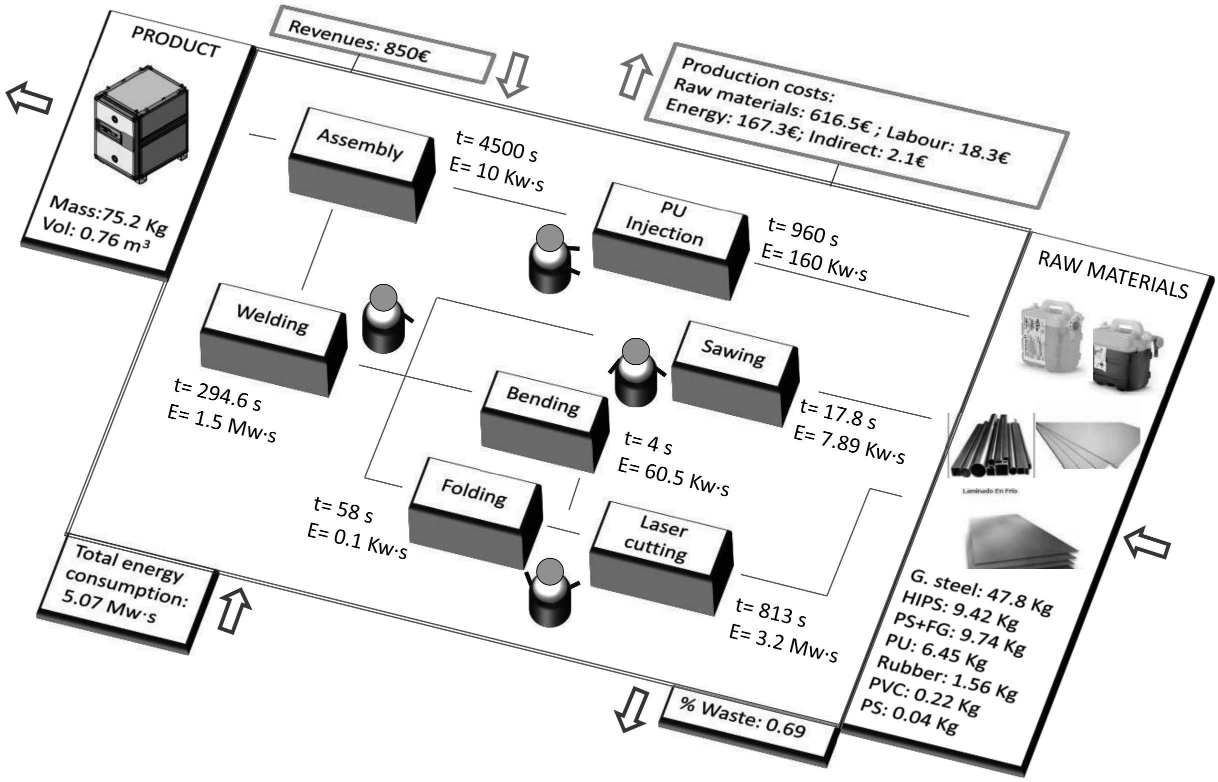

Figure 3. Isothermal container production. Manufacturing line and flows exchanged

Money flows associated to the production system of one product unit are also obtained. All metrics and sustainability indicators are summarized in Table 2, where can be comparatively analyzed with those obtained later from the product redesigned. It can be observed that the amount of material removed is a reduced percentage of the raw materials acquired and the highest production costs are due to the raw materials purchase. For an annual production of 2365 containers, 1.78 working hours are needed and a net operating profit of 45.4 €/h is obtained in each unit manufactured.

Next, an isothermal container more sustainable was projected. Alternatives of redesign were proposed for each part of the container taking into account the fulfilment of the product specifications. Alternatives are identified as A and initial designs are identified as D_i in Table 1. The selection of low-impact materials as i.e. flax fibre for the thermal insulation and the inner wall and the reduction of materials as i.e. the use smaller sizes for some components of the container structure, were the sustainability strategies applied in this case.

A lower environmental impact is achieved for the alternatives proposed because lower E99 are obtained. Mass and energy consumptions are also smaller for the redesign alternatives, so an improvement of the economic dimension of the sustainability is expected.

Table 1. Redesign of the isothermal container

Container part		Raw Materials	Requirements		Energy (Kw·s)	Mass (Kg)	E99 (mPt)
Structure/ other components	D_i	G. steel	Mechanical strength (MPa)	275	4756	47.8	14384
	A	G. steel		275	4714	45.1	13721
Outer wall	D_i	HIPS	Impact resistance (KJ/m^2)	3-12	-	9.42	1130.4
	A	PP		4-20	-	8.57	1028.4
Inner wall	D_i	PS+FG	Food compatibility	Ok	-	9.74	1003.2
	A	PS+FF		Ok	-	8.91	908.8
Thermal insulation	D_i	Polyurethane	Thermal conduct. (Kcal/h·m·K)	0.034	160	6.45	1354.5
	A	Flax fibreboard		0.033	0	3.75	112.5
Door weatherstrip	D_i	PVC	Hardness (Shore A)	65-95	-	0.22	22
	A	Rubber		45-90	-	0.17	20.4

The inventory of the production system and the subsequent sustainability assessment were carried out for the redesigned container. Metrics and indicators finally obtained are summarized in Table 2. A decrease of the product mass, energy consumption and costs of raw materials can be observed with respect to the initial product. The product volume is preserved but since a lighter container is obtained, sustainability could be improved in the transport processes. Production costs reduce 7% due mainly to the use of organic materials as flax fibre. Annual production increases 3.6% due to reduced flax fibreboard assembly time versus PU injection time.

Table 2. Production metrics and indicators of the initial and redesigned products

Engineering metrics	Product mass (Kg)	Product vol. (m^3)	Energy (Kw·s)	Waste (%)	Raw mat. costs (€)	Annual production
Initial product	75.2	0.76	5076.9	0.69	616.5	2365
Redesign	68.1	0.76	4847.2	0.70	573.5	2450
Sustainability indicators	Environmental		Economic		Social	
	GW (Kg CO2)	E99 (pt)	VA (€)	EE (€/pt)	Working hours	Hourly wage (€/h)
Initial product	202.87	17.9	45.4	2.54	1.78	10.2
Redesign	149.9	15.8	88.6	5.61	1.71	10.8

If sustainability indicators of both initial and redesigned container are compared, we observed that E99 reduce 11%, VA increase 95.1% and hourly wage increase 5.8%. It was assumed that sales revenues and the workers number of the company are not modified. In addition, the PU replacement by organic materials, could be avoid the vapours emission in assembly process and reduce the possibility of respiratory disease in workers.

Since a lower environmental impact, an increase of the company economic profit and an improvement of the working time spent by the workers group is achieved for each manufactured product unit, a more sustainable container could be developed.

4 CONCLUSIONS

This work proposes a sustainability assessment methodology aimed at design engineers to consider economic, environmental and social aspects simultaneously when developing products. The three dimensions of sustainability are quantified using a set of metrics and indicators that facilitate the communication of sustainability results during the product design decision-making process.
The redesign of an isothermal container for the transport and storage of food is carried out. Production inventory was supported by the responsible company of the product manufacturing. The fulfilment of specifications for each component of the product and the application of suitable sustainability strategies were taken into account to project a new container. The use of organic materials is advantageous. As a consequence of the selection of flax fibre for the thermal insulation of the container, an improvement of the product sustainability indicators at the manufacturing stage was achieved.

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