PROMOTING SUPPLY CHAIN SUSTAINABILITY THROUGH INDUSTRIAL PACKAGING ECO-DESIGNING

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ABSTRACT

The climate change and the new regulations imposed to slow down this process have pushed major actors around the world to apply sustainable measures in order to meet governmental obligations. The packaging industry has a major role in fighting climate change and the environmental social and financial disasters. In fact, packaging requires substantial number of natural resources and is often disposed of in ways that harm the environment. Supply chain managers realized that packaging design is the root to solve all the problems packages create throughout their entire life cycle. Therefore, a thorough study about influencing the design process should be prioritized. This paper provides a systematic review of industrial packaging eco-design applied to the supply chain. It aims to conceptualize the definition of industrial packaging eco-design and supply chain sustainability to categorize main parameters to its implementation and to identify the limitations of current research and its prospects.

Keywords: Ecodesign, Sustainability, Circular economy, Industrial packaging, Supply Chain

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1 INTRODUCTION

In a fast-recovering world after the Covid19 pandemic, supply chains play a crucial role to restore industrial and commercial activities to their previous level. However, it should be recommended to build on the environmental positive impact of the lockdown and adopt newly designed and nature-friendly supply chains to replace the old models. Considering the pressing need for a healthier and sustainable ecosystem, Sustainable Development Goals (SDG's) were established, and the concept of the circular economy was proposed by academic and industrial thinkers and adopted by policy makers to tackle global environmental issues by closing the loop of the product lifecycle (Charef et al., 2021; Korhonen *et al*., 2018). Developing a circular economy requires efforts from different actors and englobes suppliers, manufacturers, recycling processors, distributors, retailers, consumers, and waste collection service providers (Zhu et al. 2022). Achieving this target will accomplish the sustainability need of each organization.

There are two different types of supply chains: business-to-business (B2B) and business-to-consumer (B2C). In the B2C, the product is directed to the end-consumer while in the B2B ones the goods and services are exchanged between companies which explains why the B2B supply chains are generally shorter and provide a better flow of information between the different participating actors. In the case of the B2B supply chains, the packaging waste is considerable in quantity compared to the B2C but has the advantage to be easily collectible and reusable. In the case of the B2C supply chains, packaging waste is much more geographically widespread and difficult to collect and reuse. Therefore, implementing eco-design strategies for the industrial packaging of the B2B supply chains will make great improvements towards its impact on the environment and helps to contribute efficiently to supply chain sustainability.

The design phase is a key phase in the development of sustainable products (Gaha et al. 2013, Gaha et al. 2014 and Gaha et al. 2015). Hence, packaging eco-design takes a product-centric view and focuses on reducing and eliminating environmental and human health-related impacts as well as resource depletion. Building on this idea, the package's entire lifecycle should be examined in the design phase with circularity objectives. Thus, packages should be designed in accordance with the value propositions of their circular economy models to ensure their reuse.

Two strategies need to be defined in parallel with circular design and sustainable materials management: design for recycling and design for dematerialization. The first focuses on using specific design techniques to increase material recoverability in the recycling process. The latter aims at reducing packaging materials while maintaining or even improving functionality. In some cases of dematerialization, the product may be replaced by a service that uses fewer resources.

In this context, this study is focusing on the eco-design of packages for business-to-business supply chains to achieve sustainability. This paper is divided into four major parts. First, a brief presentation of the research methodology is discussed, then reviews of the state-of-the-art research about supply Chain sustainability and then industrial packaging are presented. The final part was consecrated to present a model for eco-designed packaging for the B2B supply chain.

2 RESEARCH METHODOLOGY

The research methodology used in this article is based on a systematic approach through a literature review conducted from September 2022 to November 2022. We used two main databases: Science Direct and Taylor & Francis.

The main keywords used in the literature review were packaging design, design phase, eco-design packaging, life cycle assessment (LCA), sustainable supply chain and circular economy. Thirty-eight (38) papers were reviewed, and eleven (11) articles were selected and exploited for this review. The criteria used to select the most significant articles were based on the relevance of the titles, keywords, and abstracts. Moreover, the recency of the articles was a determinant factor, as the state of the art in the field is rapidly growing in recent years. Most selected articles are literature reviews of circular economy and packaging in the supply chain industry published mainly between 2017 to 2022.

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3 SUPPLY CHAIN SUSTAINABILITY

Supply chain sustainability has emerged as a goal for companies to consider the environmental and human impact of their products throughout the entire life cycle along the supply chain.
The main objective is to minimize environmental impacts considering factors like energy usage, water consumption, transportation and especially waste production. It also incorporates addressing global issues such as climate change, deforestation, and human rights. This needs to be achieved while maintaining revenue and profitability.
Herbes et al. (2018) identify that consumers mostly focus on the end-of-life stage of packaging and are mostly unaware of the negative impacts of packaging in the upstream and middle-stream supply chain.
To achieve the targets fixed by the legislation standards for supply chain sustainability, a series of indicators should be specified to enable designers to measure their product's actual environmental impacts. In the context of this research, sustainability indicators are applied to measure the sustainability of the package according to several aspects. These indicators are usually categorized based on the economic-social-environmental aspects. However, it is important to cover the economic-environment criteria to enable stakeholders to carry out a life cycle assessment of their systems.
In this context, designers should take into consideration the following indicators (Daaboul et al. 2013) presented in the table 1.

Table 1. Sustainability indicators by Joanna Daaboul et al.

Theme	Indicators	
Materials or substance management	Mass	
	Recycled material integration (% product)	
	Renewable materials integration (% product)	
Pollution and human health	Air	CO2 emission; GHG emissions(g/FU)
		Other pollutants: Particles (g/FU)
		Photochemical ozone creation potential (kg ethene eq)
	Water	Freshwater ecotoxicity (Kg DCB-eq)
		Eutrophication potential (Kg PO4 eq.)
	Soil	Solid waste (Kg)
		Materials toxicity (Reach)
		Emissions to industrial/agricultural soils (Kg/ FU)
Fossil fuel resources	Raw materials consumption (Kg/FU)	
	Abiotic depletion potential (kg Sb eq)	
Energy	Total primary energy (MJ)	
	Electricity consumption (kWh/FU)	
Climate change	Global warming potential (kg CO2 eq)	
Ecosystem quality	Ecotoxicity (kg DCB-eq)	
	Acidification potential (kg SO2 eq)	
	Land use and occupation /transformation	
Recycling index	Material recycling rate	
	Dismantling easiness and time	
	Economical efficiency/benefit	
	Material compatibility	

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4 INDUSTRIAL PACKAGING ECO-DESIGN

Industrial packaging is typically larger and more durable than primary packaging, and it serves a different purpose, mainly for the transportation and storage of goods. Therefore, the environmental impacts of industrial packaging may differ significantly from those of primary packaging. As a result, eco-design models that have been developed for primary packaging may not be entirely applicable to industrial packaging.

Furthermore, industrial packaging is often used in larger quantities than primary packaging, and the scale of its use may require separate eco-design models to ensure that its environmental impact is properly managed. For instance, a separate eco-design model for industrial packaging may be required to optimize the use of materials, reduce waste, and ensure efficient transportation of goods.

Supply chain managers are becoming more and more concerned about achieving sustainability to meet the new regulations. Recent research activities about sustainable supply chains and the importance of packaging design in achieving that goal have grown over the recent years, especially after the COVID19 pandemic. The focus now has shifted to the sustainability of product-packaging along all the actors in the supply chain. Therefore, much attention was given to the design phase and especially the conceptual design phase (Kong et al. 2022)

Within the concept phase, the engineers can define eco-friendly packages, material, functionality, and possible recycling strategies for the product in a fundamental way. In order to achieve this goal, the engineer needs a lot of eco-related information of the product, e.g., CO2-emission, disassembly procedures and reliability information. (Bracke et al. 2017).

Bracke et al. (2017) divided the concept phase into two main categories; the first one concerns the definition of the product characteristics and its interaction with the packaging, and the second phase is the development of the packaging concept. They also highlighted that within decision-making of the reusability of the packaging, it is not always true that recycling and reusing generate low costs. In certain cases, it can generate an increase in transport costs and thus more CO2 emissions.

Conceptual design is a critical process for the design of products and has the potential to reduce environmental impact. Upon selecting appropriate materials, the next phase is to generate multiple packaging design concepts. It should be emphasized that this is an iterative process from material selection to conceptual design given their interconnected nature (Zhu et al. 2022). They then presented a framework that includes the parameters influence that designers should consider in the whole design phase and that will affect the entire supply chain.

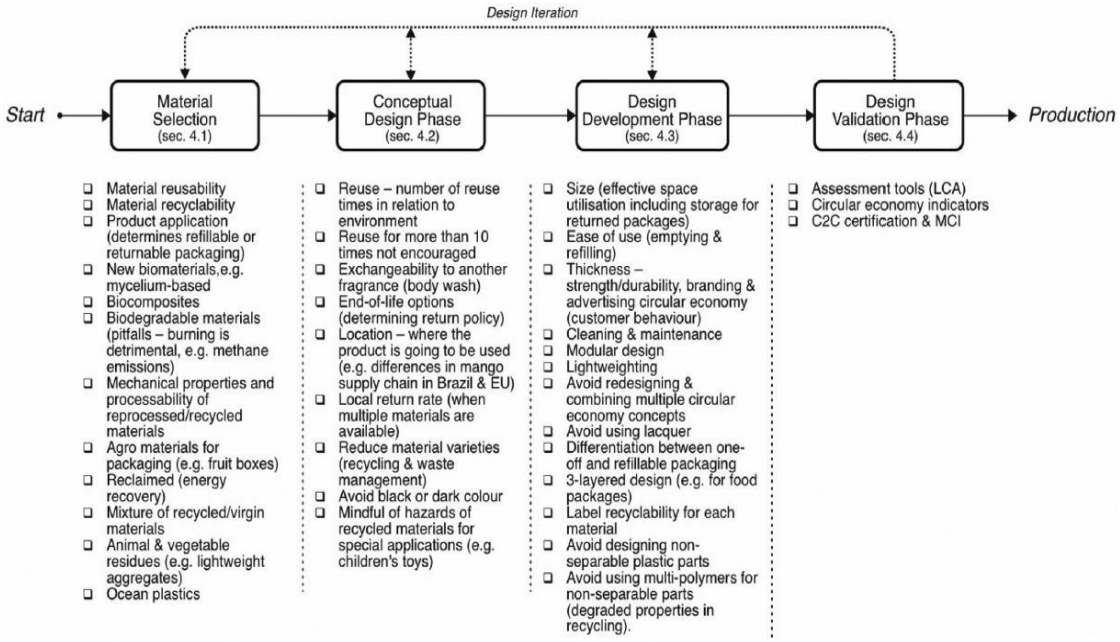

Figure 1. Packaging design framework by Zhu et al. (2022)

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Azzi et al. (2012) conducted a review that showed that research interest in packaging design has increased significantly over the years. This is due to the impact of packaging on the supply chain costs and performances, especially with the migration towards more sustainable ones to meet environmental requirements.

They then proposed a framework for packaging designers that illustrates the most important aspects related to an innovative packaging solution. They stated that packaging design should take place inside the heart of a star. Five important factors are taken into consideration: Safety, Ergonomy, Sustainability, Logistics, and Marketing while considering regulations, procedures, and standards. Figure 2 illustrates the model that Azzi et al. (2012) presented.

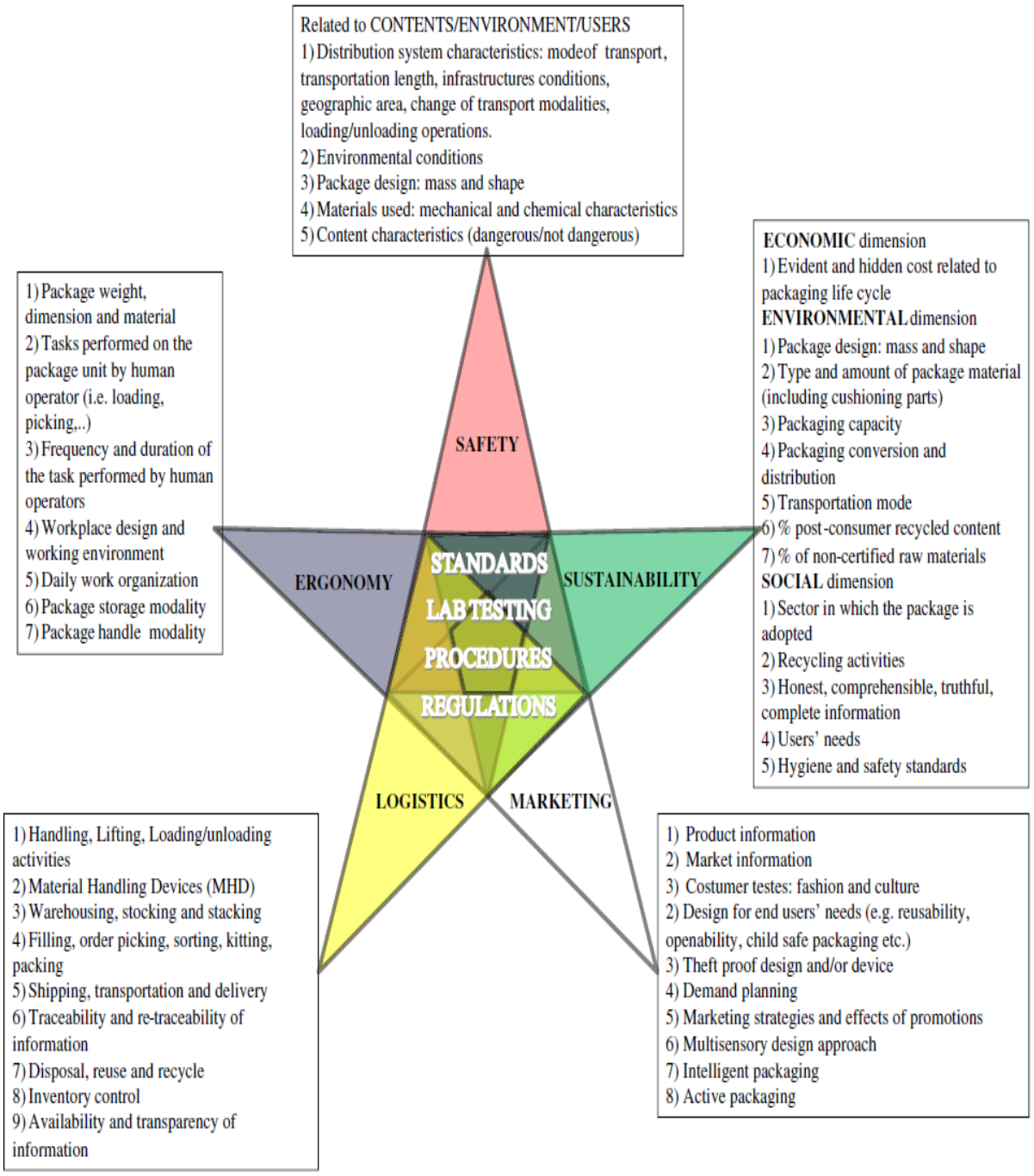

Figure 2. Framework for drivers integrated in packaging design by Azzi et al. (2012)

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Shamraiz *et al.* (2017) conducted a literature review from 2007 to 2017 on tools and case studies for sustainable product designs. All the tools presented pointed always to the integration of environmental aspects into product design and development through a product's life cycle.
Eco-design and sustainable design focus on the concept of a life cycle where products should be designed while considering all their life cycle phases from extraction of raw material to disposal of these products.
Shamraiz *et al*. (2017) divided the tools into two categories: Partial sustainable product design (P-SPD) tools and Sustainable Product Design (SPD) tools.
In both categories the authors mentioned that the term sustainable should be used for only the ones who account for all three aspect of sustainability and those were the SPD tools while the P-SPD tools focused on only two aspects: environmental and economic dimensions. Thus, it suits better the early design phases. This explains why we only considered the economic-environment indicators in section 3 of this paper.
It is possible to advocate that, P-SPD tools are more suitable for early design phases because they can help designers identify potential environmental issues and opportunities for improvement at an early stage. By using P-SPD tools in the early design phases, designers can make informed decisions and optimize their designs for sustainability from the start.
While social sustainability is an important aspect of sustainability, it may not be as relevant in the early design phases as environmental sustainability. Social sustainability may be more relevant in later stages of the design process, such as during manufacturing or distribution, when issues such as labor rights and fair trade become more critical.
Therefore, we would conclude that P-SPD tools, excluding social sustainability, are more suitable for early design phases because they can help designers optimize their designs for environmental sustainability from the start, which can have a significant impact on the overall sustainability of the product.
The study highlighted the fact that life cycle assessment (LCA) is the most used method for eco-design.
It is based on the ISO14044 international standard that specifies principles and framework for carrying out a life cycle. A life cycle assessment accounts for all the resources consumed and the substances emitted during the cycle of your product. Resources can be energy carriers like electricity and fuels, or materials and chemicals. Substances emitted can be greenhouse gases emitted to air or phosphate contributing to the pollution of water bodies.
There are many LCA softwares and SimaPro is one of the most used within the research community. This article will be a preparation for a thorough study of the parameters that may influence the design process of industrial packaging.
We will be using environmental indicators to assess the impact of packaging design via MidPoints and Endpoints.
There are 18 midpoint indicators such as climate change, human toxicity, land use, water use etc... and 3 Endpoints such as human health, natural environment, and natural resources. The study that will continue with the parameters identified through this research will be based on the environmental indicators regarding packaging in the supply chain industry.

5 RESULTS AND DISCUSSION

Most of the studies found in the literature focused on several aspects of the design process of industrial packages. Some papers focused on the conceptual design phase of the packaging design iteration while others focused on the drivers to integrated packaging design while emphasizing on the marketing aspect.
Most of the reviewed articles focused mainly on packages designed for end consumers and few are the ones who mentioned industrial packaging. However, there was not much importance given to the transport aspect. Transport means are presented as the part that can be influenced to reduce emissions that harm the environment and using more efficient vehicles is the key to achieving sustainability.

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Table 2. Attributes of eco-designed packages in previous research

Design phase	Sustainability indicators and design parameters covered	Reference
1) Problem definition	-Social aspects were considered as well as quality parameters. -Stakeholders' requirements in terms of cost, energy use, and ease to use were considered.	Azzi et al. 2012 Herbes et al. 2018 Kong et al. 2022 Shamraiz *et al.* 2017
2)Material selection	-Evaluation of different materials -The indicators included weight reduction (mass, Vol., density, strength, etc.), cost minimization (raw material), and environmental impacts minimization (energy consumption, solid waste, etc.) -The parameters were categorized into 3 subsections: Principles of material selection / Reuse and recycled packaging material / Bio-based & agro-based materials	Azzi et al. 2012 Herbes et al. 2018 Zhu et al. 2022
3) Conceptual design phase	-The parameters considered were mainly related to end-of-life options and possible recycling strategies Re-use/ recycling/ recycled materials hazards as well as manufacturing process needs in terms of energy consumption. -Life cycle cost and environmental loads of the packages were considered to achieve eco-friendliness	Azzi et al. 2012 Kong et al. 2022 Shamraiz *et al.* 2017 Bracke et al. 2017 Zhu et al. 2022
4) Design development phase	-The parameters included covered the geometry of the package with an in-depth focus on effective space utilization in storage warehouses and during transport.	Silva *et al.* 2022 Zhu et al. 2022
5) Design validation phase	-Circular economy indicators and life cycle assessment as well as quality control methods were considered as indicators for the sustainability of packages	Zhu et al. 2022

Figure 3 presents a new model of the parameters to influence the design of industrial packaging. A product package takes place in this diagram at the center of a circle that represents the link between

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two important structures. The first one represents the parameters of a sustainable supply chain and the second one represents the parameters of packaging design. The circle represents a link between these two categories of parameters to reach eco-designed packages. The particularity of this diagram is that it englobes the transport phase, represented with the letter T in a circle, between all the actors of the supply chain starting from the extraction of raw materials until the return of packages for recycling or re-use. Indeed, the mean of transport is not the only way to reduce emissions and achieve sustainability. Packaging design with lightweight solutions and efficient package Vol. percentage enables optimized track load thus reducing the number of trips, carrying more products and a better CO2 emission per product as well as cost. It is also applicable for the trips implied to the return of packaging waste after use. This will reduce the quantity of vehicles needed for transport as capacity increases (Silva *et al.* 2022).

The designer's main focus at the beginning of the design phase is to select the material that best meets the criteria of; reusability/recyclability or multi-material usage while considering mechanical properties and the available infrastructures per region for the recyclability of the chosen material. The material also interacts with the product that the package will englobe, therefore the designer must also consider the amount and type of cushioning that separates the product and the package to use.

After this phase, the designer should consider the aspect of transportation through the different stakeholders of the supply chain, he needs to design a package that is easy to handle/lift/load and unload while respecting the standard logistical methods used worldwide such as pallets and forklifts. This leads to the modification of the geometry parameters of the package to optimize the space inside a single product, which increases the number of items in a single pallet and therefore the number of pallets transported in a single trip resulting in a CO2 emission reduction per package. In parallel, the designer should also consider the storage aspect whether at the manufacturer or in warehouses. The package has to protect the product from different alteration risks such as temperature and humidity.

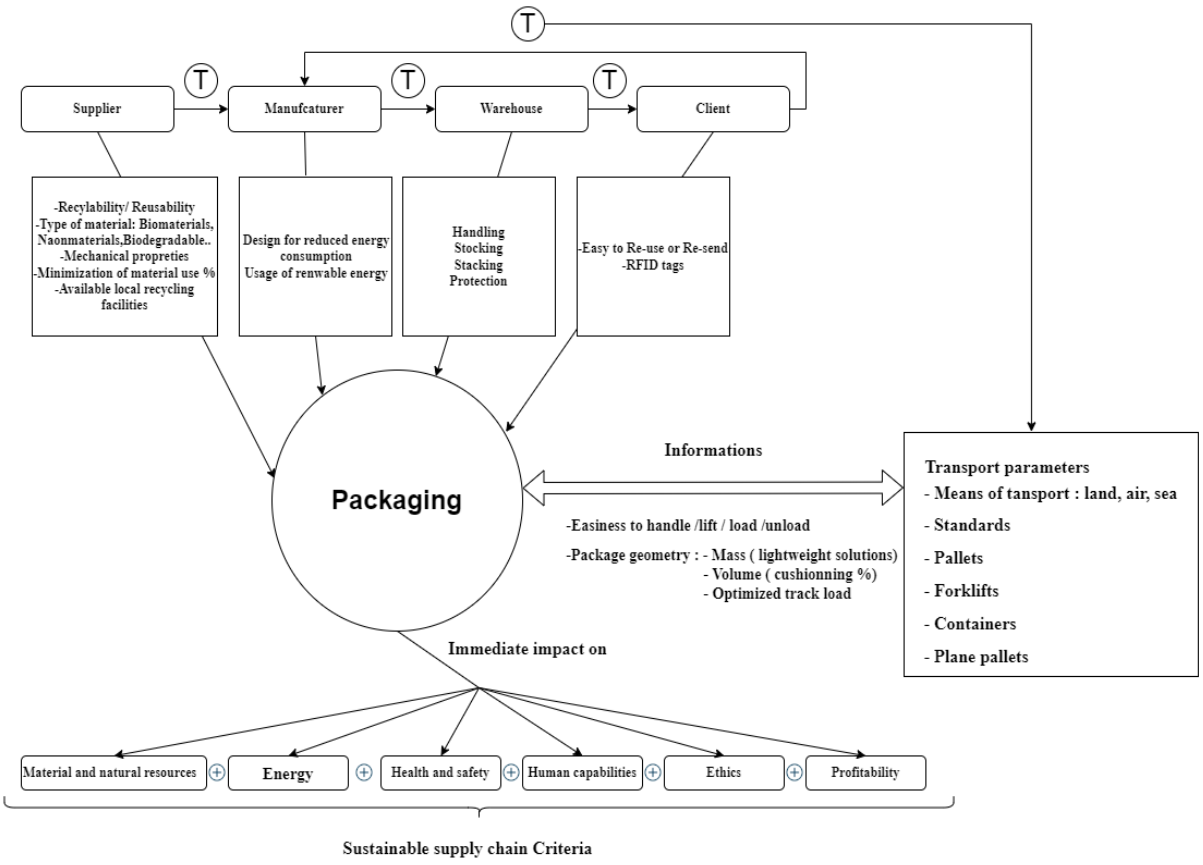

Figure 3. Proposed model

The packaging has a direct link with the sustainable supply chain criteria which represents material and natural resources, energy use, health and safety, human capabilities, ethics, and profitability. Innovations applied to the package design from all the information collected by the different actors of

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the supply chain will help achieve the mentioned criteria and will have an immediate impact on the supply chain sustainability.

6 CONCLUSION

The present paper has presented the parameters that can be influenced in the design phase of industrial packages to achieve supply chain sustainability. A literature review presented the state of the art in this field and presented the tools used to assess packaging impact on the environment. As climate change is pushing major actors to apply sustainable measures, packaging design was presented as an influential key to contribute to sustainability. A model was proposed detailing the parameters of a sustainable supply chain and the parameters of the packaging design, which mainly englobe the conceptual design phase, as a link towards promoting eco-design of industrial packages.
Among the perspectives of this study is to use these parameters in a mathematical model that can be implemented on the CAD design tools to eco-design future packages and asses their environmental impact as early as the design phase.

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REFERENCES

Azzi, A., D. Battini, A. Persona, F. Sgarbossa (2012), “Packaging Design: General Framework and Research Agenda”, Packaging Technology and Science, Pages 435-456, https://doi.org/10.1002/pts.993.

Bracke, S., Yamada, S., Kinoshita, Y., Inoue, M., & Yamada, T. (2017). “Decision making within the conceptual design phase of eco-friendly products”, Procedia Manufacturing, Vol. 8, Pages 463-470, https://doi.org/10.1016/j.promfg.2017.02.059

Charef, R., Ganjian, E., Emmitt, S., 2021. Socio-economic and environmental barriers for a holistic asset lifecycle approach to achieve circular economy: a pattern-matching method. Technol. Forecast. Soc. Chang. 170, 120798. https://doi.org/10.1016/j.techfore.2021.120798.

Herbes, C., Beuthner, C., Ramme, I., (2018), "Consumer attitudes towards biobased packaging e a cross-cultural comparative study" Journal of Clean Production, Vol. 194, pages 203-218, https://doi.org/10.1016/j.jclepro.2018.05.106

Daaboul. J, Valet F., Penciuc D., Andriankaja H./ Université de Technologie de Compiégne (2013), Eco-design tools for light weight solutions, Sustainable and efficient Production of Light weight solutions.

Gaha, R., Benamara, A., & Yannou, B. (2014). Eco-design of a basin mixer in geometric modeling phase. In Key engineering materials (Vol. 572, pp. 7-11). Trans Tech Publications Ltd.Korhonen, J., Honkasalo, A., Seppälä, J., 2018. Circular economy: the concept and its limitations. Ecol. Econ. 143, 37–46. https://doi.org/10.1016/j.ecolecon.2017.06.041.

Gaha, R., Benamara, A., & Yannou, B. (2013). A feature-based methodology for eco-designing parts on detail phase. In Design and Modeling of Mechanical Systems: Proceedings of the Fifth International Conference Design and Modeling of Mechanical Systems, CMSM´ 2013, Djerba, Tunisia, March 25-27, 2013 (pp. 645-654). https://doi.org/10.1007/978-3-642-37143-1_76.Springer Berlin Heidelberg.

Gaha, R., A. Benamara, and B. Yannou. 2015. “An Environmental Impact/Cost Model for Evaluating Multiple Feature-Based Machining Methods.” In Design and Modeling of Mechanical Systems - II. Lecture Notes in Mechanical Engineering, edited by M. Chouchane, T. Fakhfakh, H. Daly, N. Aifaoui, and F. Chaari. Cham: Springer. https://doi.org/10.1007/978- 3-319-17527-0_3 .

Kong, L., Wang, L., Li, F., Tian, G., Li, J., Cai, Z., ... & Fu, Y. (2022)., “A life-cycle integrated model for product eco-design in the conceptual design phase”, Journal of Cleaner Production, Vol. 363, 132516, https://doi.org/10.1016/j.jclepro.2022.132516

Nathalie Silva, Henrik Pålsson (2022), “Industrial packaging and its impact on sustainability and circular economy: A systematic literature review”, Journal of Cleaner Production, Vol. 333, 130165, https://doi.org/10.1016/j.jclepro.2021.130165

Shamraiz Ahmad, Kuan Yew Wong, Ming Lang Tseng, Wai Peng Wong (2018), “Sustainable product design and development: A review of tools, applications and research prospects”, Resources, Conservation & Recycling, Vol. 132, Pages 49-61, https://doi.org/10.1016/j.resconrec.2018.01.020

Zhu Z., Liu W., Ye S., Luciano Batista (2022), “Packaging design for the circular economy: A systematic review”, Sustainable production and consumption, Vol. 32, Pages 817-832, https://doi.org/10.1016/j.spc.2022.06.005

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