Recycling of plastic waste: contributions of sustainable innovation and the circular economy of plastic

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Abstract. The scarcity of natural resources and the generation of plastic waste without proper disposal are problems that concern the world population and are related to the linear economy model. The generation of value from the recycling of plastic waste is of paramount importance for the industry and scientific research, after all, it can be used to reverse environmental degradation and also assist in more sustainable processes. Given this problem, our study aims to identify in the literature, information about plastic waste management and how sustainable innovation and circular economy contribute to this goal. Based on a systematic literature review, a content analysis was performed. The survey of articles for research was done in the Scopus database, combining the following keywords: "sustainable innovation AND plastics" and "plastic circular economy AND sustainable innovation". The results highlighted circular economy applications in plastic waste management and potential practices to increase circularity. The Circular Economy model for plastics is still recent, and the transition process is in its early stages, as is scientific research on the subject.

Keywords: Recycling, **s**ustainable innovation, plastic waste, plastic circular economy, circular economy.

1 Introduction

The level of plastic production is growing rapidly – more than half of waste and plastic products have been manufactured in the last 25 years [28]. Inevitably, the increase in the number of products also leads to an increase in the amount of waste (plastics) [20]. Considering the future scarcity of raw materials, there is a clear need to develop sustainable products in a circular economy [51].

More than 300 million tons of plastic are manufactured worldwide each year, but only 10% are recycled and more than 7 million tons end up in the oceans [21]. The COVID-19 pandemic has progressed rapidly, and preventive measures implemented to control and mitigate its high transmissibility have led to increased demand and consumption of plastic products by the general population, healthcare, and service workers [57].

The EC could be exploited in the work environment of the different sectors of organizations, so stakeholders can share the values obtained through this model [58]. This circular economic model is based on restoration and regeneration [52]. It is an economy based on the principles of designing waste and pollution, keeping products and materials in use, and restructuring natural systems [56].

Some authors claim that sustainability can help organizations implement the Circular Economy (CE) [27]. Sustainability could be defined as the "balanced integration of

economic performance, social inclusion, and environmental resilience, for the benefit of current and future generations" [19].

Recycling is a process that depends on a value chain involving different stakeholders, such as waste management companies, recyclers, packaging material producers, retailers, and the government [18]. Discussions about recycling should be guided by the motivation of a CE, based on the end of the material life cycle and the creation of new regulations that encourage the disposal of plastic waste, recycling, and increasing the use of recycled materials in the production of new plastic packaging [18].

There are not many studies in the current literature that talk about the union of CE and Sustainable Innovation to minimize the use of plastic waste. The motivation for the present study comes from this gap. Therefore, the research aims to answer the following question: "How can sustainable innovation and the circular economy of plastic contribute to the recycling of plastic waste?"

To answer the research question, the study will investigate the existing literature, and find the reported practices. Later, present alternatives to future studies. The scope of this study aims to contribute with a review of the literature to raise companies and researchers' awareness to not neglect plastic recycling, which is currently a global concern and responsibility.

2 Methodology

A systematic literature search was performed to identify relevant studies on these themes. The article survey process was carried out in the Scopus database due to its broad coverage of the study area. There was no restriction as to the country or sector of origin. Only papers published in English and referring to the last five years (2017-2021) were selected. This period was defined to search for the most recent studies, and for current and rising issues of debate. The following keywords were used in the search string: "sustainable innovation AND plastics" and "plastic circular economy AND sustainable innovation". Additional important references were also included in this research, and later in the article to enrich the research.

After selecting the best-qualified articles, and those that corroborate with the themes and the research question, the coding process began in the Atlas software. This process led to a list of 14 codes. These codes were analyzed to find joint themes of codes, culminating in the structuring of this research. This step was fundamental to defining the criteria for the inclusion/exclusion of references in the article.

The structure of the article and the resulting assumptions lay an important foundation for future studies, which may contribute to the knowledge and formation of new management models, more innovative and sustainable processes for recycling plastic waste, and consequently, a more effective transition to the circular economy. At the end of the paper, we present a table with suggestions for future studies.

3 Literature review

3.1. Sustainable innovation

Climate change has intensified the search for better efforts in social and environmental conservation, motivating organizations to do more to develop sustainable technologies. [14]. The innovation of the business model is considered fundamental for organizations to achieve sustainability [38] and when inserted into a sustainable system, it needs to be seen as a coevolutionary process, involving companies with an innovative profile in a broad context of institutions, infrastructures, and consumption practices.

All goods and services have environmental, social, and associated risks, as they consume natural and environmental resources during production and consumption [8]. The growing awareness of these issues, and their implications for society and the economy, has led policymakers to rethink legislative and financial measures to support companies to innovate in their businesses [43]. Compliance with regulations entailed an innovative degree of effort by parts of companies [8]. Environmental regulations and laws have a highly beneficial impact on collaboration and relationship management in sustainable supply chains [41]. Companies that adopt certifications for more conscious production become more competitive [12].

Collaboration in sustainable product development adds value to the result: ecological product and production cost reduction. These benefits come from supply chain integration [14]. Innovation, by improving the efficiency with which inputs are converted into a product, is also an important driver of improving the environmental performance of the business [8]. Sustainable innovation, should be seen as something socially inserted, involving engagement, collaboration, and communication, with a wide range of actors and social fields [42].

3.2. Circular Economy and Plastic Circular Economy/New Plastic Economy

Circular economy

The circular economy (CE) is considered a system whose value is generated along the production chain. For this system to have worked, long-term partnerships must be established between entrepreneurs and large companies, which will be the key actors [55]. According to Geissdoerfer et al. (2017), CE is: "a regenerative system in which the input of resources, waste emission, and energy leakage are minimized by deceleration, closing, and narrowing of material and energy circuits". Business stakeholders relate the circular economy predominantly to established technological business practices and models, thus leaving a considerable margin for innovation in these areas, such as social or organizational business models [30]. Currently, many companies are taking advantage of technological advances and strategic partnerships with large companies, generating value between partners and the community. Based on

this premise, it is expected to achieve risk and cost reduction and improve business values and social impact [55].

The literature indicates that the circular economy faces changes in product design, production, consumption, and recycling. CE seeks to preserve the environment from plastic pollution and promote development and innovation in industry and human life [50]. Improving circular practices requires redesigning products and packaging, eliminating chemical and toxic substances, and assisting and facilitating disassembly and recycling processes [55]. Modifications can increase the level of complexity in the process of transitioning to the circular economy, and the use of digital technology as a tool can be essential to overcome obstacles [29].

The figure below summarizes the transition from a linear economy to a circular economy. LE follows the process of producing, buying, and discarding, while CE must follow the processes of reducing, reusing, and recycling seeking greater efficiency.

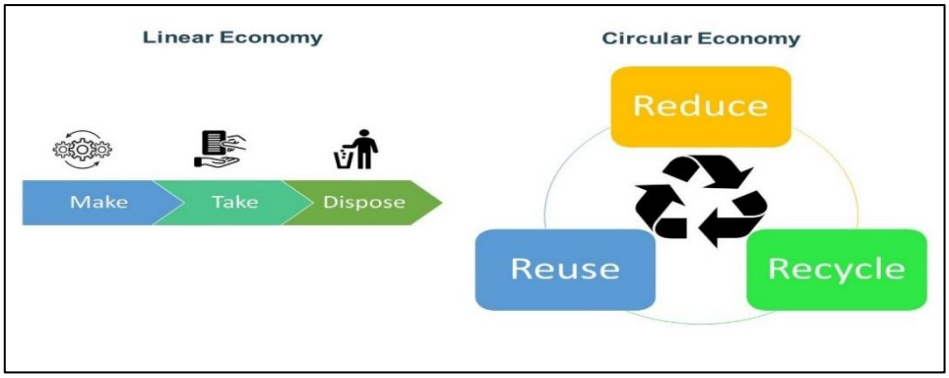

Fig. 1. The transition from Linear Economy to Circular Economy

New Plastic Circular Economy

The New Circular Plastic Economy (NCEP) aligns with the principles of the circular economy and the ambition to achieve better economic and environmental results, drastically reducing the loss of plastics in natural systems, such as the ocean, and deadland of fossil raw materials [44]. The overall view of (NCEP) is that plastic never becomes a waste, on the contrary, it will return to the economy as a new product [56]. It is also necessary to adopt more circular approaches to the life cycle of plastic, to not only capture the economic benefits but reduce the environmental impacts caused by the take, make, use and dispose value chain [47].

Recycling plastic waste is aligned with the goals of the circular economy. The quality and value of plastic products are maintained [24]. The method promotes CE, but a huge amount of plastic waste produced daily exceeds the available recycling facilities, and

the limit at which plastic can be recycled. This causes the loss of essential properties, which limits permanent recycling [15].

Reuse of wasted materials to manufacture new products is relevant to minimize resource consumption and negative environmental impacts. Reusing wasted material enables the development of local business networks that create jobs and improve economic performance [39]. Even if EC aims to design out waste, it needs to go a step further and consider the impact of raw materials, the entire product value chain, and end-of-life options to achieve sustainability [4]. Stakeholders in plastic waste management prioritize other policy interventions, such as value chain coordination and gradual integration, followed by the need to increase investments for innovation in the sector [36].

3.3. Plastic recycling

Establishing sustainable levels and cycles of plastic materials requires reliable knowledge of the provenance of what will be destined for recycling. It also requires careful consideration of its composition and intrinsic properties [17]. The recyclability of plastic depends largely on its quality [22]. In product design, the industry should not only consider the technical properties required for application in specific products, but also the intended ones [54]. To maximize the recovery of plastic packaging material and develop new technologies, industries constantly invest in R&D and innovation activities [22].

It should be a common objective between the regulation, company, and engineering, to create cycles of sustainable materials that generate benefits and value for recycling [17]. Companies are obliged to meet the demands of various centers of people or organizations involved in the plastic transformation chain [12].

A new legally linked international instrument, based on the Montreal Protocol, would aim to increase the recycling rate of new and existing plastics. In support of this, the goal would be to encourage innovation in design and materials to increase the recyclability of new products [46]. In today's market, the creation and development of plastic packaging largely control the degree of recycling [22]. Only a small percentage of production (about 14%) is recycled globally [52].

Plastic waste management around the world

The predominance of plastics in the modern lifestyle is indisputable. Plastic is a versatile material that can be used in a wide range of applications, from plain packaging to high-tech industrial practices [35]. The environmental management of plastic packaging waste is an issue that generates concern, as it causes potential threats to the oceans and the environment after poor disposal management [25]. The amount of waste generated due to the COVID-19 pandemic effectively threatens existing waste management flows. The pollution resulting from plasticization can impose serious risks

to human health and the environment, and with this, the need for monitoring plastic waste in the post-COVID-19 context [45] increases.

The results reported in Table 1. report what is happening in various parts of the world concerning studies and management of recyclable or non-recyclable plastic waste. The survey was made about the last five years.

Table 1. Results found in the period (2017-2021)

REFERENCES	FINDINGS
(Jang et al., 2020)	In South Korea, non-recyclable plastic waste is deposited in disposable bags and paid for by families based on their weight - called "pay-as-you-throw". The bags are collected by the local government and treated in incineration facilities and landfills.
(Comissão Europeia, 2018)	Europe has actively responded to the problem of single-use plastics, including a regulatory policy based on the 10 largest plastic waste found on Europe's beaches.
(Schwarz et al., 2021)	Studies report that by recycling (and sorting) the 15 most sought-after polymers in Europe, CO2 emissions from the life cycle of plastics can be reduced by 73%.
(Martínez Urreaga et al., 2020)	Economic feasibility analysis shows that using recycled plastics generated from agricultural plastic waste can lead to significant savings in material costs.
(Schmidt et al., 2020)	In European countries, it has been shown that material efficiency indicators for recycling pet bottle waste are better suited for better environmental performance than indicators based on insums.
(Kawashima et al., 2021)	The chemical industry and the plastics value chain are facing significant challenges from the point of view of resource conversion and environmental burden.
(Gupta et al., 2019)	The plastic bottle is considered non-degradable plastic waste (it takes about 700 years to common), and less than 10% are being recycled.
(Liliani et al., 2020)	Bioplastics are considered an ideal substitute for conventional plastic packaging
(Hahladakis, Iacovidou, 2018)	Currently, only about 5% of the material value of plastic packaging is captured after a cycle of use.
(Filimonau, 2021)	Care with food protection and hygiene will be the explanation for the increasing patterns of plastic waste generation, resulting from the disposal volume of hand sanitizers, disinfectants, and cleaners during the COVID-19 pandemic.

4 Discussion

From this research, we identified the components of CE, which, supported by sustainable innovation, generate positive impact and economic growth. We define circular economy as an economic system, centered on the 3Rs "reduction, reuse, and recycling" of materials in production consumption practices, aiming to achieve sustainable development. This movement is enabled by management model innovation and more responsible consumers. It is a collaborative movement. The literature review highlighted the close relationship between themes and their interdependence regarding

the valuation of their impacts (social, economic, and environmental) to achieve the goal of a more sustainable world [1].

Effectively, changes in the routines of plastics processing companies are due to pressure from the external environment, caused mainly by the following factors: changes in environmental legislation (solid waste legislation); resource use (disposal and scarcity); and competitors' strategies (innovations) [12]. Importantly, the first factor was more effective, as it acted as a driver for the other changes. However, even today, business models do not take into account the environmental and social consequences of value creation and delivery. In this regard, Lewandowski (2018) suggests that it is important to combine the business model elements on how to apply circular economy principles to plastics.

Studies conducted in plastics industries revealed that companies presented themselves as competitive and successful in adopting the following practices: (1) Innovation for sustainability; (2) Managing the circular flow of resources; (3) Building infrastructure for sustainability, contributing to the search for new routines and building new organizational structures [12].

Finally, the study allows us to elaborate an integrative framework between EC, NCEP, sustainable innovation and recycling, which is presented in Figure 4. The theoretical pillars that support the framework are:

- The guidelines of organizations on sustainability should be based on the three main dimensions of sustainable development: economic, environmental, and social [14];
- The influence that government incentives can have on the product and companies contributes to recycling and sustainable innovation [5];
- The New Plastic Circular Economy is aligned with the principles of the circular economy: reduce, reuse, and recycle [44].

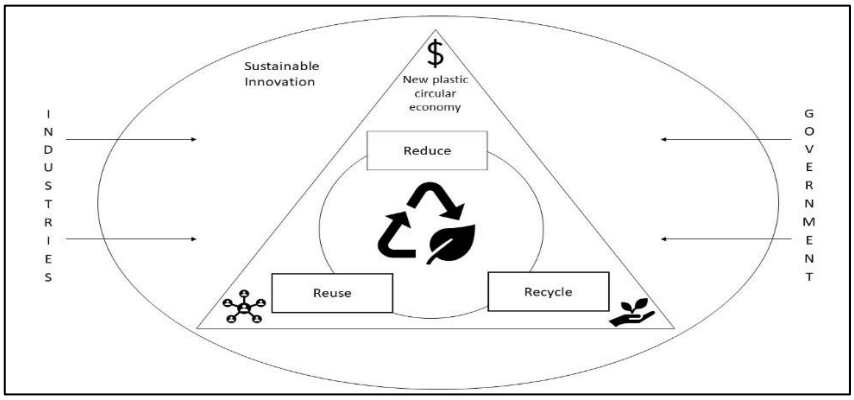

Fig. 2. Integrative framework

5 Conclusion

The research confirms on several points: the scarcity of raw material resources, the rampant consumption of plastics and the irresponsible disposal by organizations and the world population have a high price and serious consequences for nature and all living beings on the planet. High consumer demand for plastic packaging materials and single-use materials designed for immediate disposal has resulted in huge amounts of plastic waste to be managed in treatment and disposal. Therefore, it is believed that this problem can move towards a better resolution through innovative and sustainable practices.

The COVID-19 pandemic showed how dependent we are on plastic: personal protective items, plastic product packaging to facilitate hygiene and prevent the spread of the virus. COVID-19 expanded the use of disposable plastics exponentially. Today, we extract numerous benefits from plastic waste, but in the long term, increased consumption volume is likely to result in negative impacts for everyone.

6 Limitations and future studies

Some limitations can be identified from the survey of the articles analyzed. Important topics such as sustainable innovation in processes and design of products produced with plastic waste, still have shallow or incipient content in the literature. The phases of plastics recycling and the professionals that perform this collection process have not received the proper attention so far. The plastic transformation industry presents relevant characteristics to be studied, such as its composition. The importance of new research in this area is mainly due to the time that items produced from plastic can remain in the soil. Innovative studies in this area could foster and generate valuable public policies.

As researchers, we are aware that not only the lack of information in the literature may represent a limitation, but also the period we considered in the database. As a result, we decided to elaborate from the bibliographical references researched, a table with suggestions for future studies in several related themes such as Sustainable Innovation Management, Circular Economy, and Plastic Waste Recycling.

Table 3. Suggestions for future studies

REFERENCES	FUTURE STUDIES SHOULD...
(Millette et al., 2019)	Develop research on economic and technical feasibility, to later evaluate the establishment of a domestic pet packaging recycling facility (Polyethylene Teephthalate).
(Tsai et al., 2020)	Identify processes that promote effective waste separation, sorting equipment lines, recycling development, and waste minimization at points of origin and transfer, prior to sorting and treatment processes.
(Tsai et al., 2020)	Survey the types of products and applications in polymers. Identify possible forms of contamination of plastic waste - compromising recycling potential and waste management

(Veelaert et al., 2020)	Point out the differences between post-industrial and post-consumer plastic waste.
(Liliani et al., 2020)	Improve, through co-innovation, the properties of bioplastics and replace conventional plastic packaging
(Patrício Silva et al., 2020)	Present the destination, behavior, degradability, and effects of personal protective equipment - its additives, potential pathogen transfer and chemical contaminant adsorption capacity – due to COVID-19.
(Veleva & Bodkin, 2018)	Investigate how innovations in management models can generate rational/irrational reasons in consumers, change their behavior and adopt CE practices.
(Aschemann-Witzel & Stangherlin, 2021)	Apply new theories of consumer behavior and environmental psychology, in addition to conducting this research in more diverse cultural contexts.
(Tsai et al., 2020)	Report through a case study on the implementation of solid waste management methods, emphasizing differences in consumption behaviors of CE, aiming to meet the demands of everyday life.
(Niesten et al., 2017)	Explore the concept of governance and collaboration in the context of sustainability.
(Bashir et al., 2020)	Investigate the type of experimentation required of companies in the transition to sustainable business models and the types of issues that companies should explore at such an initiation point.
(Kawashima et al., 2021)	Prove that polylactic acid (PLA) helps reduce greenhouse gas (GHG) emissions as a bio-based material, plus contribute to waste management.
(McDevitt et al., 2017)	Propose public policies that meet microplastics, to mitigate problems and assist in the innovation process of new eco-friendly products.
(Kawashima et al., 2021)	Explore the subsequent direction of plastics - which requires an integrated scheme on resource movement, carbon neutrality, and a social system to promote post-use treatment under the concept of CE.

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