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Sustainable Value Roadmap for the Plastics Industry

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Abstract

The plastics industry has revolutionized several sectors, from packaging to automotive, enabling companies to develop innovative products and enhance their economic competitiveness. However, the exponential growth of this industry has also resulted in a concerning increase in plastic waste, leading to environmental repercussions such as microplastic contamination, marine pollution and plastic landfills. Therefore, researchers, governments, and industrial stakeholders are starting to work collaboratively to address this sustainability issue by adopting a life cycle perspective. Nevertheless, plastic waste generation is not slowing down, and waste management strategies, along with other actions across the value chain, need to be improved. While limiting single-use plastics and promoting sustainable consumer practices is crucial, these measures alone may not be sufficient. Figuring out how to maximize products and materials' lifespan by exploring circular economy opportunities is just as important as minimizing global consumption. This research explores the challenges and opportunities faced by the plastics industry and draws a prototype roadmap to identify sustainable business opportunities and routes of implementation. It builds on previous works on sustainable value roadmapping by defining a vision, identifying drives, highlighting business opportunities and discussing enablers. Results systematize and expand opportunities and challenges identified in scientific literature and industrial reports whilst clearly outlining a vision.

Keywords: plastics; sustainability; roadmap; bussiness opportunities

1. Introduction

Plastic consumption is growing, and in 2021, approximately 390.7 mega tonnes of plastics, fundamentally fossil-based plastics, were produced around the world, namely in China (32%), North America (17%), remaining geographies of Asia (17%), and the European Union 27+3 (15%) [1]. Its versatility, durability and competitive cost [2] have made plastic a pivotal material for several applications, spanning different sectors, such as packaging, construction, automotive, agriculture, electric and electronics and even the medical sector [3]. For instance, in Europe, the plastics industry significantly impacts the market with a 400 million euros turnover, more than 52,000 small and medium companies and a direct employment estimated above 1.5 million people [1].

However, the significant growth of this industry worldwide has raised several concerns [4]. Of particular significance are the environmental repercussions deriving, for example, from the manufacturing of short life span products (single-use plastics) [5], the increasing greenhouse gas emissions related to the production processes or the inadequate waste management strategies implemented [6]. Many of these issues have garnered significant attention due to far-reaching effects, such as the proliferation of microplastic pollution in terrestrial, marine, and freshwater ecosystems that is affecting human health and natural ecosystems [7].

Furthermore, the urgency to address the sustainability concerns impacting the plastics industry across the life cycle has resulted in an international negotiation process between the United Nations member states. Given these global efforts, companies have been pushed to incorporate sustainable practices in a holistic perspective and adopt sustainable business models to protect their financial performance [4]. Nevertheless, to accomplish this, it is imperative to find

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valuable business opportunities and the associated strategies that will enable the plastics industry to transition toward sustainability.

One effective approach in this context is the use of roadmapping, which originated in strategic management as a method for organizing, systematizing, clarifying and centralizing information to support decision-making and the formulation of strategies [8]. Roadmaping generally focuses on answering three main questions: Where are we now? Where do we want to go? And how do we get there? [9]. Furthermore, while incorporating both factors within the organization's control and influenced by external aspects, roadmaping often considers elements, such as technology push, market pull or the identification of value-creating opportunities [10].

While commonly associated with strategic management in industry, roadmapping has often been used by expert panels and international regulatory bodies to delineate long-term goals and support directives aimed at local policymakers (i.e., governments). An example of this is the European Commission's efforts to mitigate the effects of climate change, as seen more recently in the European Green Deal [11].

Hence, in the context of sustainability, the roadmapping approach has been proven to be very effective in shaping long-term strategy vision and implementation. It can facilitate the discussion of potential/challenges of new technologies/industrial sectors [10,12] and support the definition of sustainability-driven corporate or public strategies.

This study explores the challenges and opportunities the plastics industry faces in its path towards sustainability in 2030. Moreover, it aims to establish a sustainable value roadmap for the plastics industry, including identifying potential sustainable business opportunities and outlining implementation strategies. This research, based on the sustainable value roadmap tool, defines a vision, identifies the key drivers propelling the transition, highlights prospective business opportunities, and finally addresses crucial enablers in implementing the business opportunities.

2. Methodology

This paper follows the sustainable value roadmap tool (SVRT) originally proposed by Despeisse et al. [13], which was later applied in a framework to explore the potential of additive manufacturing technologies adoption [10]. The framework, as presented in Fig. 1, consists of a systematization of four key roadmapping components: vision, drivers, enablers, and business opportunities.

Despite being originally proposed to evaluate on a technology level [10], this paper applies the framework to sectorial sustainability analysis, more aligned with the original applications of the roadmapping technique. The timeline component of this roadmapping framework is present through the alignment of the long-term vision (1) with the sustainable development goals (2030) and climate neutrality goals (2050).

Furthermore, the identification of business opportunities follows a life cycle perspective, identifying opportunities that impact sustainability at three levels:

- Beginning of life (BoL) – Design of products and processes; manufacturing system configuration; business model.
- Middle of life (MoL) – transport; efficiency in use phase; life extension.
- End of life (EoL) – industrial symbiosis; waste management.

The business opportunities (3) are derived from the combined effect of drivers (2) and are made feasible through a set of enablers (4). The drivers, both internal (e.g., corporate strategy) and external (e.g., policy; market pull), push companies to innovate and meet sustainable development goals. On the other hand, enablers, such as technological developments, often facilitate the transition to cleaner products or manufacturing processes.

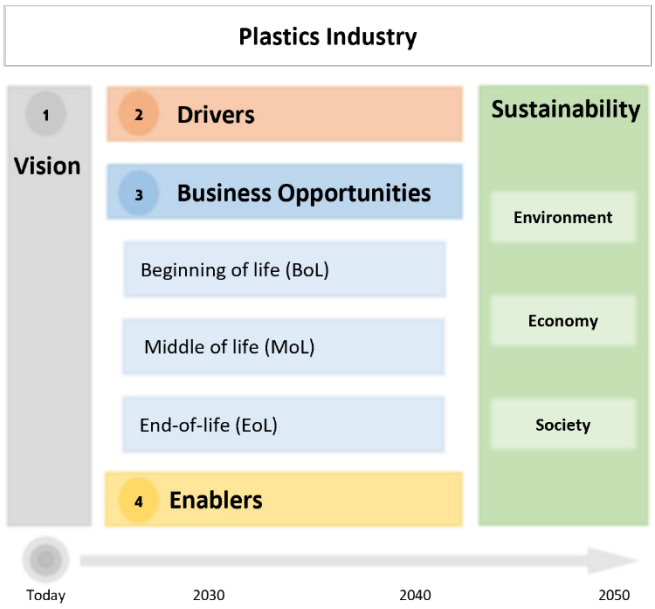

Fig. 1. Sustainable value roadmapping framework (adapted from Despeisse et al. 2017 [13]).

3. Sustainable Value Roadmapping

To develop a sustainable value roadmap, it is mandatory to include all the stakeholders to avoid missing the identification of uncaptured value. The plastics industry includes many stakeholders, encompassing, for example, plastic producers, converters, recyclers, consumers, other industrial organizations and other non-governmental and governmental institutions. Furthermore, this industry is also distributed across several geographic regions. This geographical diversity offers an opportunity for benchmarking since the status of the implementation of sustainable practices might vary based on different regional dynamics [14].

The SVRT, as described in section 2, is structured in 4 main steps: set a vision, examine the drivers behind the goals and targets, identify potential business opportunities based on the uncaptured value and finally establish the enablers required to take advantage of these business opportunities.

3.1. Vision

The creation of a vision for the plastics industry is challenging and must consider a range of perspectives spanning economic, environmental and social aspects. Hence, this vision is established based on the 2030 Agenda for Sustainable Development [15]. This agenda presents 17 sustainable development goals (SDGs), which are global targets established by the United Nations for 2030. Thus, considering the work developed by Sousa [2], Walker [7] and Khajuria et al. [16], a vision is settled for the plastics industry, encompassing, for instance, aspects presented in Table 1.

Table 1. Vision for the plastics industry.

SDGs	Vision related to the SDGs
No poverty	Foster the eradication of poverty by developing employment opportunities and sustainable products suited for populations with limited resources.
Zero hunger	Support the development of sustainable plastic products for agriculture and contribute to ending hunger by finding novel methods to reduce food waste.
Good wealth and well-being	Increase well-being and healthy lives by ensuring the safety of plastic products for human use, reducing microplastic pollution and the creation of plastic solutions for medical equipment.
Quality education	Enhance education quality by supporting research and the promotion of responsible consumption awareness.
Gender equality	Promote gender equality by generating employment opportunities and products that empower women.
Clean water and sanitation	Support clean water and sanitation through the development of products for water treatment, fostering responsible waste disposal.
Affordable and clean energy	Enable affordable and clean energy by reducing energy consumption and harnessing renewable sources.
Decent work and economic growth	Ensure decent work and economic growth by creating jobs and driving economic development through innovative products.
Industry, innovation, and infrastructure	Promote industry, innovation, and infrastructure by investing in sustainable materials and applications.
Reduced inequalities	Help to reduce inequalities by promoting diversity and inclusion in the workplace and avoiding the trade of waste in economically disadvantaged countries.
Sustainable cities and communities	Encourage sustainable cities and communities by developing sustainable infrastructure and minimizing plastic waste in urban areas.
Responsible consumption and production	Support conscientious consumption and production by manufacturing products that are recoverable or recyclable in a circular economy.
Climate action	Help to mitigate climate change by supporting life cycle analysis, decreasing greenhouse gas emissions and adopting renewable energy sources.
Life below water	Reduce plastic pollution in oceans and other water systems as well as terrestrial ecosystems.
Life on land	Reduce plastic pollution in terrestrial ecosystems.
Peace, justice, and strong institutions	Advocate for accountability and openness in its operations while upholding ethical corporate behaviour and social justice.
Partnerships for the goals	Assist in achieving the SDGs by promoting collaboration between the private sector, non- and governmental institutions, academia and consumers.

3.2. Drivers

The plastics industry faces several external and internal challenges driving the need for significant change throughout the life cycle of plastic products, from manufacturing to end-of-life. A comprehensive understanding of the industry's imperative for sustainable transformation requires the analysis of some drivers. Considering different perspectives, some examples are provided regarding external and internal drivers as presented in Table 2.

Table 2. Internals and external drivers

Driver	Driver description
Environmental concerns	Issues related to the environment have gained significant public attention as a result of a growing recognition of the adverse impacts that plastic pollution is having on ecosystems, particularly marine areas [3].
Policy	National governments along with international regulatory bodies, have implemented stringent legislation and guidelines addressing the use, production, and waste management of plastics that impact the industry practices [4,6,17].
Consumer behaviour	The shift in consumer preferences towards ecologically responsible products places pressure on manufacturers to embrace sustainable alternatives to protect the brand value [4,6].
Competition	Companies that commit to sustainability not only might enhance their corporate image but also gain competitive advantage. The competitive dynamic compels other stakeholders to follow suit, fostering a more sustainable ecosystem [18].
Technological developments	The advancements related to new processes and solutions, such as chemical recycling technologies and bio-based materials, provide viable alternatives to traditional plastics, further motivating the shift towards sustainability [6,17].
Oil costs	The fluctuating price of oil makes fossil fuel feedstock prices unpredictable, opening new opportunities for sustainable plastics, for example, bioplastics and recycled plastics [4,17].
Market opportunities and emerging goals	Markets are increasingly conducive to sustainable plastic solutions. A proactive shift toward sustainable practices capitalizes on these burgeoning opportunities [4].
Resource efficiency	Streamlining resource usage and minimizing waste, for example, through lean manufacturing and industry 4.0 technologies, has emerged as an avenue for cost reduction, making sustainability initiatives conducive to enhancing corporate profitability [19].
Innovation	Many businesses understand that the path towards sustainability, namely the inherent potential business opportunities, is a source of innovation [20].
Corporate responsibility	An increasing acknowledgement of corporate responsibility and ethical obligations bolsters the case for sustainability. Organizations are endeavouring to align their practices with the imperatives of social responsibility [18].
Employee expectations	The awareness related to sustainability concerns might also result in an increasing interest of employees in organizations that support sustainability, for example, through ethical business practices.

3.3. Business opportunities

As an output of this step of the SVRT, this section provides the business opportunities for the plastics industry. Notwithstanding, it is worth noting that in this preliminary version of the SVRT, this output only presents some of the potential opportunities with the highest potential (see Table 3).

Table 3 – Summary of the most relevant business opportunities for the plastics sector. The "✓" indicates the life cycle stage(s) impacted by each opportunity.

Opportunity	BoL	MoL	EoL
Design for longevity		✓	
Design for recycling			✓
Design for repairability		✓	
Incorporate recycled plastics	✓		
Design new product as a service business models		✓	✓
Implement new service business model focused on extending existing products' lifespan		✓	
Decentralize manufacturing		✓	
Establish industrial symbiosis' partnerships	✓		✓
Implement waste management/reutilization solutions	✓		✓

As consumers grow more aware of environmental issues, demand for long-lasting, reusable products is expected to increase. This growth will be supported by the European Union's goal of eliminating single-use plastics soon. Companies can explore this international paradigm change by adopting new product design principles aimed at improving environmental performance throughout the products' life cycle, thus increasing the perceived value of their products. Some of the most relevant and impactful design principles include [21]:

- Design for repairability: Companies can reduce waste by designing repairable products (e.g., smartphones with replaceable batteries).
- Design for longevity: Much like repairability, increasing longevity contributes to waste reduction by eliminating the need to produce and consume new products.
- Design for recycling: Companies are compelled to consider the recyclability of new products' materials during the design stage, not only by effects of market pull but also by the European Union's design for recycling work plan. Within this framework, companies in the plastics sector must rethink the manufacturing of multi-material components and design for simpler disassembly and recyclability.

Furthermore, companies can leverage the growing availability of recycled plastics by designing new products meant to be manufactured with higher quantities of these materials.

Sustainable business models have been the focus of numerous corporate and research efforts as of late. A sustainable business model intends to describe how economic, environmental and social value is created and delivered [22]. New sustainable business models must leverage technological and design opportunities to meet market expectations and develop new ways to deliver economic, environmental and social value. One of the most interesting and potentially impactful business opportunities is the adoption of product-as-service value propositions [23]. Companies can leverage new trends of design for longevity and repairability to develop business models centred on repairing and upgrading products during their life cycle instead of pushing to increase the volume of manufactured/sold units. Furthermore, there are opportunities for new service-centred business models focused on delivering value by refurbishing, retrofitting and upgrading existing products (e.g., machines), whether during their life cycle or at their end. Both business models contribute to the life cycle extension and, consequentially, to an economically sustainable reduction of plastic raw materials.

Decentralized manufacturing is key to reducing transport and is often mentioned in the plastics industry, particularly when discussing new technologies such as additive manufacturing [10]. Locally manufacturing custom-made solutions can help companies leverage previously discussed business model opportunities, such as the ones designed around retrofitting and upgrading existing products. Overall, with growing environmental concerns and logistic complexities and inherent vulnerabilities, there are opportunities to establish local suppliers of plastic components.

Finally, companies should explore opportunities to close the loop, whether by establishing symbiotic partnerships or by investing in end-of-life/waste management solutions. Local networks within the plastic sector can promote opportunities to reduce waste by using it as raw material for other products. As an example, lower-grade recovered waste plastic can often be used in products with low mechanical and aesthetic requirements. Alternatively, companies can explore opportunities to retrieve end-of-life products and incorporate the material in new products. An example of this dynamic is the recovery of agricultural irrigation tape by the original manufacturer when delivering the replacement product. After properly cleaned and recycled, the material can be used to manufacture new tape. Because the entire cycle is controlled by the same company, there is a good level of control of the recycled material quality and contamination with other materials.

Closing the loop reduces the consumption of raw plastic, contributes to lower raw material prices and minimizes the dependence on external suppliers and price uncertainty due to the oil crisis.

3.4. Enablers

After identifying some potential business opportunities, it is mandatory to determine some of the enablers that can effectively realize these possibilities, namely internal and external resources. Some examples are provided based on previous industry reports and research [24–27]:

- Recycling: Scaled-up mechanical recycling and improvement of chemical recycling to handle larger

volumes and difficult-to-manage plastic waste, respectively.
- Sorting and separation: Enhancement of sorting and separation technologies to improve efficiency during the recycling processes.
- Recycling content tracking: Adoption of systems to audit the recycled content of products while promoting transparency.
- Blockchain: Application of blockchain technology for transparent and traceable management of the forward and reverse supply chains.
- Waste to energy: Development of technologies with improved efficiency to convert plastic waste into energy.
- Additive manufacturing: Exploration of additive technologies towards the development of new geometries, production decentralization and plastic waste reduction during manufacturing.
- Bioplastics and biodegradable plastics: Adoption and development of bioplastics and biodegradable plastics as alternatives to fossil-fuel-based plastics.
- Renewable energy: Incorporation of renewable energy sources across the supply chain, from manufacturing processes to waste management plants.
- Circular-design expertise: Investment in workforce experience regarding circular design principles along with certification that ensures not only the implementation of sustainable practices but also its technical viability.
- Sustainability auditing: Conduction of regular audits of companies to evaluate and improve sustainable practices.
- Investment pipelines: Establishment of investment channels to support sustainable investments and projects.
- Research, development, and innovation: Allocation of funding for research projects and innovation initiatives.
- Consumer education: Enhancement of consumer education campaigns and programmes funds to raise awareness and support responsible consumption.
- Circular economy networks: Collaborations of companies and circular economy initiatives to share knowledge and design integrated business practices.
- Partnerships: Forged strategic partnerships across the entire supply chain to avoid the loss of value between suppliers, manufacturers, and distributors.

4. Conclusions and outlook

Many studies have focused on the sustainability impact of the plastics industry, mainly from an environmental and economic perspective, as global consumption continues to increase despite recent legislative efforts by the European Union. Notwithstanding this adverse international scenario, this paper discusses existing sustainability drivers while identifying some interesting opportunities and enablers to increase sustainability in the sector. In terms of opportunities, business models focused on reducing consumption by offering long-lasting products that are designed to be repairable or even upgradable seem to be the most impactful solution. However, there are still questions regarding the widespread acceptance by consumers. Despite a general trend towards growing sustainability concerns, some global demand patterns don't seem to focus on sustainable solutions but rather on ease of use and accessibility. Some recommendations to address and potentially change this trend might include, among many others, consumer education and awareness campaigns, collaboration across the supply chain, policy advocacy and incentives or innovation in product design.

On the topic of limitations, as interesting as the existing roadmapping frameworks may be, they often fail to discuss both internal and external factors that can limit the adoption of sustainable solutions. Those limitations should not be seen as barriers to sustainability, particularly because, in some cases, they are merely linked to the current development state of potential enablers. Some examples of areas that require further development include:

- Quality of recycled material: Guaranteeing the quality and uniformity of recycled material is still challenging [3]. However, it is improving with recent recycling content tracking efforts.
- Perceived quality of recycled products: In various applications, consumers might associate recycled material with lesser quality [28], which, in some cases is clearly a biased perception.
- Demand for cleaner products: Despite recent growth, the number of consumers willing to pay a premium for cleaner products is still limited [6].
- Consumption trends: Most consumers still value ease of use and accessibility/cost over sustainability [29], and marketing strategies are still heavily focused on short product cycles and frequent launches of new product iterations. It is unclear how receptive consumers are to repairable products, particularly if that means maintaining them for longer periods.
- Mechanical recycling: Despite continuous development and improvement, there is still a need to scale up mechanical recycling processes to improve efficiency when dealing with various materials in large quantities [24].
- Chemical recycling: By overcoming some mechanical recycling issues, chemical recycling techniques open up the possibilities to a broader spectrum of materials [24]. Chemical recycling processes must be closely analysed and monitored to ensure an improved sustainability performance, due to the potential production of pollutant contaminants.
- Economic sustainability: A sustainable transition is considerably dependent, for example, on competitive solutions, investments in technology and infrastructure, or even suitable financing. Nevertheless, limited data is available to compressively evaluate the economic impacts of different strategies in a life cycle perspective [30].
- Social sustainability: As is often the case, the social dimension is less discussed than its economic and environmental counterparts. Some plastic components are still manufactured in less developed countries, without significant supervision of labour conditions. The same can be highlighted for the raw material supply chain. Moreover, social issues within the plastics industry affect different stakeholders across the supply chain [31] and might include, for example, the exposure of workers to hazardous materials [32].
- Stakeholders' participation: Technological developments alone are not enough to ensure the adoption of sustainable

practices. The involvement of stakeholders across the supply chain (e.g., plastic producers, manufacturers, recyclers, policymakers, industrial organizations) is crucial. It is paramount for future research to comprehend the intricacies of stakeholder perspectives and investigate how divergent goals and priorities may facilitate or limit the implementation of sustainable practices. Targeted actions and policies can be developed by considering the various levels of influence that different stakeholders possess and identifying any obstacles to active engagement.

This paper discusses the sustainability of the plastics industry by applying a roadmapping tool to study potential drivers, enablers and opportunities to increase sustainability and meet the vision. This paper is an initial approach to the topic, and further work is still needed to provide an in-depth look at the sustainability of the plastics sector. Overall, despite recent technological improvements and legislative pressure, there is still a long road to achieving carbon neutrality in the sector.

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References

[1] Plastics Europe, 2022, "Plastics – the Facts 2022."
[2] de Sousa, F. D. B., 2021, "The Role of Plastic Concerning the Sustainable Development Goals: The Literature Point of View," Cleaner and Responsible Consumption, **3**, p. 100020.
[3] Hsu, W.-T., Domenech, T., and McDowall, W., 2022, "Closing the Loop on Plastics in Europe: The Role of Data, Information and Knowledge," Sustain Prod Consum, **33**, pp. 942–951.
[4] Dijkstra, H., van Beukering, P., and Brouwer, R., 2020, "Business Models and Sustainable Plastic Management: A Systematic Review of the Literature," J Clean Prod, **258**, p. 120967.
[5] Kiessling, T., Hinzmann, M., Mederake, L., Dittmann, S., Brennecke, D., Böhm-Beck, M., Knickmeier, K., and Thiel, M., 2023, "What Potential Does the EU Single-Use Plastics Directive Have for Reducing Plastic Pollution at Coastlines and Riversides? An Evaluation Based on Citizen Science Data," Waste Management, **164**, pp. 106–118.
[6] Siltaloppi, J., and Jähi, M., 2021, "Toward a Sustainable Plastics Value Chain: Core Conundrums and Emerging Solution Mechanisms for a Systemic Transition," J Clean Prod, **315**, p. 128113.
[7] Walker, T. R., 2021, "(Micro)Plastics and the UN Sustainable Development Goals," Curr Opin Green Sustain Chem, **30**, p. 100497.
[8] Rampa, R., and Parmentier, G., 2023, "The Affordances of Technology and Strategic Roadmapping: An Exploration of Its Instrumental, Symbolic, and Political Functions," Journal of Engineering and Technology Management, p. 101778.
[9] Kerr, C., and Phaal, R., 2022, "Roadmapping and Roadmaps: Definition and Underpinning Concepts," IEEE Trans Eng Manag, **69**(1), pp. 6–16.
[10] Despeisse, M., Yang, M., Evans, S., Ford, S., and Minshall, T., 2017, "Sustainable Value Roadmapping Framework for Additive Manufacturing," *Procedia CIRP*.
[11] European Commission, 2019, *The European Green Deal*, Brussels.
[12] Kumar, S., and Czekanski, A., 2018, "Roadmap to Sustainable Plastic Additive Manufacturing," Mater Today Commun, **15**, pp. 109–113.
[13] Yang, M., and Despeisse, M., 2016, "Sustainable Value Roadmapping Tool," *R&D Management Conference 2016 "From Science to Society: Innovation and Value Creation."*
[14] Alayón, C. L., Säfsten, K., and Johansson, G., 2022, "Barriers and Enablers for the Adoption of Sustainable Manufacturing by Manufacturing SMEs," Sustainability, **14**(4), p. 2364.
[15] United Nations, 2015, *Transforming Our World: The 2030 Agenda for Sustainable Development*.
[16] Khajuria, A., Atienza, V. A., Chavanich, S., Henning, W., Islam, I., Kral, U., Liu, M., Liu, X., Murthy, I. K., Oyedotun, T. D. T., Verma, P., Xu, G., Zeng, X., and Li, J., 2022, "Accelerating Circular Economy Solutions to Achieve the 2030 Agenda for Sustainable Development Goals," Circular Economy, **1**(1), p. 100001.
[17] Baldassarre, B., Maury, T., Mathieux, F., Garbarino, E., Antonopoulos, I., and Sala, S., 2022, "Drivers and Barriers to the Circular Economy Transition: The Case of Recycled Plastics in the Automotive Sector in the European Union," Procedia CIRP, **105**, pp. 37–42.
[18] Hariyani, D., Mishra, S., Hariyani, P., and Sharma, M. K., 2023, "Drivers and Motives for Sustainable Manufacturing System," Innovation and Green Development, **2**(1), p. 100031.
[19] Ghaithan, A., Khan, M., Mohammed, A., and Hadidi, L., 2021, "Impact of Industry 4.0 and Lean Manufacturing on the Sustainability Performance of Plastic and Petrochemical Organizations in Saudi Arabia," Sustainability, **13**(20), p. 11252.
[20] Borland, H., Bhatti, Y., and Lindgreen, A., 2019, "Sustainability and Sustainable Development Strategies in the U.K. Plastic Electronics Industry," Corp Soc Responsib Environ Manag, **26**(4), pp. 805–818.
[21] Mestre, A., and Cooper, T., 2017, "Circular Product Design. A Multiple Loops Life Cycle Design Approach for the Circular Economy," The Design Journal, **20**, pp. S1620–S1635.
[22] Cardeal, G., Höse, K., Ribeiro, I., and Götze, U., 2020, "Sustainable Business Models – Canvas for Sustainability , Evaluation Method and Their Application to Additive Manufacturing in Aircraft Maintenance," (2018), pp. 1–24.
[23] Bocken, N. M. P., Short, S. W., Rana, P., and Evans, S., 2014, "A Literature and Practice Review to Develop Sustainable Business Model Archetypes," J Clean Prod, **65**, pp. 42–56.
[24] SYSTEMIQ, 2022, *ReShaping Plastics: Pathways to a Circular, Climate Neutral Plastics System in Europe*.
[25] Bhubalan, K., Tamothran, A. M., Kee, S. H., Foong, S. Y., Lam, S. S., Ganeson, K., Vigneswari, S., Amirul, A.-A., and Ramakrishna, S., 2022, "Leveraging Blockchain Concepts as Watermarkers of Plastics for Sustainable Waste Management in Progressing Circular Economy," Environ Res, **213**, p. 113631.
[26] Gonçalves, A., Ferreira, B., Leite, M., and Ribeiro, I., 2023, "Environmental and Economic Sustainability Impacts of Metal Additive Manufacturing: A Study in the Industrial Machinery and Aeronautical Sectors," Sustain Prod Consum, **42**, pp. 292–308.
[27] Nielsen, I. B., and Hakala, H., 2023, "External Enablers for the Circular Economy: A Case Study of the Food Packaging Industry," J Clean Prod, **417**, p. 137915.
[28] Polyportis, A., Mugge, R., and Magnier, L., 2022, "Consumer Acceptance of Products Made from Recycled Materials: A Scoping Review," Resour Conserv Recycl, **186**, p. 106533.
[29] Sheoran, M., and Kumar, D., 2022, "Benchmarking the Barriers of Sustainable Consumer Behaviour," Social Responsibility Journal, **18**(1), pp. 19–42.
[30] P, G.-G., AM, A., D, K., S, N., D, T., D, T., F, A., and H, S., 2023, "Environmental and Economic Assessment of Plastic Waste Recycling," (KJ-NA-31-423-EN-N (online)).
[31] Spierling, S., Knüpffer, E., Behnsen, H., Mudersbach, M., Krieg, H., Springer, S., Albrecht, S., Herrmann, C., and Endres, H.-J., 2018, "Bio-Based Plastics - A Review of Environmental, Social and Economic Impact Assessments," J Clean Prod, **185**, pp. 476–491.
[32] Ardolino, F., Palladini, A., and Arena, U., 2023, "Social Life Cycle Assessment of Innovative Management Schemes for Challenging Plastics Waste," Sustain Prod Consum, **37**, pp. 344–355.