The Role of Circular Supply Chains in Achieving Sustainability Goals: A 2023 Perspective on Recycling, Reuse, and Resource Optimization

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Abstract

With sustainability hitting the top of the agenda in businesses worldwide, supply chain management is taking a closer look at mechanisms by which to alleviate environmental impacts. One of the techniques often proposed is the implementation of circular supply chains. The process involves the use of recycling, reuse, and reverse logistics in product recovery. In this essay, the above-mentioned mechanisms have been extensively discussed, assumptions have been made on their level of implementation in 2023, and a futuristic scenario of 2030 has been drawn, where new, modern, and futuristic technologies have led to the realization of a resource-free or resource-optimized supply chain. The most important aspect discussed in this essay is the assumption that all three practices studied will not only be socially and environmentally good in 2023 but, more importantly, a profitable business decision. The essay also underscores the fact that these practices would not just be seen as a part of supply chain strategy but also as a part of company strategy.
Three potential strategies have the potential to make supply chain management more sustainable in 2023. These strategies are recycling, reuse, and resource optimization. It is believed that these strategies may not only be socially and environmentally favorable, encompassing a review that suggests waste as an opportunity instead of a problem, another review implying why organizations should opt for circular supply chains, and a paper that discusses the difficulty and the benefits of reverse logistics. Circularity in supply chains will not only provide social and environmental benefits but may also lead to making more profit. This change, hence, calls for the integration of circular practices into supply chain management strategies. The integration in strategy is only feasible if the approaches resorted to are cost-effective and, in some instances, provide more value addition. As a result, this essay discusses recycled products as products providing more value while also discussing challenges and opportunities in integrating circular supply chains into traditional supply chain management.

Keywords: Circular economy,Sustainability goals,Supply chain optimization,Recycling practices,Resource efficiency,Waste reduction,Reuse strategies,Sustainable sourcing,Eco-friendly supply chains,Closed-loop systems,Environmental impact,Green logistics,Circular supply chains,Circular business models,Zero waste initiatives.

1. Introduction

The growing emphasis on supply chain sustainability is a response to escalating global environmental challenges, such as resource scarcity and the increasing pressure for waste management. As businesses face the urgent need to adapt, the concept of circular supply chains has garnered significant attention, offering a promising model for mitigating these challenges. Circular supply chains, characterized by closed-loop processes that prioritize resource recovery, reuse, and reduction of waste, provide not only ethical and environmental benefits but also practical business advantages. However, while there is growing support for these practices, research into closed supply chains remains relatively scarce. This special issue aims to bridge this gap by exploring the philosophical, ethical, and business justifications for closed production processes, suggesting that the adoption of circular models is not only a strategic necessity but also a pathway to fostering interdisciplinary collaborations. These innovations offer a sustainable way forward, enabling businesses and policymakers to address the complex, interconnected issues surrounding resource use, scarcity, and environmental impact.

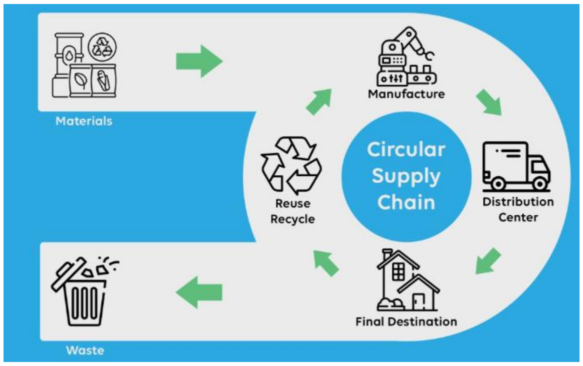

Fig 1: The Circular Supply Chain Model and the Role of Industry

1.1. Background and Significance

In an influential paper, it was pointed out that "it would be hard to find an area in management today that is generating more excitement and is in greater need of focused effort than that of the environment." We might just as easily replace "environment" with "sustainability" as we move into the second quarter of the 21st century. In operations and supply chain management, there has been a shift in research and management interest from a sole focus on efficiency through traditional supply chain management practices to a focus on effectiveness, particularly in response to consumption patterns that have been viewed as unsustainable from an environmental perspective.

Hence, we now find ourselves in an era where models of consumption and production systems are faced with a pressing need to evolve. While once linear processes of "cradle to grave" dominated the conceptualization of production and supply chains, there is now a push towards circular processes of "cradle to cradle." In particular, a core part of contemporary operations and supply chain management research has been concerned with the ways in which the recycling, reuse, and resource optimization functions of the proposed circularity allow us to transgress the performance bounds on traditional supply chain systems and, in doing so, challenge consumption production faith systems long held by practitioners and researchers alike to be true. Given that there is a growing interest to shift towards sustainability-driven consumption and production practices, addressing the fundamental question of how supply chains can be used as a means to achieve long-term environmental goals is becoming increasingly critical. Often, this question settles on which sets of decisions and specifically, on the approaches for orchestrating the management of supply chains in ways that bring about the desired objectives. In a world of competing objectives and trade-offs, developing practices that aim to appropriately and efficiently manage resources in the closed systems of supply chains is of paramount importance. It would be extremely beneficial for industry to have access to a wide-ranging set of recommendations on these fronts, made more so by integrating the lessons from across multiple practice-relevant perspectives.

1.2. Research Objectives

The purpose of this essay comprises several research objectives based on the following guiding questions: 1. Are circular supply chains, i.e., embracing the connection between logistics and operations, important for closing the loops by means of recycling, reuse, and resource optimization in order to achieve sustainability goals? If yes, how should these loops be designed? 2. How can such concepts contribute to meeting sustainability objectives? Simply put, how does reuse or recycling of certain waste products, e.g., end-of-life products, in the logistics or operational functions lead to a reduction in the environmental impact of that chain, and ideally lead to a more effective use of raw materials? 3. What is the current state of the art with respect to different industries? Are there in certain industries already existing best cases in terms of recycling, reuse, and resource optimization? If so, what are the underlying principles for closing the loop? Are there general practices possible, and hence can the approaches be generalized over industries? If so, what are the operational conditions under which this principle works? In what way can existing logistics networks be reused such that meeting sustainability goals is guaranteed? 4. Which technological advances are being developed that can support the closing of the loop on the operational dimension between logistics and operations? What part of the design of the logistics network and operational processes can be automated or supported by means of modern ICT? What is the state of the art in terms of recycling, waste planning, etc.?

Equ 1: Resource Utilization Efficiency (RUE)

$$RUE = \frac{Resource\ Input - Waste}{Resource\ Input}$$

Where:

- $Resource\ Input$ is the total amount of resources (materials, energy, etc.) entering the supply chain.
- $Waste$ is the amount of material discarded or lost.

2. Circular Supply Chains: Concepts and Frameworks

Current research maintains an enduring focus on sustainability themes and topics. As a subset of sustainability, boards of directors and CEOs have pushed forward research streams related to traditional supply chain management themes (e.g., efficiency improvements, cost reduction, process improvement). In this research brief, we re-examine key topics and themes that were once neglected but are now being actively studied. One such key topic is "circular supply chains" and "reverse logistics" systems that are being used in various multi-tiered product and resource recovery contexts. These supply chain and end-of-life recovery processes have begun to dominate research in sustainability. These frameworks focus on design and usage practices such as localized production, recycling, and remanufacturing.
The definition of circular supply chains continues to evolve over time, but a broad definition refers to a system of activities that are considered to be at the organization and lead to sustainability. Traditionally, at the forefront of supply chain progressions, traditional supply chain management has been driven by issues of efficiency and effectiveness. Thus, although regulatory pressure may sometimes need to become "green," some traditional decisions will lead to issues of sustainability. Circular supply chains fit into modern beliefs of sustainable supply chain theory by deeply considering the lifecycle of products and recycling them, or better yet, by reusing them. Although there are some theoretical differences, such as the end-of-life processes recognized in some reverse logistics frameworks, end-of-life processes and recovery stream discussions are linked sustainably to a complex system of remanufacturing, recycling, reproduction, and pollution disclosures. Circular supply chain management goes against linear or traditional perspectives and is enriched by sustainability exigencies. Additionally, forward-looking management typologies and recurrent decoupling validation are needed for the successful remanufactured or recycled service products.

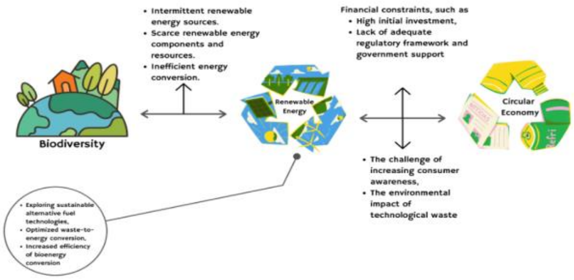

Fig 2: Circular Economy Framework

2.1. Definition and Components

In the quest for both corporate and public sustainability, the use of resources is turning from supply chains with one direction—linear—into supply chains with the second dimension—circular supply chains. A circular supply chain integrates an extended period of a life cycle of products. The focus is on the possibility of returning a product or a part of a product to the supply system, while the remainder is reused or regenerated and returned to the original balance of supply. The core of a circular supply chain is usually defined as one or both of two elements: recycling and resource efficiency. The return of part of the product can be accomplished by separating and extracting whole parts from residual waste. The other part of recycled material has been contaminated and hence transformed into a useful raw material by detoxification.
This recycled part can be reused directly or can be reformulated to generate completely new materials. The material flow starts with the purchases of raw

materials, followed by the use of fabricating, assembling, marketing, using, and finally disposal. Technological development especially triggers opportunities for rethinking the components. Consequently, we discuss marketing the return of the old engines after ten years of use with a low mileage for purposes of leasing opportunity for the undertaking of up to a maximum of 100,000 km. This knowledge and these technologies can be integrated into supply chain management through a new vision of the value of non-sellable products. Looking at the components and also the need for increasing the harmonization of phases implies a need for developing a holistic approach toward a model of a remanufacturing facility. Each phase in the manufacturing and marketing process is interdependent and thus must be analyzed using a systemic approach. So, for example, changes in the design and production process have their implications on the sales and marketing policies of the respective products.

2.2. Benefits and Challenges

Circular supply chains offer many opportunities for waste reduction. The recycling of products will lead to increased reuse of all types of components and materials, saving natural resources and energy and reducing overall product waste. Over time, recycling will also lead to the reduction of finite resources used in industry. Further benefits include increased resource security as well as a reduction in greenhouse gas emissions due to reduced extraction and manufacturing effort. Technological solutions are available and have been shown to be effective but not yet widely deployed. On the other hand, barriers for circular supply chains exist. Some of these are industrial and cost barriers. Another important one is the requirement of technological solutions and know-how for disassembly of goods. Other market-related forces reduce the market potential of circular supply chain approaches to a niche and forestall their breakthrough. The investment cost in disassembly systems that separate components and can sort and recycle them is a significant barrier to circular supply chains for many supply chains. The development of yet more powerful and energy-efficient fractionating systems can diminish but not remove this barrier. As a result, while rental systems and product recovery can be profitable, recycling in many supply chains isn't. In addition to these technological barriers, there are a number of other critical barriers, predominantly on the demand side. While some of these barriers, such as consumer resistance to returns systems, are presumed to be insurmountable, there is room for individual companies and supply chains to address many others, such as lack of customer encouragement for recyclability or resistance to second-hand inputs in manufacturing. Indeed, a number of companies operate successful return systems bolstered by a strong brand to create consumer acceptance. By engaging in a continuous dialogue about the successes of individual companies and pushing the boundaries, it is hoped that the extent of these resolvable customer barriers to enable the circular supply chain concept will gradually expand. In the meantime, we hope to incrementally address and resolve the processing barriers. These obstacles can be weighed against the benefits. The area for investigation is the counteractions for each challenge and benefit. A number of these have been suggested and argued and indicate the potential for progress and constructive change.

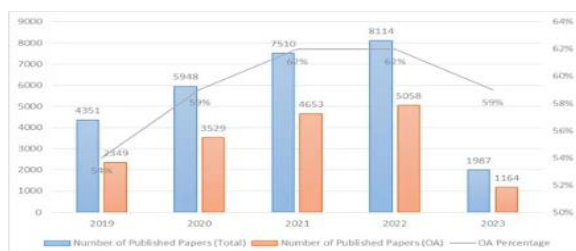

Fig : Development Goals towards Sustainability

3. Linking Circular Supply Chains to Sustainability Goals

Given the importance of achieving sustainability goals and the greater involvement of stakeholders, including customers, in a company's ethical track record, the business case for incorporating circular supply chains into a company's operations en route to meeting those goals must be made. First, a company can mitigate its environmental footprints through the responsible management of resources and internal operations. Second, a company can capitalize on the economic advantages created by a sustainable operational backdrop, including decreased costs, improved efficiencies, and increased economic capital. Finally, a company must be involved in its surrounding community and ethical issues beyond. The arguments strongly advocate for adherence to sustainable and circular practices from each of the three dimensions: people, profits, and planet, in a positive societal feedback loop.

Adoption of best-in-class supply chain practices that capitalize on human, profit, and planetary well-being has provided opportunities to seek holistic value and derive a competitive advantage for the business world over a number of years. Those same opportunities continue to resonate in the use of the circular supply chain model to progress toward sustainability goals. The environmental pillar of supply chain management focuses on circularity, or what is known in the business literature as the circular economy. Critical to linking sustainable project supply chain management and the project-product portfolio blending of supply chain literature with circular supply chains are threads of the closed-loop supply chain, including recycling, reuse, and reverse logistics.The integration of circular supply chains into business operations plays a crucial role in advancing sustainability goals by fostering a closed-loop system that emphasizes recycling, reuse, and reverse logistics. This approach reduces waste, conserves resources, and minimizes environmental impact, aligning with the growing emphasis on the environmental pillar of supply chain management. By adopting circular practices, companies not only contribute to environmental sustainability but also enhance their operational efficiencies, reduce costs, and bolster their competitive advantage. The circular economy framework, which emphasizes resource recovery and reallocation, supports the responsible management of materials across the supply chain, enabling businesses to deliver greater value while minimizing their ecological footprint. Moreover, this model promotes a symbiotic relationship between businesses and communities, as it encourages ethical practices and strengthens the social fabric through sustainable, locally-oriented supply chains. In essence, the circular supply chain model provides a robust pathway for companies to meet sustainability goals while generating long-term benefits for both the environment and society.

Fig 3: Supply Chains for a Sustainable Future

3.1. Environmental Impact

Developing CSCs helps industries minimize the negative environmental consequences associated with the production, use, and disposal of products. These supply chains are inherently designed to reuse products at the end of their lives, as well as to ensure that products can be easily recycled and fed back into the manufacturing process. Furthermore, a CSC focuses on the optimization of resources, resulting in the production of less waste and a reduced environmental footprint. Successful implementation and operation of a CSC have seen many cases in the past thirty years, which have demonstrated that the positive impacts continue to be of benefit to a wide variety of ecosystems. Not only do the reuse and recycling of products help to sustain natural resources, but they also have a direct impact on the reduction of pollution in the air, water, and soil, thereby minimizing the negative impacts on human and animal health. Why should the environmental dimension be considered in supply chains? The transition from a first- or second-tier supply chain to a fully optimized CSC is an essential step in minimizing any negative consequences of doing business. The expected benefits of adopting a CSC have to be communicated and embraced. How a CSC is developed depends on how optimal resource reuse and the social/economic impacts of a decision are. Although there are numerous positive consequences of a CSC, other dimensions also need to be considered and optimized. Therefore, ensuring the development of a truly sustainable enterprise is far-reaching and includes stakeholders from inside and outside the ecosystem. Further research into the other dimensions is required in order to fully understand what defining and limiting factors can be.

3.2. Economic Benefits

Despite the vast potential of circular supply chains to contribute to sustainability, it is likely that stakeholders from business, such as contract or logistics partners, might question the "added value" of implementing new technologies or processes to close the loop. In this context, first of all, we assert that the greatest potential direct benefit is to "turn waste into value," achieving narrow economic results. In particular, by employing a data-validated model, it is possible to identify the savings that can be achieved in costs in a circular supply chain by recovering materials for recycling, repairing or upgrading used products for reuse, or both. Further enabling cost savings is interaction with the life cycle of a product, scheduled maintenance and upgrades, improved availability of spare parts, and even the prediction of potential product returns.

Adopting circular supply chain business models and reverse logistics is not only economically feasible when considering operational costs: making the phases of product consolidation, remanufacture, or recycling more efficient can lead to substantial cost reductions in the order of 10–67% on their own. Additionally, the optimization of these operations can positively impact the original manufacturing of the equipment, realizing cost savings of 4–33%. At the same time, a higher pace of refurbishment under current capabilities within the retail industry leads to higher profits, realizing returns of 1–5 million. Similarly, the reduced cost of repair can lead to substantial cost savings amounting to 4.5 -- 9.5 million for a global Original Equipment Manufacturer, reflecting 1–2% of their annual operating expenses and making repairs up to 69% more cost-effective. When it comes to the reprocessing of waste in terms of common spares in the electronic industry, the value of material can be up to 1775% the cost of reprocessing. However, while closed-loop practices propose a significant potential for profit, a minimum volume of returned products is essential in financially justifying such strategies. Nonetheless, to justify the long-term need for financial investment in technologies, a clear value has to be shown for stakeholders. Our research indicates that further study into the implementation economics of stochastic remanufacture operations is warranted. We will use data-validated performance materials to investigate the mechanics of the market and link turnover figures with circular supply chain business model strategies, in order to evaluate the return on investment in such activities given a variety of operational and industry fluid parameters, considering also ecological benefits. Adding ecological criteria also provides the necessary robustness, linking economic and environmental sustainability, particularly via ending regulatory responsibility for recovery and return mechanisms and a potential source of competitive advantage in the market.

3.3. Social Responsibility

Promoting adherence to ethical practices based on community and social responsibility is an important objective at any stage of the supply chain. For circular supply chains, it is essential for companies to be able to show social responsibility in engaging their local community and developing the workforce. This might be achieved through engaging in the local education system and workforce development initiatives to build human capital. Participants argue that being able to account for the workforce all the way through the supply chain and demonstrate that their rights and fair wages are upheld makes circular supply chains more likely to be seen as a system that contributes to the common good. Further, local engagement and trust within communities can be leveraged to increase the return on investment for some companies. Stakeholder buy-in from key community partners can have an impact on controlling community response and workforce recruitment, setting the conditions for a more resilient and robust supply chain. Furthermore, the extent of stakeholder involvement in a company can offer distinctions that enhance brand loyalty.

Participants argue that the zero-waste social responsibility calls for circular practices and materials recycling content within new products. Being able to track the materials back to the source increases social responsibility commitments. In this instance, zero waste is supported through a closed materials loop and emissions reductions within the community. Perhaps one of the critical reasons that the supply chain should consider the broader discussion of its role in the community is that the impacts of the supply chain are felt directly within the communities with which they interact. Supply chains have long understood the imperative to engage in the community to further their business goals. Increasingly, targets aim to partner with groups whose primary goal is to work with communities. Interviewees and survey respondents argue that supply chains are not just critically linked to local economies, but also to local social welfare and could thus benefit from adopting circular design principles and joining the communities in which they operate to create social license to operate. Companies looking to launch new circular supply chains are aware that acting outside of regulations might harm the business and sometimes turn into negative financial impacts in the long term. This narrative also resonates with the literature, where firms looking to implement circular supply chain initiatives need to consider the necessary licenses and regulations if they are to operate and link to local communities. Arguably, therefore, not incurring fines, penalties, or damage to a firm's reputation and social license to operate can provide efficiency benefits to firms. Companies must meet sustainability criteria and community and customer pressure in order not to lose customers and maintain their license to operate.

Equ 2: Recycling Efficiency (RE)

$$RE = \frac{Recycled\ Materials}{Total\ Materials\ Collected}$$

Where:

- $Recycled\ Materials$ is the quantity of materials that are reused or recycled.
- $Total\ Materials\ Collected$ is the total amount of materials available for recycling (including recyclable waste).

4. Technological Innovations and Tools for Circular Supply Chains

Over the past several years, numerous technological innovations and tools have emerged to support the evolution toward a more circular and holistic supply chain model. In this section, we offer a high-level overview of many such innovations, which businesses can leverage toward achieving the full benefits of a circular supply chain, such as improved resource efficiency, investment protection, the opening up of new markets, and gaining competitive advantage. Below, the discussion is divided into three subsections pertaining to the specific objectives the tools are most often used to support, namely recycling, reuse, and resource recovery; inventory control and traceability; and platforms for digital supply chain management.

Solutions facilitating the recycling, reuse, and resource recovery processes. Much of the newest technology in the field of circular supply chains is focused on the end-of-life goods supply chain and, in particular, toward solutions to trace and manage a reverse supply chain. Tools for improving industrial processes are also under research in risk management applications due to changes in the supply of raw materials and the current impact of geopolitical events. Manufacturers are developing advanced tools such as optical sorting and material composition analyzers, which enhance the ability to recycle goods or released products as components. Models for forecasting have also appeared in this context, as have methodologies for supply chain network design for a circular economy. Tools to manage the lifecycle of goods and materials continue to be developed in the form of reverse logistics and closed-loop supply chain models, which include qualitative as well as quantitative factors, such as the corporate social responsibility image of companies. Specific examples include frameworks for reusable goods inventory management and design guidelines to make systems infrastructure more robust against human error. Other emerging research looks toward the future, such as goods recovery techniques for physical goods recycling facilities.

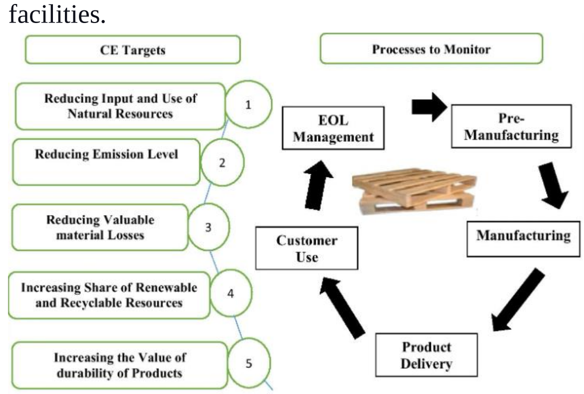

Fig 4: Digital technologies and circular economy in supply chain management

4.1. Advanced Recycling Technologies

Recycling is identified as one crucial element to design and improve the functioning of circular supply chains. The need to make recycling processes more efficient and effective is being targeted by a number of technology sectors. These technology developments, which include advanced sorting and material recovery techniques as well as the reconstitution of input materials into proper material, also need to be linked with supply chains to ensure that these refined materials reach the markets and profits are realized due to more efficient use of resources and reduction in environmental impact. After briefly addressing some of the technologies, we illustrate their importance with empirical examples. It is also important to search and develop advanced recycling technologies with a future perspective, i.e., recycling technologies that are widely applicable across components and that are nearly future-proof and will offer a long-term sustainable solution for inventory schemes. There are, however, no clear guidelines or stepping stones available in the literature on how to move towards the development of such advanced recycling technologies. To achieve that, ongoing research and development is required, which is heavily dependent on the long-term strategies of industry players and technology providers. Collaborations between the various sectors can be expected to be beneficial here. Economic benefits of the technologies discussed above are, as mentioned before, not immediate and heavily dependent on the availability of cost-effective waste collection and processing infrastructures. However, another incentive that companies could have to develop these waste processing techniques, in times of pressure from sustainable procurement policies, may be to gain better access to raw materials at competitive prices in the future, as recycling becomes a necessity due to shortages of valuable resources. Clearly, advanced sorting techniques are essential to improve the efficiency of advanced recycling techniques.

4.2. Digital Platforms and Traceability Systems

Digital platforms play a crucial functional role in a circular economy context where tight control of material flows is essential. Systems are in place that track production inputs and monitor individual product components for efficiency and performance throughout the lifetime of the product. The production input stream goes beyond an actor and ensures that the production resources are also used in the same regime in a systematic way, measuring their inefficiencies at every point. In fact, production networks become joint systems rather than an extension of a single company. New sensors can track and monitor materials in real time because of digital technology down to 12 meters of detail. Tracking resources helps reduce waste in the system, and real-time monitoring on a detailed level provides insights into vulnerabilities and potential solutions in the system, often preceding predicted behaviors. This not only reduces waste, but it also provides detailed insights for suppliers or buyers in the production network to comprehend performance and potential blind spots in the architecture of the system.

The digital transformation that is currently taking place supports new ways of thinking, collaborating, and operating. The ability of digital technologies to connect people, machines, companies, and communities enables transparency, accountability, and efficiency within circular supply chains. As the value gained by collaboration across supply chain participants in the bioeconomy increases, and companies that invest in improving traceability via digital solutions see up to a similar percentage increase, it is important that everyone participates in this era of data-driven, protected, and transparent circular economic operations. The objectives of traceability in a circular economy are to collaborate across the supply chain, thereby driving value and efficiency, and to become part of initiatives that offer a multi-stakeholder approach. This is enabling real-time tracking and making operations more transparent, which is not only driving value but also driving innovative improvements in those supply chains. This strategy generally aligns with the goals of traceability in a digital revolution that champions collaboration and transparency as well as accuracy and efficiency. Concern for the privacy of data was also raised in some contexts, suggesting that wider reform that encourages consent and fair and transparent personal data management is required. This proposal also largely aligns with the goals of traceability in a digital revolution that champions collaboration and transparency as well as accuracy and efficiency. Fewer concerns regarding information accuracy were reported, due in part to the rise of integrated supply chain data. The ability to forecast and make strategic and timely decisions was improved. This aligns with the advancements in data management systems, which provide accessible, consolidated views across complex supply chain data management systems that to date do not provide such views.

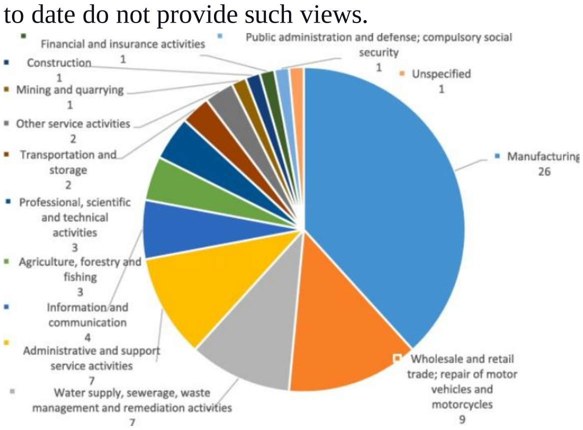

Fig : Multi-dimensional circular supply chain management

5. Case Studies and Best Practices

This section offers resistance to the former editorial board's introductory assertions that very few managers take supply chain and inter-organizational collaboration seriously. The collection of case studies shows how various industry sectors are handling the problems of recycling, reuse, and resource optimization, which are critically important to already maturing and even more to emerging markets. Commonalities among these articles are noteworthy. Throughout the articles in the special issue, some underlying themes emerge in the practices of firms that are making successful strides in enabling and supporting circular supply chains. They are managing the tension of seeing sustainability and environmental benefits as drivers for the implementation of circular practices, while managing the practices for their economic viability. Additionally, the ability to establish a market for by-products with multiple revenue streams provides the economic justification for investments with longer payback periods, and investments that indirectly improve existing business. The industry partners in these supply chains have also focused on business case and economic drivers to underpin their supply chain collaborations; indeed, these case studies show that, while regulatory and societal pressures were making the traditional business rationale more and more compelling, the enthusiasm sparked by these new drivers did not outweigh the defined business logic. All of the articles reinforce that the value of by-product reuse has brought together firms that need to cooperate to reach a common goal. At the same time, the articles mention several issues that have surfaced either as implementation challenges or important lessons learned during the development of the case study.

Fig 5: A Case Study of the Taiwan Sugar Corporation

5.1. Successful Implementation Examples

There is an increasing number of organizations that are successfully operating under circular supply chain approaches. Some companies and organizations have already implemented reuse supply chains. A prominent example is the trend of providers of washing machines, copier machines, and other utility goods starting to offer services rather than products. An Italian retailer sold only refurbished goods from 2007 to 2018. In the Netherlands, Belgium, and France, a company provides more than 20 re-manufacturing programs for hospital equipment. In the fashion industry, a Swedish company sells jackets and dresses in a subscription model; after one year of wearing these clothes, the customers can return the items. The company then offers the returned clothes again as recycled goods, makes new clothes from the materials, or disassembles the old items and turns them back into new items of perfect quality.

A few companies have also already implemented supply chains for recycling materials. One example is a Swiss paint cleaning plant provider. The company had a solution for recycling shellac from the cleaning process. An independent contractor had material collected and delivered to the provider. The provider took on recycling work and sent the cleaned material to a partner. The final quality and value are unknown. Our showcase is piloted in a hospital. In this case, a cable supplier fits the circular supply chain recycling process. It takes the cables back from the hospital and has agreements with a nearby processing facility that takes care of the recycling process. In both cases, the external parties bear the responsibility for the recycling process. In the case of the re-manufacturing company and the hospital itself, they are responsible for the recycling process within the network. The chosen supply chain is turning waste materials from a cost into a profit center.

5.2. Lessons Learned and Future Directions

The main lessons from these case studies are as follows: • A supply chain approach is needed to ensure the success of recycling, reuse, and resource optimization schemes. • Challenges around establishing supply for recycled content. • Geopolitical issues and mismanaged consumer recycling programs lead to inefficiencies and create artificial barriers to a truly circular supply chain. • Payback time is a critical period but not insurmountable. • Balanced considerations should be given between processing whole-product recycling and recycled-content raw materials or manufactured components. • Collaboration readiness is more likely to be found under a circular supply chain model. • Balancing cost, price, and service levels in recycled parts sales channels. Given the lessons presented, it is suggested that practitioners can be informed of the best practices for circular supply chain implementation and the recurrent issues that must be avoided in the future. The circular supply chain necessarily involves whole organizational and boundary reformation from the linear factory pattern, either from remanufacturing to recycling or vice versa. This is a learned and evolving process: Circular activities include embracing modular and flexible architectures in a process-based approach to both products and assets. At every stage in this process, changes and innovation can occur. Research and innovation can, and should, therefore investigate a variety of schemes, structures, and forms to realize the potential of the circular supply chain and to address changing external issues including electrification and digitalization. Past activities in this field have informed us that the extended supply and/or value chain is an arena of swirling innovation and evolving interrelations in a circular environment. By the year 2023, this field of study had started to embrace a minimally owned, maximally shared, and diverse product mix in circular networks of stakeholder-based control that could include distributed ledger and other digital trends to further enhance agility.

Equ 3: Material Recovery Rate (MRR)

$$MRR = \frac{Recovered\ Materials}{Total\ Waste\ Generated}$$

Where:

- $Recovered\ Materials$ is the quantity of waste materials that are successfully recovered and reused or repurposed.
- $Total\ Waste\ Generated$ is the total amount of waste generated by the supply chain.

6. Conclusion

In this essay, we have investigated the role of circular supply chains in achieving sustainability goals. We first took a perspective on recycling and reuse. The business case for recycling and reuse is strong, and both activities bring economic benefits in terms of higher revenues, lower costs, and entry into new markets. However, the social benefits are also clear, and both of these activities can contribute to securing the livelihoods of those people employed in the recycling and reuse processes. We then considered resource optimization in supply chains, and highlighted one way that research is starting to deliver innovations that can support improvements in this area. The optimization of product lifespans in supply chains recognizes that the extra product life that a product gains can have significant environmental benefits should it be used rather than something else, and hence provides a technological basis for product stewardship and reuse.

The proper collection, refurbishment and recycling of products can both limit negative environmental impacts and provide high-quality materials at lower energy levels than is necessary in primary production. Such a strategy would also reduce demand for new materials, conserving valuable raw materials, where demand is ever increasing and yet their availability and ease of extraction is reducing. For all of these reasons the sustainability calculus is very compelling.

One of the greatest impacts on the use of these strategies is technology. The ability to manage and monitor products and their sub-assemblies, tagging parts for reuse, monitoring use and predicting when the component is most likely to fail can support reuse and refurbishment. The technology and monitoring of products and components already is shifting from passive methods to active and even dynamic processes in various industries such as automotive, aerospace and the utilities. In the future, it is likely that almost all components will be ‘tagged’ to allow this degree of management, refurbishment and reuse. ‘Smart technology’ may therefore stimulate reuse and refurbishment, supporting the growth of the circular economy, with similar technological advances helping to limit the environmental impact of final disposal in favour of refurbishment and reuse, or recycling.

Businesses and other stakeholders need to take steps to address issues of technology and infrastructure if the potential is to be realised. By taking these steps now, we would have the basis for a scenario consistent with current policy goals, and on a trajectory of a significant percentage of waste being treated by a future date, compared to the current low percentage of waste diverted from landfill across the globe. For those involved in remanufacturing, reuse and refurbishment, these advances can increase their competitiveness against the continued use of new raw materials. This essay has demonstrated the potential for circular supply chains to support both economic and social measures of sustainability because of the environmental benefits they offer, and has highlighted the potential for technology. The importance of a systems perspective to sustainability is critical, and circular supply chains could provide a new component to operationalize some of the emerging thinking in this area. Businesses have pivotal roles to play in the development of such a future. Few policymakers, businesses, and indeed researchers think systematically about these possible futures.

The growing resources and wealth of the industries of the past centuries created unprecedented environmental pollution, and the continual march to improve the scale and speed of the production process has only compounded the problem. In parity to our exploration of the technology trajectory, we feel it is also critical to consider the potential human, economic and social impact of the transition to a circular future. The advent of efficient production systems may cripple developing countries and economies, whose livelihoods and economies are much more dependent on the use of primary resources and the complete life cycle of products. These countries have yet to develop advanced waste treatment facilities, and people also rely on the economic benefits of scavenging waste for temporary removal from poverty. Developed and third world nations have intertwined relationships, mostly to the cost of the poorer countries, and in such a complex network, many could lose out from a facility to store products at the end of a life with the intention to be used in the future. This essay thus argues that the implementation of a distributed reuse, recycling and recovery model to facilitate circular operations is essential, yet the implications are profound and need to be considered for policy detail.

A key area for policy engagement would be to better consider the social impacts of a global circular economy. Failure to consider these impacts could leave initial plans ineffective. Policy therefore is not simply about supporting industry: the intention needs to be how to both encourage and better manage these changes. Failure to ensure a compassionate system of change could result in a disempowered and extremely poor underclass, whilst we live in a resource bonanza. Equally, the marketing of remanufactured and refurbished goods in the face of expanding disposable income in growing economies offers massive opportunities. Manufacturing for the developing world could soon grow not from the standard model of primary new material inputs, but instead from growth in marketing refurbishing facilities. These sentiments demonstrate the important interconnectedness of environmental and social sustainability issues, supporting the need for wider systems thinking. We might suggest too that such a consideration can often be ignored in policy thinking, which tends to stress aggregate economic indicators, not broader social implications.

We identify the above considerations and implications as important openings for future research on the role of circular supply chains in sustainability targets. We also conclude that in order to seek the desirable global future with higher recycling and resource efficiency and lower emissions, we need to realise both social and environmental ramifications of policy development. We might also suggest the need for a more proactive, directive stance from industrial actors in enabling an increase in recovery and resource efficiency. It is hoped that this analysis helps provoke discussion for an ongoing research agenda for the future of circular supply chains.

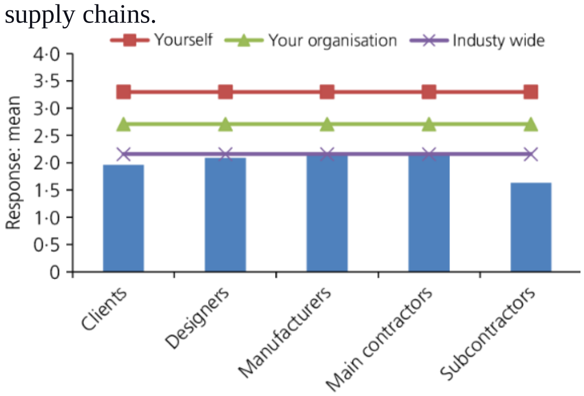

Fig : Levels of awareness for circular economy in the construction sector

6.1. Future Trends

Like any subject in supply chain management, circular SCM is subject to future advancements in technological tools. Worn wear inputs are expected to lead to more and better output quality, whereas AI-driven supply chain management systems will provide the insights necessary to take circular economy initiatives to the next level. AI-driven SCM systems' capability to predict end-of-life management routes could be used for high-value retained maintenance, upgrades, or re-manufacturing, which will greatly improve an MTS output's quality. Further advances will relate to AI applications in maintenance and production engineering, using AI-driven predictive maintenance, machine condition monitoring, predictive process control, and remote control and automation. Multi-stage manufacturing and production operations will be interconnected and operated 'mostly autonomously' and from afar, a trend already unfolding today. Shifting consumer preferences and business strategies stress environmental responsibility; the concept of the purpose-driven organization contributes to this perspective. We anticipate an accelerated push for a carbon-free and circular economy due to regulatory pushes in the years to come.

The European Battery Alliance aims to create a complete circular value chain for batteries without losing a single battery cell. We anticipate minimum battery recycling rates to be set in the coming years, especially in the context of proposals for obligatory cell and pack carbon footprints. The US legislature and administration also signal the importance of responsible battery raw material extraction, putting the country more in line with the views of the EU. The aforementioned societal and consumer behavior changes will be key drivers for turning circular supply chains and business models into the norm, not the exception. The development of new technology and the realization of new business models will, in turn, also unlock further consumer interests. There is growing interest in products in which a lot of parts have been sourced locally, generating resilience. With respect to future research, a major challenge in the pursuit of supply chain excellence hinges on the manipulation and understanding of decision-making under uncertainty about future trends. Radical innovations of new theories and models need to be formulated to develop a world inspired to continuously align with SDGs in the face of abundant future and emerging dynamics we have already begun to witness. The field of study of circular supply chains is evolving as we speak, and there are endless possibilities and realms that need to be explored quantitatively, qualitatively, and empirically. We encourage practitioners to be proactive in anticipation of these developments and invite further dialogue and scholarly interest in emerging circular initiatives in the coming years and beyond. In a world now faced with an array of challenges, the social and economic imperatives of sustainable development are intertwined. It is imperative that contemporary operations practices and strategies align with this call and become meaningful co-creators of new business, societal, and economic opportunities.

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