JPO, Vol. 4(2), 10-21

Journal of Policy Options RESDO

Environmental Innovation and Sustainability in Remanufacturing: A Strategic Review

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Abstract

The aim of this article is to present a concise review of the relationship between environmental sustainability, environmental innovation, and remanufacturing. Traditionally, the corporate environment was understood to shape firm performance based on economic, social, political, and technological factors. However, with growing global awareness of environmental concerns, sustainability and innovation in environmental practices, such as remanufacturing, have emerged as critical determinants of long-term business success. Environmental sustainability involves minimizing negative impacts on the environment while maintaining economic growth, and environmental innovation refers to new practices and technologies aimed at reducing ecological footprints. Remanufacturing, a process that restores used products to a "like-new" condition, is increasingly seen as a key strategy for achieving both sustainability and innovation, helping companies reduce waste and resource consumption. Understanding the interconnections between these concepts is vital for businesses seeking to enhance their environmental performance and meet growing demands for sustainable practices. However, in recent years, environmental factors have also become integral to the corporate environment. This shift reflects the growing recognition that businesses must consider their environmental impact alongside traditional economic and social factors. Recent research has increasingly focused on the environmental management system, which has proven to be a highly effective tool for organizations aiming to improve their environmental performance. Environmental management system helps businesses systematically manage their environmental responsibilities and ensures compliance with regulations while promoting sustainability. In addition to environmental management system, there has been a strong emphasis on environmental innovation, particularly in the areas of technological product and process innovation. Environmental innovation refers to the development and implementation of new technologies and processes that reduce environmental harm, enhance resource efficiency, and support sustainable production. These innovations enable firms to reduce waste, lower emissions, and use materials more efficiently, contributing to both environmental sustainability and improved competitiveness. By incorporating environmental factors into corporate strategy and focusing on innovation, businesses can better address the challenges of sustainability in a rapidly changing global landscape. Product innovation has been extensively researched in fields such as new product development, design for the environment, and design for remanufacturing. Studies on remanufacturing demonstrate that it can be both profitable and environmentally beneficial, as it reduces waste, conserves resources, and lowers emissions. However, there is a noticeable gap in the literature regarding process innovation, particularly in remanufacturing. While product innovation has been widely explored, the lack of attention to process innovation leaves room for further exploration. Process innovation in remanufacturing refers to improvements in the methods and technologies used to refurbish products, which can enhance efficiency and sustainability. Technological advancements in both product and process innovation play a crucial role in reducing environmental impacts by promoting cleaner, more resource-efficient practices. Therefore, there is an emerging need for more in-depth studies on process innovation, specifically in remanufacturing, to fully realize its potential in contributing to environmental sustainability and economic viability.

Keywords: Environmental Sustainability, Environmental Innovation, Remanufacturing

JEL Codes: Q55, O31, L65

1. INTRODUCTION

The world has undergone significant transformations, and organizations are striving to keep pace with these changes. However, a crucial issue is ensuring that, as they adapt to these shifts in their economic activities, organizations do not contribute to environmental degradation. Companies have a social responsibility to not only avoid harming the environment but also actively preserve and restore it by integrating environmental and social concerns into their business operations.

As Shrivastava (1994) emphasized, the focus should shift to understanding "the organization" from an environmental perspective rather than viewing "the environment" solely from the standpoint of the organization. Environmental sustainability can be achieved through the development of robust Environmental Management Systems (EMS) and the implementation of environmental innovations as part of a company's corporate social responsibility (CSR). The growing urgency of environmental degradation compels organizations to adopt these practices now, as waiting too long may force them to take drastic actions in the future to restore environmental health. Corporate social responsibility and sustainable development have become key elements in addressing environmental challenges. Two primary drivers of environmental

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practices are business performance and regulation (Williamson et al., 2006). Shrivastava (1994) also noted that organizations adopting an eco-biosphere view would establish clear ecological missions, develop comprehensive ecological strategies, and implement strong environmental management programs. The positive impact of voluntary environmental programs, such as those incorporating ISO 14001, on enhancing facilities' environmental performance has important implications (Potoski and Prakash, 2005). Similarly, Florida and Davison (2001) identified EMS as an extremely effective tool for reducing environmental costs and risks.

Developing new, environmentally improved products will be essential for steering companies and economies towards environmental sustainability (Pujari et al., 2003). Environmental innovation, which includes the avoidance or reduction of hazardous environmental impacts through new or modified processes, equipment, products, techniques, and management systems, is a critical component of sustainable business practices (Arundel et al., 2007). By embracing these innovations, organizations can both enhance their environmental performance and contribute to long-term ecological preservation. Eco-innovation is opening up new fields of innovation activities, presenting tremendous opportunities not only to save on material costs but also to discover alternative solutions for scarce resources (Bleischwitz, 2009). Inderfurth (2005) highlights remanufacturing as an emerging business area that is appealing from both economic and environmental perspectives. The remanufacturing of used products offers an ideal opportunity: it enables positive environmental outcomes while increasing firm profits by extracting additional value from used items (Galbreth et al., 2006). Remanufacturing is environmentally preferable because it retains the geometrical form of the product, thereby preserving both its economic and environmental value (Kerr and Ryan, 2001; Sundin, 2004).

This study aims to compile and integrate the most relevant research in the literature on Environmental Sustainability, Environmental Innovation, and Remanufacturing. The structure begins with an introductory section, followed by a discussion of Environmental Sustainability, addressing the growing concerns over economic, social, and environmental issues to ensure the long-term viability of society and the planet. Next, the Environmental Management System is examined, and Environmental Innovation is defined, with an explanation of its two types: product innovation and process innovation. The study then clarifies the concept of Remanufacturing. The final section includes the conclusion and paves the way for future research. Overall, this article aims to explore the interrelationship between environmental sustainability, environmental innovation, and remanufacturing, emphasizing their combined importance in promoting long-term environmental and economic benefits.

2. LITERATURE REVIEW

2.1. ENVIRONMENTAL SUSTAINABILITY

Environmental problems trace back to the Industrial Revolution in the 17th century, a period that saw the extensive use of fossil fuels for energy. By the late 20th century, these issues had reached a global scale, as industries and communities became heavily reliant on nonrenewable energy sources. The world's consumption has since outpaced its natural regeneration capacity, and by the 21st century, growing awareness of environmental threats—including resource depletion, the greenhouse effect, global warming, water pollution, toxins, rainforest destruction, and nuclear concerns—has intensified. While environmental sustainability, also referred to as ecological sustainability, is a concept of global importance, it is often ambiguously defined. The literature lacks a comprehensive number of clear definitions, making it essential to first define sustainability and sustainable development for a better understanding of environmental sustainability. Sustainability is broadly defined as the ability to meet today's needs without compromising the ability of future generations to meet their own needs (WCED, 1987). According to the U.S. Environmental Protection Agency (EPA, 2011), sustainability's core principle is that everything necessary for human survival and well-being depends on the natural environment, either directly or indirectly. Sustainability aims to maintain conditions that allow people and nature to coexist in productive harmony, ensuring that the social, economic, and environmental requirements of both present and future generations are met. Essentially, sustainability addresses three major themes—economic, social, and environmental—all of which must be coordinated to guarantee the long-term viability of both communities and the planet. The concept of sustainable development arises from the effort to combine growing environmental concerns with socio-economic issues. It offers potential solutions to the fundamental challenges faced by humanity, both now and in the future. However, for sustainable development to be truly effective, it must focus more on sustainable livelihoods, well-being, and long-term environmental sustainability, integrating social and environmental considerations with human equity (Hopwood et al., 2005). Environmental sustainability, as described by Goodland and Daly (1996), is a target that can be approached through sustainable development. This form of development entails avoiding increased throughput of materials and energy beyond the Earth's regenerative and absorptive capacities. As one of the four key forms of capital (natural, human, human-made, and social), environmental sustainability emphasizes the need to maintain natural capital. Goodland (1995) defines natural capital as the stock of environmental assets—such as soil, air, forests, water, and wetlands—that provide a continuous flow of valuable goods and services. Whether these assets are renewable or nonrenewable, they must be preserved to sustain the flow of resources necessary for human life and the environment.

Ecological sustainability requires the simultaneous maintenance of human economic activities and ecosystem health. Callicott and Mumford (1997) introduced the concept of ecological sustainability, emphasizing the preservation of ecosystems that are both inhabited by humans and economically exploited. Dyllick and Hockerts (2002) provided a definition of corporate ecological sustainability, stating that ecologically sustainable companies consume resources at a rate below their natural reproduction or the development of substitutes. The emissions produced by these companies must not accumulate in the environment at a rate that exceeds the capacity of natural systems to absorb and neutralize them. Ultimately, these companies should refrain from activities that degrade ecosystem services. Jennings and Zandbergen

(1995) explored the role of companies in building a consensus for creating an "ecologically sustainable" organization, pushing firms to adopt practices that safeguard the environment and minimize energy consumption. Vinodh (2011) noted that sustainable organizations focus on reducing production costs while avoiding environmental degradation, thereby maintaining a green and clean atmosphere. These practices ensure the long-term success of businesses while contributing to broader environmental sustainability efforts.

Wheeler and Elkington (2001) examined examples from traditional sectors, such as energy production, mining, forestry, and oil and gas, where the stakeholder approach to strategy, sustainability, and Corporate Social Responsibility (CSR) has a longer history. In these industries, corporate transparency and dialogue on environmental and social performance are often more developed due to the significant environmental impacts associated with their operations. The emphasis on sustainability in these sectors highlights the importance of integrating stakeholder perspectives into corporate strategies. Kemp (2002) explained that implementing radical technological changes, such as shifting away from hydrocarbon-based energy technologies, is likely to be a gradual and slow process. This is because such changes require long lead times and specialized skills, infrastructure, and institutional changes, including organizational shifts, regulatory updates, and new values. Furthermore, new technologies often face high initial costs as they lack the economies of scale and learning effects that reduce costs over time. Pujari et al. (2003) argue that advanced environmental technologies and products contribute to sustainability only if they provide viable green alternatives that can capture market share from conventional products. Fuller and Ottman (2004) support this view, noting that eco-friendly products must demonstrate superior efficiency in environmental performance without compromising their functional benefits to achieve long-term market success.

To achieve enhanced environmental performance or reduced environmental impact, companies must address key sustainability issues such as resource efficiency, dematerialization, and the reduction of waste and emissions (Pujari, 2006). Many companies have responded to the challenge of sustainable development by altering their business activities in areas such as purchasing (Carter et al., 2000), product development, marketing (Pujari et al., 2003), and corporate strategy (Aragon-Correa and Sharma, 2003). Integrating environmental sustainability into business operations can lead to numerous benefits, including return on investment, increased sales, improved competitiveness, and enhanced corporate image (Pujari, 2006). Companies are also adopting environmentally and socially responsible supply chain management practices. These practices are promoted to consumers through tactics such as choice-editing (removing hazardous substances from products), communication and marketing strategies, and the use of eco-labels and fair trade labels to promote sustainable products (Bleischwitz, 2009). In the past, environmental sustainability was often seen as a matter of compliance, expense, and trade-offs with other corporate goals. However, it is increasingly viewed as an opportunity for achieving both environmental and competitive success. The "green and competitive" logic, as outlined by Porter and Van der Linde (1995) and Pujari (2006), suggests that companies can enhance their environmental performance while also gaining a competitive advantage in the market.

2.2. ENVIRONMENTAL MANAGEMENT SYSTEM

In recent years, there has been a significant shift in how companies view environmental issues, largely due to the growing emphasis on sustainable development and the rise in environmental conservation awareness. Corporate managers are now under increasing pressure to incorporate ecological considerations into their decision-making processes. Non-Governmental Organizations (NGOs), consumers, and governments are demanding reduced pollution and waste, increased recycling, greater use of renewable resources, and the production of ecologically safer products. Corporate managers who want to stay competitive are adapting to these demands by integrating environmentally conscious management systems into their strategic decisions. The development of such systems is often driven by top management's sensitivity to environmental issues. Environmentally conscious management involves treating the ecological environment as a key factor in corporate decision-making and aiming to reduce or eliminate environmental harm caused by business activities. This includes redesigning products and packaging, modifying manufacturing processes, embedding environmental protection into corporate culture, and fulfilling social responsibility obligations to society (Nemli, 2000). Onkila (2011) defines environmental management as any action taken to improve corporate environmental performance. These actions range from identifying environmental impacts to managing them in ways that enhance competitiveness and reduce ecological damage.

Hopkins (2005) highlights that environmental management does not just affect specific stakeholder groups, but also the broader institution of business itself. Environmental disasters, for example, have raised public awareness of how business decisions impact society as a whole. This awareness has resulted in increased pressure for environmental regulations, which affect not only individual firms but entire industries. Today, alongside NGOs and consumers, governments are also pushing companies to engage in environmentally responsible activities. Since 1996, Environmental Management Systems (EMSs) have gained significant attention following the introduction of the ISO 14001 standard by the International Organization for Standardization (ISO). EMSs provide companies with a systematic approach to managing and improving the environmental aspects of their operations. By developing environmental policies, assessing internal processes that impact the environment, setting objectives and targets, monitoring progress, and conducting management reviews, companies can manage their environmental impact in a structured way (Darnall and Edwards, 2006).

An EMS serves as a tool that helps organizations meet their environmental responsibilities and achieve their environmental performance goals. While the specific implementation of an EMS can vary depending on the industry or activity, several common operating principles must be followed. According to the European Commission (2011), an EMS is based on Total Quality Management (TQM) principles and follows the 'Plan-Do-Check-Act' (PDCA) cycle. Rajendran and Barrett (2003) emphasize that the operating principles of an EMS, particularly ISO 14001, are rooted in this cycle, ensuring continuous improvement in environmental management practices.

The shift toward environmental sustainability in business is now a vital component of corporate strategy, driven by both external pressures from stakeholders and regulatory bodies, and internal motivations to enhance competitiveness and corporate responsibility. Although the ISO 14000 family of standards is mutually supportive, each standard can be implemented independently to achieve environmental goals. These standards serve as management tools for organizations, enabling them to manage their environmental features and assess their environmental performance. Collectively, these tools offer significant economic benefits, such as reduced raw material and resource use, decreased energy consumption, enhanced process efficiency, and reduced waste generation and disposal costs, as well as the utilization of recoverable resources (ISO, 2009). Among these standards, ISO 14001:2004 focuses on the requirements for an Environmental Management System (EMS), while ISO 14004:2004 provides general guidelines for implementing such a system. ISO 14001 acts as a management tool that allows organizations of any size or type to identify and control the environmental impacts of their activities, improve environmental performance continuously, and systematically set and achieve environmental objectives and targets. ISO 14004:2004 offers guidance on the elements of an EMS and its implementation, addressing key issues involved in environmental management. To meet the requirements of ISO 14001, organizations must provide objective evidence that can be audited, demonstrating the effective operation of the EMS in conformity with the standard (ISO, 2011).

For an organization to achieve ISO 14001 certification, several steps must be followed, including conducting a thorough review of environmental practices, formulating and implementing an environmental management action plan with performance targets, assigning internal governance responsibilities for environmental issues, and addressing identified environmental problems. ISO 14001 certification requires continuous improvement and monitoring (Potoski and Prakash, 2005). According to Florida and Davison (2001), high adopters of EMS report increased recycling activities and reductions in air emissions, solid waste, and energy consumption, leading to both economic benefits and improvements in environmental performance. Furthermore, Potoski and Prakash (2005) added that firms located in areas with more educated populations are more likely to adopt ISO 14001 standards. Anton et al. (2004) also found that firms with comprehensive EMSs experience lower toxic emissions, particularly those with a history of high pollution intensity. Reductions in off-site transfers and on-site releases per unit of output are among the benefits of EMS implementation. Regulatory and market-based pressures indirectly influence toxic emissions by encouraging institutional changes in environmental management. In line with this, Dasgupta et al. (2000) suggested that EMS adoption led to significant improvements in the compliance status of Mexican firms.

Arimura et al. (2008) expanded the literature by examining three areas of environmental impact—natural resource use, solid waste generation, and wastewater effluent—finding that ISO 14001 certification helped reduce all three. Additionally, the study found that environmental regulations do not hinder ISO 14001 adoption and that voluntary approaches like ISO 14001 can be supported by local governments through assistance programs. The findings suggest that command-and-control regulations and voluntary approaches can work in tandem. Nawrocka (2008) explored how EMSs, specifically ISO 14001, can be used to initiate and control environmental improvements through supply chain cooperation. The standard offers an optional supplier selection criterion, enabling companies to influence their suppliers' environmental performance. However, companies that do not focus on environmental work within their supply chains miss the opportunity to impact the environmental profiles of their suppliers through ISO 14001. Rehfeld et al. (2007) found that ISO 14001 has a significant positive effect on environmental product innovation, as EMSs foster sustainable product development. Bolat and Gozlu (2003) studied the factors influencing ISO 14000 EMS implementation in Turkish firms. Surveying 66 firms, they identified four key factors driving implementation: (1) the desire for improvements in financial performance, (2) expectations of environmental process improvements, (3) competition, and (4) stakeholder-related issues. They found that expectations for improvement, environmental attitudes, and stakeholder concerns were the most significant factors influencing ISO 14000 EMS adoption. Additionally, factors such as firm age, sales revenue, foreign capital involvement, export orientation, prior ISO 9000 implementation, environmental awards, and total quality management (TQM) practices also played a role in EMS adoption.

The ISO 14000 family of standards, particularly ISO 14001, provides a robust framework for organizations to manage their environmental impact, offering both economic and environmental benefits. Through continuous improvement and stakeholder engagement, organizations can enhance their sustainability performance while addressing regulatory and market pressures. According to Florida and Davison (2001), Environmental Management Systems (EMS) have been widely adopted by larger manufacturing plants, particularly those that are more committed to total quality management (TQM) and generally more innovative. These companies are primarily motivated by the need to increase productivity and comply with government regulations. EMS adoption has helped these firms streamline operations and address environmental challenges, enhancing both efficiency and regulatory compliance. However, a key difference between large firms and smaller ones, particularly Small and Medium-sized Enterprises (SMEs), is the lack of impartial regulation (Brio and Junquera, 2003). Biondi et al. (2002) pointed out that public policy-making bodies responsible for environmental control often focus more attention on larger companies, leaving SMEs with less oversight and support. Despite this, SMEs represent more than 99% of all enterprises in Europe and are considered the backbone of the European industrial system (The European Commission, 2010). Due to their sheer number and diversity, it is challenging for public policy bodies to monitor and regulate the environmental performance of SMEs effectively.

While the focus of interventions is often tailored to the sector and specific circumstances of a company, SMEs face increasing environmental pressures that will be crucial to their future survival (Sanchez et al., 2003). Environmental legislation, though general in nature, applies equally to SMEs and large companies, but the immediate challenge for SMEs is how to meet these regulations with fewer resources. The question of how SMEs will cope with environmental pressures remains critical, given their collective impact on the environment. Although individual SMEs may be small in size, they collectively form a significant group whose cumulative environmental impact is substantial. As such, it is inevitable that SMEs will need to implement EMS to manage their environmental responsibilities effectively. Florida and Davison (2001) highlighted that EMS is a valuable tool not only for managing environmental costs and risks within a company but also for fostering positive relationships with key stakeholders on controversial environmental topics. EMS plays an instrumental role in coordinating community relationships and managing external perceptions, while also contributing to the bottom line by improving operational efficiency and mitigating risks. While larger firms have been quicker to adopt EMS due to regulatory pressures and size advantages, SMEs, though underregulated, will increasingly need to integrate such systems to ensure compliance, sustainability, and future competitiveness. EMS offers a practical solution for managing environmental risks and costs, benefiting companies of all sizes in the long run.

2.3. ENVIRONMENTAL INNOVATION

In recent years, environmental issues have gained strategic importance in response to recent developments and rising concerns from investors, regulators, customers, and society as a whole. As organizations strive to enhance their economic strength by leveraging advancements in science, technology, and industry, they also contribute significantly to environmental degradation. While businesses are major contributors to environmental problems, they also hold significant responsibility for addressing and solving these issues. No matter their size, organizations must integrate environmental considerations into their activities. Their approach should not be limited to reactive measures that address problems after they arise but should adopt a proactive stance that seeks solutions before these problems surface. A more active, forward-looking approach is essential as organizations move toward greener, more sustainable practices. Environmentally friendly organizations will be seen as the future of business, requiring continuous innovation and improvements in processes to preserve the environment. The OECD (2009) defines innovation as the implementation of new or significantly improved products, processes, marketing methods, or organizational techniques in business practices, workplace organization, or external relations. The UK's Department for Innovation (2008) emphasized the importance of all types of innovation in maintaining competitiveness and addressing environmental and demographic challenges. There is a consensus that both organizations and economies must innovate to sustain and strengthen their competitive positions. Innovation has thus become a strategic issue and a key policy driver.

Geffen and Rothenberg (2000) highlighted the connection between material use, production processes, and environmental effects in manufacturing facilities. They underscored the significant role suppliers play in acquiring and integrating external information, which can support deep-seated environmental innovation within a company. Environmental innovations, often referred to as eco-innovations, focus on the interaction between human activities and their impact on natural ecosystems. Arundel and Kemp (1998) outlined that environmental innovation includes new or modified processes, techniques, systems, and products designed to reduce or eliminate environmental damage. Florida et al. (2000) identified two dimensions of the relationship between business performance and environmental improvement. The first dimension involves environmental innovations that reduce costs by improving production processes. The second dimension refers to environmental improvements as a byproduct of changes aimed at reducing other costs, improving productivity, and enhancing plant performance. An example of this is a company adopting a chemical-free procedure for paint removal to accelerate the production process while simultaneously reducing the use of polluting chemicals (Florida and Davison, 2001).

Environmental innovation encompasses both technological and non-technological changes that reduce environmental impact. While technological changes are focused on products and processes, non-technological changes can involve marketing, organizational structures, and institutional adjustments. These changes may include modifying existing practices, developing alternatives, or creating entirely new practices. More radical changes, such as creating new methods and alternatives, generally result in higher environmental benefits (OECD, 2009). The Oslo Manual by the OECD (2005) provides an internationally recognized framework for measuring innovation and identifies four types of innovation: product innovation, process innovation, marketing innovation, and organizational innovation. Technological Product and Process (TPP) innovations include technologically new products and processes, as well as significant technological improvements in both. If a TPP innovation is introduced to the market, it is classified as product innovation; if it is used within a production process, it is considered process innovation. TPP innovations involve various activities in science, technology, organization, finance, and commerce, and firms that implement such innovations are categorized as TPP-innovating firms.

Process innovation refers to the implementation of a new or significantly improved production or delivery method, involving changes in techniques, equipment, or software. Product innovation involves the introduction of a new or significantly enhanced good or service, with improvements in technical specifications, materials, user-friendliness, or other functional characteristics (OECD, 2005). According to Lager (2002), product innovation aims to develop new products, improve product properties, and enhance product quality.

Bergfors and Larsson (2009) highlighted that product innovation is driven mainly by market needs and external customers, while process innovation is driven by the needs of production and internal customers. Although product and process innovations may be distinct in their objectives, they can also overlap within a single innovation project. Recognizing the importance of distinguishing between these two types of innovation remains crucial. Pujari (2006) noted that leading firms have adopted eco-innovations by focusing on sustainability proactively rather than reactively addressing environmentally problematic features. These firms have integrated tools like "design for environment" (Pujari, 2006; Gehin et al., 2008), "life cycle assessment" (Gehin et al., 2008; Tingström and Karlsson, 2006), "environmental effect analysis" (Tingström and Karlsson, 2006), and "life cycle environmental cost analysis" (Kumaran et al., 2001) into their new product development planning. Additionally, technologies such as Computer-aided design (CAD) and Computer-aided engineering (CAE) have been instrumental in developing environmentally conscious products (Vinodh, 2011). Frondel et al. (2007) revealed that cleaner production technologies dominate in seven OECD countries, with 76.8% of facilities investing in cleaner production processes, though less frequently in new products. Their study showed that cost savings, general management systems, and specific environmental management tools tend to favor cleaner production. Meanwhile, regulatory measures and strict environmental policies are more influential for end-of-pipe technologies, which focus on mitigating environmental impacts after production.

The strategic importance of environmental innovation is growing, and organizations must adopt proactive measures to address environmental challenges. Technological and non-technological innovations, especially those that emphasize cleaner production, can drive both environmental improvements and business performance. Moving forward, innovation will remain a critical factor for organizations as they navigate the demands of sustainability and global competition. Montabon et al. (2007) found that Environmental Management Practices are positively linked with product and process innovation. Papinniemi (1999) emphasized that the core aspect of process innovation is enabling profitable business and manufacturing processes. While product innovation focuses on introducing novel features that appeal to consumers, process innovation offers benefits to customers by improving the operational aspects of production. Baer and Frese (2003) suggested that process innovation can bring multiple benefits to an organization, contributing to competitive advantage. However, many organizations have implemented these innovations without achieving notable success.

Rehfeld et al. (2007) identified a positive correlation between environmental organizational measures and environmental product innovations in the German manufacturing sector. Waste disposal measures and product take-back systems play critical roles in environmental product innovations, regardless of other factors or company characteristics. Furthermore, environmental product innovations often drive environmental process innovations, as changes in production processes are frequently triggered by product modifications.

Brent and Labuschagne (2004) demonstrated that integrating product and process design with manufacturing planning and control is key to creating a "Green System" that minimizes environmental impact by managing the flow of waste and maximizing resource efficiency. This approach helps produce sustainable components. Bovea and Wang (2007) emphasized that manufacturing practices, product design, and environmental concerns intersect critically when organizations adopt environmentally conscious practices. Inderfurth (2005) added remanufacturing as an important aspect of this intersection.

Chen and Wang (2008) noted that practical aspects of environmentally conscious design include minimizing material usage, selecting enhanced materials, designing for easy disassembly, promoting product reuse, reducing energy consumption, manufacturing without hazardous waste, and using clean technologies. Inderfurth (2005) also stressed the importance of remanufacturing in this context. Product Design for Environment (Ashley, 1993) involves creating environmentally preferable features such as recyclability, disassembly, maintainability, refurbishability, and reusability. These features are treated as design objectives, not limitations. Gehin et al. (2008) described Design for Environment as a global strategy that improves environmental performance by adopting a novel approach to product and process design, using Life Cycle Analysis data to assess and quantify environmental impacts. Pujari et al. (2003) argued that the Design-for-Environment approach integrates environmental considerations into traditional New Product Development (NPD), adding complexity while meeting stakeholder demands for eco-performance without compromising core product benefits.

In the realm of eco-innovation or sustainable development innovation, companies focus on New Product Development. Hall and Vredenburg (2003) noted that product innovations for sustainability are often driven by public policy or market demand. While disruptive innovations such as wind power and hybrid cars are notable examples, most sustainable innovations involve incremental changes, such as remanufactured products, recycled materials, and organic or eco-friendly products (Pujari, 2006). Environmental innovation can be driven by both technology push and market pull factors. New eco-efficient technologies fall under the category of technology push, while consumer preferences for environmentally friendly products drive market pull. Cleff and Rennings (1999) differentiated between ecological product and process innovations, finding that strategic market behavior (market pull) drives product innovation, while regulatory frameworks (regulatory push/pull) play a stronger role in process innovation. The regulatory framework, particularly environmental policy, is a critical factor in eco-innovation, as noted by Porter and Van der Linde (1995). Gehin et al. (2008) agreed, stating that environmental awareness in industry is largely driven by regulations and standards, which push companies to reconsider their production processes. Diverse standards have encouraged firms to rethink and redesign their operations to align with environmental goals.

Environmentally innovative firms tend to rely less on strict government regulations compared to more passive companies. These innovative organizations often respond effectively to soft, voluntary environmental policy measures. However, hard regulatory measures, such as command-and-control instruments or mandated duties, remain essential for encouraging non-innovative firms to adopt integrated environmental practices (Rennings, 2000).

Fischer et al. (2003) observed that policymakers frequently choose alternative instruments for environmental protection. A critical factor influencing this choice is how different policies affect company incentives to develop cleaner production technologies. The right mix of policy tools can either encourage innovation or lead to compliance with minimal effort. Boons (2008) noted that companies vary in their approaches to reducing ecological impacts. While some firms actively develop and market environmentally friendly technologies, others comply with governmental regulations governing production processes. Some companies focus more on communication or lobbying activities related to environmental issues, while others remain largely inactive, making little effort to mitigate their ecological impact. This diversity in approaches highlights the importance of tailoring policy measures to suit different types of companies, from proactive innovators to those requiring more regulatory pressure to implement sustainable practices.

2.4. REMANUFACTURING

The remanufacturing industry emerged during the Second World War as a solution to resource scarcity and the unavailability of natural resources due to the conflict. Manufacturing activities shifted towards rebuilding used parts and remanufacturing products from original materials to meet increasing demands. Even in wartime, industries sought alternative paths for economic and industrial growth by repurposing existing materials. In the last few decades, remanufacturing has grown significantly due to both environmental requirements and its economic advantages. This practice is now prevalent in various industries, particularly in the automotive sector. Examples of remanufactured products include automobile parts, military vehicles, aircraft components, industrial robots, furniture, home appliances, computers, printers, and medical equipment, among others. The standard definition of remanufacturing, according to the Automotive Parts Remanufacturers Association (APRA, 2010), is the restoration of worn, discarded, or used durable products to a "like-new" condition. Ijomah et al. (1999) further described remanufacturing as restoring a non-functioning complex assembly to a fully functional state through rebuilding and replacing component parts. Later, Ijomah (2008) expanded this definition, emphasizing that remanufacturing involves restoring products to at least their original performance specifications and offering warranties comparable to those of new products. This approach is seen as a crucial strategy for waste management and environmentally conscious manufacturing.

Sundin and Bras (2005) offered a broader definition, describing remanufacturing as a process of rebuilding a product through cleaning, inspecting, disassembling, replacing defective components, reassembling, and testing to meet or exceed new product standards. The remanufacturing process typically includes phases such as disassembly, cleaning, testing, repair, inspection, updating components, replacing parts, and reassembly (Rathore et al., 2011; APRA 2010; Sundin and Bras, 2005). Detailed steps for remanufacturing have been outlined by Kerr and Ryan (2001), with Sundin and Bras (2005) presenting a simplified flowchart for the process. Zwolinski et al. (2006) noted that during remanufacturing, products are often enhanced to improve reliability, simplify maintenance, or introduce advanced controls. This upgrade phase is crucial for ensuring the long-term viability of remanufacturing, as it prevents the extension of inefficient or outdated products' life spans. Remanufacturing focuses on individual components and conserves both material and energy used in producing new parts, offering substantial environmental benefits. Unlike recycling, which provides lesser environmental advantages, remanufacturing overhauls the entire product assembly, ensuring that remanufactured products meet customer expectations for new products (Shah et al., 2010). Refurbished products, by comparison, do not match the quality of remanufactured products. From an environmental and economic perspective, remanufacturing reduces the costs of manufacturing and disposing of used products and components. It allows companies to use fewer resources while maintaining the same level of service. This reduction in resource intensity enhances the eco-efficiency of product systems (Kerr and Ryan, 2001). The remanufacturing process varies depending on the strategy used. Some companies opt for total disassembly before inspecting for errors, while others perform inspections first to identify parts that need replacing. Accurate inspection early in the process can reduce the need to process products that will later be discarded. In some cases, the inspection phase occurs after cleaning and disassembly, although this is not always efficient. Visual inspections are typically conducted on products arriving at remanufacturing facilities to identify major defects. Detailed inspections are easier once the product has been cleaned. Choosing an efficient remanufacturing strategy is essential, as each process and product type is unique (Sundin and Bras, 2005). Remanufacturing offers a viable solution for reducing environmental impact and conserving resources while providing customers with products that meet the same standards as new ones. However, the success of remanufacturing depends on selecting the right strategy for each specific product and process.

Over the past few decades, remanufacturing has garnered increasing attention, leading to numerous studies exploring its various facets. Most of the academic focus has been on the environmental benefits of remanufacturing and its suitability for product design. However, there is still a lack of comprehensive studies that view remanufacturing as a business process, and there remains a gap in developing influential tools and techniques that enable companies to manage and control these complex operations (Ijomah et al., 1999). Sundin and Bras (2005) highlighted that remanufacturing offers companies the added advantage of a "green image," which can lead to tangible business benefits. The fundamental business proposition of remanufacturing lies in the reuse of resources that were initially employed during the manufacturing process, making it an advantageous practice (Östlin et al., 2008). Remanufacturing offers both upstream and downstream environmental benefits. Upstream, it reduces the consumption of raw materials, while downstream, it decreases waste production (The European Commission, 2008).

According to Steinhilper (2001), remanufacturing allows companies to produce the same product at roughly half the cost of a new one. On average, remanufactured products are priced between 40% and 80% of their new counterparts, with a median of 60%. This creates a win-win scenario for both consumers, who get a lower-priced product, and remanufacturers, who can still operate profitably. Remanufacturing retains the value of materials, energy, labor, and manufacturing processes invested in a product. However, it guarantees the quality of a product as good as new, unlike mere repairs or refurbishments (King et al., 2006). Beyond being environmentally beneficial, remanufacturing is also more profitable for manufacturers who handle returned products. It not only reduces the final disposal costs of products and components but also lowers the environmental impact and costs associated with manufacturing (Kerr and Ryan, 2001). Heese et al. (2005) found that in competitive markets, companies can initiate product take-back and remanufacturing programs to reduce production costs or expand market share, often at the expense of their competitors. Firms that engage in take-back programs should also lower the prices of new products to surpass the profits customers would make by selling their used items in secondary markets. Remanufacturing adds value not only by reducing production costs but also by enhancing

customer service, corporate image, and environmental responsibility (Toffel, 2004).
Remanufacturing is often seen as superior to other end-of-life strategies, such as repair or reconditioning, because it yields higher-quality products with extended lifespans, making it more commercially viable (King et al., 2006). End-of-life strategies like remanufacturing can help companies improve both profitability and environmental performance, often exceeding legal requirements (Gehin et al., 2008). Remanufacturing reduces the use of raw materials, saves energy, and preserves value added during the design and production processes. However, many products are not initially designed for remanufacturing, requiring the process to be adapted to suit existing products. These adaptations can raise costs, prompting companies to reassess the overall benefits of remanufacturing (Zwolinski et al., 2006). Nasr and Thurston (2006) identified two key levels of remanufacturing design: the product strategy level, which focuses on sales, marketing, service, and reverse logistics, and the product and manufacturing engineering level, which involves more comprehensive design considerations. Hatcher et al. (2011) recognized that the design phase of a product's life cycle significantly affects its cost, manufacturing process, and end-of-life options. The aim of Design for Remanufacturing (DfR) is to improve the remanufacturability of products by considering various design issues related to the remanufacturing process. DfR might involve standardizing parts or selecting more robust materials to enhance the efficiency of remanufacturing. This approach is most likely to be adopted when Original Equipment Manufacturers (OEMs) engage in remanufacturing for environmental, legislative, or financial reasons, or as a means of providing spare parts. Matsumoto and Umeda (2011) emphasized that designing products for remanufacturing can significantly improve the efficiency of the remanufacturing process. Matsumoto and Umeda (2011) also outlined three core requirements for successful remanufacturing: (1) developing systems for collecting used products, (2) establishing effective remanufacturing processes, and (3) promoting consumer demand for remanufactured products. Companies can achieve these goals by creating new collection channels, developing reverse logistics systems, and designing products specifically for remanufacturing. Remanufacturing not only offers significant environmental and economic benefits but also requires strategic adaptations in design, logistics, and process management. As companies continue to explore remanufacturing as a sustainable business practice, they must balance these considerations to maximize the potential of remanufactured products in meeting both customer expectations and environmental goals. Remanufacturing is a value recapturing process that focuses on adding value to the material and components used in the initial production of a product. This process plays a significant role in fostering a sustainable society by reducing energy consumption, minimizing carbon emissions, and creating skilled employment opportunities. Design for Remanufacture (DfR) is an essential part of this process, as it enhances both the remanufacturing practice and the associated business models, leading to increased competitiveness and innovation. Despite these benefits, the ability to effectively design for remanufacturing remains inadequately understood or underutilized, particularly by independent remanufacturers who often have limited control over the product design process. Original Equipment Manufacturers (OEMs), on the other hand, have greater control and potential to influence remanufacturing through the design process, yet only a small number of OEMs are currently involved in remanufacturing (Gray and Charter, 2007).
Nasr and Thurston (2006) argue that the social benefits of the remanufacturing process, such as decreased energy and material consumption and reduced waste, cannot be fully realized without integrating DfR into the product development process. In addition to environmental benefits, DfR and recycling offer significant economic returns for manufacturers, providing a comparative advantage in sustainable production. Key areas of focus for DfR include designing products for disassembly, ensuring reliability and durability for multiple life cycles, and creating modular designs that allow for easier upgrading and remanufacturing. These considerations make remanufacturing more efficient and economically viable. Rubio and Corominas (2008) have shown that remanufacturing is compatible with lean production practices, and combining manufacturing, recovery, and disposal strategies can generate economic benefits for companies. However, Kerr and Ryan (2001) note that the contribution of remanufacturing to eco-efficiency and sustainability is limited by the suitability of products for remanufacturing. Factors such as product design, the condition and volume of returned products, and the costs of remanufacturing relative to other alternatives influence whether remanufacturing is feasible.
Remanufacturing is widely recognized as a strategy for extending product life cycles, closing material loops, and reducing overall material consumption. It creates a second life for products by reducing the need for new materials and offering significant environmental benefits (Nasr et al., 2011). For remanufacturing to be successful, products need to be designed with this process in mind. Steinhilper (2001) proposed eight criteria for evaluating a product's suitability for remanufacturing, including technical, quantitative, value, and time considerations, as well as innovation, disposal, competition with OEMs, and market behavior. OEMs hold significant advantages over independent remanufacturers and may have a greater incentive to engage in remanufacturing (Matsumoto and Umeda, 2011). Despite the general consensus that remanufacturing is both efficient and profitable, many OEMs still hesitate to adopt remanufacturing due to concerns about costs and internal competition between remanufactured and new products (Ferguson and Toktay, 2006). However, remanufacturing offers significant opportunities for OEMs to increase profits and gain insights into product failure modes and durability (Gerrard and Kandlikar, 2007). Gehin et al. (2008) emphasize that reverse logistics and disassembly are particularly challenging for OEMs, as they often fall outside their core competencies. Consequently, designing products for remanufacturing involves not only product design but also the supply chain and process considerations associated with remanufacturing activities.
Hammond et al. (1998) found that remanufacturing processes can be significantly improved through the application of lean production techniques, leading to cost savings and increased efficiency. Lean remanufacturing practices help streamline the process and improve the overall value proposition of remanufactured products. Additionally, the rise of international legislation aimed at reducing environmental impacts has pushed manufacturers to consider remanufacturing as a way to comply with regulations while remaining competitive in a global market. These competitive, legislative, and

environmental pressures have the potential to make remanufacturing a more widely adopted practice in the future (Steinhilper, 2001). In the long term, remanufacturing may become an integral part of the manufacturing industry, with new products incorporating remanufactured components, much like how reprocessed materials from the steel industry are used today. Although the uptake of remanufacturing has been slow, awareness of its benefits and its potential to contribute to a sustainable economy is growing. As industries continue to recognize the environmental and economic advantages of remanufacturing, it is likely to play an increasingly important role in the future of manufacturing.

3. CONCLUSION

There has been increasing recognition of the importance of addressing economic, social, and environmental challenges to ensure the long-term viability of society and the planet, a concept central to environmental sustainability. This approach seeks to balance human needs with the capacity of natural systems to continue providing resources such as water, materials, and energy, which are essential for human health and well-being. Environmental sustainability emphasizes not only the responsible use of these resources but also their preservation and regeneration for future generations. According to the United States Environmental Protection Agency (EPA, 2011), the essence of environmental sustainability lies in ensuring that current and future generations have access to the vital resources necessary to maintain a healthy environment. This concept plays a crucial role in safeguarding both ecological and human systems, making it a key pillar for global development strategies. As environmental issues become increasingly prevalent and critical, governments, organizations, and the academic world are taking proactive measures to address these challenges.

Governments are introducing regulations and policies aimed at mitigating environmental damage, while organizations are integrating sustainable practices into their operations. The academic community is conducting research to find solutions that prevent environmental problems before they escalate. One of the most effective tools in this effort is the Environmental Management System (EMS), which provides organizations with a structured framework to manage their environmental responsibilities. EMS helps businesses reduce their environmental impacts, improve resource efficiency, and enhance their overall performance, thereby promoting sustainability. By implementing EMS, organizations can systematically identify, monitor, and manage their environmental risks, ensuring continuous improvement in their environmental performance while also complying with regulatory requirements. Large organizations often implement Environmental Management Systems (EMS) as part of their corporate social responsibility or voluntary environmental actions. Studies on EMS are comprehensive and productive, offering a wide range of insights into its effectiveness and benefits. EMS is a valuable framework for reducing environmental impacts and improving organizational performance. However, innovation plays a critical role in ensuring long-term sustainability, particularly environmental innovation, which focuses on new or modified processes, techniques, systems, and products that reduce or eliminate environmental damage (Arundel and Kemp, 1998).

The literature on environmental innovation has extensively examined technological product and process innovations. Product innovation has received significant attention, especially in areas like new product development, product design for the environment, and design for remanufacturing. These innovations aim to minimize environmental impact through sustainable product designs and practices. Despite the wealth of research on product innovation, there is a noticeable gap in studies focusing on process innovation. Lager (2002) emphasized that process innovation is crucial for reducing production costs, increasing yields, enhancing production volumes, and improving product recoveries, all of which contribute to reduced environmental impacts. Process innovation also provides organizations with a competitive edge in both local and global markets by making their operations more efficient and sustainable. Another key element of environmental innovation is remanufacturing. Interest in remanufacturing is growing rapidly, as organizations recognize its potential to drive both profitability and environmental benefits. Remanufacturing involves restoring used products to a "like-new" condition, which not only helps reduce waste and conserve resources but also extends the life cycle of products. This approach can significantly lower environmental impacts, as it reduces the need for new raw materials and decreases energy consumption.

Overall, remanufacturing is gaining importance as a viable strategy for creating a more sustainable economy, benefiting both businesses and the environment. Based on the literature review in this study, several key recommendations can be made to advance environmental sustainability efforts. First, since the majority of organizations worldwide are small and medium-sized enterprises (SMEs), it is crucial to not only measure and evaluate the environmental hazards and impacts of large organizations but also to focus on SMEs. Given their significant presence, SMEs must be included in environmental assessments to help them implement sustainable practices. Further studies should specifically address how SMEs can leverage environmental actions to gain competitive advantages while contributing to environmental protection. Additionally, it is essential to incorporate remanufacturability into product design processes. By planning for products to be easily remanufactured, companies can support remanufacturing processes, which reduce waste, conserve resources, and extend product life cycles. This design approach will enhance sustainability across industries and promote the circular economy. Considering the ongoing degradation of environmental conditions, the growing concerns about reaching the earth's environmental limits, and increasing consumer demand for environmentally responsible practices, more research is needed on process innovation in remanufacturing. Such studies will provide valuable insights into optimizing production methods, reducing environmental impacts, and promoting sustainable business operations.

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