The CERA Project Presents:

GREEN MANUFACTURING AND GREEN SUPPLY CHAIN MANAGEMENT

Leaders International

This paper comes as part of a series of whitepaper conducted under the Corporate Entrepreneurship Responsibility Alliance (CERA) project, that are meant to raise awareness and spread knowledge on related topics under the project's mandate. The CERA project is funded by the Embassy of Netherlands to Jordan and implemented by Leaders International. The project addresses the national imperative of promoting a transition in the enterprise ecosystem that would contribute to realizing the growth potential of SMEs. It is focused on tackling one of the key constraints that face Jordanian enterprises, namely the availability and quality of local supply chains. The project will rely on supply chain requirements and internal procurement needs of larger enterprises and will build on the concept of Corporate Entrepreneurship Responsibility as an entry point to create an alliance committed to supporting the growth of the local industry in underserved regions of Jordan.

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Introduction

In today's interconnected world, resource management and population growth present significant challenges, with environmental concerns paramount. Climate change disrupts the delicate balance of our planet, making it critical to address these issues. Businesses increasingly recognise the importance of environmental considerations in their operations, striving to cut costs and enhance product quality. Embracing green manufacturing practices fosters innovation and showcases a commitment to social responsibility. The primary goal is to mitigate industrial damage to the environment, necessitating the development of sustainable manufacturing strategies. The term "green" encompasses various principles, such as ethical production and environmentally friendly practices in manufacturing. Over the past fifty years, rapid industrial growth and economic globalisation have escalated environmental issues like pollution and resource depletion, leading organisations to expand their focus from internal processes to their entire supply chains. This shift has given rise to concepts like Sustainable Supply Chain Management (SSCM) and Green Supply Chain Management (GSCM). The manufacturing ecosystem includes a diverse range of stakeholders—suppliers, manufacturers, retailers, consumers, and policymakers—who are increasingly understanding the benefits of green manufacturing. As a result, industries are motivated to adopt these strategies to lessen their ecological footprint and enhance economic performance.

Given that the manufacturing sector is a major consumer of energy and resources, contributing significantly to greenhouse gas emissions and issues like climate change, the implementation of green manufacturing is essential. This approach can be adopted across all manufacturing domains, minimising waste and pollution while promoting economic growth and conserving resources. In addition to comprehensive laws and regulations, national initiatives have been introduced to manage specific emissions effectively, ensuring better control over industrial activities' environmental waste.

Environmental Impact of Manufacturing

Manufacturing is inherently material- and energy-intensive, contributing significantly to environmental degradation through various mechanisms.[1] The production processes require substantial amounts of water and raw materials and release toxic chemicals, generate waste, and emit greenhouse gases.[2] These impacts are evident at every product's life cycle stage, from resource extraction to disposal. The reliance on fossil fuels for energy exacerbates the problem, leading to high carbon emissions and posing risks to human health and the environment.[3] Addressing these challenges has become crucial, as the cumulative effects of manufacturing practices are detrimental to global sustainability.

There is an increasing emphasis on green manufacturing practices to combat the environmental footprint of the manufacturing sector. Implementing energy-efficient technologies and harnessing clean energy sources like solar and wind can significantly reduce energy consumption and greenhouse gas emissions. Additionally, minimising waste generation through better recycling techniques and using less toxic materials can mitigate the adverse effects associated with manufacturing.[4] The ongoing research and efforts in green manufacturing aim to transform the industry, fostering a more sustainable approach that prioritises environmental health and resource conservation while still meeting production demands.

What is Green Manufacturing?

Green manufacturing is focused on minimising waste and pollution through carefully integrating product and process design, ultimately aimed at sustainability. This method involves a commitment to reducing hazardous substances from the design phase to the manufacturing phase, thereby enhancing the overall environmental impact of the production system.[5] By incorporating environmentally conscious techniques, such as eco-design and clean production practices, green

[1] Gutowski 2004
[2] Gutowski 2004
[3] Dornfeld et al. 2013
[4] ibid
[5] ibid

manufacturing emphasises the importance of resource efficiency throughout the product life cycle.[6] Internal measures, including environmental auditing and monitoring, further support these objectives, fostering a systemic approach to improved environmental outcomes;[7] such an approach meets regulatory compliance and reduces the economic risks associated with environmental liability, making it a vital component of modern manufacturing.

In response to growing environmental concerns, green supply chain management (GSCM) has emerged as a cohesive strategy that connects supply chain and environmental management.[8] This comprehensive approach involves various stakeholders, including vendors, manufacturers, and customers, and is characterised by internal environmental management, green procurement, and eco-design practices.[9] Many companies have recognised that adopting green technologies can positively influence their operations by minimising energy-related costs and enhancing relationships with suppliers and customers.[10] GSCM aims to balance environmental impacts, social benefits, and profit generation, fostering a competitive advantage for businesses that embrace these practices as part of their long-term environmental responsibilities. Research indicates that medium and large-sized firms are generally more progressive in implementing GSCM practices compared to smaller firms, highlighting the varying levels of commitment within the industry.[11]

Importance of Green Manufacturing

Green manufacturing is increasingly becoming a crucial aspect of modern business, especially for organisations engaged in the global market. As the demand for sustainable practices rises, companies must adapt to the realities of limited resources and heightened competition.[12] Greening manufacturing efforts not only address energy consumption but also consider waste management and the social implications of production, such as fair trade and child labour practices.[13] The need for industries to reduce their environmental impact is underscored by

[6] Maruthi and Rashmi 2015
[7] Dornfeld et al. 2013
[8] Jum'a *et al.* 2021
[9] Saade et al. 2019
[10] Jum'a *et al.* 2021
[11] ibid
[12] Dornfeld et al. 2013
[13] ibid

literature highlighting the reciprocal relationship between green innovation and sustainability.[14] By embracing these principles, businesses can enhance their operational efficiency and position themselves favourably in a market that values ecological responsibility.[15]

On the other hand, the adoption of Green Supply Chain Management (GSCM) practices offers a pathway for organisations to minimise their environmental footprint while ensuring long-term financial sustainability.[16] GSCM emphasises efficient use of resources, waste reduction, and environmentally considerate end-of-life product strategies. This approach benefits businesses by lowering operational costs and meeting the increasing consumer demand for sustainable products.[17] Moreover, manufacturers, particularly in the electrical consumer goods sector, recognise that reusing, remanufacturing, and recycling can lead to shorter product life cycles and reduced expenses. Ultimately, integrating green principles into manufacturing strengthens competitive advantage in the global marketplace and fosters a commitment to environmental stewardship.

Reasons to Pursue Green Manufacturing

Pursuing green manufacturing is essential for several compelling reasons. Firstly, it significantly reduces the environmental impact of production processes, helping to address pressing issues like climate change and resource depletion.[18] By implementing sustainable practices, companies can enhance their brand image, making themselves more attractive to increasingly eco-conscious consumers.[19] Moreover, green manufacturing often leads to greater operational efficiencies, resulting in cost savings and improved profitability.[20] It fosters innovation by encouraging the development of new technologies and processes that prioritise sustainability. Additionally, regulatory compliance and potential incentives for adopting green practices can further drive profitability.

[14] Rantala et al. 2018
[15] Paul et al. 2014
[16] Abdellatif and Graham 2019
[17] ibid
[18] Green et al. 2012
[19] ibid
[20] Zhu et al. 2007

This paper highlights three reasons that play essential roles in creating a more cohesive environment and encouraging enterprises to pursue green manufacturing (i.e. regulatory pressure, economic incentives, and competitive advantages)

Regulatory Pressure

Governments, recognising the significant environmental challenges posed by industrial waste and emissions, have taken proactive steps to establish regulations, policies, and laws aimed at enhancing environmental performance in production activities.[21] These regulations not only drive organisations to limit the use of non-renewable energy and curtail greenhouse gas emissions but also provide critical support in the form of capital for acquiring renewable production equipment and offering sustainable energy advisory services.[22] As a result, government intervention becomes a vital asset for businesses, helping them to overcome barriers to environmental protection and fostering a more sustainable future.

Economic Incentives

Economic incentives play a crucial role in driving the adoption of sustainable practices within the manufacturing industry. As regulatory pressures intensify, businesses are increasingly recognising that implementing green manufacturing programs yields significant financial benefits. For instance, pollution prevention and product stewardship minimise waste generation and reduce costs associated with waste management and material consumption, thereby enhancing profit margins.[23] Furthermore, integrating supply chain management with green practices allows companies to reduce costs while addressing environmental concerns.[24]

Larger organisations, in particular, benefit from economies of scale, as they can leverage the cost savings from green initiatives to enhance their competitiveness, attract investors, and gain

[21] Dornfeld et al. 2013
[22] Jum'a, L. *et al.* 2021
[23] Dornfeld et al. 2013
[24] Vanalle et al. 2017

eligibility for loans and grants.[25] This strategic shift towards sustainability fosters a more environmentally responsible industry and strengthens financial performance, highlighting the intertwined relationship between economic incentives and sustainable development.

Competitive Advantages

Green manufacturing offers significant competitive advantages for companies by enhancing their market position and fostering consumer loyalty. As awareness of environmental issues grows, individual consumers and other industries increasingly support businesses with strong eco-friendly practices. By adopting green manufacturing strategies, companies can enhance their image, attract environmentally conscious customers, and differentiate themselves from competitors, ultimately driving revenue and increasing market share.[26] Additionally, businesses prioritising sustainability can mitigate supply chain risks, particularly concerning volatile resources like water.[27] The integration of innovative, environmentally protective practices not only streamlines operations and reduces costs but also positions firms as leaders in sustainable practices, aligning with consumer demand and regulatory pressures.[28] This dual focus on competitiveness and environmental responsibility enables businesses to thrive in a rapidly evolving market landscape.[29]

[25] Baumann-Pauly et al. 2013
[26] Delmas 2001
[27] Dornfeld et al. 2013
[28] Chang, 2011
[29] Lin et al. 2020

Factors influencing the adoption of green manufacturing

The adoption of green manufacturing is significantly influenced by various factors that encompass both internal and external dimensions. Key drivers include regulatory pressures from governmental bodies, which create a framework for compliance and motivate firms to adopt environmentally friendly practices.[30] Additionally, as mentioned previously, customer awareness and demand for sustainable products push organisations to integrate green strategies into their operations.

Internal factors such as the commitment of top management, effective organisational communication, and employee empowerment also play crucial roles; these elements foster a culture of sustainability within the company.[31] Furthermore, the implementation of environmental management systems, such as ISO standards, serves as foundational steps towards adopting green practices.[32] Other aspects, including the size of the firm and resources allocated for training and development, are essential in determining the pace and extent of transitioning to sustainable manufacturing practices.[33] Collectively, these factors shape how firms navigate the complexities of green manufacturing adoption, leading to more environmentally responsible production processes.

[30] Mathiyazhagan et al. 2013
[31] Muduli et al. 2013
[32] Jum'a *et al.* 2021
[33] Ibid

Steps to Pursue Green Manufacturing

Green manufacturing involves a strategic approach emphasising sustainability and responsibility throughout production.[34] It begins with adopting a comprehensive systems perspective to evaluate and enhance manufacturing practices, considering both vertical and horizontal aspects of the system. Manufacturers should minimise harmful inputs and outputs that affect the environment and human health while lowering net resource usage. Additionally, the temporal effects on the system must always be taken into account. This framework can be refined by implementing key strategies, such as using less material and energy, substituting toxic materials with nontoxic and renewable alternatives, reducing unwanted outputs through cleaner production practices and industrial symbiosis, converting outputs into inputs through recycling, and rethinking ownership structures to focus on product service systems and supply chain optimisation.

Steps To Pursue Green Manufacturing	(1) Adopt a comprehensive systems approach to evaluate processes
	(2) View the system holistically across vertical and horizontal dimensions
	(3) Reduce or eliminate harmful inputs and outputs
	(4) Lower net resource use
	(5) Consider temporal effects on the system.
	(6) Use less material and harness energy efficiency
	(7) Substitute toxic materials with nontoxic and renewable alternatives.
	(8) Reduce unwanted outputs through cleaner production and industrial symbiosis
	(9) Convert outputs to inputs via recycling
	(10) Change ownership and production structures to promote product service systems and optimize supply chains

[34] Helu and Dornfeld 2013

Strategising the Green Manufacturing Process

Green manufacturing is an approach that seeks to minimise the environmental impact of production processes while maximising resource efficiency and sustainability.[35] Companies can enhance efficiency by strategically selecting manufacturing sites based on energy sources and transportation costs.[36] This involves looking beyond just production and considering the entire supply chain.[37] Furthermore, incorporating green product design is crucial in the manufacturing process. Changes in design can significantly affect the ease of disassembly, repair, and recycling of materials. Manufacturers have a unique opportunity to create products that meet consumer needs and facilitate easier recovery and remanufacturing.[38] By focusing on how a product can be disassembled and reused, companies can enhance the lifecycle of their products and minimise waste, ultimately fostering a circular economy.

Moreover, adopting standards like ISO environmental management systems provides a structured approach for industries to demonstrate their commitment to sustainability.[39] These standards help establish practices that ensure continuous improvement in environmental performance. By evaluating the impacts of different processes at a singular level and across the entire system, manufacturers can better understand the interplay between various factors that affect the environment.[40] This holistic viewpoint is essential for developing strategies that reduce harmful outputs and promote responsible resource use throughout the supply chain.

Two essential methods by which green manufacturing can be easily implemented and enhanced incorporate the lean manufacturing approach and environmental management tools.

[35] Helu and Dornfeld 2013
[36] Diabat & Govindan, 2011
[37] Paul et al. 2014
[38] ibid
[39] Maruthi and Rashmi 2015
[40] Helu and Dornfeld 2013

Lean manufacturing

Lean manufacturing is a systematic approach focused on the elimination of waste within production processes, enhancing efficiency and productivity.[41] By emphasising concepts such as Just in Time (JIT), lean manufacturing minimises excess inventory and resources, ensuring that materials are purchased and products are produced only as needed.[42] This approach encourages continuous quality monitoring, allowing for immediate corrections of defects as they arise. Additionally, assembly processes and machinery design supports swift changeovers, fostering a flexible and responsive production environment. By standardising tools, processes, and workplace arrangements, lean manufacturing promotes simplicity and consistency, making it a valuable strategy for companies aiming to optimise their operations and reduce environmental impact.[43]

Environmental Management Tools

Effective environmental management is crucial for sustainable development in today's industrial landscape. Various tools and strategies have been developed to reduce the environmental impact of manufacturing processes and services. These tools focus on minimising waste, enhancing resource efficiency, and promoting eco-friendly practices. Below is a descriptive list of key environmental management tools.

1. **Mass Balance:**[44] A method that assesses the inputs and outputs of a process to evaluate its efficiency. By understanding the flow of materials and energy, businesses can identify waste areas and improve overall effectiveness.

2. **Pollution Prevention:**[45] Focused on implementing emission control strategies before and during waste generation. This includes using fewer materials and energy and opting for environmentally friendly alternatives to reduce potential emissions at source.

[41] Dornfeld et al. 2013
[42] Maruthi and Rashmi 2015
[43] ibid
[44] Paul et al. 2014
[45] Dornfeld et al. 2013

3. **End-of-Pipe Control:**[46] Techniques applied after emissions and waste have been generated before release into the environment. This approach includes recycling, waste collection, and treatment processes to manage waste effectively.

4. **Environmental Restoration:**[47] Strategies are employed to remediate damage caused by emissions and waste once released into the environment. This tool focuses on restoring ecosystems and mitigating negative impacts.

5. **Zero Emission Technologies:**[48] Innovations aimed at maximising resource productivity while generating virtually no waste. This concept promotes waste recycling into energy and emphasises cleaner production practices.

6. **Industrial Ecology:**[49] A framework that encourages the integration of industrial processes with ecological principles. It focuses on creating closed-loop systems where waste from one process becomes input for another, thereby reducing overall waste.

7. **By-Product Synergy:**[50] A strategy where waste materials from one industry are used as raw materials by another. This collaboration maximises resource use and minimises waste generation across sectors.

8. **Cleaner Production:**[51] Techniques that enhance the efficiency of production processes to reduce waste and emissions. This includes optimising resource use and adopting best practices in manufacturing.

9. **End-of-Life Treatment:**[52] Practices that ensure responsible disposal or recycling of products at the end of their lifecycle. This includes collecting equipment and recycling components to minimise landfill use.

[46] Dornfeld et al. 2013
[47] ibid
[48] Maruthi and Rashmi 2015
[49] ibid
[50] ibid
[51] ibid
[52] Maruthi and Rashmi 2015

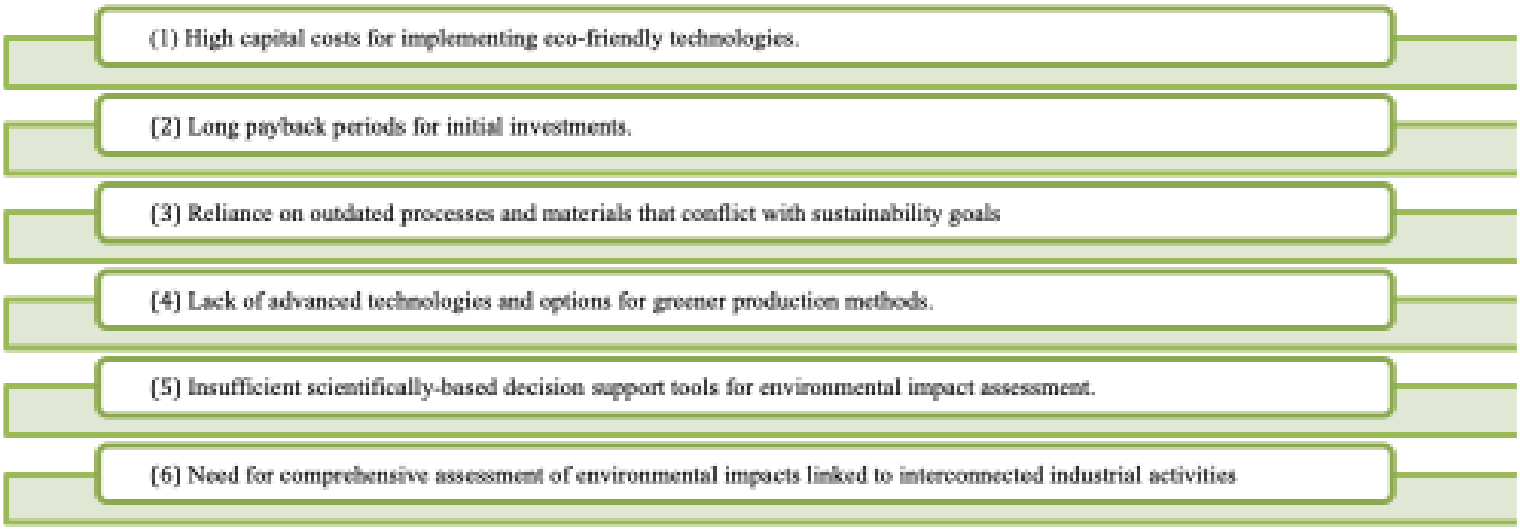
Adopting these environmental management tools enables industries to minimise their ecological footprint while promoting sustainability. By integrating these practices, businesses can create a more resilient and environmentally responsible production system that benefits the planet and their bottom line.

Limitations of the Green Manufacturing Process

Green manufacturing, while promising to enhance sustainability within the industrial sector, faces several significant limitations that hinder its widespread implementation. One primary obstacle is the high capital costs associated with adopting green technologies and processes. Many companies are deterred by the initial investment required for emission control and waste management systems, which may not yield immediate economic returns.[53] Even as the focus shifts towards pollution prevention, the financial burden remains a considerable barrier, impacting the decision-making process of manufacturers who must outweigh short-term costs against long-term benefits.

Moreover, a substantial technological barrier arises from the current reliance on certain processes, materials, or technologies that may not align with eco-friendly practices. The lack of advanced alternatives constrains manufacturers from fully embracing green strategies. Additionally, the absence of scientific decision-support tools further complicates the issue.[54] Manufacturers struggle to implement meaningful changes without effective analytical frameworks to evaluate the environmental impacts of specific processes. Given the systemic link between manufacturing and other industries, it is crucial to assess the environmental footprint comprehensively to devise robust solutions.

[53] Dornfeld et al. 2013
[54] ibid



Developing Economies and Green Manufacturing

The relationship between developing economies and green manufacturing is complex and multifaceted. Developing economies often face the challenge of balancing economic growth with environmental sustainability. As these nations industrialise, they may attract environmentally detrimental industries, sometimes because developed nations relocate their high-pollution operations to reduce costs. Furthermore, developed nations are often held responsible for environmental problems in developing countries because they have relocated many of their high-polluting industries abroad. By moving these industries to countries with looser environmental regulations, developed countries reduce pollution at home while shifting the environmental burden to less-regulated regions. This practice allows developed nations to maintain cleaner domestic environments, but it causes significant pollution and environmental degradation in developing countries, which bear the brunt of these industries' impacts. Consequently, developed nations are blamed for the environmental issues developed countries face, as these issues stem from industries originally established or financed by wealthier nations. Therefore, greening the manufacturing industry in developing economies still faces multiple hurdles brought on by the high transition costs and the composition of the global industry.

The Case of Jordan

The case of Jordan showcases the complex dynamics of adopting green manufacturing practices in the context of varying environmental pressures in developing countries. Researchers argue that developed nations typically exhibit a stronger cultural and political commitment to environmental protection, supported by comprehensive environmental regulations.[55] Consequently, organisations in these countries face greater pressure to comply with strict environmental laws and address the concerns of stakeholders focused on environmental issues. In contrast, many organisations in developing countries—including Jordan—often adopt a reactive approach to environmental management, primarily due to a lack of robust regulations, governmental commitment, and public awareness.[56]

Air pollution is a significant concern, particularly in hotspot areas like free industrial zones, where manufacturing activities heavily contribute to air quality degradation. Industries in Jordan, especially larger ones, generate substantial pollution that can negatively impact public health if emissions are not carefully controlled.[57] Research indicates that the adoption of Green Supply Chain Management (GSCM) practices is lagging across organisations of all sizes, with varying levels of adoption based on firm size.

Despite these challenges, a notable trend toward a green economy is emerging in Jordan. Manufacturers are showing interest and commitment to environmental protection, even in the absence of stringent governmental regulations.[58] This proactive approach is reflected in their adoption of various GSCM practices, positioning them uniquely in terms of environmental sustainability. A diverse range of manufacturing companies across multiple sectors—including chemicals, construction, food supply, furniture, garments, mining and minerals, plastic products, and printing and paper—have begun to adopt greener manufacturing practices. This includes participants in the CERA project implemented by Leaders International.

[55] Abdellatif and Graham 2019
[56] Ibid
[57] Jum'a *et al.* 2021
[58] Abdellatif and Graham 2019

The strategic patterns for green manufacturing adopted by ISO-certified holders in Jordan have included agile, lean, and caretaker patterns. Among these, agile patterns demonstrate superior performance on environmental and operational indicators, although financial performance remains moderate.[59] However, resistance to adopting green manufacturing practices can arise from shareholders due to concerns about increased short-term costs.[60] The initial expenses can reduce profit margins for shareholders and company owners, creating a reluctance to embrace such changes, particularly in light of the already high production costs in the country.

Furthermore, it is important to recognise that an eco-centric supply chain, while beneficial for the environment, does not inherently promote economic development in the region. This can be a demotivating factor, especially in a country with a weak economy and limited capacity for job creation. While GSCM practices can help mitigate the negative impact of harmful products on the environment and contribute to lowering the global carbon footprint by reducing harmful emissions, the specific effects within Jordan's manufacturing sector remain under-researched and warrant further study. As globalisation accelerates, Jordan needs to find strategies to protect its environment without adversely affecting businesses, particularly small and medium enterprises (SMEs). This raises the question: can these companies navigate this transition in the short term?

In conclusion, while there is growing commitment to green manufacturing and GSCM in Jordan, significant challenges and research gaps persist, particularly regarding the impact of these practices on the manufacturing sector and the local companies' ability to transition effectively in response to environmental pressures.

[59] Migdadi and Elzzqaibeh 2018
[60] Wang et al. 2016

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