Chapter 1
Towards a Greener Future: Integrating Life Cycle Assessment for Sustainability in Industry 5.0

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ABSTRACT

Life cycle assessment (LCA) is being considered as an essential means for promoting sustainability in Industry 5.0, a paradigm promoting human-centered, resilient, and environmentally friendly industrialization. Life Cycle Assessment (LCA) assesses the environmental pressure of products and procedures throughout their life cycle, from raw material and energy extraction through end-of-life disposal, allowing firms to locate and minimize ecological footprints. Integrating life-cycle assessment (LCA) into Industry 5.0 can help businesses develop smarter, more sustainable manufacturing practices using technologies such as artificial intelligence and the Internet of Things (IoT) to reduce waste and improve resource efficiency. Such alignment facilitates the creation of circular economy models, enabling the reuse and recycling of materials and lowering reliance on limited resources. Also, the human-centric vision of Industry 5.0 guarantees that sustainability objectives are balanced with preserving labor conditions and societal prosperity.

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1. INTRODUCTION

Industrial revolutions have fundamentally changed humanity and the world it lives in. The first of these was the First Industrial Revolution in the late 18th century, when agrarian economies moved to industrialized production, and each successive revolution brought several revolutionary technologies that changed both production and overall societal structures (Forward, 2024). The First Industrial Revolution (1760–1840) was marked by mechanization, most prominently in the textile industry, and was fueled by inventions like the steam engine, as well as power looms (Sharma & Gupta, 2024). This time provided the foundation for the Second Industrial Revolution (1871–1914), which introduced electricity and assembly line production, increasing efficiency and output even more, as well as impacting social changes such as exploitation of workers and urbanization (Hasan et al., 2024). Also, the third industrial revolution; taking root in the late 20th century, brought digital technologies and automation, further transforming communication and production processes (Jin et al., 2024).

Lastly, the Fourth Industrial Revolution is Industry 4.0 marked by smart technologies, artificial intelligence, and the Internet of Things (IoT). However, as the shift toward Industry 5.0, a distinct construct is taking shape, focusing on human-centric, sustainable, and resilient approaches within industrial frameworks (Martini et al., 2024). On the other hand, Industry 5.0 focuses on building a balance between advanced technologies with human capabilities where it tries to combine customized production with one of the pressing global issues such as climate change and the environment. Sustainability in modern industrial processes has become essential in the industries growing and developing, extracting raw materials, polluting the environment, and producing waste, which makes them one of the biggest threats to the environment. Increasing evidence of climate change impacts, biodiversity loss, and the unsustainable use of natural resources is driving an urgent need to adopt sustainable practices. In this new era, industries not only need to generate greater productivity but also reduce their ecological footprint and reaffirm long-term availability by incorporating sustainability into core operations (Satheesh & Shukla, 2024). Life Cycle Assessment (LCA) is an indispensable tool to assess and enhance sustainability in industrial processes. LCA is a robust analytical approach for evaluating the environmental aspects associated with all the stages of a product's life cycle from resource extraction to end-of-life. LCA has its origins dating back to the early 1960s, responding to worries about environmental pollution and resource depletion (Vacchi et al., 2024).

LCA was later developed into a powerful tool for decision-making in environmental management, eventually improving those decision-making processes across different industries within this field. Relevancy of LCA nowadays is a framework for where to look for improvements across the life of the products or processes. LCA quantifies these impacts like greenhouse gas emissions, energy consumption, and water usage, allowing industries to make decisions that are consistent with sustainability (Sarkar et al., 2024). Additionally, it promotes transparency and accountability among stakeholders by offering credible data that can inform policy decisions and consumer choices. To promote sustainability in industrial practice, the chapter strives to understand how LCA can be integrated into the industry 5.0 paradigm. These aims to explore how LCA can be demonstrated in the different sectors and identify good practices and case studies on LCA. The chapter also discusses the importance of LCA in the fight against climate change and maximizing resource use at a time when sustainable development is necessary. In the end, integrating Life Cycle Assessment into industrial practices is an opportunity for creating sustainability in addition to Industry 5.0 challenges. This holistic approach not only paves the way for a more sustainable future but also enables industries to stay competitive in a rapidly shifting marketplace that prioritizes environ-