Chapter 1

Technology-Enabled Circular Economy

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ABSTRACT

The circular economy represents a transformative paradigm shift from traditional linear "take-make-dispose" models to regenerative systems that maximize resource utilization and minimize waste generation. Digital technologies—including artificial intelligence (AI), blockchain, Internet of Things (IoT), big data analytics, and digital twins—serve as critical enablers for this sustainability transition. This chapter systematically examines how technology-enabled solutions facilitate sustainable production and consumption patterns across industrial sectors. Through comprehensive analysis of emerging digital innovations, implementation frameworks, and empirical evidence from recent literature, this work demonstrates that strategic technology integration significantly enhances circular economy maturity by improving

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resource traceability, optimizing material flows, enabling predictive maintenance, supporting reverse logistics, and facilitating innovative circular business models such as product-as-a-service.

1. INTRODUCTION

The global economy faces unprecedented sustainability challenges characterized by resource depletion, environmental degradation, climate change, and escalating waste generation. Traditional linear economic models—predicated on extracting virgin resources, manufacturing products, and disposing of them after use—have proven fundamentally unsustainable in an era of planetary boundaries and growing population demands (Bag et al., 2021). The circular economy has emerged as a compelling alternative paradigm that decouples economic growth from resource consumption by designing out waste, keeping products and materials in use, and regenerating natural systems (Chauhan et al., 2022). This systemic approach aligns with multiple United Nations Sustainable Development Goals, particularly those addressing responsible consumption and production (SDG 12), climate action (SDG 13), and sustainable cities and communities (SDG 11).

Concurrently, the Fourth Industrial Revolution has ushered in transformative digital technologies that fundamentally reshape production systems, supply chains, and consumption patterns. Technologies such as artificial intelligence, blockchain, Internet of Things, big data analytics, and digital twins offer unprecedented capabilities for monitoring, optimizing, and transforming industrial processes toward sustainability (Alsaoudi et al., 2025). These digital innovations provide the technical infrastructure necessary to operationalize circular economy principles at scale, enabling real-time visibility into material flows, predictive analytics for resource optimization, automated decision-making for waste minimization, and platform-based circular business models (Khan et al., 2021).

Despite growing recognition of technology-enabled circularity as a critical pathway toward sustainable development, several knowledge gaps persist. First, while numerous studies examine individual technologies or specific circular practices, comprehensive frameworks integrating multiple digital enablers across the circular economy lifecycle remain limited (De Mattos Nascimento et al., 2024). Second, empirical evidence on the actual performance impacts of technology deployment in circular systems requires further consolidation (Cuevas-Pichardo et al., 2025). Third, implementation challenges, success factors, and contextual conditions enabling effective technology adoption for circularity need systematic examination (Mora-Contreras et al., 2025). This chapter addresses these gaps by providing a comprehensive analysis of technology-enabled circular economy transformation.

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