Chapter 3
Emerging Technologies Enabling Sustainable Business Models Under Resource Constraints

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ABSTRACT

This research examines how emerging technologies enable sustainable circular business models under resource constraints and thermodynamic limitations. Through analysis of seventeen case studies spanning biotechnology, digital platforms, and advanced manufacturing, it reveals that AI, IoT, biotechnology, and advanced materials function as selective enablers rather than universal solutions, addressing specific thermodynamic and economic barriers while creating new dependencies. Technology-enabled business models demonstrate competitive advantages through service-based revenue models and enhanced resource efficiency. Platform-based approaches show superior scaling characteristics, though contextual dependencies limit universal replication. Policy frameworks emerge as necessary but insufficient enablers. The research identifies significant environmental and social trade-offs requiring systematic attention.

INTRODUCTION

The global economy confronts unprecedented resource constraints that fundamentally challenge traditional linear business models predicated upon continuous

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material throughput and waste generation. Climate change pressures have intensified dramatically, with atmospheric CO_2 concentrations exceeding 400 parts per million for the first time in human history whilst global emissions have increased approximately 90% since 1970. Concurrently, the transition to clean energy technologies has created acute resource bottlenecks: projected lithium demand potentially exceeds available reserves by a factor of two under aggressive electrification scenarios, whilst many critical materials face geographically concentrated supply chains vulnerable to disruption.

These converging pressures expose the fundamental limitations of linear "take-make-waste" economic models that treat the planet as both an infinite source of materials and an unlimited sink for waste. Traditional approaches to value creation through virgin resource extraction and disposal are reaching physical and ecological limits, creating existential challenges for businesses dependent upon predictable access to affordable materials whilst generating environmental costs that threaten long-term economic stability.

Circular economy principles offer an alternative paradigm that seeks to decouple economic value creation from virgin resource consumption through strategies including material loop closure, product lifecycle extension, and natural system regeneration. However, implementing circular business models encounters significant practical barriers rooted in thermodynamic constraints, economic disadvantages, and operational complexities that have historically limited adoption despite growing environmental pressures and resource scarcity concerns.

Thermodynamic laws impose fundamental physical limits on material cycling. The Second Law of Thermodynamics dictates that all material and energy processes irreversibly dissipate quality over time, rendering perfect recycling without losses impossible. Even aggressive recycling regimes typically recover only one-third of valuable metals such as gold and copper from end-of-life products. Each recycling iteration involves quality degradation requiring additional energy inputs and supplementary virgin materials, constraining the theoretical circular potential of most material systems.

Economic barriers create additional implementation challenges. Circular alternatives often exhibit cost disadvantages compared to conventional linear approaches that benefit from established scale economies and externalised environmental costs. Traditional accounting systems fail to capture the full cost of resource depletion and environmental degradation, creating market failures that systematically favour virgin material consumption over circular approaches that internalise broader sustainability considerations.

Operational complexities further impede circular business model implementation. Coordinating reverse logistics networks, managing variable material quality streams, and establishing reliable secondary markets require sophisticated capabilities that