
From Resource Circulation to Sustainable Value Creation

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Abstract

This paper examines the relationships among circular economy, green innovation and sustainable production systems through a structured review of recent academic contributions. It considers circular economy as a systemic approach to resource circulation, value retention and business-model transformation, while recognizing that circularity cannot be considered equivalent to sustainability without evaluating its environmental, economic and social outcomes. The review further examines green innovation as a mechanism through which firms translate environmental pressures, technological capabilities, organizational resources and institutional incentives into cleaner products, processes and managerial practices. Particular attention is given to the influence of regulation, stakeholder pressure, knowledge management, digitalization and organizational capabilities on environmental innovation and corporate performance. The final part addresses sustainable manufacturing, Industry 4.0 and sustainable supply-chain management, emphasizing the growing convergence between technological modernization, circular production, environmental management and interorganizational coordination. The reviewed literature suggests that sustainable production depends less on isolated environmental practices than on the integration of technological, organizational and institutional mechanisms across product life cycles and supply networks. Digital technologies can strengthen traceability, resource efficiency and circular material flows, but their contribution remains conditional on managerial capabilities, sustainability-oriented operations and appropriate governance arrangements. Overall, the paper highlights the need for integrated production strategies capable of combining circularity, innovation, supply-chain coordination and multidimensional performance measurement.

Keywords: Circular economy; Green innovation; Sustainable production; Industry 4.0; Sustainable supply chains

JEL classification: Q01; Q55; Q56; L23; M11

Introduction

Growing environmental pressures, resource scarcity and concerns regarding the ecological consequences of conventional production systems have encouraged firms and policymakers to reconsider the organization of production and consumption. The circular economy has consequently emerged as an alternative to linear models based on extraction, production, consumption and disposal. Its principal objective is to maintain products, components and materials

within productive systems for longer periods through durability, reuse, repair, refurbishment, remanufacturing and recycling. However, the literature increasingly stresses that circularity should not automatically be interpreted as sustainability. Circular strategies may reduce material losses while simultaneously generating additional energy requirements, rebound effects or environmental burdens elsewhere in the value chain. Sustainable production therefore requires an assessment that extends beyond material recirculation and incorporates environmental impacts, economic viability and social considerations. This broader interpretation also places organizational design and business models at the center of the transition. Product architecture, reverse logistics, partnerships, customer relationships and mechanisms of value capture must be reorganized so that resource retention becomes economically feasible. The circular transition consequently represents a systemic transformation involving firms, consumers, institutions and supply networks rather than a collection of isolated waste-management practices. Within this transition, green innovation and sustainable production systems provide complementary mechanisms through which circular principles can be transformed into operational practices. Green innovation encompasses new or improved products, processes, technologies, organizational arrangements and business models designed to reduce environmental pressures while maintaining or strengthening economic performance. Its development depends on a combination of external and internal conditions, including environmental regulation, stakeholder expectations, competitive pressure, customer demand, managerial commitment, knowledge capabilities and organizational routines. At the same time, the expansion of Industry 4.0 has introduced new opportunities for improving resource efficiency, production flexibility, lifecycle information and supply-chain visibility. Digital technologies can facilitate monitoring, traceability, predictive maintenance, reverse logistics and more precise resource allocation, thereby supporting both circularity and environmental management. Nevertheless, technological modernization does not necessarily generate sustainable outcomes by itself. Its effects depend on how technologies are selected, integrated and governed within production systems. Sustainable production should therefore be approached as the coordinated integration of circular business models, green innovation, digital capabilities and sustainable supply-chain management. Such integration requires firms to move beyond fragmented environmental initiatives and establish organizational systems capable of connecting technological change with measurable environmental, economic and social performance.

1. Circular Economy: Conceptual Foundations, Business Models and Measurement

1.1. Conceptual Foundations and the Transition from Linear to Circular Systems

Geissdoerfer et al. (2017) distinguish circular economy from the broader concept of sustainability, showing that circularity emphasizes resource loops, efficiency and economic value while sustainability also incorporates wider social and environmental objectives. Kirchherr et al. (2017) reinforce this distinction by documenting substantial fragmentation across circular-economy definitions and showing that recycling and reuse frequently receive greater attention than systemic transformation, consumption change and social considerations. Murray et al. (2017) similarly argue that circular economy should be understood as an interdisciplinary attempt to reconcile economic activity with regenerative resource flows, while cautioning that its social dimension remains comparatively underdeveloped. Korhonen et al. (2018a) further describe circular economy as an essentially contested concept whose interpretation varies across firms, policymakers and researchers. Taken together, these contributions indicate that circularity should not be treated as an automatic synonym for sustainability. Closed loops and material recovery become meaningful only when they contribute to broader environmental and social

objectives. Research and policy should therefore define circular production through explicit system boundaries, governance principles and sustainability criteria rather than relying exclusively on recycling rates or material-efficiency indicators.

Ghisellini et al. (2016) position circular economy within traditions of ecological economics, industrial ecology and cleaner production and emphasize implementation across micro, meso and macro levels. Merli et al. (2018) reinforce this multi-level perspective by showing that circular-economy research encompasses industrial symbiosis, waste management, cleaner production and business-model transformation, although social and institutional dimensions remain less developed. Homrich et al. (2018) further demonstrate that circular economy operates as an umbrella integrating earlier approaches such as cradle-to-cradle design, industrial ecology, performance economy and resource-efficiency strategies. Blomsma and Brennan (2017) add a historical perspective by showing that many practices now described as circular predate the contemporary discourse and become systemically significant only when coordinated across product life cycles and value networks. Together, these contributions imply that circular production requires integration rather than isolated environmental interventions. Firms may adopt reuse, recycling or remanufacturing individually, but genuine circularity emerges when organizational, technological and inter-firm arrangements connect these practices into coherent systems of resource circulation and value creation.

Korhonen et al. (2018b) caution that circular strategies remain constrained by thermodynamics, rebound effects, path dependence and system-boundary problems, meaning that increasing material circulation does not necessarily reduce total environmental pressure. Geissdoerfer et al. (2017) reinforce this concern by treating circular economy as one possible pathway toward sustainability rather than as sustainability itself. Blomsma and Brennan (2017) similarly distinguish systemic transformation from the simple relabeling of conventional resource-efficiency practices, emphasizing coordination across products and value networks. Murray et al. (2017) add that environmental improvements must ultimately be reconciled with economic and social objectives if circularity is to support sustainable development. Considered jointly, these contributions suggest that circular production systems should be evaluated according to their net outcomes rather than the presence of circular practices alone. Recycling, reuse or remanufacturing may reduce some pressures while creating others through energy demand, rebound or shifted burdens. Robust evaluation therefore requires life-cycle and system-level assessment capable of determining whether circular interventions actually reduce resource use and environmental damage while supporting broader sustainability objectives.

1.2. Circular Business Models, Product Design and Value Creation

Bocken et al. (2016) demonstrate that circular production requires alignment between product-design strategies and business-model arrangements, distinguishing approaches that slow resource loops through durability and repair from those that close loops through reuse and recycling. Lewandowski (2016) reinforces this firm-level perspective by adapting the business-model canvas to circular value propositions, reverse logistics, partnerships and take-back systems. Pieroni et al. (2019) further show that firms need structured innovation processes capable of connecting sustainability objectives with viable mechanisms for value creation and capture, rather than relying on isolated environmental tools. Geissdoerfer et al. (2020) add that circular business models differ substantially in how they extend product life, intensify utilization, retain value or recover materials. Taken together, these contributions indicate that circular production cannot be achieved through technological efficiency alone. Product architecture, ownership arrangements, customer relationships, logistics and revenue mechanisms must evolve together. Firms therefore need organizational configurations in which environmental

objectives are incorporated into the economic logic of production so that maintaining products and materials at higher value becomes commercially durable.

Ranta et al. (2018b) show that circular practices can create economic value by reducing material inputs, retaining product functionality and generating revenue from reuse, maintenance, remanufacturing and recovery. Nußholz (2018) complements this perspective by mapping how circular strategies interact with value propositions, partners, customer relationships, activities and cost structures, thereby identifying where economic incentives may support or obstruct material retention. Ünal et al. (2019) further demonstrate through an SME case that circular value creation depends on product design, stakeholder collaboration, resource efficiency and organizational capabilities rather than on one isolated operational practice. Lüdeke-Freund et al. (2019) broaden this interpretation by identifying multiple circular business-model patterns, including repair, redistribution, refurbishment, remanufacturing, recycling and cascading. Together, these contributions imply that there is no universal organizational formula for circular production. Firms must select and combine mechanisms according to their products, technologies, markets and supply networks. Circularity becomes economically sustainable when technically feasible resource-retention strategies are supported by customer incentives, interorganizational collaboration and revenue structures that reward extending rather than prematurely replacing product and material value.

Ranta et al. (2018a) demonstrate that circular-business adoption differs across China, the United States and Europe because regulations, cultural expectations, market institutions and established production conventions shape organizational incentives. Geissdoerfer et al. (2020) similarly emphasize organizational experimentation, suggesting that firms need to test different configurations before identifying circular models compatible with their competitive environments. Bocken et al. (2016) show that such experimentation must coordinate technical product choices with economic arrangements, while Lüdeke-Freund et al. (2019) demonstrate that the available strategic repertoire contains several distinct circular patterns rather than a single transition pathway. Considered jointly, these contributions indicate that circular business models are institutionally embedded. A technically viable approach may diffuse rapidly in one environment but remain unattractive elsewhere when regulation, infrastructure, consumer demand or market conventions provide weak support. Circular-economy policy should therefore move beyond general targets and create enabling conditions for specific business-model configurations, including reverse-logistics infrastructure, appropriate regulation and market incentives that make resource retention economically credible across different national and sectoral contexts.

1.3. Circularity Indicators, Sustainability Outcomes and Implementation

Saidani et al. (2019) show that circular-economy indicators differ considerably according to scale, strategic objective, sustainability dimension and intended user, making single measures such as recycling rates insufficient for evaluating overall circularity. Moraga et al. (2019) reinforce this concern by distinguishing indicators that measure preservation of materials, products, components or functions from those assessing wider environmental consequences. Kristensen and Mosgaard (2020) further demonstrate that many micro-level indicators focus heavily on material circulation while giving limited attention to economic and social outcomes. De Pascale et al. (2021) confirm this fragmentation by identifying substantial diversity in indicator definitions, methods and system boundaries across sectors and levels. Taken together, these contributions indicate that circularity measurement must be explicitly aligned with the purpose and boundaries of each production system. Higher recycling, reuse or recycled content should not automatically be interpreted as superior sustainability performance. Firms and policymakers therefore need multidimensional measurement systems combining resource circulation

with environmental effects, economic viability and relevant social outcomes so that reported circularity reflects substantive improvements rather than narrow or symbolic indicators.

Haas et al. (2015) demonstrate that global and European economies remain only partially circular because large material stocks, dissipative uses and energetic consumption place physical limits on the extent to which materials can be recycled into production. Kalmykova et al. (2018) complement this macro-level perspective by showing that circular transformation requires coordinated interventions across sourcing, design, manufacturing, distribution, consumption and end-of-life management. Schroeder et al. (2019) broaden the assessment by linking circular-economy practices with several Sustainable Development Goals, including responsible production, energy, cities, economic development and climate action. D'Amato et al. (2017) further demonstrate that circular economy represents only one component of a wider sustainability agenda that also includes ecosystem integrity, renewable resources and social considerations. Together, these contributions imply that circular production should not be reduced to closing material loops within individual firms. Physical constraints and wider sustainability objectives require reductions in virgin-material demand, longer product lifetimes and more efficient use of existing stocks. Circular strategies should therefore be evaluated according to their contribution to broader environmental and development objectives rather than according to material recirculation alone.

De Jesus et al. (2018) show that eco-innovation provides an important mechanism through which circular-economy principles can be translated into new technologies, products, processes, organizational practices and business models. Kalmykova et al. (2018) reinforce this implementation perspective by demonstrating that circular strategies need coordination throughout the value chain rather than concentration at the manufacturing stage alone. Moraga et al. (2019) add that implementation success should be assessed through both circularity and environmental performance because material retention may still involve emissions, energy use or displacement effects. Schroeder et al. (2019) further show that circular practices can contribute to several wider development objectives when their economic, environmental and social consequences are considered jointly. Considered together, these contributions suggest that sustainable circular production requires a continuous connection between innovation, implementation and evaluation. Eco-innovation can create the capabilities needed to redesign value chains, but multidimensional indicators are necessary to determine whether those changes produce meaningful sustainability gains. Circular transformation should therefore link technological and organizational innovation with system-level performance measurement across the complete production and consumption cycle.

2. Green Innovation: Drivers, Firm Performance and Institutional Conditions

2.1. Drivers, Capabilities and Organizational Enablers of Green Innovation

Hojnik and Ruzzier (2016) show that eco-innovation emerges from the interaction of regulatory pressure, market demand, environmental management systems, cost considerations and firm characteristics, while distinguishing the drivers of innovation development from those of adoption and diffusion. Bossle et al. (2016) reinforce this perspective by demonstrating that external incentives become effective only when firms possess managerial capabilities and a strategic orientation capable of converting environmental pressure into sustained innovation. Díaz-García et al. (2015) further show that eco-innovation is shaped simultaneously by regulatory, technological, market and organizational conditions, making single-factor explanations inadequate. Triguero et al. (2015) add that the determinants of environmental innovation vary according to whether firms adopt reactive end-of-pipe solutions or cleaner preventive technologies. Taken

together, these contributions indicate that eco-innovation policy should be differentiated according to both firm capabilities and the type of technological change sought. Regulation and market demand can stimulate environmental action, but durable transformation requires organizational resources that support movement from pollution control toward preventive and resource-efficient production. Policy should therefore combine external incentives with capability-building measures, particularly for SMEs facing stronger financial and technological constraints.

Cai and Li (2018) demonstrate that technological capabilities, environmental organizational capabilities, competitive pressure, green customer demand and market-based policy instruments can stimulate eco-innovation, which then improves environmental performance and indirectly supports economic outcomes. El-Kassar and Singh (2019) complement this perspective by showing that green innovation generates stronger organizational performance when supported by big-data capabilities, managerial commitment and appropriate human-resource practices. Singh et al. (2020) further emphasize the human foundations of environmental transformation by demonstrating that green transformational leadership and green human-resource management create conditions favorable to innovation and improved environmental performance. Cep-tureanu et al. (2020) add that eco-innovation capability in manufacturing SMEs depends on strategy, internal structures, operations and organizational routines rather than on isolated technological investments. Together, these contributions imply that sustainable production requires complementary organizational assets around environmental technology. Firms are more likely to obtain durable environmental and economic benefits when leadership, employee competencies, data systems and operating routines reinforce innovation. Green transformation should therefore be embedded within corporate strategy and management systems instead of being confined to separate environmental projects.

Mubarak et al. (2021) show that Industry 4.0 technologies and open innovation can strengthen green-innovation performance by combining digital capabilities with external knowledge exchange. El-Kassar and Singh (2019) similarly demonstrate that data capabilities can support environmental innovation when accompanied by managerial commitment and appropriate organizational practices. Bossle et al. (2016) add that strategic orientation and organizational learning determine whether firms transform external sustainability pressures into persistent innovation activities, while Cai and Li (2018) show that competitive and customer pressures can reinforce these internal capabilities. Considered jointly, these contributions suggest that digital transformation can become an important enabling infrastructure for sustainable production, but digital technologies alone do not guarantee environmental improvement. Their contribution depends on how firms use information, collaboration and managerial capabilities to identify resource-efficiency opportunities and redesign products and processes. Eco-innovation strategies should therefore connect digitalization with open knowledge networks, employee capabilities and explicit environmental objectives so that technological modernization supports measurable improvements in production sustainability.

2.2. Green Innovation, Competitiveness and Corporate Performance

Weng et al. (2015) show that stakeholder pressures from governments and competitors, together with employee conduct, can stimulate green-innovation practices that improve both environmental and organizational performance. Doran and Ryan (2016) refine this perspective by demonstrating that demand, supply and regulatory pressures affect different forms of environmental innovation differently and that economic gains are not uniform across innovation types. Tang et al. (2018) further distinguish green product and process innovation and show that managerial environmental concern conditions some of their performance effects, emphasizing the importance of how managers interpret and implement environmental objectives. Dangelico

(2016) adds that successful green-product innovation requires environmental considerations to be incorporated from early design stages rather than through corrective modifications after production decisions have already been made. Taken together, these contributions indicate that stakeholder pressure can initiate environmental change, but the resulting performance depends on innovation type, managerial commitment and integration with product-development processes. Sustainable production strategies should therefore move beyond reactive compliance and incorporate environmental objectives into design, investment and operational decision-making so that external pressures are transformed into durable organizational capabilities.

Hojnik et al. (2018) demonstrate that internationalization can strengthen firm performance partly through eco-innovation because exposure to foreign markets increases access to environmental knowledge, customer requirements and new competitive opportunities. Huang and Li (2017) reinforce this relational perspective by showing that knowledge integration and stakeholder relationships support the development of green products and processes and can subsequently strengthen organizational performance. Guo et al. (2019) further show that Chinese SMEs can overcome some internal resource constraints through external technical and market knowledge acquisition, with environmental innovation mediating part of the resulting performance gains. Fernando et al. (2019) add that environmental innovation can generate stronger sustainable business outcomes when firms complement technological products with service capabilities that help customers derive value from greener solutions. Together, these contributions imply that green innovation increasingly depends on knowledge flows extending beyond organizational boundaries. International markets, suppliers, customers and technical partners can provide resources that firms do not possess internally. Sustainable production should therefore be supported by collaborative networks and external knowledge acquisition that connect environmental innovation with commercially viable products and services.

Kunapatarawong and Martínez-Ros (2016) broaden the green-innovation debate by showing that environmental innovation also has employment consequences, indicating that cleaner production can reshape workforce requirements as well as environmental and financial outcomes. Doran and Ryan (2016) similarly caution that different eco-innovation types generate heterogeneous performance effects, making generalized assumptions about automatic competitiveness gains inappropriate. Weng et al. (2015) nevertheless demonstrate that well-implemented green innovation can simultaneously improve environmental and firm performance when stakeholder pressures and internal organizational behavior reinforce one another. Guo et al. (2019) add that smaller firms can improve their environmental and economic performance by converting externally acquired knowledge into green innovation. Considered jointly, these contributions suggest that the economic effects of sustainable production are multidimensional and context dependent. Green innovation can strengthen competitiveness and environmental performance, but it may also alter employment structures, skills requirements and organizational routines. Firms and policymakers should therefore evaluate eco-innovation through a broader performance framework encompassing environmental outcomes, productivity, market opportunities and workforce adaptation rather than focusing exclusively on short-term financial returns.

2.3. Environmental Regulation, Knowledge and the Green Transition

Yuan and Xiang (2018) show that environmental regulation can promote green development in manufacturing through innovation, although the effectiveness of this mechanism depends on regulatory design and industrial conditions. Ramanathan et al. (2017) reinforce this interpretation by demonstrating that regulatory pressure may stimulate innovation without producing uniform performance effects, since technological resources, managerial responses and imple-

mentation strategies shape firms' capacity to transform compliance requirements into competitive improvements. Rubashkina et al. (2015) similarly challenge the assumption that environmental regulation necessarily undermines industrial competitiveness by showing that innovation responses can partly offset compliance costs in European manufacturing. Fernando and Wah (2017) add evidence from Malaysia that regulatory compliance, market orientation and technological development can jointly improve environmental performance, with regulation operating as an important eco-innovation stimulus. Taken together, these contributions support a conditional version of the Porter hypothesis. Environmental regulation can encourage cleaner production and technological upgrading, but positive results depend on firms' capacity to respond productively. Sustainable industrial policy should therefore combine credible environmental constraints with innovation incentives, market signals and technological support rather than treating regulatory stringency as sufficient on its own.

Cainelli et al. (2015) demonstrate that environmental innovation requires distinctive organizational resources, external relationships and knowledge capabilities because firms must address both technological novelty and environmental externalities. Albort-Morant et al. (2018) reinforce this capability perspective by showing that organizational knowledge and cooperative relationships can strengthen green-innovation performance, highlighting the importance of accessing expertise distributed across organizational boundaries. Shahzad et al. (2020) further show that knowledge creation, sharing and application contribute to environmental performance when they are translated through green innovation and an explicit environmental strategy. Ghisetti and Pontoni (2015) add that policy instruments and R&D investments produce heterogeneous environmental-innovation effects across technological, sectoral and institutional settings. Together, these contributions imply that sustainable production depends on both external policy conditions and firms' internal capacity to absorb, combine and apply environmental knowledge. Conventional R&D resources may therefore be insufficient when organizations lack environmental learning routines or collaborative networks. Public support should promote dedicated green capabilities, knowledge exchange and sector-specific innovation mechanisms capable of translating policy incentives into cleaner products and processes.

Zameer et al. (2020) show that green production can contribute to competitive advantage when cleaner processes are combined with organizational creativity and a credible green brand image, thereby connecting environmental improvement with both internal efficiency and external market positioning. Fernando and Wah (2017) similarly demonstrate that market orientation can reinforce the environmental effects of regulation and technology, suggesting that customer demand can strengthen incentives for cleaner production. Shahzad et al. (2020) add that environmental strategy and green innovation convert organizational knowledge into improved environmental outcomes, while Ramanathan et al. (2017) emphasize that managerial and contextual conditions determine whether environmental regulation ultimately strengthens firm performance. Considered jointly, these contributions indicate that green competitiveness is produced through interaction among regulation, knowledge, innovation and market positioning rather than by any single factor. Firms can obtain stronger economic returns from sustainable production when environmental compliance is transformed into distinctive capabilities and credible customer value. Green industrial policy should therefore encourage organizations to integrate regulatory response, knowledge management, technological innovation and market strategy within a coherent long-term approach to environmental competitiveness.

3. Sustainable Production Systems: Manufacturing, Industry 4.0 and Sustainable Supply Chains

3.1. Sustainable Manufacturing and Industry 4.0

Moldavska and Welo (2017) show that sustainable manufacturing should be understood as an integrated objective combining economic, environmental and social performance across the product life cycle rather than as a narrow measure of production efficiency. Stock and Seliger (2016) connect this broader conception with Industry 4.0 by showing that digital technologies can improve resource efficiency, equipment utilization, lifecycle information and material recovery when they are deliberately oriented toward sustainability objectives. Ghobakhloo (2020) reinforces this perspective by arguing that digitization can support energy management, production flexibility and new business models, while rejecting the assumption that technological modernization automatically produces sustainable outcomes. Machado et al. (2020) similarly call for stronger integration between sustainable-manufacturing and Industry 4.0 research because digital capabilities influence sustainability through the way production systems are designed and managed. Taken together, these contributions indicate that digital transformation and green transformation should not be treated as independent processes. Smart manufacturing contributes to sustainability when technological investments are embedded within lifecycle thinking, resource-productivity objectives and organizational strategies that explicitly connect digital capabilities with environmental and social performance.

De Sousa Jabbour et al. (2018) demonstrate that Industry 4.0 can reinforce environmentally sustainable manufacturing only when advanced technologies are supported by environmental-management capabilities, managerial commitment and employee competencies. Kamble et al. (2018) broaden this organizational perspective by linking smart manufacturing with economic, environmental and social sustainability while emphasizing governance, workforce adaptation and performance measurement as important implementation conditions. Yavuz et al. (2023) provide empirical support by showing that sustainable operations practices mediate the relationship between Industry 4.0 technologies and sustainable performance, indicating that technology generates benefits largely through organizational routines. Bai et al. (2020) further demonstrate that different digital technologies have distinct sustainability implications and should therefore be selected according to multiple performance criteria rather than assumed to provide equivalent benefits. Together, these contributions imply that digital investment alone is insufficient for sustainable-production transformation. Firms require management systems, employee capabilities and operational practices capable of translating technological functionality into measurable sustainability improvements. Technology selection should therefore be coordinated with organizational readiness and explicit sustainable-operations objectives.

Bonilla et al. (2018) caution that Industry 4.0 can generate rebound effects, additional energy consumption and electronic waste even while improving efficiency and production optimization. Bai et al. (2020) reinforce this need for differentiated assessment by showing that digital technologies vary substantially in their environmental, economic and social consequences. Moldavska and Welo (2017) provide the wider evaluative foundation by emphasizing that sustainable manufacturing requires attention to long-term system performance and multiple stakeholder interests rather than isolated technical indicators. Yavuz et al. (2023) further demonstrate that sustainable performance improves when digital technologies are mediated through explicit sustainable operations practices. Considered jointly, these contributions suggest that the sustainability of smart manufacturing depends on how both the benefits and the resource costs of digitalization are managed. Firms should therefore evaluate digital technologies across their life cycles, including energy requirements, equipment turnover and electronic waste. In-

dustry 4.0 can support sustainable production most effectively when efficiency gains are accompanied by organizational practices that prevent rebound effects and align technological modernization with broader environmental and social objectives.

3.2. Green and Sustainable Supply-Chain Systems

Fahimnia et al. (2015) show that green supply-chain management extends environmental responsibility beyond individual manufacturing facilities toward purchasing, suppliers, logistics, reverse flows and performance assessment across the network. Rajeev et al. (2017) reinforce this value-chain perspective by documenting the expansion of sustainable supply-chain research from predominantly environmental concerns toward broader economic and social dimensions. Ahi and Searcy (2015) add that this broader scope requires multidimensional performance systems capable of measuring emissions, resource use, costs, operational outcomes and social effects rather than relying on isolated environmental indicators. Geng et al. (2017) provide cumulative empirical support by showing that green supply-chain practices in Asian emerging economies are associated with improvements in environmental, operational, economic and social performance, although contextual factors moderate several relationships. Taken together, these contributions indicate that sustainable production should be evaluated across interconnected supply networks rather than within firm boundaries alone. Environmental improvements at one stage may simply shift pressures elsewhere when suppliers, logistics providers and downstream actors are excluded. Firms therefore need integrated performance systems capable of assessing whether supply-chain interventions generate balanced sustainability gains across multiple organizational and geographic stages.

Silvestre (2015) demonstrates that sustainable supply-chain trajectories in emerging economies are shaped by institutional voids, environmental turbulence and rapid economic change, making direct transplantation of practices from mature economies inappropriate. Koberg and Longoni (2019) complement this perspective by showing that lead firms in global supply chains rely on governance mechanisms, standards, collaboration and supplier relationships to extend sustainability requirements across geographically dispersed networks. Touboulic and Walker (2015) further emphasize that such processes cannot be understood solely through operational optimization because power, institutional pressure, stakeholder relationships and long-term organizational change also shape supply-chain behavior. Dubey et al. (2017) add that enduring sustainability requires organizational capabilities capable of embedding environmental and social objectives in procurement, production, logistics and stakeholder coordination. Together, these contributions imply that sustainable supply-chain governance is strongly context dependent. In emerging economies especially, firms may need to combine standards with supplier development, capability building and adaptive governance. Sustainability therefore depends not only on imposing requirements but also on creating institutional and relational conditions that enable suppliers to meet them under heterogeneous economic and regulatory environments.

Khan et al. (2021) show that sustainable supply-chain research increasingly connects environmental performance with digitalization, resilience, circularity and broader operational outcomes, reflecting a shift toward more integrated production systems. Geng et al. (2017) reinforce this development by demonstrating that green supply-chain practices can generate multiple dimensions of performance simultaneously, while also showing that industry, certification, export orientation and firm characteristics influence the magnitude of these effects. Koberg and Longoni (2019) add that governance and supplier collaboration are essential for translating sustainability objectives across complex global networks, and Ahi and Searcy (2015) emphasize that appropriate metrics are needed to determine whether these interventions actually improve system-wide performance. Considered jointly, these contributions suggest that the future of

sustainable production lies in combining technological modernization with supply-chain coordination and multidimensional measurement. Digital tools can improve visibility and traceability, but their value depends on governance mechanisms that translate information into supplier and operational change. Firms should therefore integrate sustainability metrics, collaborative governance and technological capabilities within a coherent supply-chain strategy rather than treating them as separate management initiatives.

3.3. Integrated Sustainable Supply Chains, Circular Production and Performance

Touil et al. (2023) show that green-supply-chain adoption among Moroccan SMEs is encouraged by economic and energy-efficiency considerations, stakeholder pressure and supportive governmental incentives, demonstrating that environmental practices become more attractive when ecological and managerial objectives converge. Esfahbodi et al. (2017) reinforce this perspective by showing that governance pressures stimulate sustainable-supply-chain practices, although financial benefits vary according to the specific intervention adopted. Sahoo and Vijayvargy (2021) further demonstrate that internal environmental management, green purchasing, customer cooperation, eco-design and investment recovery generate stronger sustainability outcomes when implemented as coordinated practices rather than isolated initiatives. Feng et al. (2018) add that green supply-chain management can improve financial performance indirectly through environmental and operational improvements. Taken together, these contributions suggest that sustainable supply-chain practices create economic value through intermediate organizational mechanisms rather than through automatic direct returns. Firms should therefore assess green supply-chain transformation through interconnected environmental, operational and financial outcomes while building policy and stakeholder conditions that strengthen the incentives for sustained adoption.

Nascimento et al. (2019) demonstrate that Industry 4.0 technologies can be integrated with circular-economy principles through reverse logistics, digital connectivity and additive manufacturing to support the recovery and reuse of industrial materials. Mastos et al. (2020) provide an operational counterpart by showing that Internet-of-Things technologies and digital tracking can improve scrap-metal management and strengthen the traceability of material flows within supply chains. Luthra and Mangla (2018) nevertheless show that implementing Industry 4.0 for supply-chain sustainability in emerging economies faces significant organizational, technological, strategic, legal and ethical barriers, with organizational constraints particularly influential. Touil et al. (2024) complement this implementation perspective by showing that sustainability-oriented supply-chain quality management can improve financial performance through better coordination and reduced transaction-related inefficiencies among Moroccan firms. Together, these contributions indicate that digital technologies can strengthen circular and sustainable supply chains when they are embedded within appropriate organizational and interorganizational systems. Digitalization therefore becomes environmentally meaningful when information, traceability and automation are translated into improved material recovery, quality management and coordination rather than being pursued as technological modernization alone. Touil et al. (2024) demonstrate that integrating sustainability with supply-chain quality management can create financial benefits, suggesting that environmental coordination need not remain separate from firms' conventional performance objectives. Feng et al. (2018) help explain this relationship by showing that environmental and operational improvements mediate the financial effects of green supply-chain management, indicating that profitability may emerge progressively through improved processes rather than immediately after adoption. Luthra and Mangla (2018) add that organizational capabilities, skills and strategic commitment are necessary for digital technologies to support sustainable supply chains in emerging-economy contexts. Nascimento et al. (2019) further show how digital technologies can contribute directly to

circular production by enabling material recirculation and reverse flows. Considered jointly, these contributions imply that the convergence of digitalization, circularity and supply-chain sustainability requires coordinated organizational transformation. Firms in emerging economies should combine technological investment with managerial capabilities, quality systems and collaborative supply-chain practices so that environmental improvements become embedded in routine operations and generate durable economic as well as sustainability benefits.

4. Discussion

The reviewed contributions first demonstrate that circular economy should be interpreted as a systemic production transformation rather than as a simple extension of recycling practices. Geissdoerfer et al. (2017) distinguish circularity from sustainability by emphasizing that resource loops represent only one component of broader environmental and social objectives, while Kirchherr et al. (2017) identify considerable conceptual fragmentation in existing definitions. Murray et al. (2017) similarly underline the interdisciplinary character of circular economy while questioning its comparatively weak treatment of social considerations. These conceptual concerns are reinforced by Korhonen et al. (2018), who point to thermodynamic limits, rebound effects and system-boundary problems that can restrict the environmental benefits of circular strategies. At the organizational level, Bocken et al. (2016) and Geissdoerfer et al. (2020) show that circular transition requires alignment between product design, value propositions, resource-retention strategies and revenue mechanisms. Lüdeke-Freund et al. (2019) further demonstrate that firms can select among several circular business-model patterns rather than follow a single trajectory. Consequently, circularity appears to generate stronger sustainability outcomes when material-retention mechanisms are incorporated into coherent business and production systems. This also explains why Saidani et al. (2019) and Moraga et al. (2019) emphasize multidimensional indicators capable of distinguishing material circulation from broader sustainability performance.

A second result concerns the role of green innovation as an organizational and institutional mechanism connecting environmental objectives with competitive and operational performance. Hojnik and Ruzzier (2016) show that eco-innovation is influenced simultaneously by regulatory pressure, market demand, environmental management and firm characteristics, while Bossle et al. (2016) emphasize the importance of managerial capabilities and strategic orientation in transforming external pressure into sustained innovation. Cai and Li (2018) similarly demonstrate that technological and organizational capabilities can convert competitive and environmental pressures into eco-innovation and improved environmental performance. These findings indicate that external incentives have limited effects when firms lack the internal resources required to respond to them. This interpretation is reinforced by El-Kassar and Singh (2019), Singh et al. (2020) and Mubarak et al. (2021), who associate green innovation with managerial commitment, human-resource practices, data capabilities, digitalization and knowledge exchange. From a performance perspective, Weng et al. (2015) and Tang et al. (2018) show that environmental innovation can improve environmental and organizational outcomes, although the magnitude of these effects depends on innovation type and managerial conditions. Ramanathan et al. (2017) and Rubashkina et al. (2015) likewise suggest that regulation can stimulate innovation without generating uniform competitive effects. Green innovation therefore functions most effectively when regulatory incentives, knowledge resources, managerial capabilities and market orientation evolve together.

The third major finding concerns the progressive convergence of circularity, green innovation, digitalization and sustainable supply-chain management. Stock and Seliger (2016), Ghobakhloo (2020) and Machado et al. (2020) indicate that Industry 4.0 can improve resource productivity,

lifecycle information and production flexibility when digital transformation is explicitly connected with sustainability objectives. However, Bonilla et al. (2018) caution that digitalization may also increase energy consumption, equipment turnover and electronic waste, demonstrating that technological modernization requires lifecycle evaluation. At the supply-chain level, Fahimnia et al. (2015), Rajeev et al. (2017) and Geng et al. (2017) show that sustainability increasingly extends across procurement, suppliers, logistics, production and reverse flows. This network perspective is particularly relevant in emerging economies, where Silvestre (2015) highlights institutional constraints and contextual uncertainty. The findings of Touil et al. (2023) are consistent with this interpretation by showing that green-supply-chain adoption among Moroccan SMEs is associated with economic and energy-efficiency motivations, stakeholder pressure and government incentives. Touil et al. (2024) further connect sustainability-oriented supply-chain quality management with financial performance. Together with Nascimento et al. (2019) and Luthra and Mangla (2018), these contributions suggest that digital technologies contribute to sustainable and circular production only when they are supported by organizational capabilities, coordinated supply-chain governance and appropriate institutional conditions.

Conclusion

This paper has examined the complementary roles of circular economy, green innovation and sustainable production systems in the transformation of contemporary production. The literature indicates that circular economy provides an important framework for reducing dependence on virgin resources, extending product lifetimes and retaining the economic value of materials and components. Nevertheless, circularity cannot be evaluated independently from its wider sustainability consequences. Recycling rates, recycled content or material recirculation provide only partial evidence of environmental improvement when energy consumption, rebound effects, emissions and social outcomes are excluded. Circular production therefore requires coherent business models, appropriate product design, reverse logistics and multidimensional performance measurement. Green innovation strengthens this transition by enabling firms to redesign products, processes and organizational practices in response to environmental pressures. Its effectiveness, however, depends on organizational capabilities, managerial commitment, knowledge systems, employee competencies and supportive institutional conditions. The evidence reviewed in the paper consequently supports an integrated interpretation of sustainable production in which technological change, organizational transformation and environmental governance operate jointly. Firms seeking long-term sustainability improvements should therefore avoid treating circularity and green innovation as independent environmental initiatives and instead incorporate them into broader production and competitive strategies. The convergence between sustainable manufacturing, Industry 4.0 and sustainable supply-chain management further extends this integrated perspective beyond organizational boundaries. Digital technologies can increase visibility, improve resource allocation, facilitate traceability and support reverse material flows, but these benefits remain conditional on the organizational systems through which technology is implemented. Sustainable operations practices, employee capabilities, quality-management systems and collaborative supplier relationships determine whether digital investments translate into measurable environmental and economic improvements. The reviewed literature also demonstrates that emerging-economy conditions deserve particular attention because institutional capacity, infrastructure, financing constraints and stakeholder relationships can influence the adoption and effectiveness of sustainable practices. Evidence from Moroccan firms reinforces the importance of combining stakeholder pressure, economic incentives, energy efficiency and supply-chain coordination when encouraging greener production systems. Future research should consequently devote greater attention to

the combined effects of circular business models, eco-innovation, digitalization and supply-chain governance rather than examining these dimensions separately. Greater use of lifecycle measures and multidimensional performance indicators would also improve understanding of whether technological and organizational transformations generate genuine reductions in environmental pressure. Sustainable production should ultimately be assessed according to its capacity to reconcile resource efficiency, environmental performance, organizational viability and long-term value creation throughout interconnected production and supply systems.

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