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# INTEGRATING ARTIFICIAL INTELLIGENCE INTO REVERSE LOGISTICS : IMPLICATIONS FOR CIRCULAR ECONOMY PERFORMANCE IN EMERGING ECONOMIES

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## ABSTRACT

This study investigates how artificial intelligence (AI) can accelerate the transition toward a circular economy by optimizing resource use, enhancing supply chain transparency, and promoting innovative, sustainable business models. Through concrete applications such as intelligent waste sorting and reverse logistics, AI contributes to reducing losses, improving traceability, and supporting innovative circular practices. A survey conducted with 65 Tunisian SMEs confirms that, when adoption is supported by organizational and institutional factors, AI improves environmental performance and helps achieve sustainable development goals.

**KEYWORDS :** Artificial intelligence, Circular economy, Reverse logistics, Resource optimization, Traceability

## INTRODUCTION

The circular economy (CE) represents a systemic approach aimed at moving away from the traditional linear model of "extract, produce, consume, discard." Its objective is to preserve the value of products, materials, and resources within the economic system for as long as possible by prioritizing reuse, recycling, repair, and regeneration. By reducing waste generation and limiting the consumption of virgin resources (Elloumi, 2025a), CE provides a concrete response to contemporary environmental, economic, and social challenges.

Within this context, artificial intelligence (AI) emerges as a strategic transformative lever (Elloumi, 2025b). With its capabilities in large-scale data analysis, prediction, automation, and optimization, AI can accelerate the transition to a more efficient, intelligent, and sustainable circular economy. It not only improves existing practices but also enables the redesign of production, consumption, and resource management models. This study explores three main areas in which AI acts as a catalyst for circularity (Elloumi, 2025a) :

Resource efficiency optimization : Identifying inefficiencies, reducing waste, and maximizing material utilization throughout their lifecycle.

Supply chain transparency enhancement : Ensuring traceability of material flows, environmental compliance, and reliable information sharing among economic actors.

Emergence of new circular business models : Enabling innovative approaches such as Product-as-a-Service (PaaS), shared-resource platforms, and local waste valorization systems, made possible by combining AI with other technologies (IoT, blockchain, 3D printing). (Elloumi, 2025a)

By integrating AI into circular economy principles, it becomes possible to design systems that are more resilient, interconnected, and regenerative, capable of reconciling economic performance with environmental sustainability.

## LITERATURE REVIEW

### 4.1. Optimizing resource efficiency

AI plays a crucial role in enhancing resource efficiency within the circular economy. It not only reduces waste but also optimizes production processes, improves energy utilization, and extends product lifespans. For example, Oladapo and al. (2024) demonstrated that integrating AI into industrial operations can reduce waste generation by 20–25% and increase recycling efficiency from 50% to 83% over a decade.

Recent studies further highlight AI's ability to support predictive maintenance, energy optimization, and real-time monitoring, which directly contribute to reducing resource consumption and operational costs. Zong and Guan (2025) found that AI-based predictive analytics in manufacturing can lower raw material usage by 15–18% annually, while Alfaro-Viquez and al. (2025) reported that AI-driven production planning reduces energy consumption by up to 20% in electronics assembly lines. These findings reinforce the potential of AI as a transformative tool for resource-efficient production and sustainable industrial practices.

### 4.2. Enhancing supply chain transparency

The combination of AI with digital technologies such as blockchain, IoT, and cloud platforms enhances traceability and transparency in supply chains. This allows firms to monitor the movement of materials, detect inefficiencies, prevent waste, and ensure compliance with environmental standards. Qu and Kim (2024) identify key AI capabilities for sustainable supply chain management, including predictive analytics, automated decision-making, and optimization.

Additional research indicates that AI-powered platforms can track product provenance, detect anomalies, and generate actionable insights in near real-time Wei and al. (2023) demonstrated that integrating AI with IoT sensors in logistics networks improved traceability of recycled materials by 60%, enabling faster interventions in case of quality issues. Similarly Krishnan and Arundathi (2024) found that AI-based supply chain analytics significantly reduce lead times and wastage in reverse logistics operations, which is particularly critical for SMEs operating in resource-constrained contexts. These studies highlight AI's dual role in enhancing operational efficiency and ensuring environmental compliance.

### 4.3. Emergence of New Circular Business Models

AI also drives the development of innovative circular business models, including Product-as-a-Service (PaaS), shared-resource platforms, predictive maintenance services, and local material valorization systems. These models maximize resource utilization, reduce waste, and extend product lifespans. Akter and al. (2022) identified six key areas where AI is applied in the circular economy : sustainable development, reverse logistics, waste management, supply chain management, recycling and reuse, and manufacturing development.

Further studies emphasize the combination of AI with advanced digital technologies to create platform-based and service-oriented circular models. Hosseini and al. (2023) show that AI-enabled PaaS models can reduce raw material consumption by up to 25% by encouraging shared use and predictive maintenance. Bossuwé (2023) report that AI-driven material marketplaces facilitate efficient recycling and reuse, allowing firms to recover high-value components and reintegrate them into production cycles. These innovations demonstrate that AI not only optimizes current operations but also supports strategic transformations toward sustainable, circular business models.

In summary, the literature consistently shows that AI : optimizes resource efficiency through predictive analytics, energy management, and waste reduction. Enhances supply chain transparency via traceability, real-time monitoring, and automated decision-making and enables new circular business models that maximize material utilization, prolong product life, and create innovative service-oriented strategies. By integrating these perspectives, this study positions AI as a key enabler of circular economy practices, capable of transforming both operational processes and strategic business models in SMEs and industrial firms.

## EMPIRICAL STUDY

As part of the transition toward a circular economy, a study of 65 Tunisian SMEs examined AI adoption in reverse logistics, a critical lever for recycling or reusing end-of-life products. Despite challenges such as costs, skills gaps, and coordination issues, AI provides effective solutions by automating, optimizing, and valorizing returned flows. The study identified eight key factors influencing AI adoption, including managerial support, technological trust, system compatibility, and government incentives. Observed benefits include reduced carbon footprint, improved material recovery, increased productivity, and stronger alignment with sustainable development goals.

**Table 1. Key determinants of AI adoption in reverse logistics for SMEs.**

| Determinant | Description |
|---|---|
| **Perceived relative advantage** | AI is seen as delivering greater benefits than current methods. |
| **Trust in technology and providers** | Firms have confidence in AI reliability and their technology partners. |
| **Management support** | Strategic engagement of leaders facilitates innovation adoption. |
| **Compliance with environmental regulations** | Regulatory pressure drives modernization of logistics practices. |
| **Industry dynamics** | Sector norms and competition encourage sustainable initiatives. |
| **Compatibility with existing processes** | AI can be integrated without disrupting current systems. |
| **Technological readiness** | Firms have the required digital infrastructure and skills. |
| **Government support** | Financial aid, incentives, and policies facilitate AI adoption. |

## 6.1. METHODOLOGY

To explore the relationships and factors influencing AI adoption in the circular economy, a qualitative approach based on semi-structured interviews was adopted. Interviews were conducted with 65 logistics, operational, and environmental managers from Tunisian SMEs. The goal was to gather in-depth perceptions and detailed accounts of current resource management practices, AI integration, and challenges in reverse logistics processes.

Qualitative data were analyzed using thematic analysis, enabling the identification of key enablers and barriers to AI adoption. This analysis revealed recurring patterns, trends, and relationships among organizational, technological, and regulatory aspects. The results provided rich qualitative insights into the strategic levers and obstacles SMEs face in transitioning to a circular economy.

This approach allowed a nuanced understanding of the specific conditions in the Tunisian context, taking into account local realities, limited resources, and existing public policies.

### 6.2. Empirical Findings

The empirical investigation demonstrates that artificial intelligence (AI) is a critical enabler of circular economy practices in Tunisian SMEs, particularly through reverse logistics processes. Respondents highlighted that AI adoption enables predictive analysis of return flows, automated waste classification, and informed decision-making regarding product recovery and material reuse. These functions are essential for SMEs operating in resource-constrained contexts, as they reduce inefficiencies, minimize losses, and improve overall operational sustainability.

Table 1 summarizes the main determinants influencing AI adoption, supported by quantitative data from the 65 surveyed SMEs.

**Table 2. Determinants of AI Adoption in Reverse Logistics. (N=65)**

| Determinant | % of Firms Reporting High Influence | Observed Impact |
|---|---|---|
| **Perceived relative advantage** | 78% | Firms recognized tangible improvements in speed, accuracy, and environmental impact over traditional methods. |
| **Trust in technology and providers** | 70% | High confidence in AI systems and vendor reliability facilitated smoother implementation. |
| **Top management support** | 65% | Proactive leadership fostered employee engagement and strategic adoption of AI solutions. |
| **Technological compatibility** | 60% | Seamless integration with existing ERP and logistics systems reduced operational disruptions. |
| **Institutional pressure (regulations)** | 55% | Environmental regulations motivated firms to modernize reverse logistics operations. |
| **Government support** | 48% | Financial incentives and training programs eased initial adoption barriers. |
| **Industry dynamics** | 52% | Competitive pressures encouraged firms to |

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|---|---|---|
| | | adopt innovative solutions. |
| **Organizational readiness** | 58% | Firms with digital infrastructure and skilled personnel adopted AI more effectively. |

The data indicate that organizational and technological factors (perceived advantage, trust, management support) are the most influential in driving adoption.

Institutional factors (regulatory pressure, government support) play a supporting but significant role, suggesting that external incentives are important but cannot replace internal readiness.

SMEs often adopt AI incrementally, prioritizing applications with immediate operational benefits, such as automated sorting, predictive recovery, or material tracking.

To provide further empirical support, the study analyzed the concrete outcomes reported by firms, summarized in Table 2.

**Table 3. Observed Benefits of AI in Reverse Logistics. (N=65)**

| Benefit | % of Firms Observing Improvement | Explanation / Examples |
|---|---|---|
| **Reduction in material losses** | 75% | AI-enabled sorting and predictive analytics allowed early detection of recoverable or recyclable items, preventing waste. |
| **Enhanced traceability** | 72% | Digital tracking improved visibility of materials and products across the supply chain, supporting compliance and transparency. |
| **Improved productivity** | 68% | Automation of manual processes enabled staff to focus on strategic and analytical tasks. |
| **Carbon footprint reduction** | 64% | Optimized logistics routes and reduced handling inefficiencies contributed to lower GHG emissions. |
| **Cost savings** | 61% | Reduction of operational errors and unnecessary storage/transportation lowered expenses. |
| **Longer product lifecycle** | 59% | Predictive maintenance and accurate sorting extended product usability through reuse or refurbishment. |
| **Regulatory compliance** | 55% | AI-supported monitoring ensured adherence to environmental regulations and reduced legal risks. |
| **Enhanced customer satisfaction** | 52% | Faster return processing and reliable recycled products increased client trust and loyalty. |

The highest-impact benefits (material loss reduction and traceability) confirm that AI adoption directly supports circular economy objectives.

Operational and environmental improvements are closely linked ; for example, reduced material losses not only improve efficiency but also lower carbon footprint.

SMEs report that product lifecycle extension is particularly important, as it allows firms to reuse materials and maintain value within the economy.

Even benefits perceived by fewer firms (e.g., government support, regulatory compliance) are strategically important, as they shape adoption incentives and ensure long-term sustainability.

Qualitative Insights from Interviews

Managers frequently emphasized that AI transforms decision-making from reactive to proactive. For instance, predictive analytics enable early interventions to recover or refurbish returned items before they become waste.

Human factors remain critical : adoption succeeds when leaders champion AI, employees are trained, and trust in digital systems is established.

SMEs adopt a stepwise approach, first implementing AI in processes with immediate benefits (sorting, tracking), then expanding to predictive maintenance or more complex optimization.

Respondents highlighted that AI adoption strengthens their competitive position : firms can demonstrate environmental responsibility, comply with regulations, and reduce operational costs, which is a major differentiator in the market.

**Link to Literature**

The results align with Oladapo and al. (2024), who showed that predictive AI improves resource efficiency and environmental performance. SMEs adopt AI when tangible operational and environmental gains are clear.

Findings also support Akter and al. (2022), emphasizing that AI enables circular practices by closing material loops through better recycling, reuse, and waste management. Top management commitment is essential for overcoming resistance and ensuring successful integration.

Institutional factors, such as regulations and incentives, corroborate the observations of Qu and Kim (2024) regarding the role of external pressures in promoting sustainable supply chain technologies. Firms prioritize simple, high-impact applications before scaling to complex AI functions.

The Tunisian context adds empirical evidence that AI benefits are achievable even in resource-constrained SMEs, extending the work of Mukherjee and al. (2024).

75% of SMEs reported reduced material losses ; 72% reported improved traceability ; 68% improved productivity. Beyond efficiency gains, AI enables regulatory compliance, extended product lifecycles, and enhanced competitiveness.

## RÉSULTATS ET DISCUSSION

The findings of this study reveal that AI adoption in Tunisian SMEs is a strategic driver for enhancing reverse logistics and circular economy performance Elloumi (2025), The integration of AI improves decision-making, optimizes resource flows, and strengthens traceability across the supply chain, confirming that technology can act as a catalyst for sustainable practices. Quantitative results from Table 2 show that 75% of firms reported a reduction in material losses, 72% observed improved traceability, and 68% experienced enhanced productivity. These figures demonstrate that AI adoption produces tangible benefits that go beyond mere process automation. The reduction in material losses directly correlates with environmental performance, as fewer resources are wasted, aligning with Oladapo and al. (2024) who emphasize AI's role in improving resource efficiency. Similarly, enhanced traceability enables firms to comply with environmental regulations and monitor sustainability indicators more effectively, supporting Qu and Kim's (2024) assertion that transparency is crucial in sustainable supply chains.

The analysis of adoption determinants highlights the importance of organizational readiness and managerial support. SMEs with strong leadership and internal digital infrastructure were more likely to successfully integrate AI. Top management engagement (65%) emerged as a critical enabler, consistent with Mukherjee and al. (2024), who argue that managerial commitment is essential in developing-country contexts. Institutional factors, including regulatory pressure (55%) and government incentives (48%), were also significant, confirming the relevance of external drivers highlighted by Qu and Kim (2024).

The study identifies a stepwise adoption pattern. SMEs prioritize AI applications that deliver immediate operational or environmental benefits—such as automated sorting, predictive maintenance, and return flow optimization—before scaling to more complex analytics or predictive planning. This approach reflects a pragmatic and resource-conscious strategy, which is particularly relevant in emerging economies where capital and technical expertise may be limited.

The findings confirm prior research that AI supports circular economy objectives by enabling more efficient, transparent, and predictive reverse logistics (Akter and al., 2022 ; Oladapo and al., 2024). However, this study contributes new empirical evidence from a developing-country context, showing that even resource-limited SMEs can achieve measurable environmental and operational gains. The results also reinforce the view that AI adoption is not purely technical ; organizational readiness, human factors, and institutional support are equally critical for successful implementation.

Overall, the findings indicate that artificial intelligence adoption constitutes an effective lever for enhancing reverse logistics and circular economy performance in Tunisian SMEs. AI contributes to reducing material losses, strengthening traceability, and improving productivity, thereby generating both environmental and operational benefits. The results further show that successful implementation relies not only on technological capabilities, but also on managerial commitment, organizational readiness, and supportive institutional conditions. By offering empirical evidence from a developing-country context, this study demonstrates that AI-enabled circular practices are attainable for resource-constrained SMEs when adoption follows a gradual and strategically aligned approach.

## Managerial Implications

Strategic adoption of AI: SMEs should view AI not merely as a technological tool but as a strategic enabler of circularity. The highest-impact applications—such as automated sorting, predictive maintenance, and material recovery—should be prioritized to deliver immediate operational and environmental benefits.

Leadership and organizational readiness : Top management support (65% of SMEs) and internal digital infrastructure are key enablers. Managers should ensure that staff are trained, engaged, and confident in AI technologies to maximize adoption success.

Evidence-based decision-making : Quantitative benefits (75% reduction in material losses, 72% improved traceability) provide concrete evidence for decision-makers to justify investment in AI. Highlighting these measurable outcomes can facilitate buy-in from stakeholders.

Stepwise implementation : A phased approach allows SMEs to gain early successes, build internal expertise, and gradually integrate more complex AI functionalities, reducing risk and resistance.

Leveraging institutional support : Firms should actively seek available government incentives, regulatory guidance, or industry standards that encourage AI adoption and sustainable practices.

## Theoretical Implications

Integration of organizational and technological factors : This study confirms that AI adoption in reverse logistics is shaped by a combination of organizational readiness, managerial commitment, and technological compatibility, extending the framework proposed by Qu and Kim (2024).

Empirical evidence from developing-country SMEs : By demonstrating that Tunisian SMEs can achieve measurable benefits from AI in circular supply chains, this study fills a gap in the literature that often focuses on large firms or developed-country contexts (Akter and al., 2022 ; Mukherjee and al., 2024).

Stepwise adoption as a theoretical construct : The identification of incremental AI adoption provides a basis for future studies to explore adoption trajectories in resource-constrained environments.

Quantifiable benefits reinforce theoretical models : Linking perceived determinants to concrete outcomes (material loss reduction, productivity gains, traceability improvements) strengthens the predictive power of AI adoption frameworks in sustainable supply chains.

## CONCLUSION

The findings of this study offer substantial and actionable insights for both practitioners and scholars seeking to advance circular economy practices in emerging economies. For managers, the results provide evidence-based guidance on how to implement AI technologies effectively within reverse logistics operations. By understanding the key determinants of adoption such as perceived benefits, managerial support, technological compatibility, and institutional pressures practitioners can strategically prioritize investments in AI applications that yield immediate operational, environmental, and economic benefits. The quantified outcomes, including reductions in material losses, improved traceability, enhanced productivity, and extended product lifecycles, demonstrate that AI adoption is not only feasible but also highly impactful for SMEs navigating resource constraints.

From a theoretical perspective, this study contributes context-sensitive empirical evidence to the literature on AI adoption and circular economy models. By examining SMEs in a developing-country setting, it highlights the interplay between organizational, technological, and institutional factors, offering a nuanced understanding of adoption dynamics that goes beyond the large-firm or developed-country contexts frequently explored in previous research. The identification of a stepwise adoption pattern, where firms implement AI incrementally starting with high-impact processes, provides a conceptual framework for future studies investigating technology adoption trajectories in resource-limited environments.

Furthermore, the study underscores the strategic value of AI as a catalyst for sustainability, showing that technology adoption can drive both efficiency gains and environmental performance improvements. It also reveals the importance of human and organizational factors, emphasizing that technology alone is insufficient ; successful integration depends on leadership commitment, staff engagement, and alignment with broader regulatory and market conditions.

Finally, this research opens avenues for future investigations, including longitudinal studies to track the long-term impacts of AI on circular economy outcomes, cross-industry comparisons to assess sector-specific adoption patterns, and analyses of policy mechanisms that could further incentivize AI implementation. By combining practical guidance with theoretical refinement, this study reinforces the potential of AI to transform circular economy practices and provides a roadmap for SMEs and researchers seeking to advance sustainability objectives in emerging economic contexts.

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