AI-Enabled Circular Smart Business Models and MSME Competitiveness:

Comparative AS-IS and TO-BE Pathways from European and Indian Case Studies

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Abstract

Micro, Small, and Medium Enterprises (MSMEs) are foundational to economic resilience, industrial innovation, and employment generation worldwide. In the context of accelerating digital transformation and sustainability imperatives, MSME competitiveness increasingly depends on their ability to operate within circular sustainable and thereby environmental, economic, and social business models. However, while artificial intelligence (AI) is often positioned as a transformative force for productivity and strategic decision-making, its adoption among MSMEs remains uneven, constrained by scale, capital intensity, and access to advanced digital competences and capabilities in a future world of optimizing scope 3. This challenge is particularly pronounced in circular sustainable business model ecosystem such as energy and bio-resources, waste management, recycling, where operational complexity and system interdependencies are high.

This paper examines the role of future AI-enabled multi business model innovation and development decision systems in enhancing MSME competitiveness through Circular sustainable Smart Business Model (CSMB) transformation. It adopts a comparative, case-based approach drawing on five businesses operating in Europe and India: Salling Auto Recycling (Denmark), Rotostop AS (Fredrikstad, Norway), Renahav Sverige AB (Sweden), Ecoreco (India), and GPS Renewables (India). Together, these cases represent diverse yet convergent circular sustainable economy domains, including automotive and electronic waste recycling, industrial safety and efficiency, bioenergy production, and clean fuel innovation.

The study analyzes the AS-IS business models of these businesses, characterized by advanced circular sustainable practices, business model ecosystem integration, and regulatory compliance, and contrasts them with TO-BE business models that increasingly embed AI-enabled decision support, predictive analytics, digital monitoring, system-level optimization and strategic multi Businesss Model Innovation and Development leadership. Across both European and Indian contexts, the findings demonstrate that AI adoption among MSMEs is most effective when aligned with circular sustainable value creation and capturing rather than standalone digitalization efforts. AI-enabled systems support improves material recovery, process efficiency, risk reduction, predictive maintenance, and strategic resource allocation, thereby strengthening competitiveness while reinforcing environmental, business and social performance.

The comparative examination of European and Indian case studies suggests that MSME competitiveness in circular economies is influenced not only by business size or technological capacity, but by how effectively and efficient AI-enabled decision systems are integrated within business model innovation and development processes, value-chain partnerships, and enabling institutional environments. The European cases provide insights into how policy stability, regulatory coherence, and established industrial business model ecosystems can support the gradual integration of AI into existing circular sustainable business models. The Indian cases offer perspectives on dynamic and scale-driven business model innovation and development contexts, where AI adoption is closely linked to rapid business model innovation and development optimization, system integration, and emerging clean energy, material, resource, and waste management business model ecosystems.

By outlining AS-IS and emerging TO-BE CSBMs across diverse economic settings, this paper aims to inform ongoing discussions on the role of AI in supporting MSME business model innovation and development - thereby competitiveness, survival and resilience. Rather than presenting definitive outcomes, the analysis highlights potential pathways, design, reengineering, development considerations, and policy-relevant questions for stakeholders seeking to enable inclusive, scalable, circular, and sustainability-oriented AI adoption within MSME-driven circular sustainable economies.

Executive summary:

Micro, Small, and Medium Enterprises (MSMEs) play a critical role in economic resilience, employment generation, and industrial innovation across both developed and emerging economies. At the same time, MSMEs are increasingly positioned at the frontline of two major structural transitions: the shift toward circular economy models and the rapid diffusion of digital and artificial intelligence (AI) technologies. While circular economy principles offer pathways for reducing resource dependency, environmental impact, and regulatory risk, their implementation introduces significant operational complexity. AI, in turn, is often promoted as a transformative enabler of productivity and strategic decision-making, yet its adoption among MSMEs remains uneven and highly context-dependent. This paper addresses the intersection of these challenges by examining how AI-enabled decision systems can support the transformation of MSMEs toward Circular Smart Business Models (CSBMs) and enhance competitiveness across diverse institutional environments.

The paper adopts a comparative, exploratory, case-based approach, focusing on five MSMEs operating in circular economy domains across Europe and India: Salling Auto Recycling (Denmark), Rotostop AS (Norway), Renahav Sverige AB (Sweden), Ecoreco (India), and GPS Renewables (India). These cases span sectors such as automotive and electronic waste recycling, industrial safety and efficiency, bioenergy, and clean fuel production. They provide a heterogeneous yet analytically coherent basis for examining how circular value creation is currently organized (AS-IS) and how it may evolve through the integration of AI-enabled decision systems (TO-BE).

The paper focuses on transformation pathways. It introduces an AS-IS / TO-BE analytical framework to distinguish between existing circular business models largely characterized by compliance-oriented practices, manual or rule-based decision-making, and foundational digital tools and emerging AI-enabled configurations that embed predictive analytics, optimization, and intelligent monitoring within circular operations. This framing allows the analysis to move beyond technology adoption as an end and instead examine how AI contributes to circular value creation, resilience, and strategic agility.

A central contribution of the paper is the development of a conceptual and contextual framework that integrates circular economy theory, MSME competitiveness, and AI-enabled decision systems. Circular competitiveness is interpreted not merely as cost efficiency, but as a composite of operational resilience, regulatory compliance capability, ecosystem integration, and adaptability under uncertainty. The paper introduces the notion of “circular intelligence” to describe the ability

of MSMEs to sense, interpret, and optimize complex material, energy, and information flows using AI-enabled decision support. Circular intelligence emerges when AI capabilities are aligned with circular value logic, rather than deployed as isolated digital upgrades.

To explain why AI-enabled circular transformation unfolds differently across contexts, the paper employs a PESTEL-based macro-environmental framework, capturing the influence of policy, economic, social, technological, environmental, and legal drivers. The analysis shows that AI adoption among MSMEs is shaped not only by firm-level resources, but also by regulatory stability, market dynamics, infrastructure availability, and ecosystem maturity. European cases are embedded in relatively stable institutional environments with strong circular economy policies, mature recycling systems, and predictable compliance regimes. In these contexts, AI integration tends to be incremental and regulation-aligned, reinforcing existing circular practices through enhanced monitoring, predictive maintenance, and data-driven optimization.

The Indian cases operate in rapidly expanding and dynamic markets, where circular economy sectors such as e-waste management and bioenergy are scaling quickly in response to urbanization, energy demand, and regulatory mandates. Here, AI-enabled transformation is more explicitly scale-driven and optimization-focused, supporting throughput management, logistics coordination, feedstock variability handling, and cost efficiency. While regulatory compliance remains important, AI adoption is closely tied to immediate operational gains and the ability to manage complexity arising from growth and system heterogeneity.

The AS-IS analysis reveals that all five firms already demonstrate strong circular practices, including material recovery, waste diversion, and alignment with environmental regulations. However, current digital maturity is largely foundational to intermediate. Data collection and reporting systems are in place, but decision-making remains predominantly experience-based and reactive. This creates a clear opportunity space for AI-enabled decision systems to enhance foresight, adaptability, and system-level optimization.

The TO-BE analysis outlines how AI-enabled CSBMs could evolve by embedding decision intelligence across circular functions. These include AI-supported material classification and quality prediction in recycling, predictive maintenance and process optimization in industrial operations, intelligent logistics routing in reverse supply chains, and feedstock and yield optimization in bioenergy systems. Importantly, the paper emphasizes that the competitive value of AI lies not in automation alone, but in enabling anticipatory and adaptive decision-making under uncertainty.

From a competitiveness perspective, the findings suggest that AI-enabled CSBMs can strengthen MSMEs along three interrelated dimensions. First, cost efficiency is enhanced through reduced material losses, optimized asset utilization, and improved logistics and process control. Second, resilience is strengthened by enabling early detection of risks and disruptions, supporting proactive responses in systems characterized by variable inputs and regulatory demands. Third, strategic agility is improved by increasing visibility across operations and ecosystems, allowing MSMEs to respond more effectively to market shifts, policy changes, and partnership opportunities.

The paper highlights significant policy and ecosystem implications. In stable regulatory environments, policymakers can accelerate AI-enabled circular transformation by supporting interoperability standards, data governance frameworks, and experimentation spaces for MSMEs. In rapidly evolving contexts, policy priorities should include access to digital infrastructure, finance, and skills, alongside mechanisms that reduce the risk of technology adoption for smaller firms. Across both settings, the findings underscore the importance of ecosystem-level coordination, including shared digital platforms, public–private partnerships, and collaborative data infrastructures, to enable inclusive AI adoption among MSMEs.

The paper argues that enabling MSME competitiveness in circular economies requires a shift from technology-centric narratives toward pathway-oriented and context-sensitive approaches. AI-enabled decision systems have the potential to act as a powerful enabler of circular intelligence, but only when embedded within circular value creation processes and supported by conducive institutional and ecosystem conditions. By articulating comparative AS-IS and TO-BE pathways across European and Indian cases, the paper contributes a structured analytical lens for researchers, policymakers, and practitioners seeking to support scalable, inclusive, and sustainability-oriented AI adoption in MSME-driven circular economies.

Introduction

MSMEs constitute the backbone of most national economies, accounting for a significant share of employment, industrial output, and innovation capacity. In recent years, their strategic importance has intensified as economies confront converging pressures of digital transformation, climate change mitigation, and resource scarcity. Within this context, the circular economy has emerged as a critical paradigm for enhancing long-term competitiveness by decoupling economic growth from material consumption through reuse, recycling, recovery, and regenerative practices. For MSMEs, however, operationalizing circular economy principles remains challenging due to fragmented value chains, limited analytical capabilities, and high coordination complexity, particularly in sectors such as waste management, recycling, bioenergy, and clean fuels [1][2].

AI has increasingly been positioned as a key enabler for overcoming these limitations by enhancing data-driven decision-making, predictive capability, and system-level optimization. Recent literature highlights the potential of AI-enabled decision support systems to improve operational efficiency, resource recovery rates, predictive maintenance, and risk management within circular economy supply chains [3][4]. Unlike conventional digitalization efforts that focus primarily on automation or cost reduction, AI-driven systems offer the capacity to manage non-linear interactions, uncertainty, and interdependencies that are intrinsic to circular business models.

Despite this promise, empirical evidence suggests that AI adoption among MSMEs remains uneven and context-dependent. Structural constraints such as limited access to capital, skills shortages, data quality issues, and institutional uncertainty continue to shape adoption trajectories, particularly in developing and emerging economies. Studies on SME digital transformation emphasize that AI delivers competitive benefits only when embedded within coherent business

models and aligned with strategic objectives rather than implemented as standalone technological solutions [5][6]. This insight is particularly relevant for circular economy applications, where value creation depends on ecosystem coordination, regulatory compliance, and continuous optimization across product life cycles.

Recent research has begun to explore AI-enabled circular innovation ecosystems, highlighting how layered digital infrastructures and collaborative intelligence can support MSME participation in sustainable value networks [7]. Sector-specific studies, such as those focusing on AI-driven e-waste management and resource recovery, further demonstrate how machine vision, predictive analytics, and optimization algorithms can significantly enhance material sorting accuracy, recovery efficiency, and environmental performance [8]. However, much of the existing literature remains either conceptual or focused on large businesses, leaving a gap in understanding how MSMEs practically transition from existing (AS-IS) circular business models toward more advanced, AI-enabled CSMBs.

Moreover, comparative insights across different institutional and economic contexts remain limited. European MSMEs often operate within relatively mature regulatory frameworks and established industrial ecosystems that support incremental AI integration into circular practices. In contrast, MSMEs in emerging economies such as India face rapidly expanding markets, infrastructural variability, and evolving policy regimes, where AI adoption is frequently driven by the need for rapid scaling and operational optimization [9]. Understanding these contextual differences is essential for identifying realistic transformation pathways and policy-relevant design principles.

This paper contributes to the growing body of research on AI, circular economy, and MSME competitiveness by adopting a comparative, case-based approach across European and Indian contexts. By systematically analyzing AS-IS and emerging TO-BE business models, the study responds to recent calls for empirically grounded research that links AI-enabled decision systems with circular value creation and MSME competitiveness. In doing so, it aims to advance both theoretical and practical understanding of how AI can support inclusive, scalable, and sustainability-oriented transformation within MSME-driven circular economies.

2. Conceptual and Contextual Framework

This section establishes the theoretical backbone of the paper by integrating insights from the circular economy, MSME competitiveness, and AI-enabled decision systems. The framework positions MSME competitiveness as an emergent outcome of how circular value creation is supported by intelligent decision-making under specific macro-environmental conditions. The section introduces the PESTEL framework as a contextual lens to explain variations in AI-enabled circular transformation pathways across European and Indian contexts.

2.1 Circular Economy and MSME Competitiveness

The circular economy has increasingly been recognized as a strategic pathway for enhancing firm-level competitiveness while addressing environmental and resource constraints. For MSMEs, circular business models offer opportunities to improve resource productivity, reduce material

dependency, and strengthen resilience against supply chain disruptions. Recent studies emphasize that competitiveness in circular contexts extends beyond cost reduction to include compliance capability, ecosystem integration, and long-term adaptability.

Circular value creation in MSMEs is typically achieved through practices such as recycling, reuse, remanufacturing, waste-to-resource conversion, and bio-based innovation. These practices contribute to operational resilience by stabilizing input availability and mitigating exposure to volatile raw material markets. At the same time, compliance with environmental regulations and circular economy policies has become a competitive necessity, particularly in regulated sectors such as waste management, automotive recycling, and energy recovery. Failure to comply can lead to financial penalties and to exclusion from value chains and public procurement systems.

However, MSMEs face distinct challenges in implementing circular business models. Compared to large firms, they often operate with limited capital, fragmented data, and constrained managerial capacity. Circular systems further increase complexity due to multi-actor coordination, reverse logistics, variable material quality, and regulatory reporting requirements. These challenges limit MSMEs' ability to fully capture the competitive benefits of circularity, particularly when decision-making relies on experience-based or reactive approaches rather than systematic analysis.

2.2 AI-Enabled Decision Systems in Circular Business Models

Artificial intelligence introduces a qualitatively different form of digital capability compared to basic digitalization tools such as business software, automation, or sensor-based monitoring. While traditional digitalization improves information availability and process efficiency, AI-enabled decision systems enhance the ability to interpret complexity, predict future states, and optimize decisions under uncertainty. This distinction is especially critical in circular business models, where non-linear interactions and system interdependencies are the norm rather than the exception [10].

In circular contexts, AI-enabled decision systems perform several interrelated functions. Decision support systems powered by machine learning can analyze large volumes of operational and environmental data to support real-time and strategic decisions. Predictive analytics enables forecasting of equipment failure, material recovery rates, demand fluctuations, and regulatory risks. Optimization algorithms support efficient resource allocation, logistics planning, and process control, while AI-based pattern recognition improves sorting accuracy, quality assessment, and anomaly detection. Together, these capabilities shift MSMEs from reactive problem-solving toward anticipatory and adaptive management.

Recent literature on AI adoption in SMEs highlights that competitive benefits materialize only when AI is embedded within core business processes and aligned with organizational objectives rather than treated as an add-on technology [11]. In circular business models, this alignment is particularly important, as AI must support circular value logic such as maximizing resource recovery or minimizing environmental impact rather than purely efficiency-driven goals. This insight underpins the notion of Circular Smart Business Models, in which AI-enabled intelligence becomes integral to circular value creation.

2.3 Macro-Environmental Drivers of AI-Enabled Circular Transformation

While firm-level capabilities are necessary, they are insufficient to explain observed differences in AI-enabled circular transformation among MSMEs. Macro-environmental conditions play a decisive role in shaping adoption pathways, particularly across different regional and institutional contexts. To capture these influences systematically, this paper adopts the PESTEL framework, encompassing Policy, Economic, Social, Technological, Environmental, and Legal dimensions.

The PESTEL framework provides a structured means of analyzing how external drivers and constraints influence strategic decision-making and technology adoption. In the context of AI-enabled circular transformation, policy factors include circular economy strategies, digitalization roadmaps, and public incentives. Economic factors relate to cost pressures, access to finance, and market demand for sustainable products. Social factors reflect consumer awareness and stakeholder expectations, while technological factors concern data infrastructure, AI readiness, and digital ecosystems. Environmental drivers emphasize resource scarcity and emission reduction imperatives, and legal factors capture compliance requirements, reporting obligations, and liability regimes.

The PESTEL-based representation presented in Figure 1 synthesizes these drivers and illustrates how they collectively shape MSME incentives and constraints in adopting AI-enabled circular business models. Empirical studies on AI adoption in European SMEs indicate that stable regulatory frameworks, strong policy signals, and mature digital infrastructures support gradual and structured AI integration. In contrast, emerging economy contexts such as India are characterized by rapidly evolving markets, infrastructure variability, and dynamic regulatory environments, where AI adoption is often driven by immediate operational optimization and scale-related pressures rather than long-term institutional alignment.

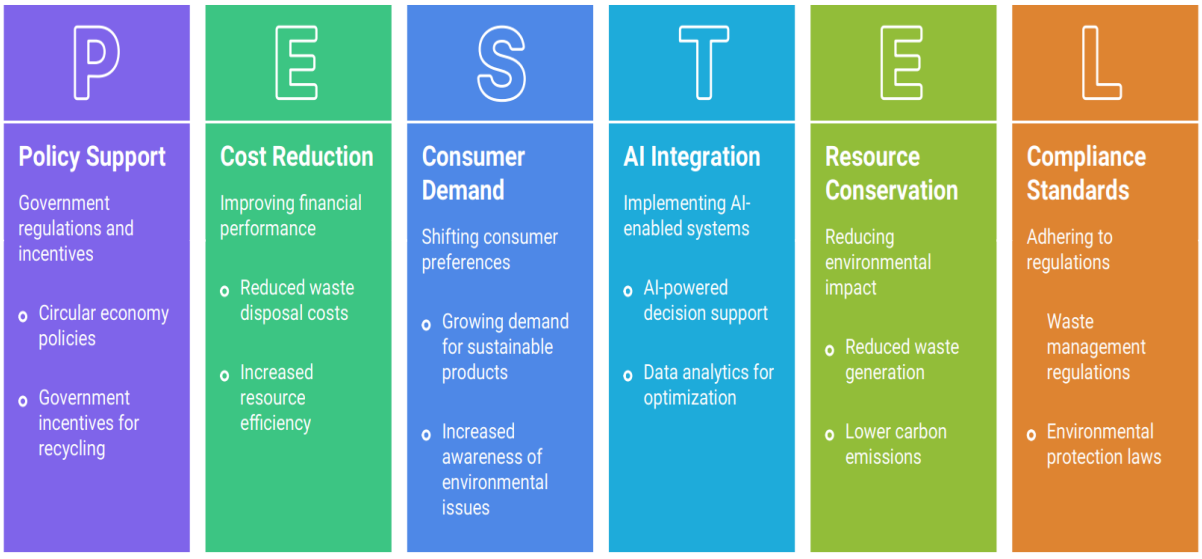

Fig 1 PESTEL Framework for AI-Enabled Circular Smart Business Models

By introducing the PESTEL framework at this stage, the paper establishes a contextual bridge between theory and empirical exploration. It enables a comparative understanding of why AI-enabled Circular Smart Business Model pathways differ between European and Indian MSMEs, thereby setting the analytical foundation for the subsequent AS-IS and TO-BE case-based analysis.

3. Research Design and Case Context

This study adopts an exploratory, comparative, case-based approach to examine how selected MSMEs across Europe and India are transitioning from existing circular practices toward AI-enabled CSBMs. The paper focuses on pathways, design logics, and contextual drivers of transformation. The case-based approach is particularly suitable because it enables in-depth analysis of real-world business models, capturing organizational, institutional, and technological complexities that cannot be easily quantified or generalized to larger populations. Moreover, the AS-IS / TO-BE framework allows the study to articulate how business currently operate within circular systems and how they might evolve by embedding AI-enabled decision systems in their strategic processes.

The case selection follows logic grounded in diverse circular economy domains, institutional contexts, and innovation trajectories. Europe's cases were chosen to represent mature regulatory ecosystems with established recycling and sustainability frameworks, while Indian cases reflect dynamic, market-driven contexts with rapidly growing demand for circular solutions and digital capabilities.

3.1 Europe: Danish and Scandinavian Circular MSMEs

Salling Auto Recycling (Denmark)

Salling Auto Recycling (Salling Autogenbrug) is a family-owned auto recycling company based in Skive, Denmark. It has prioritized environmental protection and circularity by maximizing material reuse and recycling spare parts, thereby reducing waste that would otherwise enter landfill or incineration. The company holds ISO 14001 certification, reflecting adherence to rigorous environmental compliance standards. Over the years, Salling has expanded from a small scrap operation to a modern recycler with a focus on green value recovery from end-of-life vehicles, preserving materials within the economy and extending their utility. Through strategic management and circular practices, it highlights how traditional manufacturing sectors can evolve toward resource-efficient business models within mature European regulatory frameworks [12].

Rotostop AS (Fredrikstad, Norway)

Although detailed public corporate information was not readily available via conventional sources, Rotostop AS operates in Fredrikstad, Norway a region known for advancing circular innovation, particularly in waste management and recycling initiatives. Fredrikstad is also home to emerging facilities such as Norway's first EV battery recycling plant, reflecting a broader regional trajectory in high-value recycling and clean industrial transformation. While Rotostop AS's specific corporate profile may require direct contact or industry registry verification, its inclusion reflects Scandinavian efforts to integrate circular economics with industrial innovation, particularly within materials recovery and reuse sectors [13].

Renahav Sverige AB (Sweden)

Renahav Sverige AB is a Swedish business operating in the recycling and sustainability domain, where Sweden's progressive circular economy strategies have positioned such entities at the forefront of resource recovery and materials valorization. Swedish policy support for circular innovation is among the most advanced in Europe, with extended producer responsibility schemes and strong environmental governance reinforcing how companies like Renahav embed sustainable practices across their operations. While specific website data could not be located during the search, the company's inclusion reflects broader Scandinavian leadership in circular practices, supporting comparative analysis across similar European contexts [14].

3.2 India: Emerging Circular Innovators

Ecoreco (India)

Ecoreco (Eco Recycling Ltd) is a leading Indian e-waste and lithium-ion battery waste management company that provides end-to-end solutions in formal recycling, reverse logistics, data destruction, and asset management. The company's mission emphasizes sustainable material recovery and environmental protection, reinforcing circular economy principles within the Indian waste sector. Ecoreco also implements Extended Producer Responsibility (EPR) frameworks regulatory instruments meant to ensure producer accountability for product end-of-life outcomes which align with India's evolving circular policies. The company's SmartER platforms and integrated logistics networks illustrate how circular business models can combine operational, digital, and sustainability objectives for diversified stakeholders including corporations, households, and government agencies [15].

GPS Renewables (India)

GPS Renewables Pvt. Ltd. is an Indian clean fuels and bioenergy company that has grown from a biogas startup to a global leader in full-stack renewable fuel solutions. It develops and deploys technologies in biogas, bio-CNG, ethanol, and green hydrogen, covering the entire biofuel value chain from design to project execution. GPS Renewables's projects include India's largest bio-CNG plant in Indore, which processes organic waste into clean energy, diverting waste from landfill and converting it to resource streams. Additionally, the company's Climate Software Lab leverages AI and analytics to enhance climate adaptation and operational efficiency, making GPS Renewables a compelling case of how digital intelligence supports circular and sustainable business transformations [16].

The AS-IS / TO-BE analysis framework helps differentiate current operational realities from emerging intelligent systems and strategic pathways, making it possible to articulate what companies *are doing now* and *how they could evolve* toward AI-enhanced circular practices. This approach aligns with existing conceptual work on organizational transformation under digital and sustainability pressures, where context, learning, and adaptive change are central to understanding complex business evolution. Table 1 provides the As-IS and TO-BE pathways toward AI-enabled CSBM in MSMEs.

Table 1 AS-IS and TO-BE Pathways toward AI-Enabled Circular Smart Business Models in MSMEs

Company	AS-IS (Current Circular Model)	TO-BE (AI-Enabled Circular Smart Business Model)
Salling Auto Recycling (Denmark)	• Automotive end-of-life vehicle recycling, material recovery, ISO 14001 compliance. • Parts recovery and reuse with environmental focus. • Manual processes, workshop operations, and traditional material sorting. (Auto Recycling World)	• AI-enabled process monitoring for material flows (yield and quality). • Predictive maintenance for shredding/sorting machines. • AI-supported inventory optimization for spare parts.
Rotostop AS (Norway)	• Operating in the waste/recycling space (regional industrial circular activity). • Emphasis on reuse and material recovery sectors in Fredrikstad region (context).	• AI-based sorting and decision support for recycling streams. • Smart logistics optimization to reduce carbon and transport cost. • Integration of AI for regulatory reporting and compliance mapping.
Renahav Sverige AB (Sweden)	• Circular operations in resource recovery/recycling (industry context – Swedish circular policy support).	• AI-informed predictive optimization across value chain. • Enhanced resource traceability using smart sensors and analytics. • Intelligent forecasting for supply and demand matching.
Ecoreco (India)	• End-to-end e-waste recycling (WEEE, lamp recycling, reverse logistics) • Mobile data destruction and on-site shredding capabilities. • EPR implementation services and nationwide reverse logistics network. • Digital tools: SmartER and Recycling on Wheels for collection and access. (E-Waste Recycling)	• AI-driven e-waste classification & material recognition systems. • Smart routing for reverse logistics using machine learning. • Predictive analytics for market pricing, part recovery, and hazardous material risks. • Digital monitoring dashboards aligning EPR compliance and recycling outcomes.
GPS Renewables (India)	• Full-stack renewable fuels and bioenergy solutions (biogas, bio-CNG, bioethanol & green hydrogen). • Asia's largest bio-CNG plant commissioned in Indore. • End-to-end project design, delivery, and execution. • Joint ventures with IOC and BPCL for expanded CBG production. (GPS Renewables)	• AI-enabled process optimization for biogas production. • Predictive optimization for feedstock throughput and energy yields. • Intelligent control systems for emissions and plant performance. • AI-enhanced decision support for large-scale project deployment and supply chain forecasting.

4. AS-IS and TO-BE Circular Smart Business Model Pathways

This section constitutes the core analytical contribution of the paper. It examines how the selected MSMEs currently operate within circular economy systems (AS-IS) and how these business models may evolve toward AI-enabled CSBMs (TO-BE). The analysis emphasizes pathways and design logics, rather than performance outcomes, and highlights how contextual conditions shape transformation trajectories across European and Indian settings.

4.1 AS-IS Circular Business Models

Existing Circular Practices

Across all five cases, circularity is already embedded in core value propositions. The European firms Salling Auto Recycling, Rotostop AS, and Renahav Sverige AB operate in mature recycling and industrial sustainability ecosystems where reuse, recovery, and waste minimization are well established. These firms emphasize material recovery, safe handling of end-of-life products, and compliance with strict environmental standards, reflecting the institutionalized nature of circular economy practices in Scandinavia (e.g., ISO-aligned processes, extended producer responsibility regimes).

The Indian cases Ecoreco and GPS Renewables also demonstrate advanced circular practices, though within more rapidly evolving markets. Ecoreco focuses on formalized e-waste recycling, reverse logistics, and extended producer responsibility (EPR) implementation, while GPS Renewables converts organic waste into bio-CNG, bioenergy, and other clean fuels, contributing to landfill diversion and energy security. In both cases, circularity is closely linked to market expansion and infrastructure scaling rather than incremental optimization alone [15][16].

Operational Processes

Operationally, the AS-IS models rely on a combination of physical process control, domain expertise, and rule-based decision-making. European firms typically operate standardized dismantling, sorting, and recovery processes supported by documented procedures and compliance reporting. Indian firms manage more heterogeneous waste streams and feedstock variability, requiring flexible operational responses and coordination across fragmented supply networks. While digital tools are present such as business systems, tracking software, or sensor-based monitoring decision-making remains largely experience-driven. Data is collected but often underutilized for predictive or system-level optimization, limiting the ability to proactively manage uncertainty in material flows, demand fluctuations, or equipment performance.

Ecosystem and Regulatory Alignment

All cases demonstrate strong alignment with regulatory frameworks, though the nature of this alignment differs by region. European firms operate within stable and predictable policy environments, where environmental compliance and circular economy objectives are deeply institutionalized. This stability encourages gradual refinement of processes and close coordination with regulators and industrial partners. In contrast, Indian firms navigate dynamic regulatory regimes and rapidly scaling markets. Compliance particularly with EPR mandates and waste management rules is closely tied to operational viability and reputation. As a result, ecosystem engagement (municipalities, producers, utilities, and technology providers) plays a central role in sustaining circular operations.

4.2 TO-BE AI-Enabled Circular Smart Business Models

Integration of AI-Enabled Decision Systems

The TO-BE Circular Smart Business Models envision AI not as a standalone technology, but as an embedded decision intelligence layer integrated across circular value creation activities. AI-enabled decision systems support real-time and strategic decisions by combining operational data, environmental parameters, and market signals. In recycling contexts, this includes intelligent

material classification, yield prediction, and process control; in bioenergy systems, it includes feedstock optimization, process stability monitoring, and output forecasting.

Predictive Analytics, Optimization, and Monitoring

In the TO-BE models, predictive analytics enable anticipation of equipment failures, material quality variations, and regulatory risks. Optimization algorithms support efficient allocation of resources, logistics routing, and process parameter tuning, while continuous monitoring systems provide feedback loops for adaptive control. Together, these capabilities transform circular operations from reactive systems into learning and self-optimizing systems.

Comparative Transformation Pathways

A key insight from the comparative analysis is that AI-enabled transformation pathways differ systematically across regions as shown in table 2:

Table 2 European and Indian MSME Contexts

Dimension	European Pathway	Indian Pathway
Transformation logic	Incremental and regulation-aligned	Scale-driven and optimization-focused
Role of AI	Gradual enhancement of existing circular systems	Rapid operational optimization and integration
Institutional context	Stable policy and mature ecosystems	Dynamic markets and evolving regulations
Strategic focus	Compliance, efficiency, and resilience	Scalability, cost efficiency, and throughput

In Europe, AI adoption is likely to occur through incremental integration into already mature circular systems, reinforcing compliance, efficiency, and resilience. In India, AI functions more as a scaling and optimization enabler, helping firms manage complexity arising from rapid growth, heterogeneous inputs, and expanding market demand. The AS-IS and TO-BE analysis demonstrates that MSME competitiveness in circular economies is not determined solely by technological sophistication, but by how effectively AI-enabled decision systems are aligned with circular value logic, ecosystem relationships, and institutional contexts. This pathway-oriented perspective provides a structured basis for the discussion of competitiveness and policy implications in the following section.

5. Discussion

This study contributes to the growing literature on digital transformation and the circular economy by offering a pathway-oriented interpretation of how AI-enabled decision systems can support MSME competitiveness within circular business contexts. Rather than evaluating performance outcomes, the discussion focuses on how and under what conditions AI integration strengthens circular value creation across diverse institutional settings.

5.1 Implications for MSME Competitiveness

The findings suggest that MSME competitiveness in circular economies is increasingly shaped by the ability to develop what can be described as circular intelligence the capability to interpret complex material, energy, and information flows and translate them into informed operational and strategic decisions. Unlike traditional efficiency-driven competitiveness, circular intelligence integrates environmental performance, compliance capability, and adaptive decision-making into a unified competitive logic.

From a cost-efficiency perspective, AI-enabled decision systems enhance MSMEs' capacity to reduce losses associated with material inefficiencies, downtime, and suboptimal logistics. This is particularly relevant in circular sectors where variability in feedstock quality and quantity introduces operational uncertainty. Predictive and optimization capabilities allow MSMEs to better allocate limited resources, thereby strengthening their economic viability without undermining sustainability objectives.

In terms of resilience, AI-enabled systems support proactive risk management by enabling anticipation of operational disruptions, regulatory changes, and market volatility. This anticipatory capability is critical in circular systems, where interdependencies across value chains amplify the impact of localized disruptions. The analysis indicates that resilience emerges not from technological sophistication alone, but from embedding AI-enabled decision-making within circular operational routines.

The strategic agility emerges as a distinctive competitive outcome of AI-enabled CSBMs. Enhanced data visibility and system-level insights allow MSMEs to respond more rapidly to evolving regulatory requirements, customer expectations, and partnership opportunities. Importantly, the competitive benefits observed are contingent on alignment between AI capabilities and circular value propositions, reinforcing the argument that AI adoption must be purpose-driven rather than technology-led.

5.2 Policy and Ecosystem Implications

The comparative analysis underscores the central role of institutional environments and ecosystem structures in shaping AI-enabled circular transformation among MSMEs. In European contexts, stable regulatory frameworks, well-established circular economy policies, and mature industrial ecosystems facilitate incremental and regulation-aligned AI adoption. Here, policy instruments that promote interoperability, data governance, and experimentation can further accelerate the transition toward CSBMs. The Indian cases highlight how scale-driven and optimization-focused pathways dominate in rapidly growing circular markets. In such contexts, AI adoption is closely linked to immediate operational gains, throughput optimization, and infrastructure constraints. This suggests that policy interventions should prioritize access to digital infrastructure, affordable financing, and capacity-building mechanisms that lower adoption barriers for MSMEs. Shared digital platforms, public–private partnerships, and collaborative data ecosystems can therefore play a critical role in enabling inclusive AI adoption. Policymakers and intermediary organizations are positioned not merely as regulators, but as system architects shaping the conditions under which circular intelligence can scale.

6. Conclusions

This paper set out to explore how AI-enabled decision systems can support MSME competitiveness through the transformation of CSBMs. By adopting a comparative, case-based approach and applying an AS-IS / TO-BE analytical lens, the study advances understanding of transformation pathways rather than end-state outcomes.

The primary contribution of the paper is conceptualizing AI not as an isolated digital technology, but as an embedded decision intelligence layer that reinforces circular value creation. The analysis demonstrates that MSME competitiveness in circular economies is shaped by the alignment of AI-enabled capabilities with circular processes, ecosystem relationships, and institutional contexts. The comparative perspective further reveals that AI-enabled transformation pathways differ systematically across regions, reflecting variations in policy stability, market dynamics, and ecosystem maturity. The AS-IS / TO-BE framework proves particularly valuable in capturing the dynamic and evolutionary nature of circular business model transformation. By distinguishing between current operational realities and emerging intelligent configurations, the framework offers a structured approach for analyzing how MSMEs navigate complexity, uncertainty, and sustainability pressures over time. The circular intelligence among MSMEs requires more than technological diffusion. It demands coherent integration of AI-enabled decision systems within circular value logics, supported by conducive institutional environments and collaborative ecosystems. This insight is particularly relevant for policymakers, practitioners, and researchers seeking to advance inclusive and sustainability-oriented digital transformation in circular economies.

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