RESEARCH ARTICLE

The Circular Transformation: How Intrapreneurship and Innovation Ecosystems Reshape Enterprises

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Abstract

The transition to a Circular Economy (CE) offers a vital pathway for traditional enterprises seeking to meet rising sustainability demands. In practice, many enterprises navigate this transition through hybrid models, blending circular initiatives with existing linear structures as part of an incremental evolution. Organizational complexity further shapes this progression, making internal innovation and strategic collaboration essential. This study explores how environmental awareness, intrapreneurship, and innovation ecosystems enable CE adoption within established firms. A decision tree analysis of 200 survey responses from professionals and master's students engaged in corporate work-study programs in France reveals that employee-driven innovation is the strongest predictor of CE engagement. Focusing on traditional enterprises, where structural inertia is greater than in startups, our findings show that aligning internal capabilities with external collaboration is critical to advancing circular practices. The study offers actionable insights for business leaders and policymakers aiming to foster sustainable economic transformation.

Keywords:

JEL Codes:

Introduction

The transition to a Circular Economy (CE) is reshaping how enterprises address sustainability and innovation. Growing public awareness, stricter regulations, and evolving consumer expectations are pressuring businesses to adopt more sustainable practices (Melati et al., 2021). Startups often attract attention for their agility in exploiting circular opportunities, leveraging flexibility and innovative capacity to quickly adapt to CE-driven

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market gaps to meet the demand for sustainable solutions (Geissdoerfer et al., 2020; Henry et al., 2020; Kirchherr et al., 2023; Van Opstal & Borms, 2023).

Traditional enterprises, although equally critical to systemic change, navigate a different dynamic transition. As established organizations with deeply embedded linear processes, they must contend with entrenched operational practices, infrastructure investments, and organizational resistance to change, all of which constrain their capacity for rapid innovation toward CE (Bocken et al., 2016; Kirchherr et al., 2023; Truong et al., 2024; Zucchella & Urban, 2020). In response, many of these traditional enterprises adopt hybrid models, blending circular initiatives with existing linear structures as part of a gradual and pragmatic transition process (Awan & Sroufe, 2022; Zaccone et al., 2022). This hybridization reflects the necessary adaptation to the structural, cultural, and operational realities of established enterprises.

Therefore, this study focuses on understanding the transformation processes within traditional enterprises as they progressively adopt Circular Economy principles. From the traditional business model toward the hybrid/circular business model a question remains: *How do traditional enterprises, with their structural complexities and established practices, embark on and manage the complex journey toward adopting CE principles?*

Addressing this question requires recognizing that the transition toward Circular Economy practices depends on a variety of enablers operating at different levels.

Policy frameworks and market dynamics are widely recognized as key enablers as they play fundamental roles in enabling the transition toward a Circular Economy (CE). Policy provides the regulatory and financial frameworks necessary to drive circular practices. The European Union (EU), through initiatives such as the Circular Economy Action Plan (CEAP) and the Circular Economy Package, has established strategies aimed at decoupling economic growth from resource use and reducing environmental impact (Brinsi, 2024; Peyravi et al., 2024). Moreover, policy efforts promoting knowledge transfer and collaboration among stakeholders are crucial for building trust and fostering innovation, as reflected in EU research and innovation frameworks advancing circular economy initiatives (Brandão & Santos, 2024).

Similarly, market forces significantly influence the adoption of CE practices. Rising consumer demand for sustainable products creates market pull effects that encourage businesses to prioritize circularity (Kumar et al., 2025). Entrepreneurs and small and medium-sized enterprises (SMEs), often at the forefront of sustainable innovation, contribute by introducing new products, services, and business models aligned with CE principles. However, market barriers such as inadequate infrastructure and high initial investment costs persist, underscoring the complementary role of public support measures like grants and subsidies in fostering circular innovations (Ren & Albrecht, 2023).

While policy and market dynamics are widely recognized as critical enablers of circular transformation, this study focuses on another essential but comparatively less examined dimension: the role of internal organizational drivers and collaborative structures as enablers for CE transition. Specifically, we investigate how environmental awareness, intrapreneurship, and innovation ecosystems interact to facilitate CE adoption within traditional enterprises. By examining these internal and network-based enablers, the study addresses a gap in understanding the organizational mechanisms that underpin progressive circular transitions.

Intrapreneurship, defined as employee-driven innovation within an organization, offers a key mechanism for fostering circular transformation (Batista-Canino et al., 2025). Employees motivated by growing environmental awareness can initiate innovative projects that challenge entrenched norms and align with CE principles. What often begins as small-scale initiatives has the potential to evolve into transformative strategies, particularly when supported by leadership commitment, resource allocation, and a culture of experimentation (Buratti et al., 2023).

To scale and operationalize these intrapreneurial efforts, enterprises increasingly rely on innovation ecosystems. These ecosystems provide the collaborative infrastructure necessary to share resources, exchange knowledge, and co-create solutions, bridging the gap between individual initiatives and systemic change (Adner, 2017; Andriamanantena, 2024; Andriamanantena et al., 2022). Although innovation ecosystems often originate from entrepreneurial networks, they evolve into complex structures capable of driving large-scale sustainability innovation (Asgari & Asgari, 2023). For traditional enterprises, they are crucial for embedding

CE practices into business models and addressing challenges that demand interdisciplinary and cross-sectoral collaboration.

To investigate the selected enablers of CE adoption in traditional enterprises, we analyze data from 200 survey respondents in France, including employees, managers, business owners (CEOs), and master's students specializing in innovation management and entrepreneurship. These students were selected because they are engaged in work-study programs within established enterprises involved in CE transition initiatives. Although oriented toward future entrepreneurial careers, their current roles embed them directly in traditional firms, providing practical insights into intrapreneurial initiatives, sustainability strategies, and organizational innovation dynamics.

The unit of analysis for this study is therefore the enterprise specifically, traditional firms engaged in progressive circular transformation viewed through the perspectives of individuals, actively participating in their operational or innovation processes. The findings contribute to the literature by demonstrating that CE adoption in traditional enterprises follows a hierarchical transformation, where employee-driven initiatives, formalized sustainability practices, and innovation ecosystems interact to facilitate sustainable transitions.

The article is structured as follows: first, it presents an overview of the type of enablers and the conceptual framework that interlinks environmental awareness, intrapreneurship, innovation ecosystems, and CE adoption. This is followed by a detailed methodology section, outlining the data collection process, decision tree analysis, and key analytical approaches used in this research. The subsequent sections present the empirical results and a comprehensive discussion, leading to practical recommendations for fostering sustainable innovation within traditional enterprises.

Literature review

Enablers of Circular Economy

The transition toward a Circular Economy (CE) is increasingly supported by the identification of various enablers that facilitate the shift from traditional linear production and consumption systems to more sustainable and circular models. Based on a review of recent literature (e.g. Sharma et al., 2023; Supanut et al., 2024; Mishra et al., 2024; de Vasconcelos Gomes et al., 2024), we identify six main categories of enablers: technological, organizational, financial, regulatory and policy, ecosystem and stakeholder, and cultural and social factors. Each of these enablers plays a crucial role in advancing CE practices. However, despite the growing interest in the literature, several challenges and gaps persist in understanding how these enablers interact and contribute to the broader CE transition.

Cultural and Social Enablers

The role of organizational culture and social norms in supporting CE adoption is becoming increasingly recognized. Organizational culture is a key enabler of circular economy practices because it shapes how sustainability is perceived and acted upon within the firm (Ababio & Lu, 2023; Supanut et al., 2024). Similarly, social norms and community expectations often influence an enterprise's commitment to sustainability, driving them to align with societal values regarding resource conservation and waste reduction (de Vasconcelos Gomes et al., 2024). Community support also plays a crucial role in the CE transition, as local communities can provide the social legitimacy required for businesses to implement circular practices successfully (Rizos et al., 2016). Despite growing recognition of these cultural factors, limited research has been conducted on how specific cultural shifts, such as environmental awareness, influence organizational behaviors in the circular economy context.

Technological Enablers

Technological innovations are widely recognized as pivotal to the successful implementation of CE strategies. The adoption of digital technologies, such as Artificial Intelligence (AI), the Internet of Things (IoT), and

blockchain, enables enterprises to optimize resource usage, improve supply chain management, and monitor material flows in circular systems (Santolin et al., 2023; Väisänen et al., 2019). Scholars have long emphasized the importance of technological solutions such as eco-design and reverse logistics in closing the loop in production processes (Lacy et al., 2020; Sharma et al., 2024). However, much of the early research has focused on individual technological solutions without sufficiently integrating how technological adoption interacts with organizational capabilities, employee engagement, and cross-functional collaboration (Rejeb et al., 2022).

Organizational Enablers

Internal organizational factors, such as leadership commitment and employee engagement, are essential for the successful transition to CE practices. Strong leadership is important in setting a clear sustainability vision and ensuring that circular economy initiatives are prioritized and resourced within the organization (Supanut et al., 2024). Additionally, fostering a culture of employee engagement through training programs and incentives ensures that employees at all levels contribute to the adoption of circular economy practices (Supanut et al., 2024). Organizational enablers also include adopting circular supply chain management practices, which are necessary for ensuring the efficient use of resources across the value chain (Soleimani et al., 2023). However, while much research has highlighted leadership and employee engagement, fewer studies have explored the interplay between intrapreneurship (employees acting as internal innovators) and organizational transformation in the CE context.

Financial Enablers

Financial support mechanisms are vital for overcoming the economic barriers that SMEs (Small and Medium Enterprises) face when transitioning to circular economy practices. Government subsidies, grants, green financing (such as green bonds), and innovative financing mechanisms provide enterprises with the necessary capital to invest in circular technologies and processes (Mishra et al., 2024; Sharma et al., 2024). Financial enablers also include cost savings derived from circular practices, such as waste reduction and resource efficiency, which help businesses justify their initial investments in sustainability (Supanut et al., 2024). However, although financial incentives are widely recognized as essential, there is still limited research on how financial enablers interact with technological and organizational enablers in supporting CE adoption.

Regulatory and Policy Enablers

Policy frameworks and regulations are equally important in creating a supportive environment for CE adoption. Government policies promoting sustainability, such as recycling regulations, waste reduction targets, and tax incentives, incentivize businesses to adopt circular practices. In the construction sector for example, regulatory support is necessary to encourage reuse, recycling, and waste reduction (Alotaibi et al., 2024; Zhao et al., 2025). While early research has focused on external regulatory pressures, recent studies indicate that the role of policies in shaping organizational behavior, especially in the context of small enterprises, remains underexplored.

Ecosystem and Stakeholder Enablers

The transition to a circular economy requires collaboration across a variety of stakeholders, including suppliers, customers, research institutions, governments, and non-governmental organizations. The development of innovation ecosystems enables the exchange of knowledge, resources, and expertise, which accelerates the implementation of circular solutions (Alka et al., 2024; Andriamanantena et al., 2022). Ecosystem enablers also include industrial symbiosis, where different industries collaborate by exchanging by-products, energy, and materials, creating a mutually beneficial system that reduces waste (de Vasconcelos Gomes et al., 2024; Seles et al., 2022). While these collaborations are essential for scaling circular economy initiatives, research has largely focused on isolated case studies of successful partnerships without fully exploring how these ecosystems can be systematically supported or expanded.

Table 1 A Comprehensive Overview of the Main Categories of Circular Economy Enablers

Enabler Category	Sub-categories	Description	Key References
Cultural & Social Enablers	- Organizational Culture - Social Norms - Community Support	Cultural and social factors, such as organizational sustainability culture and community engagement, play a key role in supporting circular practices.	(Ababio & Lu, 2023; Supanut et al., 2024 ; de Vasconcelos Gomes et al., 2024 ; Rizos et al., 2016)
Technological Enablers	- Digital Technologies - Blockchain Technology - Disruptive Technologies	Technologies such as AI, IoT, and blockchain enable the optimization of resources, transparency in circular practices, and efficiency.	(Santolin et al., 2023; Väisänen et al., 2019 ; Lacy et al., 2020; Sharma et al., 2024 ; Rejeb et al., 2022).
Organizational Enablers	- Leadership Commitment - Employee Engagement - Circular Supply Chain Management	Internal organizational factors such as leadership vision, employee involvement, and efficient supply chain practices are crucial for adopting circular practices.	Supanut et al., 2024; Soleimani, 2023
Financial Enablers	- Financial Support - Green Financing - Cost Savings	Financial resources, such as government grants, green bonds, and cost savings from resource efficiency, support the transition.	Sharma et al., 2023; Supanut et al., 2024; Mishra et al., 2024
Regulatory & Policy Enablers	- Government Policies - Tax Incentives - Extended Producer Responsibility (EPR)	Policies and regulations that create an enabling environment for circular practices, such as incentives and recycling regulations.	(Alotaibi et al., 2024; Zhao et al., 2025)
Ecosystem & Stakeholder Enablers	- Collaboration & Partnerships - Industrial Symbiosis - Stakeholder Alignment	Successful circular economy adoption requires collaboration and resource sharing with stakeholders, including suppliers and customers.	(Alka et al., 2024; Andriamanantena et al., 2022 ; de Vasconcelos Gomes et al., 2024; Seles et al., 2022)

Source: Authors

While the literature covers various enablers of Circular Economy (CE) adoption, the interaction between organizational mechanisms and social dynamics remains underexplored. This study addresses this gap by focusing on three key enablers: environmental awareness, intrapreneurship, and innovation ecosystems. These enablers bridge the gap between internal organizational behavior and external collaboration, offering a comprehensive perspective on CE adoption. Environmental awareness fosters sustainable behavior, intrapreneurship drives innovation, and innovation ecosystems facilitate the scaling of circular solutions, together creating a robust framework for understanding the CE transition.

Framework for Circular Economy Transition: Environmental Awareness, Intrapreneurship and Innovation Ecosystems as Enablers of Circular Economy

This literature review has examined the importance of enablers for adoption of CE within enterprises. While prior studies have explored these enablers individually, the intersection of environmental awareness, intrapreneurship, innovation ecosystems, and CE remains underexplored. This study aims to bridge this gap by demonstrating how these interconnected mechanisms drive sustainable transformation.

Environmental Awareness as the Foundation

Environmental awareness plays a central role in driving sustainability, influencing both individual behaviors and organizational strategies. By increasing awareness of environmental issues, individuals are more likely to engage in pro-environmental decision-making, embrace responsible consumption, and adopt circular business models that minimize waste and optimize resource use (Godinho Filho et al., 2024; Wardani et al., 2025). This awareness, rooted in education and exposure to sustainability concepts, not only enhances consumer knowledge but also encourages sustainable purchasing behaviors, fostering trust in products aligned with Circular Economy (CE) principles. As a result, environmentally conscious consumers play a pivotal role in creating demand for sustainable goods and services (Vieira et al., 2024; Yang et al., 2024).

On the organizational side, environmental awareness drives employees to recognize sustainability challenges and motivates them to seek innovative solutions, which is critical for transitioning to more sustainable operations (Järvenpää, 2017). This process, known as intrapreneurship, allows individuals within the organization to translate their environmental concerns into actionable, circular economy-driven solutions. By fostering a culture of sustainability and empowering employees to act on their ideas, organizations can develop sustainable business models, eco-friendly products, and resource-efficient processes, positioning themselves to meet evolving environmental demands (Hernández-Perlines et al., 2022). Furthermore, environmental awareness at the organizational level catalyzes broader changes, guiding companies toward adopting circular practices, optimizing material flows, and contributing to systemic change. In this way, environmental awareness serves as both a foundational driver of individual behaviors and a key enabler for organizational transformation toward sustainability.

Intrapreneurship as a Mechanism for Change

Building upon environmental awareness, intrapreneurship serves as a crucial mechanism for translating sustainability values into concrete, actionable innovations within organizations. Employees who internalize environmental principles may become the driving force behind eco-innovations, which include the development of sustainable business models focused on reducing waste and improving resource efficiency (Hernández-Perlines et al., 2022). These employees, motivated by environmental consciousness, frequently take the initiative to propose new processes, products, and services that contribute to a more sustainable future. Intrapreneurial behaviors such as proactivity, risk-taking, and creativity empower individuals to actively address environmental challenges while allowing organizations to remain competitive and agile in the face of evolving market demands (Deprez, 2024; Patil et al., 2022).

Intrapreneurship thrives on employee autonomy and organizational support, enabling employees to experiment with innovative solutions without the constraints of rigid structures. Organizations that foster a culture of innovation by empowering their workforce to explore novel ideas create an environment that encourages proactive problem-solving and continuous improvement. This freedom to innovate allows companies to adapt to changing environmental regulations and market expectations, ensuring long-term competitiveness (Hernández-Perlines et al., 2022; Järvenpää, 2017). Moreover, intrapreneurship encourages organizations to design new solutions and business strategies that help them navigate environmental and sustainability challenges (Blazejewski et al., 2014).

Intrapreneurship also integrates sustainability into organizational strategies, influencing key areas such as operations, marketing, and decision-making. It enables firms to enhance their product offerings by introducing eco-friendly products and services that resonate with environmentally conscious consumers (Hartati et al., 2024). Additionally, intrapreneurship plays a key role in building organizational resilience, as companies that encourage such behaviors are better positioned to respond to disruptions and capitalize on sustainability-driven opportunities (Bayar, 2023; Nuryati et al., 2024). By fostering intrapreneurial thinking, businesses can drive innovation, enhance their sustainability goals, and achieve long-term growth (Etim, 2024; Rahmaningtyas et al., 2023).

Innovation Ecosystems as Enablers

While intrapreneurial efforts drive internal innovation, external collaboration within innovation ecosystems is essential for scaling eco-innovations and accelerating CE adoption. An innovation ecosystem is a network of diverse actors including enterprises, research organizations, financial institutions, and regulatory bodies working together to co-create value and foster innovation (Andriamanantena et al., 2022). These ecosystems align stakeholders around shared projects, integrating knowledge, resources, and expertise to address sustainability challenges and drive CE transformation. As noted by Carayannis and Campbell (2009), innovation ecosystems are systems of collaboration and competition (coopetition), where actors pursue synergies while maintaining individual objectives, thus fostering systemic change. Moreover, ecosystems enable businesses to leverage external expertise and technologies, such as AI and IoT, which can significantly enhance CE implementation (Truant et al., 2024). By facilitating partnerships and resource-sharing, ecosystems create the conditions for broad-scale CE adoption, encouraging industries such as manufacturing, energy, and agriculture to adapt circular business models (Granstrand & Holgersson, 2020; Takacs et al., 2020).

Innovation ecosystems facilitate CE adoption by integrating stakeholders, business models, and resources into cohesive frameworks. Enterprises incorporate circularity principles into their strategies, while regulatory bodies establish enabling policies, and research institutions provide sustainable solutions. For example, in Dunkirk, France, industrial symbiosis has emerged through ecosystem collaboration, where companies exchange waste and by-products, reducing resource consumption (Andriamanantena et al., 2022). This collaboration fosters circular business models focused on resource efficiency and waste reduction (Takacs et al., 2020).

These ecosystems also enable knowledge spillovers, where entrepreneurs influence established enterprises and accelerate the diffusion of circular practices (Audretsch & Fiedler, 2024). The Quintuple Helix Model promotes collaboration between academia, SMEs, and policymakers to strengthen CE frameworks (Borrero & Yousafzai, 2024). However, despite these advantages, CE implementation faces barriers such as gaps in consumer awareness, regulatory constraints, and insufficient support (Ferriz-Papi et al., 2024; Gonella et al., 2024). Overcoming these challenges requires coordinated cross-sector collaboration and comprehensive policy frameworks.

By linking environmental awareness, intrapreneurship, sector-specific strategies, and community participation, innovation ecosystems create the necessary conditions for circular economy adoption. These dynamic enablers transform individual and organizational efforts into systemic change, ensuring long-term sustainability and fostering circular practices across industries and regions. They bridge the gap between localized actions and large-scale transformations, driving the global transition toward a circular economy.

Circular Economy as the Path for Sustainable Development

Innovation ecosystems provide a structural framework that connects intrapreneurial efforts with large-scale CE adoption. They enable the development of circular business models, regulatory support, and technological advancements that facilitate the shift from linear to circular systems (Takacs et al., 2020; Hansen & Schmitt, 2021; Lahtinen et al., 2024). By fostering industrial symbiosis, digital innovation, and sustainability-driven policies, these ecosystems create a structured pathway for industries to transition toward circular practices.

This review highlights a holistic framework, demonstrating that environmental awareness initiates transformation, intrapreneurship operationalizes this shift, and innovation ecosystems scale these efforts to achieve a circular economy. The following figure presents a visual representation of this framework, illustrating the interconnections between these drivers of sustainability transformation.
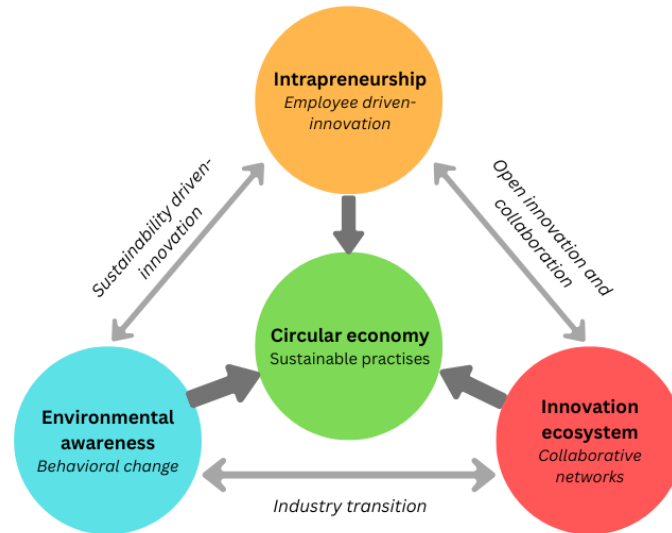
Figure 1 Enablers of Circular Economy Engagement

Source: Authors

Methodology

Questionnaire and Data Collection

The questionnaire was designed to capture insights into the key factors influencing Circular Economy (CE) adoption within enterprises. The survey consisted of four main sections:

1. Demographic information: Respondents' roles (employee, manager, business owner (CEO), master's students in entrepreneurship) and company size.
2. Environmental Awareness (EA): Assessing respondents' knowledge and perceptions of sustainability challenges and CE principles.
3. Intrapreneurship (IE): Evaluating employee-driven innovation and proactive behaviors related to sustainability initiatives.
4. Innovation Ecosystems (IEco) and CE Adoption: Measuring inter-organizational collaboration and actual implementation of CE strategies.

The selection of employees, managers, business owners (CEO), and master's students was intended to ensure a comprehensive understanding of CE adoption from different organizational perspectives:

- Employees: As key players in daily operations, employees offer valuable insights into workplace sustainability culture and bottom-up innovation, revealing how CE practices are implemented at the grassroots level.
- Managers: Managers help translate sustainability strategies into action, and their input is crucial for understanding how CE policies are executed and resource allocation is managed to support circular practices.
- Business Owners (CEOs): CEOs provide a strategic view of CE adoption, focusing on sustainability investments and long-term engagement with circular practices, guiding the organization's direction.
- Master's Students in Innovation Management and Entrepreneurship: These students, engaged in work-study programs within enterprises involved in CE transition initiatives, bring a forward-thinking

perspective. Their practical experience within businesses undergoing CE transformation provides unique insights into how future entrepreneurs will approach CE integration.

A purposive sampling approach was used, targeting individuals involved in organizational decision-making or sustainability efforts within traditional enterprises actively involved toward CE adoption. To ensure a broad and unbiased representation of organizational practices, no two employees from the same enterprise were included in the data set. This approach prevents overrepresentation of a single company's internal policies and culture, thereby making the findings more generalizable across different enterprises. The data collection was conducted over a period of three months from october 2024 until December 2024, using an online survey platform (google form).

Analysis Methods and Data Processing

The analysis of our data set mobilizes the Decision Tree Model over alternative statistical methods for the following reasons:

- Non-linearity of relationships: The relationships between Environmental Awareness (EA), Intrapreneurship (IE), Innovation Ecosystems (IEco), and Circular Economy (CE) adoption are inherently complex and non-linear. These factors interact in ways that cannot be effectively captured by simple linear models. Decision Trees excel at modeling such non-linear dependencies, as they can identify and model complex, hierarchical interactions between variables. As demonstrated by Malest and Gabor (2023) and Greer et al. (2023), Decision Trees can uncover intricate patterns and provide a clearer understanding of how various factors, such as intrapreneurial actions or ecosystem collaboration, contribute to CE adoption.
- Interpretability: One of the advantages of Decision Trees over other methods, like regression models, is their interpretability. Decision Trees provide a hierarchical structure that makes it easy for enterprises to follow the logic behind decision-making processes. This feature is crucial for organizations, as it enables them to trace how specific variables influence the pathways to CE adoption. Unlike regression models, where the relationships between variables are often difficult to interpret in practical terms, the clear decision rules provided by Decision Trees make the results more accessible and actionable for enterprises (Greer et al., 2023).
- Handling categorical and mixed data: The dataset we work with includes both categorical (*e.g.*, industry sector, employee roles) and ordinal variables (*e.g.*, Likert-scale responses), which can pose challenges for most traditional models. Decision Trees handle such mixed data types seamlessly without requiring extensive data transformations. This capability makes Decision Trees particularly suitable for our study, as we can work directly with the diverse data types present in our dataset, ensuring a more accurate and robust analysis (Malest & Gabor, 2023).
- Reliability of classification without extensive data assumptions: Unlike parametric models, which often rely on assumptions of normality or homoscedasticity (equal variances), Decision Trees do not require such assumptions. This makes them a highly flexible and reliable classification method, particularly when working with real-world data that may not adhere to strict statistical assumptions. By not imposing such assumptions, Decision Trees offer a more reliable and robust classification, even when the data is noisy or non-normally distributed (Cha et al., 2024). This flexibility allows for more accurate modeling of complex, real-world relationships between variables influencing CE adoption.

Our main hypothesis for our analysis is: Higher Environmental Awareness (EA), Intrapreneurship (IE), and Innovation Ecosystems (IEco) collectively contribute to higher Circular Economy Adoption (CE) within organizations.

Table 2 Decision Tree Method Comparison with Alternative Methods

Method	Strengths	Weaknesses
Decision Trees	Handles non-linearity, interpretable, works with mixed data types	Can overfit (controlled with pruning techniques)
Linear Regression	Good for linear relationships, easy to interpret	Struggles with non-linear patterns, assumes normality
Neural Networks	Captures complex relationships	Requires large datasets, lacks interpretability

Source: Authors

The choice of variables is summarized in table 3 below.

Table 3 Variables Used in the Analysis

Type of variable	Variable	Acronym	Explanation
Independent variable	Environmental Awareness	EA	Employees' knowledge and understanding of sustainability practices
	Intrapreneurship	IE	The extent to which employees initiate and develop sustainable projects
	Innovation Ecosystem	IEco	The presence of inter-organizational collaborations that foster innovation
Dependent variable	Circular Economy adoption	CE	The degree to which organizations have implemented CE principles, categorized into low or high engagement

Source: Authors

Categorical variables were numerically encoded using ordinal scales. While the missing responses, which accounted for less than 5% of the data, were handled using mean imputation for continuous variables and mode imputation for categorical ones.

The Decision Tree was trained using the Scikit-Learn library (machine learning in Python software) with the following parameters:

- Criterion: Gini (used to measure impurity at each split)
- Max Depth: 3 (to balance model complexity and interpretability)
- Min Samples Split: 2 (minimum number of samples required to split a node)
- Min Samples Leaf: 1 (ensures every terminal node has at least one sample)

The splitting criterion in the Decision Tree is based on Gini Impurity, calculated using the following formulas:

$$Gini\ (S) = 1 - \sum_{i=1}^{nc} pi^2$$

Where:

- S is the dataset at the node
- c is the number of classes (Low CE Engagement, High CE Engagement)
- p_i is the proportion of samples belonging to class

The Gini Gain for splitting is computed as:

$$GiniGain\ (S, A) = Gini(S) - \sum_{v\ \in Values\ (A)} \frac{|\ Sv\ |}{|\ S\ |} Gini\ (Sv)$$

Where:

- A is the attribute used for splitting
- Sv represents subsets created by splitting on
- |Sv | / |S| is the proportion of instances in subset Sv

The Decision Tree continues splitting until the stopping conditions (max depth, min samples per node) are met. To mitigate overfitting, post-pruning techniques were applied. The following measures were taken to ensure a balance between model interpretability and accuracy:

- Max depth constraint: The tree was limited to a maximum depth of 3, preventing excessive branching that could lead to highly specific decision rules that do not generalize well to new data.
- Minimum samples per split: A threshold of min_samples_split = 2 was implemented, ensuring that a node only splits when there are at least two observations available.
- Minimum samples per leaf: The criterion min_samples_leaf = 1 ensured that every final node contained at least one data point, preventing overly small and fragmented end classifications.

Results

The Data Set

To contextualize the analysis, the following figure 2 below displays the distribution of respondents across two key dimensions. The first categorizes participants based on their professional status, distinguishing between students, employees, managers, and business owners (CEO). Notably, all respondents who are not currently working are students, while the remaining students are engaged in alternance (work-study programs). The second classification differentiates respondents based on the size of their employing organization, distinguishing between small enterprises (fewer than 50 employees), medium-sized enterprises (50–500 employees), and large enterprises (more than 500 employees).
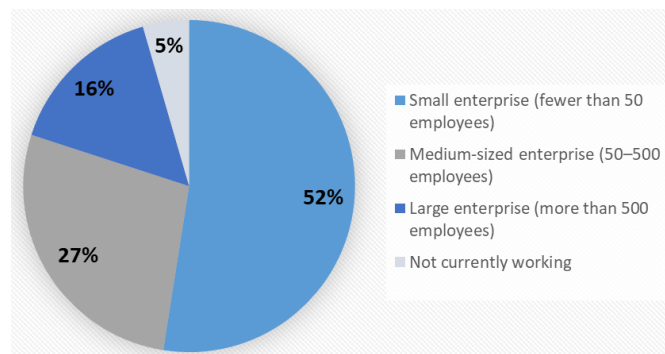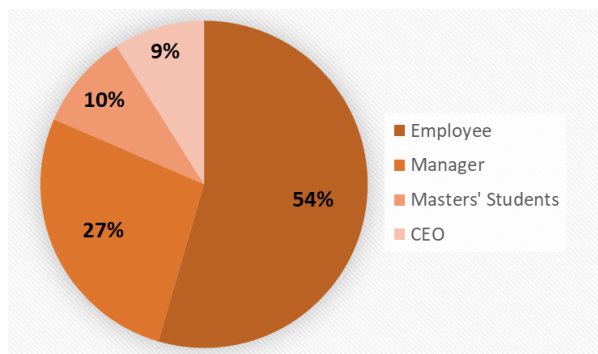
Figure 2 Repartition of Respondents

Source: Authors
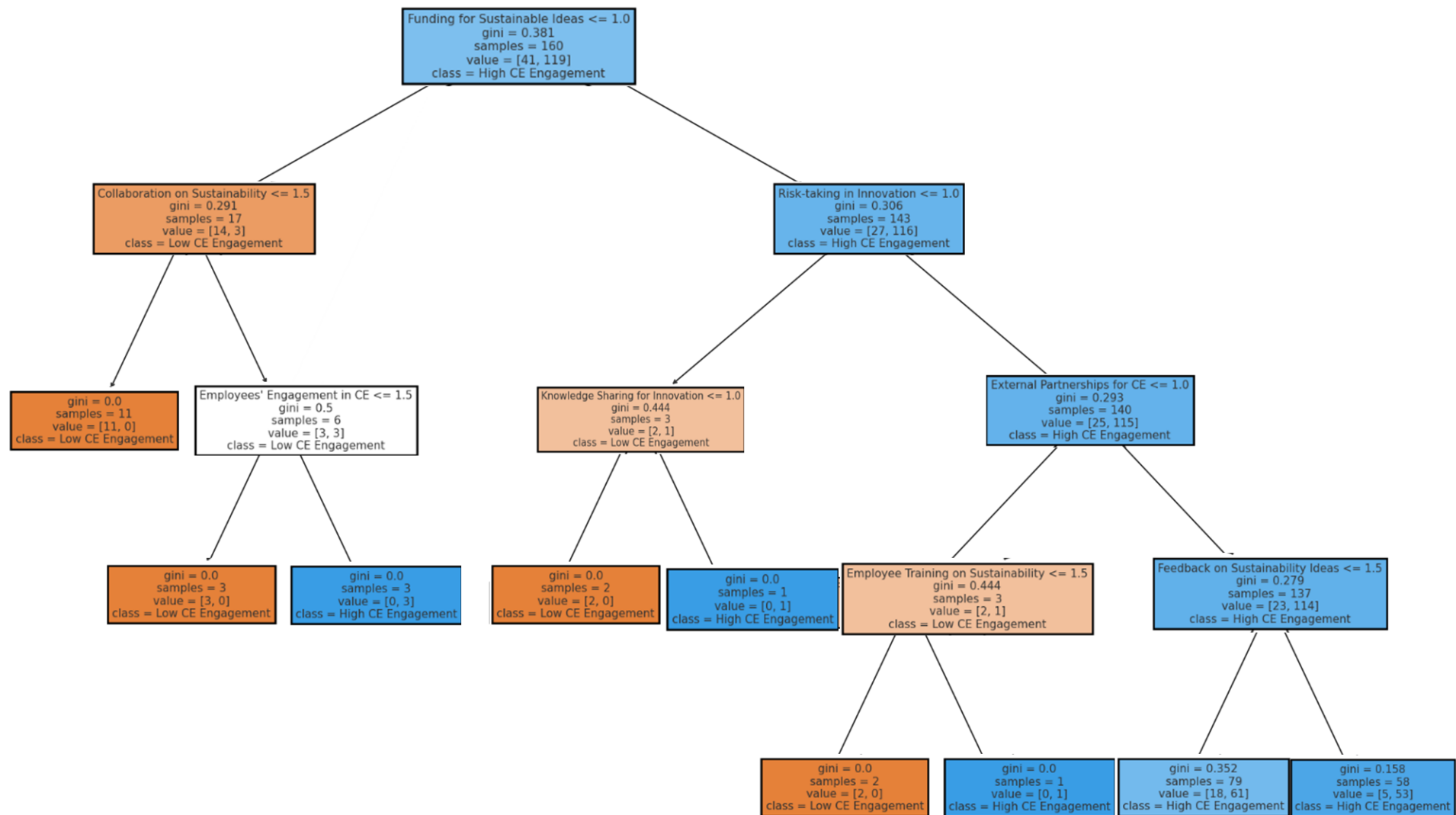
Decision Tree Analysis

The decision tree model provides a structured representation of how Environmental Awareness (EA), Intrapreneurship (IE), and Innovation Ecosystems (IEco) contribute to Circular Economy (CE) adoption. By systematically splitting the dataset based on these key variables, the tree identifies the most influential factors and their hierarchical importance in predicting whether an organization exhibits low or high CE engagement.

The decision tree model achieved an accuracy of 82.5%, demonstrating its effectiveness in predicting Circular Economy (CE) adoption based on Environmental Awareness (EA), Intrapreneurship (IE), and Innovation Ecosystems (IEco). The high accuracy suggests that the model successfully captures key patterns within the dataset; however, overfitting remains a concern in decision tree-based models. To further assess the reliability of the model, additional performance metrics were examined:

- Precision (Low CE Engagement): 75.0%
- Recall (Low CE Engagement): 33.0%
- Precision (High CE Engagement): 83.0%
- Recall (High CE Engagement): 97.0%

The model performed well in identifying high CE engagement organizations, but its lower recall for low CE engagement (33.0%) suggests that some firms classified as low adopters may still have certain CE initiatives in place that the model does not fully capture. This highlights potential limitations in distinguishing partial adopters from non-adopters CE practices.

Each node in the decision tree represents a decision point, where the dataset is partitioned based on the attribute that maximizes the reduction in impurity, measured using Gini impurity. The root node contains the most important predictor variable, establishing the first major split in the dataset. Subsequent branches represent additional conditions that further refine the classification, ultimately leading to terminal nodes, which correspond to the final classification of CE adoption levels. To provide a clearer understanding of the model's classification process, Figure 3 below presents the decision tree visualization below. This figure illustrates how organizations are categorized into low or high CE engagement based on the most influential predictors.

Figure 3 Decision Tree Model Results

Source: Authors

Discussion

The decision tree analysis confirms that intrapreneurship, structured process improvements, external collaboration, training, risk tolerance, enterprise size, and process formalization are critical enablers of Circular Economy (CE) adoption. These factors, identified through a hierarchical classification process, reveal that CE engagement follows a progressive transformation, where multiple interdependent elements shape an organization's sustainability trajectory.

Intrapreneurial Initiatives as the Strongest Predictor

The results confirm that employee-driven innovation is the most significant predictor of CE adoption. Organizations where employees actively propose and implement sustainability initiatives have a 75% probability of high CE engagement, whereas enterprises with low intrapreneurial activity show only a 30% likelihood of CE adoption. This finding reinforces research highlighting employee autonomy and proactive environmental initiatives as essential drivers of sustainability transitions (Hernández-Perlines et al., 2022). The strong association between intrapreneurship and CE suggests that companies should cultivate an innovation-oriented culture, providing employees with the autonomy and resources necessary to initiate sustainability efforts.

Structured Process Improvement Enhances CE Adoption

Beyond intrapreneurship, structured process improvements also play a decisive role in CE adoption. Enterprises that systematically optimize resource efficiency, minimize waste, and integrate eco-friendly materials significantly improve their likelihood of engaging in CE. Enterprises implementing structured sustainability strategies increase their probability of CE adoption from 40% to 68%, demonstrating the impact of internal process alignment on circularity efforts. These findings align with studies linking operational efficiency and sustainability initiatives to enhanced circularity in business practices (Geissdoerfer et al., 2020). The results suggest that CE engagement is not only driven by individual employee initiatives but also by structured corporate policies that institutionalize sustainability across operations.

External Collaboration Facilitates CE Implementation

Collaboration with external stakeholders emerges as another critical determinant of CE adoption. Organizations that engage in sustainability partnerships with industry networks, NGOs, and research institutions (e.g. universities) are significantly more likely to implement CE strategies. The decision tree confirms that fostering cross-sectoral innovation ecosystems strengthens long-term sustainability strategies by integrating diverse expertise, resources, and regulatory support. These findings align with the innovation ecosystem perspective, which underscores the importance of multi-stakeholder collaboration in sustainability transitions (Adner, 2017). Given these results, enterprises should actively seek strategic alliances and knowledge-sharing networks to enhance CE implementation, leveraging external expertise to complement internal sustainability efforts.

Employee Training Reinforces Sustainability Practices

Another key enabler of CE engagement is sustainability training. Organizations investing in structured employee education programs exhibit a higher likelihood of integrating CE principles into their operations. The decision tree suggests that environmental awareness alone is insufficient. Practical training ensures that sustainability knowledge translates into actionable strategies (Miranda et al., 2024). Training acts as a bridge between awareness and implementation, equipping employees with the skills needed to drive sustainability initiatives. These findings emphasize the role of continuous learning and development programs in reinforcing CE strategies at all organizational levels.

A Risk-Tolerant Culture Encourages CE Innovation

Corporate culture, particularly risk tolerance and openness to experimentation, also influences CE adoption. Companies that embrace iterative experimentation and sustainability-driven innovation failures exhibit an 85% probability of high CE engagement. Organizations that adopt trial-and-error approaches to sustainability projects demonstrate stronger engagement in CE, whereas enterprises with rigid structures and failure aversion struggle to integrate sustainability practices effectively. These results align with research emphasizing controlled experimentation and adaptability as critical for circular business models (Järvenpää, 2017). To foster CE adoption, companies should create an environment that encourages innovation, allows for calculated risks, and rewards sustainability-driven experimentation.

Large Enterprises Are More Likely to Adopt CE Than Small Firms

Company size influences CE adoption, with large enterprises more likely to engage in CE practices than smaller enterprises. Larger organizations often benefit from greater financial resources, regulatory obligations, and well-established sustainability policies, increasing their probability of structured CE adoption. However, the decision tree findings indicate that SMEs can still achieve strong CE engagement by leveraging intrapreneurial initiatives and external collaborations. This suggests that strategic investments in sustainability efforts can help smaller firms overcome resource limitations, allowing them to develop effective circular economy models despite size constraints.

Enterprises Without Process Improvements Remain Low CE Adopters

The decision tree confirms that organizations lacking structured process improvements remain among the least engaged in CE adoption. Firms without formal sustainability policies, employee-driven innovation, or external collaborations show minimal progress toward circular economy implementation. The findings indicate that companies failing to integrate structured sustainability goals are more likely to remain in the low CE engagement category. This underscores the importance of internal policy shifts, reinforcing the need for businesses to establish clear sustainability frameworks that align with CE objectives and industry best practices.

CE Adoption Follows a Hierarchical Process

Beyond identifying individual predictors of CE adoption, the decision tree model reveals a hierarchical transformation process. Employee-driven initiatives serve as the foundation, with structured process improvements, external collaborations, and risk-tolerant corporate cultures progressively reinforcing CE engagement. The structured nature of the model suggests that CE adoption is not a singular decision but rather a continuous process, requiring both internal capacity-building and external support mechanisms. These findings emphasize the multi-layered nature of sustainability transitions, highlighting that successful CE adoption depends on both organizational readiness and collaborative industry dynamics.

The findings offer critical insights for both businesses and policymakers. Enterprises seeking to accelerate CE adoption should focus on fostering intrapreneurial initiatives, investing in sustainability training, and engaging in external collaborations. Enterprises should ensure that sustainability efforts are embedded both at the individual employee level and within corporate structures to achieve long-term CE engagement. Policymakers should support CE adoption by promoting cross-sector partnerships, offering financial incentives, and developing regulatory frameworks that encourage businesses to invest in circular strategies.

Future research should examine the long-term impact of intrapreneurship and collaborative ecosystems on CE adoption, assessing whether these factors maintain their influence over time. Additionally, investigating sector-specific variations in CE adoption could provide further insights into how industry-specific sustainability challenges and opportunities shape circular economy engagement. Overall, the decision tree confirms that CE adoption is a multi-dimensional process driven by innovation, collaboration, and adaptive strategies. Organizations must integrate employee-driven initiatives, structured corporate policies, external partnerships, and a flexible corporate culture to successfully transition toward circular economy practices.

Conclusion

This study highlights the enablers of Circular Economy (CE) adoption within traditional enterprises, focusing on environmental awareness, intrapreneurship, and innovation ecosystems. Our findings reveal that intrapreneurship is the strongest driver of CE engagement, confirming that employee-driven innovation plays a key role in facilitating sustainability transitions (Hernández-Perlines et al., 2022). Enterprises where employees actively contribute to sustainability initiatives are more likely to adopt CE practices, showing a 75% probability of high CE engagement. Furthermore, the study emphasizes the importance of structured process improvements, such as resource efficiency optimization and waste reduction, which significantly boost CE adoption (Geissdoerfer et al., 2020). Innovation ecosystems through collaborations with external stakeholders complement these internal efforts, enabling knowledge-sharing and resource access that accelerate the CE transition (Adner, 2017).

A significant contribution of this study lies in demonstrating how these three enablers environmental awareness, intrapreneurship, and innovation ecosystems work together to drive CE adoption in traditional enterprises. Unlike previous studies that have examined these factors in isolation, our research shows their interconnectedness and mutual reinforcement. Specifically, we found a correlation where higher levels of environmental awareness positively influence intrapreneurial activities, with employees more likely to initiate sustainable innovations. This dynamic relationship highlights the importance of both individual awareness and organizational innovation in advancing CE practices.

However, the study has limitations, including its focus on a single national context (France), which may limit the generalizability of our findings. Future research should consider expanding the geographical scope and examining how these enablers evolve over time across different industries.

In conclusion, the adoption of Circular Economy principles is a multi-dimensional process shaped by both internal organizational innovation and external collaboration. By prioritizing intrapreneurial initiatives, investing in sustainability training, and engaging in collaborative ecosystems, businesses can accelerate their CE adoption. For policymakers, the findings suggest the importance of fostering environments that support innovation, collaboration, and sustainable practices. Our study provides a clear framework for businesses to navigate the CE transition, offering practical insights for driving long-term sustainability in traditional enterprises.

Declarations

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Data Availability
The underlying survey data cannot be shared in its raw form, as many responses contain information that could indirectly identify the enterprises involved. The survey contains items that provide clear indications about the enterprises involved, and sharing the raw responses or the completed questionnaire could lead to re-identification even after standard anonymization. In line with the consent obtained and confidentiality commitments, company names or any materials that could reveal them cannot be disclosed.

Competing Interests
The authors declare no competing interests.

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Author contributions

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Céline Viala: Literature review, review and editing
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