

Innovative Circular Economy as a Mechanism for Transforming Industrial Waste into Sustainable Business Models - a Review of International Experiences

Guecherou Fatiha¹

¹ University of Blida 2 -Lounici Ali -Algeria, Laboratory of Local Authorities Management and their Role in Achieving Development

Email : f.guecherou@univ-blida2.dz

Submission: 29/01/2025 | Acceptance: 24/05/2025 | Published: 30/09/2025

Abstract: This study aims to analyse the role of the innovative circular economy as a mechanism for transforming industrial waste into sustainable business models. The results indicate that this successful transformation requires integrated innovation in design, processes, business models, and supporting policies. It also showed that the mechanisms of technical transformation range from direct processing, advanced technologies, and systemic integration through industrial solidarity. Comparative analysis showed that the effectiveness of circular models is related to the extent to which they are compatible with the local institutional and economic context of each country. Finally, it emphasizes the study examines the need for a supportive policy and financing framework, and human capacity building, to enable this strategic shift towards a more sustainable and resilient economy.

Keywords: Circular Economy, Innovation, Sustainable Business Models, Industrial Solidarity.

Introduction:

The contemporary global economic system faces structural challenges resulting from the continued reliance on the linear production model, which is characterized by high rates of natural resource extraction and accelerating industrial waste generation. These dynamics exacerbate environmental pressures and threaten the physical and economic security of many sectors. In this context, the circular economy emerges as an alternative methodological framework, but its practical realization requires moving beyond traditional notions of recycling towards an innovative perspective A comprehensive redesign of systems from their roots.

The innovative circular economy focuses on transforming environmental challenges into economic opportunities through non-traditional mechanisms that redefine the value inherent in waste. This innovation manifests itself across multiple dimensions: innovation in design (products that can be repaired and remanufactured), innovation in technologies (advanced transformations), innovation in business models (shifting from selling products to providing services), and innovation in systems (industrial solidarity and corporate collaboration).

Accordingly, the main problem of this intervention¹ can be formulated as follows: **How can innovation mechanisms be employed within the framework of the circular economy to transform industrial waste into productive inputs of economic value, and how do these mechanisms contribute to the formation of sustainable and scalable business models, in light of leading global experiences?**

Importance of the research:

The importance of this research is that it bridges a fundamental knowledge gap by moving the concept of the circular economy from a traditional focus on recycling to adopting a holistic innovative perspective that transforms industrial waste into valuable economic inputs, at a time when environmental pressures are exacerbating and the need for sustainable business models is increasing. Its importance also stems from its review of pioneering international experiences that provide adaptable practical lessons, which contribute to guiding institutions and policymakers towards proven solutions that reduce the costs of experimentation and enhance economic and environmental security.

Research Objectives :

1. Rooting the conceptual framework of the innovative circular economy and defining its basic principles and multiple dimensions.
2. Investigating and analysing the mechanisms of converting industrial waste into productive inputs of economic value.
3. Classify and analyse sustainable business models arising from the innovative circular system.
4. Draw lessons and common factors for success from leading international experiences and make actionable recommendations.

Research Methodology and Tools:

This intervention relied on an integrated methodology that combines an inductive approach to transition from international case studies to the extraction of general principles, a descriptive-analytical approach to describe and analyse transformation mechanisms and business models, and a case study approach to analyse pioneering international experiences in depth. The research tools included content analysis of academic literature and international reports, qualitative analysis to understand the relationships and processes within business models, in addition to designing a unified analysis card for international experiences that included indicators such as the type of waste, the innovation mechanism, and the model. The resulting work, success factors and challenges.

In order to answer the main problem of this research and to familiarize yourself with the aspects of the topic, the intervention will be organized in three sequential axes:

1. **The conceptual framework and basic principles of the innovative circular economy.**
2. **Mechanisms for converting industrial waste into productive inputs.**
3. **Classification and Analysis of Sustainable Business Models in the Innovative Circular System - Presentation of International Experiences**

1. The Conceptual Framework and Basic Principles of the Innovative Circular Economy

1.1. The Historical Development of the Concept of the Circular Economy

The contemporary concept of the circular economy is based on a decades-long stream of thought that has crystallized through multiple intellectual stations. In the 1970s, economist Walter Stahl proposed the concept of the "Performance Economy," a direct precursor to the circular model, emphasizing the importance of extending the life of products through repair and reuse rather than just recycling. This coincided with economist Kenneth Boulding's thesis in his work *The Economics of the Grounding Spacecraft* (1966), in which he described the planet as a closed-system spacecraft, where resources are limited and its consumption requires prudent management. These foundational ideas paved the way for more sophisticated models such as Braungart's and McDonough's "Cradle to Cradle," which rejected the idea of "waste" in the first place through the intelligent design of products and systems (Stahel, 2019, pp. 15-25).

1.2. Definition of the Circular Economy

The circular economy is defined as a deliberate, design-projected industrial economic system, which aims to achieve the effective continuity of materials in the highest states of utility and value throughout their entire life cycle. This represents a paradigm shift from the traditional linear economic model (take-make-take-dispose) to a closed-loop iterative model. As one of the leading players in the field, the Ellen MacArthur Foundation defines it as an economic system that aims to preserve products, components, and materials with maximum value and the longest possible shelf life, distinguishing between the cycles of biological and technical materials, and working to achieve Restoration of natural materials and systems. This definition highlights the deliberate design aspect and the transition from resource efficiency to system effectiveness as a whole (Foundation Ellen MacArthur, 2013, p. 7).

1.3. Principles of the Circular Economy:

1.3.1. The principle of preserving natural capital and promoting renewable resources:

This principle is based on reducing the depletion of non-renewable natural resources and gradually and increasingly relying on renewable or recycled inputs. This is manifested through the control of limited stocks and the balancing of renewable resource flows, which necessitates the redesign of the production processes and products themselves to conform to this principle, which is a major challenge for technological and institutional innovation (Kirchherr, et al., pp. 222-232).

1.3.2. Optimization and Circular Circulation of Products, Materials and Components:

This principle seeks to keep products, components and materials within the economy at the highest possible value and for the longest period of time. This is achieved by designing products to be repairable, remanufactured, reused, and recycled. This includes the development of efficient reverse supply chains and sophisticated logistics systems to recover products after

use, transforming them from waste into valuable inputs in new production cycles ([Ghisellini et al, 2016](#)).

1.3.3. Waste Design Principle and Out-of-System Pollution: This principle addresses the root cause of environmental problems through intelligent design, rather than addressing the symptoms later, it not only reduces the waste emitted, but works to exclude it from the economic system from the design stage. This requires the adoption of concepts such as green chemistry, safer materials, and modular design, which reduces toxic leaks and keeps the biological cycle pure ([Korhonen, et al., 2018](#))

1.4. The Multiple Dimensions and Pillars of the Innovative Circular Economy

1.4.1. Technical and Technological Dimension:

It is the cornerstone of the implementation of the theoretical principles, as it is manifested through innovation in smart material separation technologies, the development of advanced recycling processes (e.g., chemical conversion), and the improvement of the efficiency of the collection and classification of used products via artificial intelligence and the Internet of Things. It also includes the design of products with a longer lifespan and more flexibility to adapt to repair and modernization processes ([Bocken, et al., 2016](#)).

1.4.2. Social and Employment Dimension:

The circular economy is seen not only as an eco-economic model, but also as a tool for inclusive social development. It generates new types of employment opportunities in areas such as repair, remanufacturing, reverse logistics, and participatory services. It also promotes social justice by reducing the cost of living through "product-as-a-service" models and enabling local communities to recover the value of their wasted resources ([Murray et al, 2017, pp. 369-380](#)).

1.4.3. Institutional, regulatory, and political dimension:

This dimension includes the development of policy, legal, and financial frameworks that support the circular transition, such as environmental design standards, extended producer responsibility (EPR), green tax incentives, and accounting standards that recognize the residual value of materials. It also requires building multi-sectoral partnerships between governments, industry, civil society, and academia to create a conducive ecosystem ([Geissdoerfer et al, 2017, pp. 757-768](#)).

1.5. Engines and Forms of Innovation in the Circular System:

Innovation in the circular economy is manifested through four interrelated pathways: product innovation (new materials, modular design, ease of disassembly), process innovation (cleaner production technologies, efficient reverse logistics), business model innovation (transformation from sales to service, participatory platforms), and system innovation (new policy development, collaborative networks, and sustainable culture). These forms interact to generate systematic solutions that achieve synergy between economic efficiency and environmental performance ([Rizos, et al., 2016](#)).

1.5.1. Product Innovation: Fundamental Redesign: Product innovation is a radical redesign starting from the first design stage, where the product is reimagined to be a "material value portfolio" that can be recycled across multiple cycles rather than as a final good with a limited life cycle. This includes designing products to be easily disassembled and repairable, making it easier to replace broken parts and extend lifespan. It also includes the development of innovative new materials such as biodegradable biomaterials and easy-to-detach composite materials. In addition, digital modeling and life cycle simulation tools are used to improve the environmental and economic performance of the product before the actual manufacturing stage. (Bakker, et al., 2014).

1.5.2. Process Innovation: Improving Circular Efficiency: Process innovation focuses on optimizing manufacturing processes and logistics to maximize material recovery and achieve integrated circular efficiency. This includes the development of cleaner production systems that recycle waste and energy within the plant itself, reducing reliance on external inputs. It also includes the design of intelligent reverse logistics that uses RFID technologies and the Internet of Things to track and collect used products efficiently, ensuring that high-quality materials return to the production cycle. In addition, process innovation includes the adoption of advanced technologies such as additive manufacturing and advanced recycling chemistry that allow materials to be recovered with a high degree of purity (Govindan & Soleimani, 2017, pp. 371-384).

1.5.3. Business Model Innovation: A Fundamental Shift in Value Creation: Business model innovation represents a fundamental shift in how value is created and distributed, changing the traditional relationship between producer and consumer. The most prominent form of this innovation is the "product-as-a-service" model, which transforms the traditional sales process into a service subscription, where the producer retains the physical ownership of the product and sells the function or output to the consumer. It also includes the development of digital sharing economy platforms that enable the rental or sharing of unused assets between individuals and businesses, which increases the utilization rate of assets and reduces the demand for new products. In addition, it involves the creation of specialized markets for refurbished and remanufactured products, which creates new marketing channels and contributes to building consumer confidence in these products (Tukker, 2015, pp. 76-91).

1.5.4. System Innovation: Building an enabling environment: System innovation includes the development of frameworks that support circular transformation at the macro level, requiring changes in policies, finance, and cooperation mechanisms. It consists in designing supportive policies such as extended producer responsibility systems that oblige companies to take responsibility for their products throughout their entire life cycle, as well as adopting green public procurement policies that use government purchasing power to create market demand for circular products. It also includes the development of innovative financing tools such as green bonds and leasing models linked to environmental performance, which attract investments towards circular projects. Finally, building collaborative partnerships between

companies requires the creation of circular industrial incubators where the waste of one company becomes raw materials for another, achieving horizontal integration in the use of resources (McDowall, et al., 2017).

2. Mechanisms for converting industrial waste into productive inputs:

2.1. Theoretical Framework for Waste Transformation: From Waste to Resource:

Mechanisms for converting industrial waste into productive inputs represent the backbone of the practical application of the circular economy in the industrial sector. This transformation is a paradigm shift in the treatment of waste from an environmental and economic burden that must be disposed of to an underlying asset with economic value that can be exploited. inherent in the inevitable waste through advanced conversion and processing techniques. The development of these mechanisms requires a deep understanding of the composition and properties of wastes, as well as the design of intelligent collection, separation and classification systems that ensure the quality of the inputs produced. This shift not only reduces the environmental pressure caused by traditional waste disposal, but also creates new economic opportunities and enhances resource security by reducing dependence on imported raw materials (Al-Awadhi, 2020).

2.2. Classification and Evaluation of Industrial Waste: Identifying Conversion Potential:

The actual conversion process is preceded by a critical stage of classification and assessment of industrial waste, a stage that determines the technical and economic feasibility of any conversion project. This classification requires a comprehensive understanding of the different types of industrial waste which includes organic waste, metals, plastics, chemical waste, and thermal waste (wasted energy). Integrated assessment is used across tools such as physical flow analysis to map quantity and quality of material and waste flows within the industrial system, life cycle assessment to compare the environmental impacts of different conversion options, and cost-benefit analysis to determine economic feasibility. This comprehensive assessment aims to determine the "residual value" of waste and the best route for its recovery, whether it is direct reuse, remanufacturing, mechanical or chemical recycling, or energy recovery (Salem, 2019, pp. 45-67).

2.3. Physical and Mechanical Conversion Mechanisms: Direct Recovery of Materials:

Physical and mechanical mechanisms focus on the recovery of secondary raw materials through physical separation, sorting, and processing processes without substantially altering their molecular chemical composition. These mechanisms include sophisticated automated sorting systems that use spectroscopic sensing techniques such as near-infrared and X-rays to identify and separate different types of materials (such as multiple polymer types) with high purity that allow for reuse in value-added applications. It also includes grinding, sifting and washing processes to clean and process materials, and pressing and agglomeration processes to reduce their size and improve the efficiency of their transportation and storage. These mechanisms are essential for sectors such as metals, paper, and elastomers, as they preserve the molecular structure of the original material, allowing them to be reused in applications with

similar or slightly lower added value, with significant energy and emissions savings compared to the production of new raw materials (Al-Juhani, 2021, pp. 112-130).

2.4. Chemical and bio-conversion mechanisms: Molecular recombination: When mechanical processes are not sufficient to recover pure materials, or when the residues are contaminated or complex in structure, chemical and bio-conversion mechanisms play a pivotal role in maximizing value recovery. These mechanisms break down the waste into its basic molecular components or transform it into completely new products with different chemical properties. Chemical mechanisms include processes such as pyrolysis to convert plastic waste into oil Pyrolysis or gases usable as fuel or chemical raw materials, gasification, and chemical hydrolysis. Biomechanisms include anaerobic digestion to convert organic waste into biogas (methane) and high-quality fertilizer, and fermentation to convert sugars into specialized biochemical products. These advanced technologies allow for the handling of mixed or contaminated residues and the extraction of base chemicals that can be used as an alternative to new petrochemicals, reducing dependence on fossil sources.

2.5. Industrial Symbiosis and Regional Material Networks: Closure of Loops at the Regional Level: Industrial Symbiosis is an advanced and integrated waste diversion mechanism, where collaborative networks are established between different industrial facilities that are usually located in a converged geographical area such as industrial parks or special economic zones. In these smart networks, waste or by-products of a facility (e.g. wasted heat, wastewater, or waste are transformed chemical, or solid waste) to valuable inputs or energy sources for a neighbouring facility operating in a different sector. The success of this model requires innovation in coordination, information sharing, and confidence-building mechanisms between companies that may originally be competing with each other, often facilitated through specialized digital platforms or mediation by local government bodies or supporting organizations. Industrial solidarity delivers collective benefits far beyond what can be achieved alone, such as reduced combined operating costs, reduced risks associated with raw material price fluctuations, enhanced regional competitiveness, and reduced overall environmental footprint of the industrial zone (Ministry of Industry and Mineral Resources, 2022, pp. 18-34).

2.6. Economic Stimulus Mechanisms and Supportive Policies: Enabling Transformation

The success of technical mechanisms for waste diversion cannot be separated from the existence of an enabling environment that supports public policies and carefully designed economic incentives, these mechanisms include multiple tools such as landfill taxes that make the traditional disposal option less economically attractive and direct investments towards conversion solutions, and green credits or recycling certificates that create a market for environmental services and recognize the added value of circular projects. Mandatory or voluntary recycled content standards also play an important role in creating a secure and stable demand for secondary materials, stimulating investment in conversion infrastructures and ensuring markets for produced materials. Together, these tools help address traditional market failures and correct price distortions that often make new raw materials ostensibly cheaper than

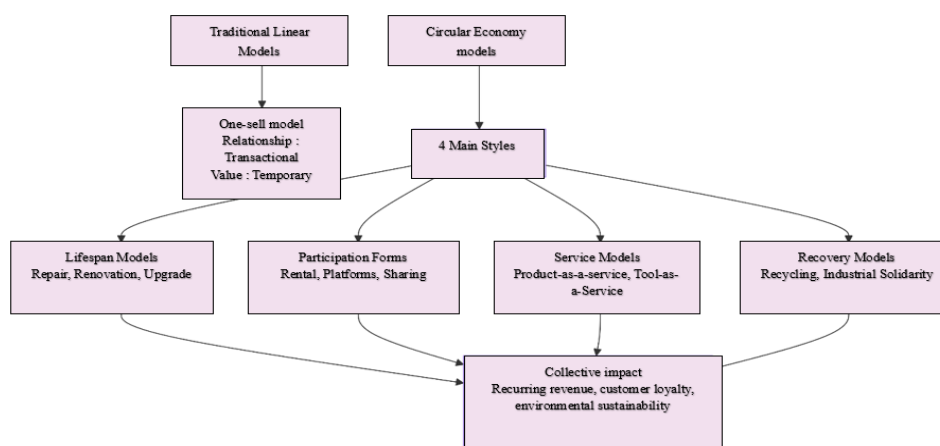
recycled materials, even as the latter saves large amounts of energy and significantly reduces emissions. (Van Ewijk & Stegemann, 2016, pp. 122-128).

3. Classification and Analysis of Sustainable Business Models in the Innovative Circular System - Global Experiences

3.1. Conceptual Framework for Circular Business Models:

Circular business models represent a fundamental shift in how value is created and distributed in a sustainable economy. They are not just marginal modifications of traditional models, but they redesign the relationship between the product, the customer, the supplier, and the environment. These models keep products, components, and materials at the highest levels of utility and value for as long as possible, and then restore and reintroduce them into the production cycle. This requires rethinking the nine core elements of the business model as defined by Osterwalder, with a particular focus on revenue sources and customer relationships and cost structure.

Figure 01: Models of Transition from Linear to Circular Economy



Source: Prepared by the researcher based on: (Al-Jaber, 2021, pp. 112-135)

The figure above provides a simplified and clear vision of the shift from the traditional linear (take-make-use-dispose) economic model towards a circular economy, through three main categories of operational models: single-sale models (focusing on circular materials and waste prevention), sharing models (e.g., platforms and leasing to maximize asset utilization), and outsourcing models (e.g., remanufacturing and industrial integration). It shows that the combined interaction of these models achieves a positive collective effect of generating repeat revenue and customer loyalty on the one hand, and enhancing customer loyalty on the one hand. Environmental sustainability on the other hand, which embodies the dual benefit of the circular economy.

3.2. Classification of Global Circular Economic Models:

Table 1: Classification of Global Circular Economic Models

Category	Core Principle	Global Examples	Global Market Share
Lifespan Extension	Maximizing product lifespan	Remanufacturing, Repair	15-20%
Participation	Maximizing asset utilization	Sharing platforms	25-30%
Product as a Service	Shifting ownership to service	PaaS (Product as a Service), Leasing	20-25%
Recovery	Material and energy recovery	Recycling, Refining	30-35%

Source: Prepared by the researcher based on: ([Saudi Ministry of Economy and Planning, 2023](#))

The market distribution of circular models in the table above reveals existing global priorities, with recovery models (30-35%) leading the scene, reflecting the current focus on remediation of existing waste. Followed by engagement models (25-30%) as a product of the digital revolution and changing consumer mindset. Product-as-a-service (20-25%) represents a proactive trend towards redesigning businesses from the roots. Lifespan models (15-20%) Finally, indicating their technical complexity and high demands. This arrangement reflects a graduation from remedial (restoration) to preventive (product-as-a-service) models, with an inverse proportion between ease of implementation and depth of economic transformation required.

3.3. Comparative analysis of global experiences: Europe, Asia, North America:

The European experience, as documented by the Ellen MacArthur Foundation (2021), shows integrated institutional development with a 42% adoption rate for circular models in the EU. While the Asian experience focuses on technical proficiency, with studies by the Tokyo Institute of Technology (2022) indicating that Japan has achieved a 98% recycling rate for electronics. The American experience is characterized by innovation in business models, with companies such as Caterpillar generating an annual revenue of \$2 billion from remanufacturing.

Table 2: Comparison of the Performance of Circular Economic Models Across Geographical Regions (2022)

Indicator	Europe	Asia	North America	Global
Model adoption rate	42%	38%	35%	38%
Annual sector growth	7.2%	11.8%	8.5%	9.1%
Investment in technologies (billion USD)	45	52	38	135
Annual number of patents	1.200	2.800	1.500	5.500

Source: Prepared by the researcher based on: (Ilen MacArthur Foundation, 2023)

The table reveals distinct regional competitive patterns in the circular economy, with Europe leading in the adoption rate of models (42%), reflecting institutional maturity and solid supportive policies, but registering the lowest annual growth (7.2%), which may indicate that it is close to saturation. In contrast, Asia clearly excels in rapid growth (11.8%) and innovation (2,800 patents), driven by massive technology investments (\$52 billion) and a strategic focus on advanced manufacturing and digitalization. North America occupies an intermediate position in most indicators, reflecting a market-based economy and a diversification of approaches between the United States and Canada. The global total (9.1% growth, \$135 billion investment) reflects a growing momentum for circular transformation, with an unequal distribution of resources and innovation between regions, creating opportunities for regional collaboration and integration to bridge gaps.

4.3. Conceptual Classification of Innovative Circular Models: The field of circular economy is witnessing a rapid evolution in business models, as the focus shifts from traditional recycling to integrated systems that redesign the relationship between the product, the consumer, and the environment. Researchers categorize these models within a hierarchical framework that reflects the degree of innovation and the depth of institutional transformation. Recent research shows trends toward "circular design" and "functional economics" models that redefine the concept of value itself.

Table 3: Evolution of the classification of innovative circular models (2015-2023)

Innovation Level	Emergence Period	Core Principle	Global Examples	Market Share
Level 1: Recycling	2015–2018	Waste treatment	Traditional recycling plants	40–45%

Innovation Level	Emergence Period	Core Principle	Global Examples	Market Share
Level 2: Functional	2018–2020	Product as a Service	Philips Lighting-as-a-Service	25–30%
Level 3: Design-based	2020–2022	Radical redesign	Dell Closed-Loop Recycling	15–20%
Level 4: Systemic	2022–2023	Integrated ecosystems	Kalundborg Industrial Symbiosis	10–15%

Source : (Geissdoerfer, et al., 2020, p. 277)

The market share distribution of circular models in the table above reveals an interesting inverse relationship between the level of innovation and the spread of the model. While traditional circular models dominate the largest share (40-45%) due to their relative simplicity and focus on addressing the problem after it has occurred, the more innovative models show smaller shares despite representing the strategic future. This phenomenon suggests that there are a time and technical gap between innovation and wide diffusion, with advanced models (such as the 10-15% systemic) requiring deeper institutional changes and more complex partnerships. It is also noted that the chronological evolution of the models (from 2015 to 2023) parallels the evolution of innovation levels, reflecting the maturity of the field and its orientation towards more integrated and less linear solutions.

5.3. Pioneering International Experiments in Innovative Circular Models:

5.3.1. The Dutch Model: Systemic Integration

The Netherlands is a leader in the development of integrated circular ecosystems, achieving a 42% adoption rate for circular models, the success of the Dutch model lies in integrated policies that combine financial incentives, smart infrastructure, and public-private R&D partnerships.

5.3.2. Japanese Model: Advanced Technical Proficiency

Japan focuses on "Precise Disassembly" in the electronics industry, with a material recovery efficiency of up to 98%. This model is based on technical innovation in separation and sorting processes, and investment in specialized human capital.

5.3.3. The American Model: Entrepreneurship and Innovation

The U.S. has a supportive environment for circular entrepreneurship, accounting for 40% of global venture capital investments. The U.S. model focuses on economic viability and scalability.

Table 4: Performance Comparison and Strategic Orientation of Global Circular Models (2023)

Indicator	Netherlands (Integrated Model)	Japan (Technical Model)	United States (Entrepreneurial Model)	Lessons Learned
Model adoption rate	42%	38%	35%	Institutional integration raises adoption rates
Annual investment (billion USD)	2.1	1.8	3.5	Diverse investments depending on the model
Annual patents	450	1,200	850	Technical specialization generates more innovation
Annual sector growth	7.5%	9.2%	11.3%	Entrepreneurship achieves faster growth
Main challenges	Coordination among parties	Labor costs	Market fluctuations	Each model faces different challenges

Source: Prepared by the researcher based on: (Eurosta, 2023), (Ministry of Environment, Japan, 2023), (Agency, 2023)

The table highlights the clear divergence in strategic approach and outcomes between the three global models. The Dutch integrated model achieves the highest adoption rate (42%), underscoring the effectiveness of a comprehensive institutional approach based on policy and coordination between different parties. The Japanese technical model shows clear leadership in innovation (1,200 patents), reflecting a strategic focus on technological development and operational efficiency. The U.S. Entrepreneurial Model It achieves the highest growth rate (11.3%) and the largest investment volume (\$3.5 billion), demonstrating the strength of the entrepreneurial environment and its attractiveness to private investment.

This comparison suggests that the success of the circular model depends on the compatibility with the national context and the available possibilities. While the integrated model is suitable for countries with strong institutional systems, the technical model is suitable for countries with advanced manufacturing capabilities, and the entrepreneurial model is suitable for countries with active venture capital markets. The data also show that there is a trade-off between

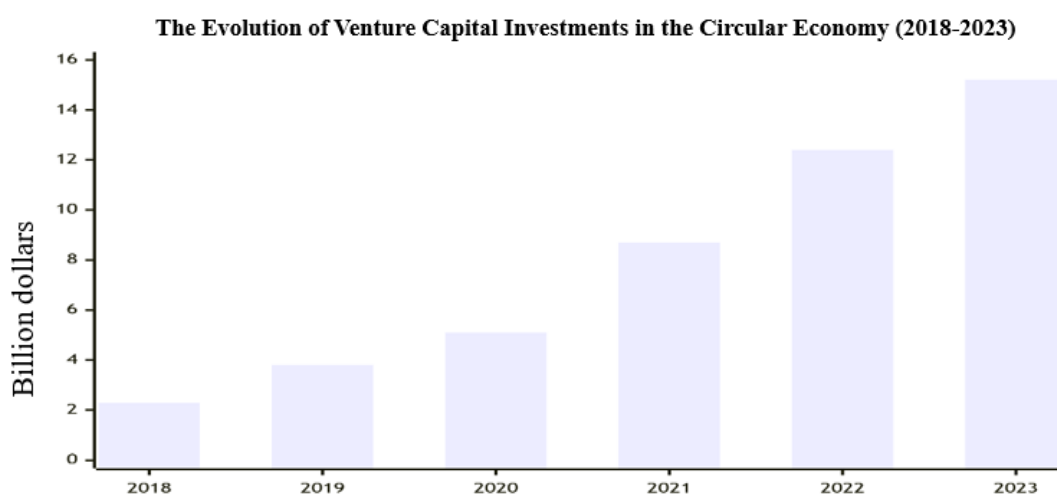
stability and growth, with the more stable model (the Dutch) registering the least growth, while the more dynamic model (the US) achieves the highest growth but with greater risk.

4.5.3. Innovation in Financing Mechanisms and Financial Instruments:

Circular economy financing instruments are witnessing a remarkable development, as innovative financial instruments such as:

1. **Performance-Linked Green Bonds:** Linking Bond Yields to Sustainability Indicators
2. **Specialty Investment Funds:** Investments for Circular Companies
3. **Performance Contracts:** Financing Linked to the Achievement of Specific Environmental Goals

Figure 2: Evolution of Venture Capital Investments in the Circular Economy (2018-2023)



Source: (PitchBook Data, 2023)

The figure shows a strong and continuous upward trend of venture capital investments in the circular economy during the period from 2018 to 2023, with data indicating a double-digit growth of more than sixfold, from \$2.3 billion in 2018 to \$15.2 billion in 2023 (estimated), with a CAGR of approximately 46%. The first was between 2020-2021 (\$5.1 billion to \$8.7 billion) with a growth rate of 70%, and the second between 2021-2022 (from \$8.7 to \$12.4 billion) with a growth rate of 43%. This upward trend reflects growing investor confidence in the viability of circular business models and their potential for growth and profitability. The continued growth despite global economic challenges also indicates the strength and resilience of the sector and its transition from nascent to maturity and expansion. These rising investments reflect the growing global interest in the circular economy as both a path to sustainable development and a promising investment opportunity.

5.5.3. The Role of Digital Technologies in Enabling Circular Models:

Digital technologies are transforming circular models by:

1. **Internet of Things (IoT):** Tracking Products Across Their Lifecycle
2. **Blockchain:** Ensuring transparency in circular supply chains

3. AI: Improving Sorting and Classification

Table 5: The Impact of Digital Technologies on the Performance of Circular Models (2023)

Technology	Improvement of operational efficiency	Cost reduction	Quality improvement	Technical Challenges
Internet of Things (IoT)	40-60%	25-35%	30-40%	Standardization, cybersecurity
Blockchain	20-30%	15-25%	25-35%	Scalability, energy consumption
Artificial Intelligence (AI)	50-70%	30-45%	40-55%	Data quality, required skills
Big Data	35-50%	20-30%	25-40%	Privacy, infrastructure

Source: (McKinsey & Company, 2015)

The table analyses the relative impact of four major digital technologies (IoT, blockchain, artificial intelligence, and big data) on the core business performance axes, with AI emerging as the most influential on efficiency (50-70%), costs (30-45%), and quality (40-55%), while the benefits of other technologies are distributed in varying proportions, highlighting unique challenges for each such as IoT cybersecurity, blockchain power consumption, and data quality for AI. The table thus provides a comparative quantitative framework that helps rationalize investment decision Strategic planning with the caveat that achieving full value requires addressing the accompanying technical and institutional challenges.

Conclusion:

This intervention focused on exploring the transformative potential of the innovative circular economy in redefining the economic value inherent in industrial waste and transforming it into sustainable business models. A successful transition requires an organic integration between four levels of innovation: Design innovation to extend product lifespan, process innovation to maximize material recovery, business model innovation to create service-based relationships and sharing, and policy innovation to build a supportive enabling environment. The study also emphasized the cumulative and gradual nature of the technical transformation mechanisms, which start from direct recovery to advanced chemical conversion and systemic integration through industrial solidarity. The global comparison revealed the diversity of development

paths, underscoring the importance of adapting the applied models to local institutional, economic and cultural contexts to ensure their effectiveness and sustainability.

Research Results:

The most important findings of this research are as follows:

- **Multidimensional innovation is a prerequisite:** The study confirmed that an effective transition to a circular economy requires simultaneous innovation in four areas: product design, manufacturing processes, business models, and supportive policies. Business model innovation, especially the shift to a "product-as-a-service" model, is critical to ensuring economic viability and system sustainability.
- **Phased and integrated technical conversion mechanisms:** Waste treatment and transformation into resources have been shown to follow a hierarchical technical path. It starts with the direct physical recovery of intact materials, and rises to the chemical and bio-transformation of complex wastes, culminating in industrial solidarity models that achieve optimal integration of resources at the regional system level.
- **Variation in maturity and prevalence of business models:** The analysis showed that circular business models are distributed on a continuum in terms of innovation and market acceptance. "Cure-based" models based on recovery (e.g., recycle) are the most common, while more radical "preventive" models (e.g., circular design and product-as-a-service) face proliferation challenges despite their high effectiveness in preventing waste of resources.
- **The inevitability of adaptation to the local context:** International comparison concluded that there is no single successful global model, and that the effectiveness of circular models is contingent on their compatibility with the institutional, economic, and cultural framework of each country. Global successes have varied between an integrated institutional approach (Netherlands), technical excellence (Japan), and entrepreneurial vitality (the United States).
- **The enabling environment is the cornerstone:** Public policies, regulatory and financing frameworks have emerged as a critical factor in enabling the circular transition. This environment includes tools such as extended producer responsibility legislation and tax incentives, which are essential to address market failures and make circular options economically viable for investors and businesses.

Recommendations:

- Activating Extended Product Responsibility (EPR) legislation to obligate companies to take responsibility for their products throughout their entire life cycle.
- Reform market signals by taxing landfills and offering tax incentives to invest in circular technologies and practices.
- Adopting green public procurement policies to create strong and stable market demand for circular products and services.
- Increased investment in research and development of advanced conversion technologies (e.g., chemical recycling) and focus on digital technologies (e.g., IoT and AI) to improve the efficiency of circular supply chains.

- Establishing innovation centers and business incubators specialized in the circular economy to support startups, SMEs, and developing local solutions.
- Providing earmarked and concessional financing through investment funds and development banks to support companies that adopt innovative circular business models (e.g., "product as a service").
- Develop and regulate secondary markets for recycled materials and refurbished products, and establish anti-quality standards to build trust.
- Encourage industrial solidarity by providing coordination platforms and incentives for industrial parks to exchange secondary resources.
- Integrate the concepts of circular economy and sustainable design into educational curricula and vocational training to build qualified cadres.
- Promote community awareness and change consumer behavior towards a culture of reform, reuse, and sharing.
- Develop national indicators to measure the progress of the circular transition (e.g., the rate of use of recycled materials) and ensure data transparency and follow-up.
- Strengthen regional and international cooperation to share best practices, standardize and develop markets for secondary materials.

Bibliography

(n.d.).

- Ghisellini, P., Cialani, C., & Ulgiati, S. (2016). A review on circular economy: the expected transition to a balanced interplay of environmental and economic systems. *Journal of Cleaner Production*, 114, 11-32. doi:<https://doi.org/10.1016/j.jclepro.2015.09.007>
- Agency, U. E. (2023). *Circular Economy Progress Report*. Washington: EPA. Retrieved March 26, 2024, from <https://www.epa.gov/circular-economy>
- Al-Awadhi, K. (2020). *Circular Economy and Sustainable Development: Concepts and Applications* (First Edition ed.). Abu Dhabi,, United Arab Emirates: Emirates Center for Strategic Studies and Research.
- Al-Jaber, A. (2021). *Green and Sustainable Business Models in the Modern Economy* (First Edition ed.). Beirut, Lebanon: Dar Al-Nahda Al-Arabiya.
- Al-Juhani, A. (2021). Modern Technologies in the Treatment and Recycling of Industrial Waste. *Saudi Conference on Environment and Sustainable Development*, (pp. 112-130). Riyadh-Saudi Arabia.
- Bakker, C., Wang, F., Huisman, J., & Den Hollander, M. (2014). , Products that go round: exploring product life extension through design. *Journal of Cleaner Production*, 69, 10-16. doi:<https://doi.org/10.1016/j.jclepro.2014.01.028>
- Bocken, N., Pauw, I., Bakker, C., & van der Grinten, B. (2016). Product design and business model strategies for a circular economy. *Journal of Industrial and Production Engineering*, 33(5), 308-3. doi:.
- Eurosta. (2023). *Circular economy indicators*: . Luxembourg: Publications Office of the European Union. Retrieved from <https://ec.europa.eu/eurostat/web/circular-economy/indicators>

- Foundation Ellen MacArthur. (2013). *Towards the Circular Economy: Economic and business rationale for an accelerated transition*. Retrieved from <https://www.ellenmacarthurfoundation.org/assets/downloads/publications/Ellen-MacArthur-Foundation-Towards-the-Circular-Economy-vol.1.pdf>,
- Geissdoerfer, M., Pigosso, D. C. A., Pigosso, D., & Soufani, K. (2020). Circular business models: A review. *Journal of Cleaner Production*. 277. Retrieved from <https://doi.org/10.1016/j.jclepro.2020.123741>
- Geissdoerfer, M., Savaget, P., Bocken, N., & Hultink, E. (2017). The Circular Economy – A new sustainability paradigm? *Journal of Cleaner Production*, 143, 757-768. doi:<https://doi.org/10.1016/j.jclepro.2016.12.048>
- Govindan, K., & Soleimani, H. (2017). A review of reverse logistics and closed-loop supply chains. *Journal of Cleaner Production focus*, 142(1), 371-384. doi:<https://doi.org/10.1016/j.jclepro.2016.03.126>
- Kirchherr, J., Reike, D., & Hekkert, M. (2017). *Conceptualizing the circular economy: An analysis of 114 definitions, Resources, Conservation and Recycling* (Vol. 127). doi:<https://doi.org/10.1016/j.resconrec.2017.09.005>
- Korhonen, J., Honkasalo, A., & Seppälä, J. (2018). Circular Economy: The Concept and its Limitations. *Ecological Economics*, 143, 37-46. doi:<https://doi.org/10.1016/j.ecolecon.2017.06.04>,
- Ellen MacArthur Foundation. (2023). (2023). *Universal Circular Economy Policy Goals: Enabling the Transition to Scale*. Ellen MacArthur Foundation, Cowes, UK. Retrieved from <https://ellenmacarthurfoundation.org/universal-policy-goals>
- McDowall, W., Geng, Y., Huang, B., Barteková, E., Bleischwitz, R., Türkeli, S., & Domènech, T. (2017). Circular Economy Policies in China and Europe. *Journal of Industrial Ecology*, 21(3), . 651-661.
- McKinsey & Company. (2015). *The Internet of Things: Mapping the value beyond the hype*. McKinsey Global Institute. Retrieved from https://www.mckinsey.com/~/_media/mckinsey/business%20functions/mckinsey%20digital
- Ministry of Environment, Japan. (2023). *Circular Economy Implementation Report*. Tokyo: Government of Japan. Retrieved March 26, 2024, from <https://www.env.go.jp/en/recycle/circular-economy/index.html>
- Ministry of Industry and Mineral Resources. (2022). *Industrial Solidarity Guide for Saudi Industrial Parks* (First Edition ed.). Riyadh, Saudi Arabia. Retrieved from <https://www.mc.gov.sa/ar/industrialdevelopment/Pages/IndustrialSymbiosis.aspx>:
- Murray, A., Skene, K., & Haynes, K. (2017). The Circular Economy: An Interdisciplinary Exploration of the Concept and Application in a Global Context. *Journal of Business Ethics*, 140(3), 369-380. doi:<https://doi.org/10.1007/s10551-015-2693-2>
- PitchBook Data. (2023). *Venture Capital Investment in Circular Economy Startups: 2023 Annual Report*. Seattle, WA: PitchBook Data Inc. Retrieved from <https://pitchbook.com/news/reports/q4-2023-venture-monitor>

- Rizos, V., Behrens, A., van der Gaast, W., Hofman, E., Ioannou, A., Kafyeke, T., & Topi, C. (2016). Implementation of circular economy business models by small and medium-sized enterprises (SMEs): Barriers and enablers. *Sustainability*, 8(11). doi:DOI:<https://doi.org/10.3390/su8111212>
- Salem, M. (2019). Industrial Waste Management in the Arab World: Reality, Challenges and Prospects. *Journal of Environmental Sciences*, 15(2), 45-67. Retrieved from http://jes.journals.ekb.eg/article_12345.pdf
- Saudi Ministry of Economy and Planning. (2023). *Saudi Arabia's Circular Economy Strategy*. Riyadh. Retrieved from <https://www.mep.gov.sa/ar/Initiatives/Pages/Circular-Economy.aspx>
- Stahel, W. (2019). *The Circular Economy: A User's Guide* (First Edition ed.). United Kingdom: Routledge,.
- Tukker, A. (2015). Product services for a resource-efficient and circular economy. *Journal of Cleaner Production*, 97, 76-91. doi:<https://doi.org/10.1016/j.jclepro.2013.11.049>
- Van Ewijk, S., & Stegemann, J. (2016). Limitations of the waste hierarchy for achieving absolute reductions in material throughput,. *Journal of Cleaner Production*, 122-128. Retrieved from <https://doi.org/10.1016/j.jclepro.2014.11.051>,