

Essay on the paradigm of frugal innovation: impact on the resilience of urban ecosystems in the face of transition ecological in Morocco.

Essai sur le paradigme de l'innovation frugale : impact sur la Résilience des écosystèmes urbains face à la transition

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Abstract

The ecological transition is currently a crucial challenge for urban areas, subject to increasing pressure on natural resources, climate change and sustainable development imperatives. In this context, frugal innovation appears as a promising method to encourage innovative solutions, affordable and adapted to the constraints of emerging countries. This study aims to examine the influence of frugal innovation on urban ecosystem resilience in Morocco.

The approach adopted is based on an empirical analysis using annual data from 2010 to 2025, mainly collected from the World Bank, the OECD, the High Commission for Planning (HCP) and the International Monetary Fund (IMF). The indices used in this research are developed from indicators representative of frugal innovation and urban resilience. Econometric analysis uses an ARDL.

The results reveal that frugal innovation has a positive impact on the resilience of urban ecosystems. They also highlight the importance of human capital, institutional quality and environmental expenditure in improving the ability of territories to adapt to the challenges of the ecological transition.

This study enriches knowledge on frugal innovation and urban resilience in the context of emerging countries and offers recommendations to policymakers to promote policies supporting a sustainable ecological transition.

Keywords: Frugal innovation; urban resilience; ecological transition; ARDL; Morocco.

Résumé

La transition écologique constitue actuellement un défi crucial pour les zones urbaines, soumises à une pression croissante sur les ressources naturelles, aux changements climatiques et aux impératifs de développement durable. Dans ce cadre, l'innovation frugale se présente comme une méthode prometteuse pour encourager des solutions innovantes, abordables et adaptées aux contraintes des pays émergents. Cette étude a pour objectif d'examiner l'influence de l'innovation frugale sur la résilience des écosystèmes urbains au Maroc. L'approche adoptée repose sur une analyse empirique utilisant des données annuelles de 2010 à 2025, recueillies principalement auprès de la Banque mondiale, de l'OCDE, du Haut-Commissariat au Plan (HCP) et du Fonds Monétaire International (FMI). Les indices utilisés dans cette recherche sont élaborés à partir d'indicateurs représentatifs de l'innovation frugale et de la résilience urbaine. L'analyse économétrique emploie un modèle ARDL.

Les résultats révèlent que l'innovation frugale a un impact positif sur la résilience des écosystèmes urbains. Ils soulignent également l'importance du capital humain, de la qualité institutionnelle et des dépenses environnementales dans l'amélioration de la capacité d'adaptation des territoires face aux défis de la transition écologique. Cette étude enrichit les connaissances sur l'innovation frugale et la résilience urbaine dans le contexte des pays émergents et offre des recommandations aux décideurs publics pour promouvoir des politiques soutenant une transition écologique durable.

Mots-clés : Innovation frugale ; Résilience urbaine ; Transition écologique ; ARDL ; Maroc.

Introduction

Over the past few decades, rapid urbanization has profoundly transformed territories around the world, making cities vital centers of production, innovation, and governance. This characteristic 21st-century phenomenon exerts increased pressure on natural resources, exacerbates socio-spatial inequalities and amplifies vulnerability to environmental risks. In this context, cities appear both as crucial drivers of development and as areas particularly exposed to the challenges of the ecological transition.

The ecological transition goes far beyond a simple technical adaptation of urban infrastructures. It requires a complete overhaul of urban systems, integrating their methods of production, consumption and governance. This transformation is based on more efficient resource management, a reduction of environmental impacts and the development of innovative solutions adapted to local specificities. However, this evolution is taking place in an uncertain context, where environmental, health and economic crises are testing the ability of cities to adapt, be resilient and transform themselves in a sustainable way.

The concept of resilience presents itself as a crucial analytical framework for assessing the capacity of urban systems to manage disruptions. The studies by (Folke, 2016) and (Brain Walker, 2012) reveal that resilience goes beyond simple resistance to shocks, also encompassing the capacity to adapt, learn, and transform. Furthermore, (Seto et al., 2012) highlight the significant impact of urban expansion as an environmental pressure, which makes the integration of sustainable strategies into urban planning essential. Research by (Elmqvist et al, 2013) also explains how urban ecosystems play a key role in improving the sustainability and resilience of cities. More recently, (Meerow et al., 2016) as well as the (*The Organisation for Economic Co-Operation and Development* | *OECD*, n.d.) demonstrate that integrated approaches to urban resilience strengthen cities' capacity to face the challenges of the ecological transition.

In this context, innovation is positioned as an essential lever to facilitate the ecological transition. Yet traditional methods of innovation show their limits when it comes to managing limited resources. This is where the concept of frugal innovation, presented by (Radjou Navi Prabhu Jaideep Ahuja Simone, 2012), finds its relevance. This model values the approach of "doing more with less", by designing simple solutions that are accessible and adapted to local particularities. At the same time, researchers such as (Levänen et al., 2015), (Hossain, 2021) and (Weyrauch & Herstatt, 2016) also highlight the crucial role of frugal innovation in promoting sustainability and optimizing available resources.

The Natural Resource-Based View, initially introduced by (Hart, 1995) and expanded by (Hart & Dowell, 2011), emphasizes that environmental capabilities and sustainable resource management provide a foundation for long-term competitive advantage. This approach encourages innovations that tackle environmental and social challenges. Recent studies have reinforced this view, demonstrating that environmental threats can drive frugal innovation through co-innovation capabilities, ultimately aiding sustainable development and ecological transition (Adomako et al., 2024).

In the context of developing countries, and especially in Morocco, these issues take on special importance. Morocco, characterized by rapid urbanization, faces major challenges related to resource management, sustainability and resilience. Although initiatives have been launched to facilitate the ecological transition, structural constraints remain, highlighting the need for creative solutions adapted to local realities.

While numerous studies have independently explored urban resilience, ecological transition, and frugal innovation, there is still a notable lack of research that examines how these elements can be integrated holistically, particularly in emerging countries such as Morocco (Liu et al., 2025; Rosca et al., 2017). This lack in the literature highlights the need for this research.

To what extent does the integration of the frugal innovation paradigm contribute to strengthening the resilience of urban ecosystems in the face of the ecological transition in Morocco?

This article examines the mechanisms by which frugal innovation enhances the capacity of urban systems to adapt, optimize their resources and evolve sustainably.

1. Literature review

1.1 Transformation of innovation paradigms in a context of ecological transition

The question of the evolution of innovation paradigms is today at the heart of scientific discussions concerning the ecological transition. This process aims to transform production, consumption and management patterns in order to reduce the ecological footprint of human activities, challenging traditional models of innovation based on technological performance, linear growth and high consumption of resources. Historically, innovation has often been viewed from a technology-centric perspective, where progress has depended heavily on the adoption of new technologies and productivity improvements. However, the pioneering work of Freeman and Lundvall went beyond this simplistic view by introducing the concept of innovation systems, highlighting the importance of interactions between companies,

institutions, knowledge and public policies in the creation and dissemination of innovation.

This conceptual evolution has progressively broadened the understanding of innovation, integrating its environmental, social and institutional dimensions. As part of the ecological transition, a new paradigm has emerged: that of sustainable innovation or green innovation. Schiederig and his colleagues define this type of innovation as encompassing products, processes, organizational practices and business models specifically aimed at reducing environmental impacts throughout the life cycle. Recent research extends this view by showing that green innovation goes beyond the introduction of clean technologies, implying a deeper transformation of production, governance, and consumption systems. From this perspective, the evaluation of innovation is no longer based solely on its economic performance, but also on its ability to contribute to sustainability, resource efficiency, and territorial resilience.

Currently, the concept of systemic innovation is becoming increasingly significant in research focused on socio-ecological transitions. This approach goes beyond mere incremental improvements to products or processes, aiming instead for a deep transformation of socio-technical systems. According to (Geels, 2002), such transitions emerge from the intricate interactions among developing innovation niches, established socio-technical regimes, and overarching macro-institutional pressures. This multi-level framework is crucial for understanding current changes linked to ecological transitions, as it underscores that change is driven not only by new technologies but also by the shifts in institutions, behaviors, infrastructure, and economic models. Building on these findings, recent literature emphasizes that effective ecological transitions rely on innovations that can alter organizational routines, modes of coordination among stakeholders, and mechanisms of value creation (Elisabeth M. C.Svennevik, 2022; Frank W. Geels, 2022).

It is in this context that the concept of frugal innovation emerges, which provides a particularly judicious response to the challenges of the ecological transition, especially in emerging countries. Popularized by (Radjou Navi Prabhu Jaideep Ahuja Simone, 2012), frugal innovation is based on the principle of "doing more with less", developing simple, affordable, robust solutions adapted to resource-limited environments. Unlike traditional innovation models, which are often capital, technology and infrastructure intensive, frugal innovation emphasizes sobriety, accessibility and local adaptation. (Hossain, 2021) points out that frugal innovation represents a crucial lever for sustainability in developing economies, as it reconciles economic constraints, social inclusion, and environmental efficiency. Other recent studies also indicate that this approach promotes the implementation of more resilient solutions, better suited to the

needs of populations and more aligned with the requirements of the ecological transition ((Albert, 2022); Iqbal et al., 2022)(Dabić et al., 2022)

The circular economy plays an essential role in transforming innovation paradigms. This model departs from the traditional linear approach of extraction, production, consumption and disposal to encourage waste reduction, resource reuse, and product life extension. Initiatives by the (Ellen MacArthur Foundation, 2013) have been instrumental in structuring this field, showing that circularity is not only an environmental strategy but also a driver of competitiveness and resilience. Recent research emphasizes the connections between frugal innovation and the circular economy. Both ideas focus on optimizing resources, cutting costs, and generating value even when faced with limitations (**Bocken & Konietzko, 2022; Dabić et al., 2022**).

However, although various authors note their theoretical convergence, some insist that their practical implementation depends a lot on institutional capacities, local infrastructures, and modes of governance, which prevents considering their relationship as automatic or uniform. In urban environments, this transformation is particularly significant. Cities account for a growing share of environmental pressures, energy needs, socio-spatial inequalities, and climate vulnerabilities. They thus become the privileged places to test innovative solutions that reconcile performance, sobriety, and inclusion. The urban ecological transition highlights that innovation must be seen as a collective process involving public, private, associative and citizen actors, in a logic of co-construction and shared learning (Bulkeley, 2013); (Meerow et al., 2016); (Elmqvist et al., 2019). In this context, frugal innovation appears as a particularly appropriate paradigm for cities in emerging countries, where budgetary, institutional, and infrastructural constraints require solutions that are accessible, flexible, and adapted to the local context.

Thus, the evolution of innovation paradigms represents a major change: innovation is no longer perceived solely as an engine of economic growth based on advanced technology, but as a multidimensional process oriented towards sustainability, efficiency, inclusion, and resilience. This theoretical redesign sets the stage for exploring frugal innovation, which is valuable for its ability to combine resource constraints, local adaptation, and ecological transition. It also justifies the examination of its role within urban ecosystems, where issues of resilience become crucial in the face of intensifying environmental, social and economic shocks.

1.2 Frugal innovation: origin and conceptual evolution

Frugal innovation is a relatively recent concept within the field of innovation management,

though its theoretical and practical origins can be traced back to longstanding dynamics associated with resource-constrained environments and the development of emerging economies. It emphasizes creating simple, accessible, sustainable, and effective solutions while utilizing minimal resources.

1.2.1 : Origins of frugal Innovation

The concept of frugal innovation has gained traction in emerging economies like India, where various constraints drive the need for innovative solutions to meet basic needs. In these settings with limited resources, organizations and entrepreneurs have adopted strategies that emphasize simplicity, accessibility, and optimizing capacity over heavy investment in technology. The term frugal innovation was popularized by (Radjou Navi Prabhu Jaideep Ahuja Simone, 2012), describing it as the capability to achieve "more with less." According to these authors, frugal innovation extends beyond merely cutting costs; it challenges traditional innovation models by creating effective, affordable, and context-specific solutions that address essential user needs. However, this concept lacks a unanimous definition in existing literature. **(Bhatti & Ventresca, 2013)** argue that reducing frugal innovation to mere cost-cutting is too simplistic. They propose that it signifies a new model of value creation rooted in organizational creativity, efficient resource use, and adaptability to contextual constraints. Likewise, (Nirmalya Kumar, 2012) highlighted frugal engineering, showing that high-performance products can be developed with considerably fewer resources. Recent studies highlight that frugal innovation has progressed from its early use in emerging economies to becoming a strategic approach for tackling sustainability challenges. It is now widely acknowledged for boosting resource efficiency, fostering sustainable value creation, and enhancing organizational resilience across various economic contexts **(Barnikol & Liefner, 2024; Van Tuijl et al., 2024; Zhang et al., 2024)**. While there is general consensus on the origins of frugal innovation in resource-constrained environments, literature reveals significant differences in its conceptualization, objectives, and scope. This diversity underscores the need for further research to deepen our understanding of how frugal innovation contributes to sustainable development and territorial resilience.

1.2.2 : Conceptual Evolution of frugal innovation

Frugal innovation has become an integral part of emerging economies. Here, limitations in economic, social, and infrastructure resources have driven the creation of novel solutions to address fundamental needs. In these settings, organizations and entrepreneurs prioritize simplicity and accessibility, making the most of available resources instead of relying heavily

on advanced technology. Within these environments, organizations and entrepreneurs prioritize simplicity, accessibility, and maximizing capacity over heavy technological investment. The popularization of frugal innovation is often credited to (Radjou Navi Prabhu Jaideep Ahuja Simone, 2012), who described it as the skill to "do more with less." Far from being just about cutting costs, this concept defies traditional innovation models by developing effective, affordable solutions tailored to meet essential needs. Nonetheless, this concept is not uniformly defined in academic literature. **(Bhatti & Ventresca, 2013)** argue that reducing frugal innovation to mere cost-cutting oversimplifies the concept. They see it as a new value creation model rooted in organizational creativity, efficient resource use, and adaptability. (Nirmalya Kumar, 2012) similarly emphasize frugal engineering, showing that high-performance products can be crafted with significantly fewer resources. Recent research indicates that frugal innovation transcends mere coping with resource scarcity. It has emerged as a strategic tool for enhancing competitiveness, sustainability, and resilience. Organizations now increasingly leverage this concept to develop solutions that yield economic, social, and environmental benefits. This shift reflects a change in viewpoint, where frugality is recognized as a strategic capability for performance enhancement and resource optimization (Chandni et al., 2021; De Marchi et al., 2022). While there's consensus on the origins of frugal innovation in resource-limited settings, the literature shows significant differences in its conceptualization, goals, and scope. This variation underscores the need for further research to better grasp how frugal innovation contributes to sustainable development and regional resilience.

1.3 The ecological transition and the challenges of urban ecosystems

The ecological transition has become an essential element of public policies and scientific research, particularly in response to worsening climate change, depletion of natural resources, increasing urbanization, and rising social inequalities-environmental. Cities, home to more than half of the world's population and a major contributor to greenhouse-gas emissions, are at the heart of this transformation. Thus, the ecological transition goes beyond simply reducing environmental impacts; it requires a restructuring of production systems, consumption, governance and urban planning.

However, the literature reveals various interpretations of this transition. Early works, such as those of (Geels, 2002), argue that transitions rely mainly on technological innovations capable of gradually transforming socio-technical systems. In this approach, green technologies, smart infrastructure and renewable energy stand out as the main drivers of the ecological transition.

On the other hand, (Ostrom, 2010) emphasizes that the success of environmental policies also depends on polycentric governance mechanisms favoring cooperation between different territorial actors. (Folke, 2016) points out that the resilience of socio-ecological systems is mainly based on their ability to learn, adapt and transform in the face of environmental disturbances, pointing out that technological innovations alone do not guarantee a sustainable transition.

Recent research continues to deepen this conceptual evolution. The work of (Iqbal et al., 2024) highlights that sustainable development is based on a mix of frugal innovation, entrepreneurial tinkering, and diversity of knowledge. These researchers believe that to create sustainable value, the importance lies less in the abundance of resources than in their efficient use, organizational capacities and collective learning. Similarly, the *(AR6 Synthesis Report: Climate Change 2023, n.d.)* emphasizes the need to simultaneously integrate climate policies, innovation, territorial planning, and governance to improve cities' adaptability. *(World Cities Report 2022: Envisaging the Future of Cities | UN-Habitat, n.d.)* supports this vision by highlighting that urban sustainability is based on inclusive governance, integrated resource management, and context-specific solutions. More recently, (Mahajan, 2025) demonstrated that the most effective strategies for the ecological transition combine nature-based solutions, adaptive planning, stakeholder participation and territorial innovation.

However, differences continue to exist regarding the levers for ensuring this transition. (Geels, 2002) favors a technological approach centered on socio-technical innovations, while (Ostrom, 2010), (Folke, 2016) and (Mahajan, 2025) defend a more integrated perspective where governance, institutional capacities, Collective learning and stakeholder participation are equally crucial. This scientific debate highlights that no single approach can explain the complexity of the ecological transition. The most recent research thus favors a systemic approach combining technological innovations, organizational innovations, collaborative governance and sustainable resource management.

These advances reflect the principles of the Natural Resource-Based View (Hart, 1995), which holds that conservation of natural resources, pollution prevention and environmental innovation capabilities are sustainable sources of competitive advantage. From this perspective, the ecological transition depends on the ability of organizations and territories to innovate by reconciling economic performance, resource efficiency, and environmental sustainability.

In the Moroccan context, these issues are particularly significant. The acceleration of urbanization, the increasing pressure on water resources, the effects of climate change, as well

as the requirements of the energy transition, require rethinking traditional models of urban development. Although various national strategies have been implemented to support this transition, their success remains linked to the capacity of public and private actors to develop innovative, resource-efficient solutions adapted to local realities.

The literature reveals that the ecological transition is currently an evolving field of research. Although there is a consensus on its strategic importance, debates continue about effective mechanisms for its implementation. This lack of agreement justifies the interest in exploring frugal innovation as a strategic lever, capable of combining economic performance, resource optimization, and strengthening the resilience of urban ecosystems in the Moroccan context.

1.4 The resilience of urban ecosystems

The resilience of urban ecosystems has emerged as a significant area of research due to the accelerating effects of climate change, rapid urban growth, limited resources, and increasing socio-economic vulnerabilities. As cities become hubs of population, infrastructure, and economic activities, they face heightened exposure to environmental disruptions that threaten their long-term viability. As a result, urban resilience has become a strategic goal to ensure cities can handle present and future challenges while maintaining critical functions and promoting sustainable development. Initially introduced by (Holling, 1973), resilience was defined as the ability of ecological systems to absorb disturbances while maintaining their basic structures and functions. This ecological view provided the theoretical basis for resilience research. However, current urban studies have expanded this concept by highlighting the institutional, social, economic, and governance aspects that influence cities' adaptability. Recent studies increasingly acknowledge that governance is a key factor in urban resilience. (Birchall et al., 2023) have shown that governance structures significantly affect local authorities' capacity to implement climate adaptation measures and coordinate with various stakeholders. Their research suggests that resilient areas rely not only on technical solutions but also on transparent institutions, effective leadership, and cooperative decision-making processes capable of handling environmental uncertainties. In a similar vein, (Abdillah et al., 2023) point out that climate governance is crucial for urban resilience. Their systematic literature review demonstrates that successful resilience strategies require institutional coordination, policy integration, stakeholder engagement, and sustainable resource management. They argue that fragmented governance systems hinder cities' ability to anticipate and manage environmental risks, while integrated governance frameworks enhance both

adaptability and long-term sustainability. Additionally, (Ouyang et al., 2023) stress the importance of collaborative governance in enhancing resilience amid more frequent climate-related disasters. They find that cooperation among governments, private entities, researchers, and local communities fosters knowledge sharing, improves emergency readiness, and bolsters adaptive capabilities. Their conclusion is that resilient cities need not only infrastructure investments but also governance mechanisms that promote cooperation, innovation, and collective action. While there is growing agreement on the role of governance, discussions continue about the most effective ways to enhance urban resilience. Some researchers advocate for institutional reforms and policy coordination, while others focus on stakeholder collaboration and adaptive governance as primary resilience drivers. Contemporary studies are converging on the perspective that resilience is a multidimensional process involving environmental protection, institutional effectiveness, social inclusion, innovation, and efficient resource management rather than just an ecological or technological concept. In Morocco, these challenges are particularly pronounced due to rapid urban growth, increasing water scarcity, climate variability, and regional socio-economic disparities. Although national strategies have encouraged sustainable urban development and climate adaptation, fragmented governance and resource limitations still hinder urban ecosystem resilience. Here, frugal innovation offers a promising approach by providing affordable, resource-efficient solutions tailored to local needs that can support sustainable urban development while enhancing the resilience of Moroccan cities. Overall, the literature indicates that urban ecosystem resilience has shifted towards an integrated governance-oriented view where institutional capacity, stakeholder collaboration, sustainable resource management, and innovation are seen as fundamental elements of resilient cities. Nevertheless, further empirical research is needed to better understand how frugal innovation can bolster urban resilience and aid the ecological transition within Morocco.

1.5 The role of frugal innovation in urban resilience

The growing frequency of environmental, economic, and social crises highlights the urgent need for innovative methods to bolster the resilience of urban ecosystems and ensure efficient resource usage. In this context, frugal innovation has steadily gained attention as a strategic approach that empowers cities to tackle climate change, rapid urbanization, and resource shortages with solutions that are affordable, accessible, and tailored to specific contexts. Unlike traditional innovation models that often demand significant technological and financial investments, frugal innovation prioritizes simplicity, adaptability, and resource efficiency,

making it an ideal fit for promoting sustainable urban development. Scholars increasingly recognize that frugal innovation enhances urban resilience by boosting the ability of cities and organizations to foresee, withstand, adapt to, and recover from environmental and socio-economic challenges. By optimizing available resources, promoting local expertise, and developing cost-effective solutions, frugal innovation strengthens urban systems' capacity to maintain critical functions while minimizing environmental impact and fostering long-term sustainability. Recent research supports this view from various angles. A study by (Chandni et al., 2021) identifies frugal innovation as a complex concept focused on affordability, adaptability, accessibility, resource efficiency, and sustainability, beyond merely reducing costs. Their analysis shows that the diverse definitions of frugal innovation reflect its strategic development beyond contexts bound by resource constraints. Furthermore, in 2025, claim that frugal innovation has evolved into a strategic capability combining sustainability goals with organizational flexibility and efficient resource use to create enduring value. These insights indicate that frugal innovation is increasingly seen not just as a method for addressing scarcity but as a model supporting resilient and sustainable urban growth. Despite a general agreement on the strategic role of frugal innovation in promoting sustainability and urban resilience, there are significant differences concerning the mechanisms leading to these outcomes. While Hindocha et al. primarily emphasize clarifying concepts and defining attributes, (**Escudero-Cipriani et al., 2024; Sacanamboy-Trujillo & Escandón-Barbosa, 2025**) highlight the strategic role of frugal innovation in generating sustainable value and enhancing organizational resilience. This divergence underscores the evolution of frugal innovation from a theoretical concept to a strategic asset that aids sustainable urban development. These conceptual differences underscore a gap in the current literature that lacks a unified theoretical framework on how frugal innovation boosts urban resilience. Most studies focus either on the characteristics of frugal innovation or its contribution to sustainability, leaving interactions between innovation capabilities, governance, resource efficiency, and urban ecosystem resilience underexplored. Thus, urban resilience cannot be solely explained by one aspect of frugal innovation but must consider the interplay of organizational capabilities, governance strategies, sustainability practices, and efficient resource management. This theoretical gap is notably pronounced in emerging economies where empirical studies are limited despite escalating environmental and urban challenges. In urban ecosystems, frugal innovation supports the creation of cost-effective infrastructure, decentralized public services, circular resource management, and locally tailored solutions to address climate-related risks and socio-economic

vulnerabilities. These features are particularly crucial for developing nations where financial and institutional constraints necessitate innovative methods that maximize environmental, economic, and social benefits while minimizing resource consumption. In Morocco, frugal innovation serves as a promising strategic tool for enhancing urban resilience. Rapid urbanization, increasing pressure on natural resources, climate variability, and budgetary limits demand innovative measures that are accessible, resource-efficient, and tailored to local conditions. By fostering locally driven innovation and resource optimization, frugal innovation can improve the adaptability of Moroccan cities while aiding ecological transition and sustainable urban growth. Overall, the literature reveals that frugal innovation has transitioned from a model focused on resource scarcity to a multidimensional strategy shaping sustainable urban futures.

1.6 The integration of frugal innovation into urban ecosystems

The integration of frugal innovation into urban ecosystems has emerged as a crucial strategy for tackling the challenges of ecological transition, rapid urban growth, and resource scarcity. This approach goes beyond merely developing low-cost products, advocating for the efficient use of resources, fostering stakeholder collaboration, and creating solutions that are locally adapted to improve the sustainability and resilience of urban environments. Achieving this integration demands not just technological innovation but also organizational, institutional, and social transformation. Recent studies offer various insights into the mechanisms that facilitate this integration. For instance, (Karroumi & Sedqui, 2024) highlight that implementing frugal innovation in Morocco requires organizational adaptation, efficient resource management, and innovative processes tailored to local socio-economic constraints. Their research underscores the importance of context-sensitive strategies in converting resource limitations into opportunities for sustainable urban development. In parallel, (Fu et al., 2024) assert that successfully integrating frugal innovation hinges on an interplay of factors such as leadership, organizational capabilities, entrepreneurial orientation, digital technologies, and resource availability. Their analysis reveals that no single factor suffices on its own; rather, a combination of diverse organizational and environmental conditions leads to successful outcomes. Adding another dimension, (Ur Rehman et al., 2024) emphasize the role of sustainable leadership, knowledge acquisition, and credible information in facilitating integration. They suggest that enhancing knowledge-sharing mechanisms and leadership practices can significantly boost an organization's ability to implement frugal innovation

effectively within the broader innovation ecosystem. Overall, these studies agree that integrating frugal innovation into urban ecosystems demands efficient resource management, organizational flexibility, stakeholder cooperation, and strong leadership. However, they differ on which aspects should be prioritized. While some emphasize organizational capabilities and digital advancements, others focus on local adaptation, knowledge management, and leadership practices. These differences highlight the absence of a one-size-fits-all model for integration, as the mechanisms are tightly linked to the specific institutional, economic, and territorial contexts. Moreover, the literature provides limited empirical evidence on how these integration mechanisms function within urban ecosystems, especially in emerging economies. The focus often remains on individual organizations or industrial sectors rather than treating urban areas as integrated socio-ecological systems. This knowledge gap calls for more empirical research to better understand how frugal innovation can support ecological transitions and bolster urban resilience across various territorial contexts. In Morocco, embedding frugal innovation into urban settings presents a promising means to address escalating environmental pressures, resource shortages, and swift urban expansion. By promoting collaborative innovation, effective resource use, and locally tailored solutions, frugal innovation has the potential to contribute significantly to building more sustainable and resilient cities while aiding the country's ecological transition. Ultimately, integrating frugal innovation in urban ecosystems should be seen as a complex process involving organizational strengths, leadership, governance, knowledge exchange, and contextual adaptation. Further empirical evidence is needed to clarify how these dimensions interact within Moroccan cities and enhance the resilience and sustainability of urban ecosystems.

1.7 Literature limitations and research gaps

The critical analysis of the literature reveals a growing scientific interest in frugal innovation, ecological transition, and urban resilience. Despite the expansion of research in these areas, several limitations remain, highlighting the need for further investigation.

Studies that simultaneously examine frugal innovation, the ecological transition, and the resilience of urban ecosystems remain rare. Most research deals with these concepts in isolation, without offering an integrated analysis of their interactions. This fragmentation of the literature prevents a full understanding of how frugal innovation can strengthen the resilience of urban ecosystems in the context of an ecological transition.

The literature is still largely dominated by conceptual approaches, with a notable lack of

empirical studies on the contexts of emerging countries, especially Morocco. The majority of research has been carried out in developed economies or in some countries such as India, which makes it difficult to apply their results to the Moroccan context, which has unique institutional, economic and environmental specificities.

Furthermore, there is no consensus in current research on the factors that facilitate the integration of frugal innovation into urban ecosystems. Some researchers emphasize the importance of innovation capacities, organizational resources and technologies, while others highlight collaborative governance, public policies, stakeholder networks and institutional capabilities. These disputes highlight the complexity of this phenomenon and underline the need for a more integrated approach.

Recent literature reviews, notably those conducted by Escudero-Cipriani and his collaborators in 2024, indicate that research on frugal innovation is gradually moving towards issues of sustainability, governance, and responsible value creation. However, the application of this approach to urban ecosystems and the ecological transition remains little studied, especially in emerging countries.

Faced with these observations, this research aims to fill this gap by proposing an integrated analysis of the mechanisms through which frugal innovation can strengthen the resilience of urban ecosystems in the context of the ecological transition in Morocco. It aims to enrich the scientific literature while providing practical implications and valuable recommendations to public decision-makers and local actors.

2. Theoretical Framework

To explore how frugal innovation strengthens the resilience of urban ecosystems in the context of the ecological transition, this research is based on the Natural Resource-Based View (NRBV) developed by Hart in 1995. This theory extends Barney's Resource-Based View (RBV), formulated in 1991, by introducing natural resources and environmental capabilities as essential elements for a sustainable competitive advantage. Unlike the traditional RBV perspective, the NRBV suggests that the performance of organizations and territories is based not only on their strategic resources, but also on their ability to use them effectively to address environmental issues.

According to Hart (1995), organizations that develop capacities focused on pollution prevention, sustainable resource management, the development of clean technologies and the continuous improvement of their environmental performance are better positioned to generate

sustainable economic, social and environmental value. In this context, resource scarcity constraints are not just barriers to development; they also offer opportunities to stimulate innovation, optimize the use of resources and strengthen the adaptability capacities of organizations and territories.

This approach is particularly relevant to examine frugal innovation, which relies on the creation of innovative solutions that produce added value with minimal resources. By focusing on efficiency, simplicity, accessibility and adaptation to local needs, frugal innovation encourages a more rational use of available resources, reduces environmental impacts and supports the objectives of the ecological transition.

In this context, the resilience of urban ecosystems refers to the capacity of territories to anticipate, absorb, adapt and transform themselves in the face of economic, social and environmental disruptions. According to the principles of NRBV, this resilience is strengthened when territorial actors develop innovative skills that allow them to use resources more efficiently, to promote cooperation between the parties concerned and improve their ability to adapt to change.

The Natural Resource-Based View (NRBV) thus provides a relevant theoretical framework for analyzing the relationships between the variables examined. Based on this theory (Hart, 1995), this research argues that frugal innovation is a strategic skill to optimize the use of resources and strengthen the resilience of urban ecosystems. This promotes the ecological transition by improving the capacity for adaptation, transformation, and sustainable management of territories. These theoretical links form the basis of the proposed conceptual model and research hypotheses discussed in the next section.

3. Research hypotheses

Based on the theoretical framework and the literature review, the following assumptions are

Proposed:

H1: Frugal innovation has a positive and significant effect on the resilience of urban ecosystems.

H2: The level of economic development (GDP) has a positive and significant effect on the resilience of urban ecosystems.

H3: Human capital has a positive and significant effect on the resilience of urban ecosystems.

H4: Institutional quality has a positive and significant effect on the resilience of urban

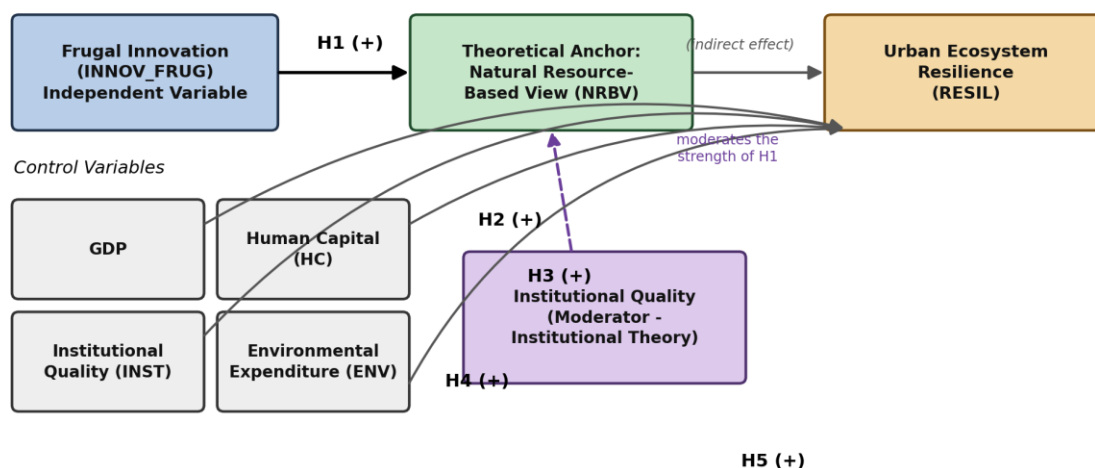
ecosystems.

H5: Environmental expenditures have a positive and significant effect on the resilience of urban ecosystems.

4. Conceptual model

The conceptual model integrates the earlier hypotheses, as depicted in Figure 1. In this model, frugal innovation is the primary independent variable, influencing urban resilience through the strategic environmental resources and capabilities of local actors, as explained by the Natural Resource-Based View. Meanwhile, the quality of institutions moderates this relationship, following Institutional Theory. To provide a more comprehensive analysis, GDP, human capital, and environmental expenditure are used as control variables.

Figure 1. Conceptual Research Model



5. Methodology

This study examines the resilience of urban ecosystems (RESIL) as the dependent variable, evaluated using various macro-environmental indicators that reflect the adaptive capacity and sustainability of Moroccan urban systems. The assessment relies on a composite index incorporating factors such as the proportion of renewable energy, CO2 emissions per capita, energy efficiency, and urban waste management practices. By adopting this methodology, the study seeks to address both the environmental and systemic aspects of resilience, aligning with the broader goals of ecological transition. Frugal innovation (INNOV_FRUG) serves as the primary explanatory variable, defined as the creation of simple, accessible, and resource-

efficient technologies. Since a direct measure of INNOV_FRUG is unavailable, it is proxied by expenditures on green innovation. To account for the influence of other contributing factors, several control variables are included in the model. These are gross domestic product (GDP) to capture economic development levels, human capital (measured by school enrollment rates), institutional quality (INST), urbanization levels (URB), and environmental expenditure (ENV). This approach aims to isolate the specific effect of frugal innovation on urban resilience. The analysis spans annual data from 2010 to 2025 a period characterized by the heightened implementation of ecological transition initiatives in Morocco. These include significant advancements in renewable energy development and the promotion of sustainable urban projects.

The data utilized in this analysis are obtained from credible secondary sources, including international organizations like the World Bank, IMF, and OECD, as well as national institutions in Morocco such as the HCP and the Ministry of Energy Transition. Before proceeding with econometric estimations, the data undergo necessary transformations, such as applying natural logarithms to stabilize variance and enable a more straightforward interpretation of coefficients in terms of elasticity. Additionally, a preliminary descriptive analysis is conducted, examining measures like means, standard deviations, skewness, and kurtosis. This step helps assess variable distributions and identify potential data anomalies. The econometric analysis begins by testing the stationarity of the time series to avoid spurious regressions. To this end, robust statistical tests like the augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) tests are employed to determine whether the variables are stationary at their levels ($I(0)$) or after first differencing ($I(1)$). Identifying the integration order of the variables is critical for selecting the most suitable econometric methodology. When a combination of $I(0)$ and $I(1)$ variables is detected, the ARDL (Autoregressive Distributed Lag) model is particularly appropriate. This approach allows simultaneous examination of both short-term and long-term relationships among variables, making it a pertinent choice for this study given the characteristics of the dataset and the relatively small sample size.

6. Construction of indices and operationalization of variables

The RESIL dependent variable is designed as a standardized composite index, calculated from four macro-environmental indicators: (i) the proportion of renewable energy in total energy consumption, (ii) per capita CO₂ emissions (with an inverted sign, a reduction meaning an increase in resilience), (iii) energy efficiency, measured by energy consumption per unit of GDP

(inverted sign), and (iv) an indicator of urban waste management (rates of recovery and recycling). Each series is first standardized according to the min-max method for the entire 2010-2025 period, with the formula:

$$I_norm = (X - X_min) / (X_max - X_min)$$

The composite index is then obtained by a simple arithmetic mean of the four standardized sub-indicators: $RESIL = (1/4) \times \sum I_norm,i$. Equal weighting was chosen due to the lack of a theoretical or empirical consensus on the relative importance of each dimension of urban resilience. This method ensures transparency, simplicity, and consistency in building the composite index.

In the absence of an official indicator for frugal innovation in Morocco, the variable INNOV_FRUG is estimated through spending on green innovation relative to GDP. This choice is explained by the fact that in Morocco, many empirical initiatives observed (such as decentralized solar technologies, low-cost drip irrigation, or artisanal waste recovery) fall under both green innovation and the frugal approach to "do more with less". However, this proxy has a known limit: it measures officially funded environmental innovation and may underestimate informal frugal practices not recorded in official statistics. This limitation is discussed in detail in the Limitations section of the study.

Table 1 presents, for each model variable, its operational definition, its unit of measurement and its source.

Variable	Operational definition	Unit	Source
RESIL	Composite index: energy share renewables, CO2/capita, efficiency energy, waste management	Index (0,1)	World bank (WDI), AMEE, HCP
INNOV_FRUG	Green innovation spending as a share of GDP	% du PIB	OCDE (Green Growth Indicators),
GDP	GDP per capita (log)	Log (USD constants)	World Bank (WDI)
HC	Secondary school enrollment rate	% gross	HCP, Institut de statistique de l'UNESCO
INST	Institutional quality index	Normalized index	Worldwide Governance Indicators
ENV	Public environmental expenditure relative to GDP	% of GDP	Ministry of Economic Affairs and Finance

The series used, as well as the code for econometric processing, will be available on request from the authors to ensure the replicability of the study.

The study is based on annual data between 2010 and 2025, totaling 16 observations. Although common in macroeconomic studies using recent national time series, this sample size remains

limited compared to the number of variables and time frames included in the ARDL model. The choice of this model is justified by its recognized robustness with small samples, compared to other cointegration methods such as the Johansen procedure. Despite this limitation, the results should be viewed as plausible structural trends rather than high-precision estimates. To strengthen the statistical power of the model, an important way is to extend the observation period through the use of sub-annual data or regional panels in Morocco in the future developments of this research.

The general specification of the model can be formulated as follows:

$$RESIL_t = \alpha + \sum_{i=1}^p \beta_i RESIL_{t-i} + \sum_{j=0}^q \gamma_j INNOV_FRUG_{t-j} + \sum_{k=0}^r \delta_k X_{t-k} + \varepsilon_t$$

- where X represents the set of control variables. The optimal selection of delays (or lags) is made based on information criteria such as AIC, SC or HQ to ensure the best model specification. To ensure the existence of a long-term relationship between variables, the ARDL cointegration test (or Bounds Test) is applied. This test involves comparing the calculated F-statistic with critical values.
- If the F statistic is greater than the upper bound → cointegration
- If it is lower than the lower terminal → absence of cointegration
- If it is between the two → indeterminate result

Confirmation of cointegration demonstrates the existence of a long-term balance between frugal innovation and urban resilience. To ensure the validity of the econometric results and the reliability of the estimated model, various diagnostic tests are carried out on the model residuals. These tests check whether the fundamental assumptions of the regression model are respected, which is crucial to obtain unbiased, efficient and interpretable estimators.

The Breusch-Godfrey autocorrelation test is used to detect a possible serial correlation in the residues. The null hypothesis states no autocorrelation, whereas the alternative hypothesis indicates a dependence between errors. This test is particularly relevant for dynamic models, especially when incorporating delayed variables. If autocorrelation is present, the estimators remain unbiased but lose efficiency, making statistical tests (t and F) potentially invalid.

The Breusch-Pagan heteroscedasticity test examines whether the variance of errors is constant (homoscedasticity) or variable (heteroscedasticity). The null hypothesis assumes a constant variance of the residuals, while its rejection indicates an irregular dispersion of the errors.

Heteroscedasticity can lead to a misestimation of standard errors, affecting the significance of coefficients and potentially leading to erroneous conclusions.

The Jarque-Bera normality test evaluates whether residues follow a normal distribution. This test is based on the asymmetry and kurtosis coefficients. The null hypothesis indicates that the residuals are normally distributed. Normality is essential for the validity of statistical tests, especially in small samples, as it ensures the reliability of confidence intervals and hypothesis tests.

Finally, the CUSUM and CUSUMSQ stability tests are used to verify the stability of the model coefficients throughout the study period. The CUSUM test checks the stability of recursive coefficients, while the CUSUMSQ test detects structural changes related to error variance. If the curves remain within the critical bands, this indicates that the model is stable over time. Otherwise, it suggests the existence of structural breaks or changes in economic relations.

7. Results

The analysis of descriptive statistics reveals a moderate dispersion in the urban resilience variable (RESIL), indicating a gradual yet relatively stable progression in Morocco's ecological adaptability during the studied period. In contrast, frugal innovation (INNOV_FRUG) exhibits greater variability, highlighting a dynamic trend of steady transformation characterized by the incremental adoption of resource-efficient and innovative solutions. Skewness coefficients close to zero and kurtosis values near 3 suggest that most variables adhere to an almost normal distribution, a conclusion further validated by p-values from the Jarque-Bera test exceeding 5%. This supports the application of traditional econometric methods. Meanwhile, the comparatively high volatility observed in environmental expenditures (ENV) underscores shifts in policy and uneven investment patterns in ecological initiatives, aligning with the transitional nature of public policies during this phase.

Variables	Moyenne	Écart-type	Min	Max	Skewness	Kurtosis	JB (p-value)
RESIL	3.45	0.52	2.61	4.28	-0.21	2.67	0.312
INNOV_FRUG	2.98	0.61	1.87	4.12	0.45	2.91	0.274
GDP	10.21	0.37	9.65	10.78	-0.12	2.45	0.401
HC	1.87	0.25	1.45	2.21	0.18	2.33	0.356
INST	0.12	0.09	- 0.05	0.29	-0.34	2.74	0.298

ENV	1.65	0.48	0.89	2.73	0.62	3.41	0.118
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The results of the ADF tests indicate that most variables are non-stationary at their level, a common characteristic of macroeconomic series. However, after applying first-order differentiation, all variables become stationary, suggesting they are predominantly integrated of order one (I(1).) Notable exceptions include variables like human capital (HC) and institutional quality (INST), which are stationary at their level (I(0).) This combination of I(0) and I(1) variables underscores the suitability of the ARDL model, which is specifically designed to accommodate mixed-series data. Furthermore, the absence of second-order integrated variables (I(2)) ensures that the assumptions underlying the ARDL model hold true, further enhancing the reliability of the chosen econometric approach.

Variables	(ADF)	First Difference(ADF)	Ordr
RESIL	-2.11 (0.24)	-5.43 (0.000)	I(1)
INNOV_FRUG	-1.89 (0.32)	-4.98 (0.001)	I(1)
GDP	-2.45 (0.18)	-6.21 (0.000)	I(1)
HC	-3.52 (0.04)	—	I(0)
INST	-3.11 (0.05)	—	I(0)
ENV	-2.03 (0.27)	-5.12 (0.000)	I(1)

The results of the ARDL cointegration test reveal that the F-statistic (5.87) significantly surpasses the critical upper bound at the 5% significance level. This provides enough evidence to reject the null hypothesis of no cointegration, thereby confirming the presence of a stable long-term relationship among urban resilience, frugal innovation, and the control variables. This finding is crucial as it demonstrates that these variables evolve together over time, despite any short-term fluctuations. It underscores the enduring structural impact of frugal innovation policies and economic dynamics on ecological resilience in Morocco. The long-term estimates further highlight that frugal innovation exerts a positive and highly significant influence on urban resilience, with a coefficient value of 0.42. Essentially, a 1% increase in frugal innovation corresponds to a 0.42% rise in resilience levels, emphasizing its pivotal role in driving the green transition. Moreover, institutional variables (INST) and human capital (HC) also exhibit positive and significant impacts, reflecting their complementary contribution to enhancing the value of innovations. GDP shows a similarly positive effect, underlining the critical role of

economic development in fostering resilience. Conversely, environmental expenditure (ENV) has only a marginally significant effect, suggesting that its efficiency depends largely on effective allocation and governance.

Variables	Coefficient	t-stat	p-value
INNOV_FRUG	0.42	3.87	0.001
GDP	0.31	2.65	0.012
HC	0.27	2.41	0.018
INST	0.35	3.12	0.004
ENV	0.19	1.98	0.052

In the short term, frugal innovation positively influences resilience, though its impact is moderate (coefficient of 0.18), suggesting that its full effects require time to manifest. This outcome aligns with the gradual nature of structural changes associated with the ecological transition. The negative and highly significant coefficient of the error correction term ECM(-1) (-0.53) confirms the presence of an adjustment mechanism driving the system toward long-term equilibrium. Practically speaking, this implies that around 53% of discrepancies are resolved annually, reflecting a relatively swift adjustment process. These findings indicate that the Moroccan economy demonstrates a notable capacity to adapt effectively to shocks stemming from innovation and environmental policies.

Variables	Coefficient	p-value
Δ INNOV_FRUG	0.18	0.021
Δ GDP	0.12	0.043
Δ ENV	0.09	0.081
ECM(-1)	-0.53	0.000

Diagnostic tests underpin the overall validity of the model. The Breusch-Godfrey test indicates the absence of autocorrelation, confirming that the errors are independent over time. Additionally, the Breusch-Pagan test demonstrates homoscedasticity, ensuring consistent residual variance and reinforcing the reliability of the estimators. The Jarque-Bera test further validates the normality of the residuals, ensuring the relevance and robustness of the statistical tests applied. Moreover, the CUSUM and CUSUMSQ stability tests reveal that the model's coefficients remain stable throughout the analyzed timeframe, ruling out any significant

structural breaks. Collectively, these results affirm the econometric soundness of the model and support the robustness of the conclusions drawn.

Test	Statistic	p-value	Conclusion
Breusch-Godfrey	1.87	0.17	No autocorrelation
Breusch-Pagan	1.54	0.21	Homoscedasticity
Jarque-Bera	1.98	0.37	Normality
CUSUM	Stable	—	Stable
CUSUMSQ	Stable	—	Stable

8. Discussion

The findings reveal that frugal innovation notably enhances the resilience of urban ecosystems in Morocco, aligning with H1. This aligns with the Natural Resource-Based View (Hart, 1995), which posits that efficient utilization of natural resources and environmental capabilities is a strategic foundation for sustainable development. In Morocco, adopting frugal innovation appears to bolster urban systems' ability to adapt to ecological and resource limitations through affordable, resource-efficient, and locally tailored solutions. These results also support previous studies emphasizing the role of frugal innovation in fostering sustainability and resilience (Levänen et al., 2015; Chandni et al., 2021; Dabić et al., 2022; Escudero-Cipriani et al., 2024). Additionally, the results show that human capital significantly enhances urban resilience, validating H3. This underscores that education, skills, and knowledge promote the adoption and spread of innovative practices, thereby boosting the adaptive capacity of urban ecosystems. This is consistent with Iqbal et al. (2024), who highlight that knowledge diversity and organizational learning are crucial drivers of sustainable and frugal innovation.

The positive influence of GDP also supports the second hypothesis, indicating that economic development provides the financial resources and investment capacity necessary to back ecological innovation and bolster urban resilience. However, the relatively moderate coefficient suggests that economic growth on its own cannot guarantee resilient urban development without the support of complementary institutional and environmental policies. On the other hand, environmental expenditure shows only a marginally significant impact, lending weaker support to the fifth hypothesis. This implies that merely increasing environmental spending is insufficient to enhance resilience. Its success hinges on the quality of governance, efficient allocation of public resources, and the ability to translate financial investments into concrete

environmental outcomes. This observation aligns with recent literature, which often argues that institutional effectiveness can be more critical than the amount of environmental investment alone. The comparison between short-run and long-run estimates offers valuable insights. Frugal innovation not only has a positive impact in the short term but also exhibits a much stronger influence over the long term. This suggests that the advantages of ecological innovation unfold gradually through learning, institutional adaptation, and continuous improvements in resource efficiency. The significant negative Error Correction Mechanism confirms a stable long-term equilibrium, emphasizing the steady adjustment of Moroccan urban ecosystems towards enhanced resilience. These findings add to the literature by providing empirical evidence from Morocco, an emerging economy that has been underrepresented in previous studies. They support the notion that urban resilience relies not just on technological advancements but also on the synergy between innovation capabilities, institutional quality, human capital, and sustainable governance.

Conclusion

This study explored the connection between frugal innovation and the resilience of urban ecosystems in Morocco during the ecological transition, employing an ARDL model with annual data from 2010 to 2025. The findings reveal that frugal innovation substantially boosts urban resilience, especially over the long term. Additionally, factors like human capital, institutional quality, and economic development play a significant role in enhancing the adaptive capacity of urban ecosystems. In contrast, environmental expenditure has a relatively minimal effect, indicating that financial resources alone are not enough without robust governance and institutional support. Theoretically, this research expands upon the Natural Resource-Based View (NRBV) by showing that frugal innovation is a strategic capability for optimizing resource use and enhancing urban resilience in the face of environmental challenges. The study also adds to the existing literature by offering empirical insights from Morocco, a country not widely explored in research on frugal innovation, ecological transition, and urban resilience.

From a practical standpoint, the findings offer valuable insights for policymakers and public authorities. By promoting frugal innovation through integrated public policies, enhancing institutional quality, investing in human capital, and encouraging locally tailored sustainable solutions, Moroccan cities can bolster their resilience while aligning with the country's ecological transition goals. However, this study has certain limitations. Firstly, the analysis is

derived from a relatively small sample spanning 2010 to 2025, which might affect the generalizability of the results. Secondly, using green innovation expenditure as a proxy for frugal innovation may not fully encompass all facets of the concept. Lastly, while the estimated ARDL model cleared all diagnostic tests, no additional robustness analysis was conducted. Future research could tackle these limitations by using larger datasets, alternative measures for frugal innovation, diverse econometric techniques, and robustness tests to further validate and generalize the findings.

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