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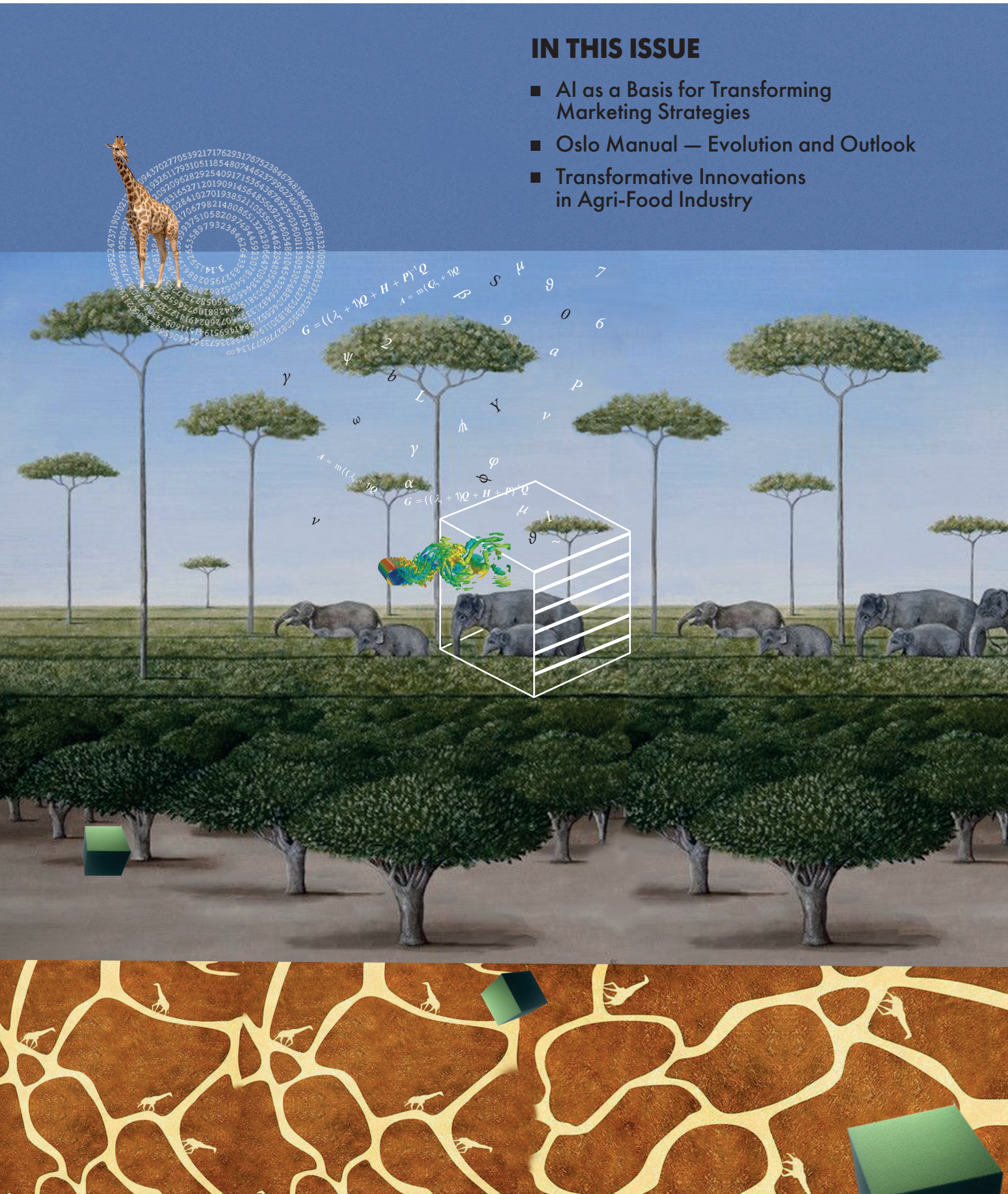

ABOUT THE JOURNAL

Foresight and STI Governance is an international interdisciplinary peer-reviewed open-access journal. It publishes original research articles, offering new theoretical insights and practice-oriented knowledge in important areas of strategic planning and the creation of science, technology, and innovation (STI) policy, and it examines possible and alternative futures in all human endeavors in order to make such insights available to the right person at the right time to ensure the right decision.

The journal acts as a scientific forum, contributing to the interaction between researchers, policy makers, and other actors involved in innovation processes. It encompasses all facets of STI policy and the creation of technological, managerial, product, and social innovations. *Foresight and STI Governance* welcomes works from scholars based in all parts of the world.

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- The exploration of the innovation lifecycle from idea to market;
- Technological trends, breakthroughs, and grand challenges;
- Technological change and its implications for economy, policy-making, and society;
- Corporate innovation management;
- Human capital in STI;

and many others.

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National Research University
Higher School of Economics

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Address:
National Research University Higher School of Economics
20, Myasnitskaya str., Moscow, 101000, Russia
Tel: +7 (495) 621-40-38
E-mail: foresight-journal@hse.ru

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Generative AI as a Disruptive Innovation: Implications for Marketing Strategic Transformations

Emad Abou Elgheit
Professor, abouelgheite@wcsu.edu
Western Connecticut State University, University Blvd, Danbury, CT 06811, United States

Abstract

This study explores the potential for small marketing firms to disrupt the market by leveraging generative AI technology within the framework of disruptive innovation theory. A qualitative approach was employed, combining a comprehensive literature review with in-depth interviews with leaders from small marketing firms. The data was analyzed using the Natural Language Processing (NLP) and thematic analysis techniques. This study is the first to apply the theory of disruptive innovation to the use of generative AI at small marketing firms. It contributes to the emerging body of knowledge on AI in marketing and offers practical guidance for scholars and practitioners to advance this field. The findings suggest that small firms can gain a competitive edge by adopting AI early, utilizing it to target underserved markets, and developing innovative, cost-effective services. The study positions generative AI as a significant technological evolution, with the potential to revolutionize the marketing industry. It identifies generative AI as a tool for enhancing efficiency, content development, customer service, and research. Small marketing firms are found to be in various stages of AI adoption, with many viewing it as a complement to human creativity. This study highlights the need for new skills, such as AI literacy and strategic thinking, while also emphasizing the continued importance of human oversight.

Keywords: disruptive innovation; generative AI; marketing firms; marketing strategy

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Introduction

Generative AI, also referred to as AI or machine creativity, falls under the realm of intelligence. It involves machines producing content, such as images, music, and text.[1] In the marketing field, generative AI plays a role in creating distinctive content for consumers. It also aids in predicting consumer behavior and enhancing marketing campaigns. The potential impact of AI on the economy, society, and technology in the marketing sector is immense. It can revolutionize how businesses connect with and engage their customers.

As per a report by the World Economic Forum, generative AI is a game changer for industries and society at large. It is expected to become a tool for businesses striving to maintain competitiveness on the market. The report emphasizes that generative AI has potential across sectors such as healthcare, education, entertainment, and marketing. By 2028 it is projected that the generative AI market will be valued at an estimated $63.05 billion (Larsen, Narayan, 2023).

The marketing industry encompasses diverse services ranging from advertising to market research. According to Statistas data, from 2022 this global marketing services market was valued at $1.8 trillion in 2021. It is anticipated to reach $2.3 trillion by 2028.[2] The marketing industry anticipates that the use of AI will grow significantly with a projected value of $22.1 billion by 2032. This growth will be driven by a compound growth rate (CAGR) of 28.6%. Currently, North America is at the forefront of this market primarily because it has embraced AI early and is home to large marketing companies. The Asia Pacific region is predicted to experience growth due to the increasing usage of the Internet and the rapid expansion of e-commerce. Key players in this market include IBM, Microsoft, Google, and Adobe, among others.[3]

Small companies play a role in adopting and commercializing disruptive technologies (Kassicieh et al., 2002). Generative AI can assist marketing firms with less than $50 million in revenue expand their market share and grow. The theory of disruptive innovation introduced by Clayton Christensen in the 1990s explains how smaller and less established companies can disrupt established players by offering innovative and cost-effective services. Over time these newcomers enhance their products or services. Gradually, they come to challenge established players (Larson, 2016).

The field of AI in marketing has recently gained interest. However, there is a lack of research on this topic. This scarcity can be attributed to the availability of this technology. Moreover, with the introduction of GPT 4.0 in 2023, advancements in this field have been rapid. As a result, researchers and practitioners alike must stay updated. Marketing professionals also need to keep pace with these advancements to remain competitive in today's evolving marketing landscape. Additionally, it is important to guide the development of this technology by conducting research and exploring its applications in marketing as the technology continues to progress.

The primary goal of this study is to investigate how small marketing firms can disrupt firms by adopting generative AI. These disruptions can be achieved by offering new services while entering at the bottom end of the market and gradually moving up the market. Furthermore, this study delves into the capabilities and expertise that organizations must possess to effectively utilize this technology. Specifically, the research addresses the following questions: 1) How can small marketing firms leverage AI to spearhead industry transformation in relation to disruptive innovation theory? 2) What novel cost-efficient solutions can these firms develop to meet evolving client demands? 3) What organizational and individual skills will be essential for future marketing agencies to work efficiently with AI technology?

Literature Review

Table 1 summarizes the earlier literature on generative AI in marketing. The body of knowledge about generative AI, specifically in marketing, is limited. Earlier studies mostly tackled the different applications, opportunities, and risks associated with the use of AI in marketing. A few studies were found that examine the changing needs of customers and clients considering the shift toward AI in general. However, no studies were found that explored the topic against an established marketing or business theory. The main lines of thought relevant to the topics include firm adoption of new technology, changing marketing needs, and organizational capabilities.

Current Generative AI Applications in Marketing

Generative AI has already been used in plenty of marketing applications as seen in Table 2. These start from broad planning, branding, and creative strategies to tactical content generation, customer service, personalization, and prediction. Genera-

[1] https://www.mckinsey.com/featured-insights/mckinsey-explainers/what-is-generative-ai, accessed 17.10.2024.

[2] https://www.statista.com/topics/5017/ai-use-in-marketing/, accessed 15.09.2024.

[3] https://www.globenewswire.com/en/news-release/2022/12/09/2571196/0/en/Generative-AI-Market-to-Worth-63-05-Billion-by-2028-Generative-AI-to-Leave-Biggest-Impact-on-Drug-Discovery-Material-Science-and-Financial-Services.html, accessed 07.09.2024.

Table 1. **Summary of Generative AI in Marketing Literature**

Topic	Findings	Sources
Generative AI applications in marketing	Numerous applications in strategy, branding, language, audio, visual, and synthetic data domains, including personalization, content creation, predictive analytics, digital advertising, customer service, and product design.	Graham, 2023; Harris, 2024
Disruptive innovation	The key components are technological enabler, business model innovation, targeting underserved customers, and pursuit of profitability.	Canavan et al., 2013; Chen et al., 2017; Christensen et al., 2003; Nogami, Veloso, 2017; O'Reilly, Binns, 2019
Firm adoption of new technologies	Organizational readiness is crucial for AI adoption, affected by management support, firm size, resources, competition, and regulations.	Fitzgerald et al., 2013; Pérez-Luño et al., 2011
Changing marketing needs and agency model in the AI era	The economy shifting to services, with high expectations for AI, major challenges include using customer data, social media threats, new digital metrics, and talent gap in analytical capabilities, Clients seek specialized expertise and measurable results, and agencies need to be agile, incorporate data/tech, and embrace innovation, personalization, and recommendation systems are important for future marketing research.	Davenport et al., 2020; Hoffman et al., 2022; Kapoor, 2017; Leeflang et al., 2014; Rust et al., 2019
Firm and individual skills needed to leverage generative AI	Firms need to balance creativity and AI, identify creative areas, and hire/train individuals with skills in innovation, tech, and customer orientation, AI positively affects employee performance/work engagement, influenced by change leadership, digitization, and AI offers potential benefits for salespeople, shifting sales skills from hard to soft skills.	Ameen et al., 2022; Montana et al., 2014; Ritz et al., 2019; Singh et al., 2019; Wijayati et al., 2022

Source: author.

tive AI has numerous applications in the language, audio, visual, and synthetic data domains.

Personalization is a discussed application of AI in the field of marketing. By analyzing consumer data, generative AI can create tailored content that directly speaks to each individual's interests and preferences. This can encompass aspects ranging from product recommendations to customized emails and advertisements that cater to the unique needs of every consumer (Dilmegani, 2023).

Another area where generative AI finds its application in marketing is *content creation*. As highlighted in an article by the Wall Street Journal "AI can generate product descriptions, blog posts and social media posts." By analyzing large amounts of data and comprehending language intricacies and tones, generative AI can efficiently produce high-quality content on an extensive scale. This proves advantageous for businesses requiring lots of content within short timeframes, such as e-commerce companies and content marketing teams (Graham, 2023). Moreover, generative AI exhibits the potential to generate marketing materials like photos and videos to create scripts for various purposes, including influencer marketing strategies.

Table 2. **Current Generative AI Applications in Marketing**

Direction	Applications
Strategy and branding	• Product concepts • Marketing strategy outlines • Brand names and slogans • Campaign ideas
Content and creative	• Language-based generative models • Audio and music • Images, videos, and 3D models • Posts, blogs, and literature
Research and analytics	• Synthetic data • Predictive analytics
Personalization	• User experience • Content
Digital advertising	• Targeting • Keywords
Customer service	• Virtual assistants • Knowledge management

Source: author, based on (Dilmegani, 2023; Gill, 2023).

Predictive analytics is another area where generative AI has made strides in marketing. It leverages data, from sources like media, web browsing behavior, and purchase history to predict which products or services individual consumers are likely to be interested in. An article published on Emerald Insight highlights how generative AI helps organizations gain insights into customer engagement patterns and uncover trends that might otherwise go unnoticed (Lee et al., 2023).

Generative AI is also being employed in *advertising to precisely target audiences and improve keyword selection*. By scrutinizing large amounts of data, it can identify hidden patterns and correlations that may elude observation leading to more precise targeted advertisements. Furthermore, generative AI aids in optimizing keyword selection by predicting which keywords will yield performance based on factors such as search volume and competition.

Improving the customer experience. Chatbots, customer service virtual assistants, and even product design are examples of how generative AI can be utilized to improve user experience. By automating tasks and offering personalized real-time assistance to customers, generative AI has the potential

to enhance customer service and improve the customer experience (Gill, 2023).

Furthermore, generative AI can also contribute to *generating branding and campaign ideas*. Through analyzing consumer preferences and market trends, generative AI algorithms can generate brand names, logos, and concepts for marketing campaigns. As of September 2023, there is growing interest among marketers and business professionals in tools specifically designed for AI-generated marketing strategy and content. Some noteworthy examples include Copy.ai, Jasper.ai, Writersonic, and Copysmith (Harris, 2023).

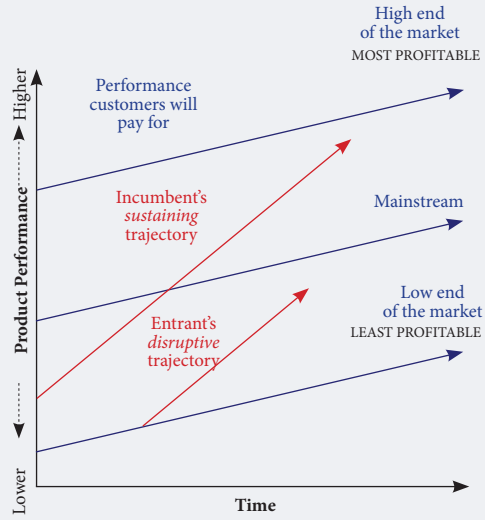
The Theory of Disruptive Innovation and Firm Growth

When a new technology or product is introduced onto the market, disruptive innovation takes place. Initially, it caters to a niche or low-end market. However, over time it improves in performance and gains acceptance. Eventually, it replaces the existing market leaders. Disruptive innovation can be a strategy for company expansion because it allows them to enter markets where the current dominant players are either reluctant or unable to compete. The key to utilizing innovation successfully is starting with a market segment and progressively enhancing the product or service. By doing so, the company can gradually improve its offerings and establish a presence on a market while incumbents prioritize their existing customer base and disregard emerging opportunities.

There are four key components of disruptive innovation:1) Technological Enabler: the new technology that must be used in a way that creates new opportunities or reduces costs in the existing market; 2) Business Model Innovation: a new business model is required to support the new technology and make it profitable; 3) Targeting Underserved Customers: disruptive innovators target customers who have been overlooked or underserved by existing companies; 4) Pursuit of Profitability: disruptive innovators must pursue profitability by scaling their operations and expanding their market share (Larson, 2016).

Christensen et al. (2015) write that disruptive innovation is characterized by two key elements: first, it initially provides a simpler, more affordable product or service that meets the needs of a previously underserved market segment, and second, it eventually improves to the point where it can compete with existing solutions for mainstream customers. They clarify that disruptive innovation is not the same as sustaining innovation, which involves incremental improvements to existing products or services. Instead, disruptive innovation creates entirely new markets and business models that eventually replace existing ones. They note that disruptive innovation can come from a variety of sources, including new business models, marketing strategies, or distribution channels (Christensen et al., 2015).

Figure 1. **The Theory of Disruptive Innovation**



Source: (Christensen et al., 2015).

Nogami and Veloso (2017) discuss the relationship between marketing and disruptive innovation, emphasizing that market and consumer needs, particularly those of low-income customers, are key to its development rather than large investments in technology. They stress the need for customized solutions for product and service development, rather than just adaptation of existing high-income market offerings (Nogami, Veloso, 2017). An empirical study on Chinese small and medium enterprises found that entrepreneurs' innovation willingness is needed for disruptive innovation. Additionally, external knowledge and a dominant position in R&D are important (Chen et al., 2017).

Changing Marketing Needs in the AI Era

The future economy is expected to be more global, service-dominated, driven by information, and increasingly automated, and will demand the abandoning of traditional business models and practices. Therefore, companies must be willing to adapt to this changing landscape to remain competitive. The economy is shifting more toward services, and goods-producing companies should transition toward service-based offerings, especially in the information service sector.

Customers have a higher standard for AI than is normatively appropriate, especially for consequential tasks, such as driving. They trust AI less and believe it lacks the affective capability or empathy needed for tasks that involve subjectivity, intuition,

and affect. Customers' risk perception is also a factor in AI adoption, and women are less likely to adopt AI than men, especially for consequential tasks. Moreover, when a consumption activity is central to a customer's identity, they may be less likely to adopt AI for that activity as they perceive it as cheating and hindering the attribution of credit after consumption (Davenport et al., 2020).

Hoffman et al. (2022) discuss the trends of personalization and recommendation systems as important areas for future research in marketing decision-making. With technology-enabled interactions, marketers have the opportunity to observe consumers engaged in new ways with products and create new sources of value for both consumers and firms. In addition, two important trends should be noted in consumer behavior: the adoption of augmented and virtual reality and autonomous products.[4] The use of virtual reality (VR) and augmented reality (AR) requires updated theories on how consumers process context-relevant information, embodiment, and presence. Meanwhile, the adoption of autonomous products raises questions about how consumers perceive and interact with these devices and their agency, autonomy, and authority (Hoffman et al., 2022).

Kapoor (2017) suggests that marketing agencies should shift from the traditional project-based model to a more holistic approach that focuses on long-term client relationships and provides a range of services beyond just advertising. This requires a shift in the organizational structure and culture, as well as investments in technology and talent development (Kapoor, 2017). Beckett (2021) discusses how the advertising agency model is changing and how agencies need to adapt to stay relevant in the industry. He notes that clients are increasingly looking for specialized expertise and measurable results, rather than just creative output. The article suggests that agencies need to become more agile and adaptable to meet the evolving needs of clients. It also discusses the importance of data and technology in modern marketing, and how agencies need to incorporate these elements into their services. Finally, it emphasizes the need for agencies to embrace a culture of innovation and experimentation to stay ahead of the curve (Beckett, 2021).

Capabilities and Skills Needed for Smaller Marketing Companies to Adopt New Technologies

To leverage AI in shaping professional marketing services' future, firms need to focus on the balanced augmentation of creativity and combine the capabilities of human intelligence (HI) and artificial intelligence (AI). Furthermore, they should ensure that potential employees possess the willingness and curiosity needed to go beyond current limits, and possess skills such as managing innovation and change, understanding technology, anticipating advancements, being customer-oriented, and being flexible. They need to identify the areas in the customer journey that most require creativity and adopt AI in business while maintaining a good standard of resources, including hiring and training creative individuals who are knowledgeable about AI technology. AI technology can assist with developing more effective marketing strategies, enhancing the customer journey, and transforming how firms attract, nurture, and convert prospects (Ameen et al., 2022).

Acemoglu et al. (2022) examine the relationship between the rise of AI and changes on the labor market in the US. The study finds that the surge in AI activity is driven by establishments with high exposure to AI, and this is reflected in changes in the skills demanded by these establishments. Specifically, these establishments cease to post vacancies that list a range of previously sought skills and start posting additional skill requirements, indicating that some tasks that workers used to perform are no longer required, while new skills are simultaneously being introduced. The study also finds that AI-exposed establishments reduce their non-AI and overall hiring (Acemoglu et al., 2022), thus generally operating as a more efficient organization.

Methods

In this paper, a qualitative research approach is employed, combining a comprehensive literature review with in-depth interviews. The literature review serves as the foundation for developing in-depth interview questions for small marketing firm leaders. The interviews are analyzed by Natural Language Processing (NLP) and thematic analysis techniques, and the results are discussed in light of the literature review.

Based on the literature review, the in-depth interview questions explore different generative AI applications, the components of the theory of disruptive innovation (i.e., product innovation, process innovation, targeting underserved customers, and business model innovation), and the foreseen changes in the labor requirements and skills in the marketing professional services industry. These 12-question interviews took about 30 minutes to complete. The list of questions is presented in Box 1.

The author interviewed 12 participants from the United States (84%), Egypt (8%), and Turkey (8%). A convenience sampling technique was used be-

[4] Autonomous products are robotic devices capable of performing everyday tasks without human oversight (so-called "substitutes for manual labor"). These include unmanned cars, robotic vacuum cleaners, automatic lawnmowers, etc.

Box 1. **The List of Interview Questions**

1. What do you see as the most promising applications of generative AI for your firm to serve its clients (e.g., strategy, product, content, digital advertising, music, videos, images, user interface, customer service, etc.)?
2. Do you believe that the integration of generative AI into marketing operations has the potential to drive changes in the traditional marketing agency business model, and if so, what specific changes do you anticipate?
3. How ready do you think your firm is for the adoption of generative AI, and which factors do you think will impact your firm's readiness?
4. What role do you see for generative AI in driving growth and competitiveness for your firm in the coming years?
5. How do you envision balancing human creativity and AI in your operations, and what areas do you think are best suited for AI?
6. What organizational capabilities do you think are necessary to leverage generative AI effectively, and how are you developing these skills within your organization?
7. How do you identify and target underserved clients and/or customers in your marketing strategy, and how could generative AI help in this regard?
8. What metrics or indicators do you use to measure the profitability of your marketing efforts, and how might these change with the integration of generative AI?
9. How do you think generative AI can enable your firm to offer new and innovative products or services to your clients, and what are some examples of this?
10. How might generative AI impact your pricing strategy and overall revenue streams, and how can your firm stay agile in responding to these changes?
11. Do you believe that generative AI can give smaller marketing firms a competitive advantage over larger firms? If so, how?
12. How do you see the integration of generative AI into marketing operations affecting the required skills for marketing professionals, and what skills do you anticipate becoming obsolete or less valuable as a result of this shift? Conversely, what new skills do you think will be necessary for marketing professionals to possess to effectively leverage generative AI in their work?

Source: author.

cause of the recent development of generative AI in the industry. The author selected participants who were already in the early stages of adoption of generative AI in their processes and organizations. The participants held chief executive officer, chief marketing officer, founder, and owner titles in marketing professional services companies with less than $50 million in annual revenue.

Results

A significant majority perceive AI as a supportive tool for human creativity rather than a substitute. When considering its impact on traditional marketing, the consensus is that conventional metrics are likely to retain their relevance. The evolution of AI is seen not as a disruptor but as a facilitator, offering a means to heighten efficiency and usher in new or improved services. Exploring generative AI applications in marketing reveals substantial interest, particularly in employing AI for automation and enhancing efficiency, with 75% of respondents showing keenness. Other notable areas of application include strategy and content development (67%), customer service and personalization (42%), research and data analysis (33%), and advertising (25%). The readiness for AI adoption among firms varies considerably. Approximately 33% of firms are highly prepared and actively utilizing AI, while another 33% are in the exploratory phase. A further 25% have already begun reaping some benefits from AI integration.

Looking toward the future, there is a strong sense of optimism about AI's role in fostering growth and competitiveness. About 75% of respondents are optimistic about AI aiding in creativity, innovation, and enhancing the speed of service delivery. Half of the respondents consider early adoption of AI as critical for maintaining a competitive edge. The relationship between AI and human creativity is predominantly viewed through a lens of complementarity. A substantial 83% believe AI enhances human creativity, especially in content creation and repetitive tasks, with a significant portion (67%) underscoring the importance of human oversight in these processes. In terms of organizational capabilities for AI integration, there is a notable emphasis on skill development. This includes fostering self-learning (25%), building internal capacity (33%), addressing responsibility and ethics (8%), enhancing AI literacy among staff (17%), and adopting pre-existing solutions (8%).

When it comes to identifying underserved clients, a dichotomy emerges. Traditional methods are still favored by 33%, but a majority of 66% recognize that while tools may evolve, fundamental marketing metrics are poised to remain consistent.

Regarding generative AI's impact on profitability metrics, sentiments are mixed. While 75% contin-

ue to rely on traditional metrics, 33% are uncertain about the potential changes brought about by AI. Nevertheless, there is optimism about AI's ability to enhance key performance indicators.

In the context of new services and offerings, 83% agree that AI contributes significantly to increasing efficiency in service delivery. About 25% perceive AI as enhancing existing services, whereas 17% anticipate the emergence of new AI-integrated services. The impact on pricing strategies reveals a focus on cost-saving (42%) and diversification (25%), with a third expecting a neutral impact. However, some uncertainty persists in this area. For small firms, AI is seen as a leveler in the competitive landscape. A majority of 75% view AI as offering competitive advantages to smaller entities, with 17% holding a neutral stance and 8% expressing scepticism due to potential cost and management challenges.

Finally, the skills shift in the industry indicates a decline in traditional entry-level skills (83%), with new competencies such as AI proficiency and strategic planning gaining prominence. Despite this shift, human skills like strategic thinking remain crucial (75%), underscoring the enduring value of human insight in the AI-augmented landscape of marketing.

Discussion

This paper examined the role of generative AI in small marketing firms' industry transformation, aligning with the theory of disruptive innovation, the emerging applications of generative AI in marketing, and the organizational capabilities and individual skills necessary for generative AI adoption. The study's results largely conform to the theory of disruptive innovation as generative AI is seen as a disruptive force that could potentially change business models, target underserved customers, and boost profitability. However, the results also highlighted potential challenges and complexities in implementing disruptive innovations.

Each of the four key components of disruptive innovation is reflected in different ways.

1) *Technological Enabler:* Generative AI is identified as a technological enabler in this case. This study found significant interest in using generative AI for various tasks such as automation, strategy and content development, customer service, personalization, research, and data analysis, which aligns with the theory's idea of a new technology creating new opportunities and reducing costs.

2) *Business Model Innovation*: This study highlighted changes in theroles and functions within marketing agencies, including a shift toward supervising or consulting roles for clients' generative AI platforms. This suggests an evolution in the business model to accommodate and capitalize on the new technology.

3) *Targeting Underserved Customers*: The participants' responses about identifying and targeting underserved clients with AI technology reflect this aspect of the theory. However, the extent to which this is being achieved is less clear, with some participants expressing uncertainty about using AI in this context.

4) *Pursuit of Profitability:* The pursuit of profitability is evident in participants' focus on efficiency, cost reduction, and enhanced performance indicators. The ability of AI to increase efficiency and speed in service delivery, reduce the need for outside hires, and lead to faster project completion times all point to the pursuit of higher profitability.

Despite these perceived benefits, some resistance was noted, emphasizing the limitations of AI and the need for human oversight. Concerns about negative impacts on junior staff, legal implications, and the necessity for human creativity were also expressed. These may indicate potential tension as the industry moves toward extensive AI adoption.

The findings align with Fitzgerald et al.'s (2013) emphasis on interdepartmental authorities for digital innovations. Participants highlighted the importance of self-learning, adaptability, and reliable analytics platforms, with 83% viewing AI as an enhancement to human creativity.

The results align with the changing marketing needs in the AI era, emphasizing the need for adaptation and embracing AI technologies (Rust et al., 2019; Leeflang et al., 2014). The responses underscored the importance of readiness, skills development, and human involvement in effectively using generative AI (Hoffman et al., 2022).

The results concurred with prior studies emphasizing the balance of human creativity with AI, the focus on creative aspects of the customer journey, and resource maintenance. New skills, including AI prompting, critical thinking, analytics, innovation management, and strategic planning, were identified as necessary for the evolving landscape (Montana et al., 2014).

Conclusion

Generative and conversational AI is the next technological evolution after the internet and mobile era. This study is the first to apply the theory of disruptive innovation to the case of generative AI for small marketing firms. It reveals a positive outlook toward the integration of generative AI in marketing operations and contributes to the emerging knowledge of generative AI in marketing. The findings entail several theoretical and practical implications to help scholars and practitioners advance this promising field.

Small marketing firms are optimistic about AI's role in their firms' future growth, viewing early adoption as a key to gaining a competitive edge over

large firms. They are already attempting to utilize the four components of the theory of disruptive innovation (i.e., Technological Enabler, Business Model Innovation, Targeting Underserved Customers, and Pursuit of Profitability) in integrating generative AI in their strategies, yet, they do so with different degrees of maturity and readiness. While the participants in this study indicated high degrees of awareness about the role of generative AI in the Pursuit of Profitability (improving efficiency and lowering costs) and as a Technological Enabler (passion and interest in learning about generative AI), they did not seem to utilize generative AI to achieve the Business Model Innovation and Targeting Underserved Customers.

The study reveals that most small marketing firms are still in their early adoption phases of generative AI. Small marketing firms see AI mainly as a tool for enhancing efficiency, content development, customer service, and research. Also, they believe AI will bring significant changes to marketing operations and roles, while they are not exactly sure how this will happen. The study defends that self-learning, adaptability, and knowledge management are key organizational capabilities necessary for adopting generative AI. The author urges marketing firms to identify and document a set of skills that are necessary for the adoption of generative AI and implement learning and development plans for their staff to achieve and monitor that adoption.

Small marketing firms see AI as an enhancer of human creativity that requires human oversight and believe that while AI may render some traditional entry-level skills obsolete, it necessitates new skills like AI literacy, critical thinking, and analytics. These include AI management, prompt engineering, analytics, problem identification, strategic thinking, and deep industry knowledge.

The author urges small marketing firms to use generative AI to create new business models that move away from fixed management or retainer fees toward more results-based models where agency fees are tied to results. Also, small marketing agencies should offer highly customized and personalized offerings to meet each client's needs with the help of generative AI. These include targeted behavioral advertising targeting and personalized email marketing. For example, generative AI can learn customer online behavior, their interactions with content, and purchase history and develop a personalized shopping human-like virtual agent to recommend products and answer questions. Integrating the latter suggestion with virtual fitting rooms and product testing can improve customer experience significantly.

Small marketing firms should use generative AI to identify underserved clients and communicate personalized and customized value to them. For example, generative AI can help to create polls, questions, and surveys of social media and email marketing to understand the needs and pain points of certain client segments. Also, generative AI is a very powerful tool to interpret unstructured data such as text, videos, and images and identify sentiments and opinions without the need for sending surveys.

While generative AI can be a valuable tool for reducing the cost of marketing services, it will be as impactful in increasing competition, and hence, lowering prices of several less strategic marketing services such as content generation. Small marketing firms must see generative AI as a catalyst to build more sophisticated and highly innovative services that maximize returns on investment for their clients.

Moreover, this study's conclusions amplify the complexity and multidimensionality of the disruptive innovation process, which, instead of being a linear sequence, is rather an intricate interplay of various elements. This insight calls for a reconceptualization of the theory to accommodate the dynamic, nonlinear process of innovation in the context of generative AI.

Further, this research sparks a discourse on the evolving skillset made necessary by AI integration, suggesting an emerging theoretical model of AI-enhanced human creativity, where traditional skills are supplemented by AI literacy, critical thinking, and analytics.

Lastly, the research invites a critical examination of existing business models in marketing, recommending a shift towards results-based models facilitated by generative AI. This introduces a new theoretical construct of 'AI-driven business model innovation' that needs further development and empirical validation.

Despite its contributions, this study has limitations that must be acknowledged. First, the sample size is relatively small and consists of participants from small marketing firms, which may limit the generalizability of the findings to larger marketing organizations. Second, the cross-sectional design of the study prevents the examination of how perceptions and the integration of generative AI in marketing operations may evolve over time. Third, the reliance on self-reported data may introduce professional desirability bias, as participants might provide answers that they believe are favorable or expected.

Future research should focus on increasing sample size and diversity, employing a longitudinal design, and utilizing mixed method approaches to better understand the impact of generative AI on marketing operations. Investigations into specific use cases, ethical and legal implications, and effective training and development strategies can provide insights into responsible AI integration and help marketing firms adapt to the changing landscape brought about by generative AI.

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Exploring Green Growth in SMEs: Global Trends, Challenges, and Future Directions

Aghnia Nadhira Aliya Putri
PhD Student, aghnia_nadhira@sbm-itb.ac.id

Pri Hermawan
Associate Professor, pri_hermawan@sbm-itb.ac.id

Isti Raafaldini Mirzanti
Assistant Professor, isti@sbm-itb.ac.id

School of Business and Management, Institut Teknologi Bandung, Jl. Ganesa No.10, Lb. Siliwangi, Kecamatan Coblong, Kota Bandung, Jawa Barat 40132, Indonesia

Maureen Meadows
Professor, ac3495@coventry.ac.uk

Rosie Sadraei
Lecturer, ad9531@coventry.ac.uk

Centre for Business in Society – CBiS, Coventry University, Priory St, Coventry CV1 5FB, UK.

Abstract

This systematic literature review examines the adoption of green growth practices at small and medium-sized enterprises (SMEs), synthesizing findings from 56 peer-reviewed articles published between 2010 and 2024. The study explores key dimensions of green growth, including environmental innovation, circular economy practices, and green financial management across various sectors and geographical regions. The analysis reveals a progressive shift in SMEs' sustainability practices, from initial awareness to ecosystem development, influenced by factors at the macro, meso, and micro levels. Key drivers identified include government policies, market pressures, and technological innovations, while primary barriers encompass financial constraints and knowledge gaps. The research highlights emerging trends such as the integration of digitalization, circular economy models, and green finance in SMEs' sustainability efforts. Additionally, it uncovers significant research gaps, particularly in understanding the long-term impacts of green growth initiatives and the role of resilience in post-pandemic recovery. This study concludes by proposing a future research agenda focusing on themes like AI-driven business model innovation, blockchain in green finance, and cross-sector policy harmonization. These findings offer valuable insights for policymakers, business leaders, and researchers in fostering sustainable practices across the SME sector.

Keywords: green growth; small and medium-sized enterprises (SMEs); environmental innovation; circular economy; sustainability

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Introduction

Both the rise of a more complex world economy and the continuing rise of the concept of green growth have created an urgent need of a new framework for development to ensure sustainable development. Organisation for Economic Co-operation and Development (OECD, 2019) defines green growth, which focuses on economic increase that ensures and sustainably applies natural resources to preserve the society wellbeing. Thus, small and medium sized enterprises, known as SMEs, are drivers of innovation and economic vitality and are seen as harbinger of global move towards more sustainable economic pattern (Tereshchenko et al., 2023; Musa et al., 2016). The need to understand the role of SMEs in supporting green growth has recently become urgent, given its omnipresence in different sectors and its contribution in both economic output and environmental impact. This research confirms that SMEs account for 70 percent or more of industrial pollution in some areas, a fact which underscores the imperative for sustainable business in this sector.

There has been minimal research focusing on green growth in SMEs, with most research focusing on specific items such as technological innovation, regulatory compliance and financial barriers (Ebrahimi et al., 2017; Gandhi et al., 2018). It clearly shows the external driver like policy support and market demand, means of accomplishment and difficulties in emerging markets like high starting costs and restricted accessibility to green financing (Musa et al., 2016; Koirala et al., 2019). Nevertheless, there is a lot of gaps in the literature. Individual factors in green growth are studied by many but there is little convergence in integrating them into a strategic approach especially regarding how SMEs build green dynamic capabilities to achieve environmental innovation. In addition, there is very little attention on the concept of value co creation. In addition, despite extensive documentation of financial constraints, less is known as to how SMEs can overcome these constraints through internal strategic capabilities. As existing research also focuses on developed economies, there are gaps in understanding how SMEs in emerging markets with different regulatory and institutional contexts transit towards green growth (Tereshchenko et al., 2023). Second, there has been little work on the temporal evolution of green strategies and geographical variations in adoption, especially in the developing region (Gandhi et al., 2018; Murray et al., 2017). This research then seeks to address these gaps and look into how green dynamic capabilities, value co-creation and contextual factors contribute to an SME's green growth trajectory.

This research seeks to fill in the significant void existing in the current knowledge base on comprehensively integrating green growth concepts to SMEs postdominant logic and the interrelations between green dynamic capabilities and value co-creation. Previous research has extensively studied some of the isolated pieces of the green practises puzzle, such as technological upgradation and regulatory compliance, but there has been little prior study of how SMEs can use dynamic capabilities to promote simultaneously both environmental performance and business objectives. Finally, geographical variations in greens practise adoption, as well as the timing of these green strategies remain underexplored.

To fill this gap, the present study employs a Systematic Literature Review (SLR) methodology to critically examine the existing body of knowledge on green growth in SMEs. By synthesizing findings from diverse studies, this research seeks to uncover gaps and trends, with a particular focus on how green dynamic capabilities and value co-creation contribute to the broader green growth agenda. In doing so, the study proposes five core research questions: (1) What is the contribution of environmental innovation to green growth in SMEs between 2010 and 2024? (2) What are the primary barriers and enablers for SMEs transitioning to a circular economy? (3) How do green dynamic capabilities and value co-creation influence green innovation and performance in SMEs? (4) How does geographical distribution affect green growth initiatives? (5) What are the key stages of green growth in SMEs, and how do various stakeholders contribute to these stages?

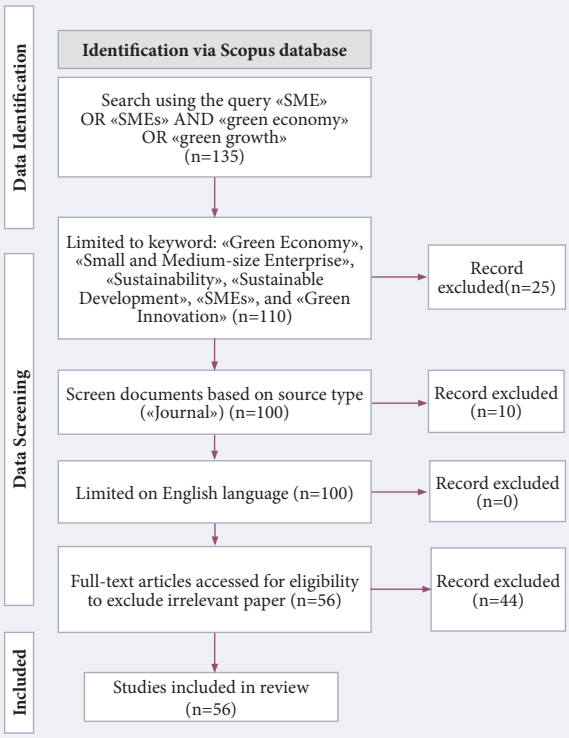
Methodology

This study examines the challenges and opportunities in SMEs' transition toward green growth by analyzing 56 peer-reviewed articles published between 2010-2024. The systematic literature search was conducted using Scopus database with the search string "SME" OR "SMEs" AND "green economy" OR "green growth", yielding 135 initial documents. Following the PRISMA guidelines (Page et al., 2021), articles were screened based on specific inclusion criteria: peer-reviewed journals, clear focus on SMEs and environmental sustainability, empirical studies with primary data, and English language publications (Figure 1). Studies that were conference papers, lacked clear methodology, or had no explicit environmental focus were excluded, resulting in 56 final articles for analysis. This approach aligns with established systematic review methodologies in sustainability research (Tranfield et al., 2003; Denyer, Tranfield, 2009).

The analysis is structured around three critical dimensions of SME green transformation: implementation barriers (including resource constraints, knowledge gaps, and market challenges), strategic approaches (such as green innovation adoption and circular economy practices), and enabling mechanisms (particularly policy support, financial instruments, and capacity building programs). By examining these dimensions through multiple theoretical lenses - including institutional theory (DiMaggio, Powell, 1983), resource-based view (Barney, 1991), and stakeholder theory (Freeman, 1984) — the study provides insights into effective pathways for SME sustainability transition. The selected articles were systematically coded and analyzed using thematic analysis following Braun and Clarke's (2006) methodology to identify recurring patterns and emerging themes in SME green transformation.

Specifically, the research focuses on how SMEs overcome resource and capability constraints when adopting green practises in light of seminal works in environmental management (Hart, 1995; Porter, van der Linde, 1995). This focus is consonant with the distinctive difficulties that small enterprises are confronted in balancing environmental responsibilities and business viability, in the face of market pressure, limited availability of green technologies, and financial resource constraint (Hillary, 2024; Revell et al., 2010). The analysis is more focused on the strategies of implementation which are suc-

Figure 1. **PRISMA Flow Diagram**



Source: authors.

cessful and the policy framework which support the achievement of environmental and economic objectives by SMEs (Parker et al., 2009).

In order to better understand, government led and private sector programmes had been implemented in Indonesia in order to encourage SMEs to adopt environmentally friendly practises. In particular, it looks into the contribution of Bank Indonesia (BI) in the development of the green business model and green financing options to help SME green transformation. Integrated education and training initiatives with regards to building the capacity of SME owners to use sustainable practises have also been implemented by BI. The main focus continues to remain on describing the general trends and enabling mechanisms of SME green growth in Indonesia.

Overview of Included Studies

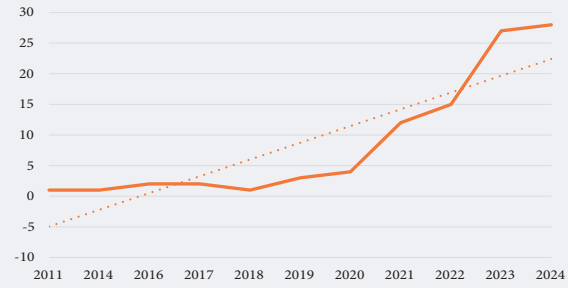
Publication trends

According to Figure 2, since 2018, there has been a steady increase in the number of publications on the topic under consideration. The time span of the study we have chosen can be divided into three periods.

1. Foundation Period of Environmental Innovation (2010–2014). It was during early 2010s when a divergence in environmental innovation approach to SMEs was taking place in different regions. In contrast, many developed economies, especially in East Asia and Europe, pursued sophisticated environmental management systems, which were developed in order to improve both ecological and competitive results. Environmental innovation could significantly improve labour productivity in South Korea's manufacturing sector when company structures and business group affiliations provide appropriate support (Woo et al., 2014). On the other hand emerging economies mainly prioritised basic environmental compliance and achieved environmental benefits via resource efficiency measures of cost reduction due to different developmental priorities and resource constraints (Silva et al., 2021; Ashton et al., 2017). Increased recognition of government support and policy frameworks to enable green innovation adoption was also taking place during this period (Chatzistamoulou, Tyllianakis, 2022). Several critical challenges that would shape future development of the research community were identified. Although constrained with limited financial resources as well as technological expertise, SMEs across all regions varied on their economic context (Rizos et al., 2016; Muzamwese, 2016). For example, standardising environmental performance measurement was one challenge developed economies had to adapt to, while developing nations had to overcome more fundamental matters such as finding ways to obtain green technologies and building rudimentary environmental management understanding where possible (Fadly, 2020; Namagembe et al., 2019). However, as studies realised that successful ecological innovation did not rely on just technological measures, but required an integrated approach which takes into account organisational capacity, market conditions and, policy support mechanisms (Woo et al., 2014; Bassi, Guidolin, 2021), there was increasing recognition of the need for such an integrated approach.

2. Transition to Circular Economy Focus (2015–2019). A dramatic shift towards circular economy principles occurred in the mid-2010s, formalised in distinct regionalised implementations. For SMEs, European nations were the first to developed complete circular economy frameworks, based upon closed-loop production systems and extended producer responsibility (Rizos et al., 2016; Cecere, Mazzanti, 2017). Through resource efficiency improvements, SMEs could enjoy significant cost savings and increased competitiveness (Arcuri, Pisani, 2021; Passaro et al., 2023). Meanwhile, Asian markets of China and Japan increased their focus on technological innovation in cleaner production systems to set new standards for processes in the manufacturing of resources (Bu et al., 2020; Gao, Yang, 2023). However, the implementation of

Figure 2. **Publication Trends (Number of Publications)**



Source: authors.

this period presented a number of challenges, much more so in developing economies. It was found that that SMEs, whilst supporting the need for structural adaptation towards circular models, faced many barriers to transition, particularly in areas of infrastructure limitations, complex supply chains, and a lack of financial viability (Muzamwese, 2016; Ilyas et al., 2020). Across different regions, studies showed that outdated equipment and limited technical capabilities prevented SMEs from executing even the most rudimentary energy efficiency measures (Tereshchenko et al., 2023; Phonthanukitithaworn et al., 2024). As a result of these challenges, SMEs have been more called to the role of support networks and knowledge sharing platforms in enabling environmental innovation (Gorondutse et al., 2020; Rajapakse et al., 2022).

3. Technology Integration and Strategic Evolution (2020-2024). In recent years, markets around the globe have proven uniquely convergent between both environmental innovation and advanced technologies. However, research exposes a clear trend regarding integration of digital solutions with environmental management systems, although implementation patterns significantly differ among regions (Ha et al., 2024; Chau et al., 2024). Studies have proven the benefits of green dynamic capabilities and digital transformation in Asian markets on environmental performance (Yousaf, 2021; Mubeen et al., 2024) as well as the lead for Asian markets in smart manufacturing integration. In the domain of ESG measures and holistic accounting of ESG impacts, European markets have leaned on policy harmonisation and standardisation of green practises (Domaracka et al., 2023; Zorpas, 2024), while North American markets have relied on market driven innovation through technological solutions (Anwar et al., 2024; Shaik et al., 2024). The current period shows challenging and opportunistic developments for future development. In particular, there is a long list of other serious barriers: high costs of implementing advanced technology, persistent skills gaps on new and complex green technologies, including for SMEs in emerging economy (Kim et al., 2021; Wang et al., 2023). Nevertheless, future development of these technologies is indicated by research in artificial intelligence in environmental management systems (Du et al., 2024), blockchain for sustainability tracking (Ling, Wang, 2024), and Internet of Things applications for resource optimization (Cheng et al., 2024). Evolved policy frameworks, market pressures, and these technological advances indicate a future where environmental innovation becomes a core part of business strategies globally and across many economic contexts (Maesaroh et al., 2024; Oliveira, Secchi, 2023).

Geographical distribution

The geographical distribution analysis of green initiatives in SMEs reveals distinct regional patterns and development trajectories across developed and emerging economies (Table 1). This analysis demonstrates how different economic, institutional, and cultural contexts shape both the focus and implementation of green practices.

Asia (38 studies). Analysis reveals three distinct evolutionary patterns in Asian SME green initiatives. First, a clear technology-driven transformation is emerging, particularly in China (14 studies) where a shift from basic compliance to proactive innovation is documented (Kannan, Gambetta, 2025; Aras, Crowther, 2008). The research shows Chinese SMEs increasingly leveraging AI and big data for environmental management - a trend that's reshaping traditional business models. Second, Southeast Asian nations (11 studies combined) demonstrate an emerging "leapfrog effect" where SMEs bypass traditional industrial development stages to adopt advanced green technologies directly. This is particularly evident in Thailand and Vietnam, where Ha et al. (2024) identifies how firms overcome resource constraints through digital solutions. However, a critical challenge emerges: the "capability gap" between technology adoption and implementation effectiveness. Looking forward, research suggests the region is moving towards a "hybrid model" combining technological innovation with traditional manufacturing strengths, though significant variations exist between developed and developing economies.

Table 1. **Geographical Distribution**

Country (number of documents)	Main Research Topic
China (14)	Green innovation, green supply chain management, environmental performance
Thailand (5)	Green economy, green supply chain management, eco-innovation
Pakistan (5)	Green dynamic capabilities, green HRM, sustainable performance
EU (5)	Circular economy, resource efficiency, green jobs
Indonesia (3)	Digital transformation, green economy implementation, green financial management
Vietnam (3)	Green product innovation, environmental management standards, resource efficiency
Turkey (2)	Green entrepreneurship, humane entrepreneurship
Malaysia (2)	Green entrepreneurship, eco-innovation capabilities
USA (2)	Green business practices, AI-driven business model innovation
ASEAN (2)	Green economic growth, green power generation
Bangladesh (1)	Environmental sustainability practices in textile SMEs
Jordan (1)	Green innovation adoption in manufacturing firms
Poland (1)	Green initiatives in SME sector
Romania (1)	Pro-environmental behavior in SMEs
Saudi Arabia (1)	Integration of lean and green manufacturing
South Korea (1)	Green supply chain management evolution
Spain (1)	Material flows cost accounting for circular economy
Sri Lanka (1)	Environmental incentives and green responsiveness
Taiwan (1)	Carbon reduction strategies in metal industry SMEs
Uganda (1)	Green practices and firm performance
UAE (1)	Green innovation adoption barriers
Ukraine (1)	Eco-innovation and circular economy strategies
Zimbabwe (1)	Energy efficiency adoption in SMEs

Source: authors.

Europe (16 studies). European research reveals a sophisticated policy-practice nexus that distinguishes it from other regions. Chatzistamoulou & Tyllianakis's (2022) analysis shows how EU circular economy directives are creating a unique "regulatory ecosystem" that shapes SME behavior. A key trend emerging from the data is the development of "integrated sustainability frameworks" where environmental initiatives are inseparable from core business strategies. However, studies from Eastern Europe (3 studies) highlight a persistent East-West divide in implementation capabilities. The research points to an emerging challenge: balancing standardization with local adaptability. Future directions suggest a move towards what Aranda-Usón et al. (2024) terms "smart sustainability" - where digital technologies and circular economy principles converge to create new business models.

North America (12 studies). North American research demonstrates a distinct market-driven approach that sets it apart from the regulatory-focused European model. Shaik et al.'s (2024) analysis reveals an emerging "technology-market convergence" where environmental initiatives are increasingly driven by consumer demand rather than regulation. A key trend is the rise of what researchers term "environmental entrepreneurship" – where green initiatives become sources of competitive advantage rather than compliance costs. The research identifies a critical challenge: the "scale-up gap" where successful pilot programs struggle to achieve broader implementation. Future trajectories suggest an increasing focus on what Abualfaraa et al. (2023) calls "precision sustainability" - using advanced analytics to optimize environmental impacts across operations.

Africa (9 studies). Unique frontier of 'developmental sustainability' is found in Africa. In Uganda, Namagembe et al. (2019) demonstrate that SMEs are integrating environmental initiatives with social development goals in a pattern that is unique to other regions. Through this research we identify an emerging trend identified as 'resource-conscious innovation' in which creative solutions are developed in response to environmental constraints. A problem however is what the researchers call the 'infrastructure-innovation gap' in which ambitious environmental goals that go beyond current infrastructure availability. Future directions point to further favouring 'adaptive green technologies' - technologies developed for resource constrained environments as identified by Muzamwese (2016).

Latin America (6 studies). The study of Latin American research shows an 'emerging 'hybrid sustainability' model that integrates organic (traditional) and environmental sustainability. In Peru, work done by Polas et al. (2022) shows that SMEs are integrating blockchain and other more advanced technology while continuing to employ traditional resource management practises. A second trend is of "collaborative environmental networks", where SMEs use their resources and knowledge to overcome limitations of an individual organisation and emerging forms of new collaboration are identified as important innovation factors. The research identifies a critical challenge: between rapid industrialization with environmental protection. Future directions point at further movement towards regional cooperation and knowledge sharing networks.

This analysis shows how the context of region matters a great deal in determining the path of green initiatives, with resultant differences in technology adoption, policy implementation and business model innovation. Although implementation paths vary widely among regions considering economic development and local resources, the research indicates a global trend towards more integrated, technological rich environmental management.

Distribution of Theoretical Frameworks in Green Growth Research

Patterns regarding the application of green growth theoretical frameworks and contributions to authorship are revealed when the green growth theoretical frameworks landscape is mined. One popular framework is the Resource-Based View (RBV) theory, with 12 applications, a 10% growth over the previous paper's results and is represented by both the established and the emerging scholars. Such collaborative authorship patterns, common in this field, are demonstrated by Silva et al. (2021) with multiple, many-institution, institutions, and more recent works (Tian et al., 2023; Hu, Chen, 2023) reveal increasing participation by Asian researchers, notably from Chinese institutions. 8 stakeholder theory applications appear diverse in their geographic coordinates of authors, from the Southeast Asian perspective of Van et al. (2019) to Aboalhool et al. (2024) expressing Turkic scholarly views.

A notable trend emerges in authorship patterns across theoretical applications, particularly in emerging frameworks like the Technology-Organization-Environment (TOE). Authors like Anwar et al. (2024) and Du et al. (2024) frequently collaborate across institutions, combining expertise from multiple disciplines. The Natural Resource-Based View (NRBV) studies show strong representation from developing economies, with Rajapakse et al. (2022) bringing valuable insights from South Asian contexts. Interestingly, studies applying Ecological Modernization Theory, though fewer in number (4 applications), demonstrate the highest level of international collaboration, as seen in Tereshchenko et al.'s (2023) work involving authors from multiple European institutions. This analysis reveals not only the theoretical evolution in green growth research but also the increasing globalization and diversification of scholarly contributions in this field (Table 2).

Research methods used

The analysis of research methodologies in SME green innovation (Table 3) studies reveals a strong predominance of quantitative approaches, with 77.4% (41 studies) employing statistical methods. Structural Equation Modeling (SEM/PLS-SEM) leads with 19 studies, demonstrating its effectiveness in uncovering complex relationships between green dynamic capabilities, innovation adoption, and performance outcomes. Survey-based research (15 studies) and regression analysis (7 studies) have been instrumental in identifying key determinants of environmental performance and mapping broad adoption patterns across different contexts. Notable works like Yousaf (2021) and Kim et al. (2021) demonstrate how these quantitative approaches have helped establish causal relationships between green practices and business outcomes.

Table 2. **Theoretical Approaches to Green Growth – Total Counts of Works and Key Literature Examples**

Study	Description
Resource-Based View (RBV) Theory – 12 studies	
Silva et al., 2021	Examines entrepreneurial orientation in green supply chain management
Tian et al., 2023	Studies green technology and market orientation
Hu, Chen, 2023	Analyzes sustainability and innovation
Stakeholder Theory – 8 studies	
Le Van et al., 2019	Analyzes stakeholder influence on green product strategy
Wang et al., 2023	Studies corporate governance and sustainability
Aboalhool et al., 2024	Examines humane entrepreneurship
Institutional Theory – 7 studies	
Gao, Yang, 2023	Studies institutional pressures on CER practices
Sun et al., 2022	Analyzes SME responses to green credit policy
Huang et al., 2022	Examines environmental protection policies
Technology-Organization-Environment (TOE) – 6 studies	
Lutfi et al., 2023	Studies factors influencing green innovation adoption
Du et al., 2024	Analyzes digital financial inclusion
Anwar et al., 2024	Studies big data analytics adoption
Natural Resource-Based View (NRBV) – 5 studies	
Rajapakse et al., 2022	Studies environmental incentives
Khan et al., 2023	Examines green effectuation orientations
Namagembe et al., 2019	Studies green supply chain practices
Ecological Modernization Theory – 4 studies	
Anwar et al., 2024	Studies big data analytics impact
Tereshchenko et al., 2023	Examines eco-innovation success
Huo et al., 2022	Studies green HRM practices

Source: authors.

Less well known, but an essential addition to quantitative findings, are the qualitative and mixed method approaches. Five studies utilise literature reviews and bibliometric analyses for mapping research trends and knowledge gaps, three of which use mixed methods combining SWOT analysis, case studies by assessing implementation challenges. In two studies that use system based approaches using evolutionary game models and two studies with detailed case studies with interviews provide insights into stakeholder dynamics and adoption processes but their lack of use indicates an underutilised methodological avenue.

Methodological patterns in current focus reveal tremendous limitations of understanding the complexities of green innovation adoption in interdependent systems. As Bouchmel et al. (2024) and Chatzistamoulou & Tyllianakis (2022) have shown, much of the current research relies heavily on cross sectional quantitative data, limiting the ability of these approaches to capture the temporal evolution of green practises in dynamically changing business environments. As noted by Ling & Wang (2024), there are a dearth of system approaches to understand the interactions of multi stakeholders, feedback loops, and emergent behaviours in green innovation ecosystems. Consequently, according to Bassi & Guidolin (2021) and Arcuri & Pisani (2021), using limited qualitative methods hinders more insightful understanding of the cultural, institutional, and behavioural factors affecting adoption decisions across various regional settings.

To mitigate these systemic limitations future research should utilise a more sophisticated methodological approach, recognising the complex adaptive nature of green innovation systems. Therefore, Shaik et al. (2024) and Wang et al. (2023) recommend integrating mixed methods to bring out both the macro level patterns and the micro level dynamics. As Qin and Hong (2023) show with advanced system approaches like agent based modelling and network analysis, a more refined mapping of the complex web of interactions among the SMEs and the stakeholders and environmental factors is needed. The emergent patterns and nonlinear relationships embedded in green innovation networks are proposed to be understood by Du et al. (2024) through big data analytics and real time monitoring systems.

In developing methodology, the field would benefit from more complex science inspired methodological innovation that would maintain analytical rigour. These calls for studies which could monitor the evolutionary coevolution of SMEs and their environmental context over time have been made by Oliveira and Secchi (2023) and Zorpas et al. (2024). Longitudinal studies focused on adaptation processes, comparative case studies on variation in system dynamics between regions or from different perspectives (stakeholders, power, place, management strategies), and participatory approaches connecting multiple stakeholders with regions' feedback loops and/or emergence patterns. Methodological sophistication, which Chatzistamoulou & Tyllianakis (2022) and Ha et al. (2024) advocate, would assist in constructing a finer understanding of how SMEs engage with and influence vibrant green innovation ecosystems, so as to subsequently enable more informed and adaptive support mechanisms and policy interventions.

Research Unit and Analysis

A systematic analysis of green SME innovation research is conducted to show how multi-level interactions shape the outcome of adoption. Research in this space exposes a fundamental tension at the macro level (15 studies) between policy design and implementation effectiveness. Contrary to regulations, policies generate better results according to Eckersley (2016), Ha et al. (2024), Zorpas et al. (2024), but such works reveal implementation gaps in policies arising from a mismatch between national policies and local capabilities. Additional studies by Chatzistamoulou & Tyllianakis (2022) and Woo et al. (2014) also illustrate that successful green innovation necessitates a match between an instrument of policy and regional economic contexts and institutional institutions.

Sectoral analysis, at the meso level (18 studies), shows sectoral influence on innovation diffusion patterns in the industry ecosystems. Yousaf (2021); Naruetharadhol et al. (2021);

Table 3. **Summary of Analytical Tools in Green Growth Studies for SMEs, by Research Method Categories**

Analytical Tool (number of papers)	Outcome
Quantitative	
Structural Equation Modeling – SEM/ PLS-SEM (19)	Identifies relationships between variables in the adoption of green practices and innovation in SMEs
Survey/ Questionnaire Analysis (15)	Provides insights into SME perceptions and behaviors related to sustainability
Regression Analysis (7)	Demonstrates factors influencing the environmental and economic performance of SMEs
Literature Review	
Systematic/ Bibliometric Analysis (5)	Maps research trends and identifies gaps in the literature
Mixed Method	
SWOT Analysis, Case Studies (3)	Offers in-depth understanding of the challenges and opportunities in adopting green practices
System Approach	
Evolutionary Game Model, MATLAB (2)	Models complex interactions between stakeholders in the green economy
Qualitative	
Case Studies, Interviews (2)	Provides in-depth insights into the process of adopting green innovation in SMEs

Source: authors.

and Kim et al. (2021) show that the green innovation leadership by manufacturing sectors goes beyond technological capability—most of these sectors have lead the way due to complex network effects. Du et al. (2024), Huang et al. (2022), Tereshchenko et al. (2023) and Bassi & Guidolin (2021) all study how supply chain pressures and knowledge spillovers contribute to self-reinforcing adoption cycles, while Bassi & Guidolin (2021) and Tereshchenko et al. (2023) point out that differences in sector specific characteristics matter and policy frameworks have to account for them.

The micro level analysis (47 studies) shows that SME responses are shaped by a complex interplay between internal capabilities and external pressures. Following Wang et al. (2023), Chatzistamoulou & Tyllianakis (2022), and Arcuri & Pisani (2021) show that access to multiple technological capabilities combined with resource limitations dictate a specific adoption trajectory. The implementation challenges investigated by Fadly (2020) and Bu et al. (2020) and the importance of organisational learning as presented by Cecere & Mazzanti (2017) and Silva et al. (2021) are also discussed. Nevertheless, the dominant focus on successful cases ((Rizos et al. 2016; Muzamwese 2016)) conceals learning opportunities from failed implementations.

Research by by Arulrajah et al. (2016); Perez et al. (2024) and Gull et al. (2024) at the individual level (5 studies), as reported in the literature, finds how leadership and employee engagement contribute in generating organisational momentum for green innovation. Zulkiffli et al. (2022); Maniu et al. (2021); Ahsan (2024); Cheng et al. (2024) however, study behavioural factors; Ahsan (2024); Cheng et al. (2024) also show the influence of management commitment. On one hand, they find that successful implementation hinges on complex social dynamics within firms, but such important aspects remain underexplored, necessitating a significant knowledge gap about how human factors influence adoption success.

This multi-level analysis (see summary at Table 4) exposes three critical systemic challenges: In fact, Passaro et al. (2023) and Oliveira and Secchi (2023) document the friction derived from the mismatch between policy design and implementation capabilities in shaping innovation diffusion. Secondly, as earlier demonstrated by Qin and Hong (2023) and Ling and Wang (2024), sector specific adoption patterns information indicates the need for more industry specific, tailored approaches. Third, little is known about the interaction between organisational capabilities and human factors, which inhibits the efficacy of intervention strategies as noted by Bouchmel et al. (2024) and Shaik et al. (2024). It is left to future research to overcome these systemic challenges through integrated approaches that recognise the dynamic interactions between different analytical levels.

Sectors of SMEs – Drivers – Barries

The sectoral analysis reveals distinct evolutionary patterns in green innovation adoption, with manufacturing leading at 57.7% of studies. A clear shift from compliance-driven to strategic adoption is evident, particularly in manufacturing where firms are integrating environmental innovations into their core business strategies (Ha et al., 2024). The textile industry shows crisis-driven rapid transformation due to environmental urgency, while technology services demonstrate market-led innovation through digital green solutions (Hossain et al., 2024; Tian et al., 2023). This multi-speed transformation across sectors indicates an overall trend toward strategic sustainability integration, though the pace and drivers vary significantly by sector.

Each sector faces unique but interconnected challenges in green innovation adoption. Manufacturing SMEs struggle with financial constraints and technical expertise gaps (Lutfi et al., 2023), while textile industries grapple with resource intensity and severe environmental impacts (Hossain et al., 2024). Technology services face immature green markets despite their digital capabilities (Huang et al., 2022), and diversified service industries encounter sector-specific barriers ranging from cultural resistance in hospitality to infrastructure limitations in retail (Elshaer et al., 2023; Bolaji et al., 2024). The persistence of these challenges across sectors suggests systemic barriers in resource availability, technical capability, and market readiness that require coordinated intervention.

The analysis suggests several promising directions for future development (Table 5). Manufacturing sectors are likely to see increased integration of digital technologies with green innovations, particularly in product development and process optimization (Kim et al., 2021). The textile industry shows potential for breakthrough innovations in water conservation and pollution control technologies, driven by urgent environmental pressures. Technology services are positioned to

lead in developing and scaling digital sustainability solutions, while diversified service industries may evolve toward sector-specific green innovation models. Cross-sector collaboration and knowledge sharing emerge as critical enablers for future development, particularly in addressing common challenges around technical expertise and resource constraints. Policy support mechanisms will need to evolve toward more targeted, sector-specific interventions while fostering cross-sector learning and innovation diffusion.

Cross-sectoral analysis reveals distinct patterns and challenges in green innovation adoption across different industries (Table 6). Manufacturing leads in systematic implementation, driven by regulatory pressures and operational benefits (Ha et al., 2024; Kim et al., 2021), while service sectors demonstrate customer-centric innovation approaches (Elshaer et al., 2023). Digital capabilities are leveraged within the technology sector for the development of sustainability solutions (Tian et al., 2023) and niche approaches are adapted within specialised industries based upon their operational context. While resource constraints as universal dilemmas, they manifest in different ways – financial and technical shortcomings undermine manufacturing SMEs (Lutfi et al. 2023), environmental impacts stress the textile industries (Hossain et al. 2024), and access to green practise is scarce for service sectors to implement in customer facing operations.

This research identifies critical success factors and future research needs in the sectors. Particularly in the case of textile's response to stakeholder pressures (Hossain et al., 2024), stakeholder engagement is clearly crucial, as well as in the case of the manufacturing industry adapting to regulatory requirements (Wang et al., 2023). Key overseers of these enablers are technology integration and employee commitment, which have been found to be enablers of VEB across all sectors, but their realisation differs across industry context. Future research should involve more comparative studies of cross sector approaches to environmental challenges, studies of failed implementation to identify sector specific barriers, as well as long term impact assessments of green initiatives. These insights indicate that supportive sector specific mechanisms are important, while leaving room to allow for cross sector learning and knowledge sharing.

Analysis by various sectors identified different patterns and challenges of green innovation adoption across different industries. Systematic implementation, underpinned by regulatory pressure and operation benefit (Ha et al. 2024; Kim et al. 2021), found manufacturing leads, while customer centric innovation is found in service sectors (Elshaer et al. 2023). The technology sector has digital capabilities to enhance sustainability solutions (Tian et al., 2023); the technology sector itself has its own niche approaches based on the operational context of the industry. Despite being a universal challenge with varying resource constraint, manufacturing SMEs face economic and technical constraints (Lutfi et al., 2023), textile industries have to face very high pressure to mitigate environmental impacts (Hossain et al., 2024), and service sector struggle to integrate green practise into customer facing operations.

The research identifies the critical success factors and future research needs across the sectors. The response by manufacturers to the regulatory requirements (Wang et al., 2023) is likely to be similar, also in the textile sector. Here, stakeholder engagement, however, is equally strong and has notably influenced the response to pressure to (Hossain et al., 2024). However, across all sectors technology integration and employee commitment are seen as enablers that emerge at varying degrees of implementation according to industry context. Future research requires additional comparative studies that evaluate cross sectoral approaches to environmental challenges; further investigation of failed implementations to learn about sector specific barriers; and to assess the long-term impacts of

Table 4. **Analysis Framework of Green Innovation in SMEs, by levels**

Research Focus	Key Findings	Research Gaps
Macro (National/Regional Economy) – 15 studies		
• National policy impacts on SME green practices • Green economic growth contribution • Regional development patterns	• Policy incentives more effective than regulations (Eckersley, 2016) • SMEs significantly contribute to green GDP growth in developing economies (Ha et al., 2024) • Regional variations in implementation success	• Limited cross-country comparative studies • Insufficient analysis of policy effectiveness • Lack of long-term impact studies
Meso (Industry/Sector Networks) – 18 studies		
• Sector-specific green innovation trends • Cross-industry sustainability practices • Supply chain transformations	• Manufacturing leads in green innovation adoption (Kim et al., 2021) • Industry networks crucial for knowledge transfer • Sector-specific barriers vary significantly	• Limited inter-industry effects studies • Few studies on emerging sectors • Insufficient focus on SME networks
Micro (Individual SMEs) – 47 studies		
• Green practice adoption factors • Innovation performance impact • Implementation strategies	• Resource constraints as key barriers (Yousaf, 2021) • Positive link between green innovation and performance • Technology crucial for implementation	• Over-reliance on single-firm studies • Limited understanding of processes • Focus mainly on success cases
Individual (Managers/Employees) – 5 studies		
• Leadership in sustainability • Environmental behaviour • Change management	• Leadership commitment crucial (Huo et al., 2023) • Employee behavior significantly impacts success • Knowledge gaps affect implementation	• Few studies on employee roles • Limited analysis of leadership styles • Lack of behavioral studies

Source: authors.

green initiatives. These insights imply the need of the need to develop sector specific assistive mechanisms while retaining the flexibility of cross sector learning and knowledge sharing.

Stage of Green Growth

The stages of green growth in SMEs reflect a progressive shift from initial awareness to full-scale ecosystem development, with distinct geographical concentrations at each stage (Table 7). The first stage, Awareness & Planning, is predominantly observed in developing Asian economies, with significant activity in Pakistan, Thailand, and Indonesia. This stage is characterized by increased understanding of environmental issues and initial planning for adopting green practices, with key stakeholders including policymakers, SME managers, and industry associations, as outlined by Gorondutse et al. (2020) and Noranarttakun & Pharino (2021).

An instance of Initial Implementation is observed in European nations (with emphasis on EU countries, Poland, Romania and Ukraine) where SMEs begin practising basic green activities aimed at resource efficiency and first stage green innovations. SMEs, their employees, environmental consultants and financial institutions are key stakeholders in this stage (Bassi, Guidolin, 2021; Wysocki, 2021). China is dominating the Advanced Integration stage with 14 studies that is able to deeply integrate green practises into business operations such as green product innovations and development of supply chain. Ha et al. (2024), Kim et al. (2021), and Chau et al. (2024) all point to the important role suppliers, customers and research institutions play here.

The Transformation & Leadership stage is primarily evident in advanced economies such as the In advanced economies like the USA, South Korea and Nordic countries, this Transformation & Leadership stage is very pronounced as SMEs

Table 5. **Analysis of Green Innovation in SMEs, by Sectors**

a) General Sectors

Drivers	Barriers	Evolution Pattern
Manufacturing – 15 studies (57.7%)		
• External pressures: Customer and regulatory demands (Ha et al., 2024) • Innovation focus: Green product development (Lutfi et al., 2023) • Operational benefits: Efficiency gains and cost reduction (Kim et al., 2021)	• Resource limitations: Financial constraints (Wang et al., 2023) • Technical gaps: Limited green technology expertise (Lutfi et al., 2023) • Implementation challenges: High transition costs (Fahad et al., 2022)	Moving from compliance-driven to strategic adoption
Textile Industry – 3 (11.5%)		
• Stakeholder pressure: Multiple stakeholder demands (Hossain et al., 2024) • Competitive advantage: Market differentiation (Chau et al., 2024) • Technology adoption: Green solutions implementation (Hossain et al., 2024)	• Environmental impacts: Severe water pollution issues • Technical limitations: Limited environmental expertise • Resource intensity: High implementation costs	Rapid transformation due to environmental urgency
Technology Services – 2 studies (7.7%)		
• Market orientation: Regional customer demands (Tian et al., 2023) • Service innovation: Low-carbon solutions (Huang et al., 2022) • Digital transformation: Technology-enabled sustainability	• Knowledge gaps: Technical expertise limitations • Market limitations	Leading in digital green solutions

b) Diversified Service Industries – 6 Studies (23.1%)

Drivers	Barriers	Evolution Pattern
A. Hospitality (1 study)		
• Customer expectations (Elshaer et al., 2023) • Green management practices	• Cultural resistance • Change management challenges	Gradual adoption as customer awareness grows
B. Retail/Warehousing (1 study)		
• Customer integration (Bolaji et al., 2024) • Green purchasing practices	• Infrastructure limitations • ICT capability gaps	Increasing green initiatives in supply chains
C. Specialized Sectors (4 studies)		
• Sector-specific regulations • Resource efficiency opportunities • Market competitiveness	• High operating costs • Technical implementation challenges • Limited expertise	Gradual transition with incentives for compliance

Source: authors.

Table 6. **Cross-Sectoral Insights**

Innovation Patterns
• Manufacturing leads in systematic adoption • Service sectors focus on customer-driven innovation • Technology sector emphasizes digital solutions • Specialized industries develop niche approaches
Implementation Challenges
• Resource constraints affect all sectors but manifest differently • Technical barriers show sector-specific characteristics • Cultural resistance varies by industry maturity
Success Factors
• Strong stakeholder engagement • Clear regulatory frameworks • Adequate resource allocation • Employee commitment • Technology integration
Future Research Needs
• More cross-sector comparative studies • Investigation of failed implementations • Long-term impact assessments • Focus on emerging sectors
Source: authors.

have fully embraced sustainability to fit it in the heart of their business model. Transformation is driven by industry leading SMEs, investors, broader society and international organisations (Tekala et al., 2024; Mubeen et al., 2024; Eckersley, 2016). In China's developed regions, advanced EU countries and countries including Singapore/Japan, the final stage – the Ecosystem Development stage – has some but limited presence. At this stage, wider green business ecosystemness is built around cross sectoration and policy contribution through working with stake holders namely governments, academics, NGOs, and the public at large (Tereshchenko et al., 2023; Zorpas, 2024; Maesaroh et al., 2024).

Case Study: Green Transformation of SMEs in Indonesia

With rising levels of environmental sustainability around the globe, businesses across the world are feeling increasing pressure to minimally impact the environment. In this respect, Micro, Small and Medium Enterprises (MSMEs) in Indonesia have assumed an important role in pushing for lasting economic growth. As SME's play a very important role in Indonesia's economy, their transition towards greener business models is crucial for Indonesia's long term sustainability. Government led initiatives as well as private sector driven initiatives for SMEs to take up environmentally responsible practises have been taken. This study provides a brief overview of the green growth adoption in the SME sector in Indonesia, featuring key elements of SME on the incorporation of sustainability in their operations and practise, thus contributing to a greener future.

Management Methods Used

Bank Indonesia (BI) has developed a green business model specifically for SMEs, structured into three stages: Eco-Adopter, Eco-Entrepreneur, and Eco-Innovator. This model allows SMEs to gradually adopt environmentally friendly practices, starting from basic sustainability principles

Table 7. **Stages of Green Growth**

Characteristics	Involved Stakeholders	Geographical Concentration
Stage 1. Awareness & Planning (Gorondutse et al., 2020; Noranarttakun, Pharino, 2021)		
• Increased awareness of environmental issues • Initial planning for adopting green practices	• Government (policymakers) • SME Managers • Industry Associations	Developing Asian economies: • Pakistan (5 studies) • Thailand (5 studies) • Indonesia (3 studies)
Stage 2. Initial Implementation (Wysocki, 2021; Bassi, Guidolin, 2021)		
• Early adoption of green practices • Focus on resource efficiency • Implementation of basic green innovations	• SMEs • Employees • Environmental Consultants • Financial Institutions	European nations: • EU countries (5 studies) • Poland, Romania, Ukraine
Stage 3. Advanced Integration (Ha et al., 2024; Kim et al., 2021; Chau et al., 2024)		
• Deep integration of green practices into operations • Green product and process innovations • Development of green supply chains	• SMEs • Suppliers • Customers • R&D Institutions	China dominance: • 14 studies focused on advanced integration • Strong emphasis on technology integration
Stage 4. Transformation & Leadership (Tekala et al., 2024; Mubeen et al., 2024; Eckersley, 2016)		
• Business model transformation toward sustainability • Leadership in green innovation • Significant contribution to green economy	• SMEs as industry leaders • Investors • Society • International Organizations	Advanced economies: • USA (2 studies) • South Korea • Germany & Nordic countries
Stage 5. Ecosystem Development (Tereshchenko et al., 2023; Zorpas, 2024; Maesaroh et al., 2024)		
• Green business ecosystem development • Cross-sector collaboration • Contribution to green policies and standards	• SMEs • Government • Academics • NGOs • General Public	Limited presence: • China's developed regions • Advanced EU economies • Singapore/Japan
Source: authors.		

and advancing to more innovative green strategies. One interviewee shared, «The gradual approach of the green business model is critical for us as SMEs; it allows us to adapt at a comfortable pace, first understanding the basics before moving to more complex green innovations.» Through these stages, BI helps SMEs integrate sustainability into their operations over time, ensuring that businesses evolve to meet environmental demands. In addition to the green business model, BI supports green financing through regulations such as Green Loan to Value (LTV) and Financing to Value (FTV), which facilitate capital access for SMEs wishing to adopt green business practices. As some financial experts noted, the financing programs like Green Loan and FTV are essential for us as they provide the necessary capital to make our green transformation possible (respondents 2 and 8).

Furthermore, BI enhances the capacity of SME owners through integrated education and training programs based on the green knowledge economy. These programs are vital for equipping SMEs with the skills needed to implement sustainable practices effectively. An interviewee emphasized, «The training on green technologies and circular economy principles has given us a solid foundation to apply sustainable practices in our daily operations. It's not just theory; we are learning how to turn these concepts into tangible actions.» These training programs introduce green technologies and the principles of circular economy practices, focusing on reducing waste and using resources efficiently. By providing these educational resources, BI helps SMEs gain the knowledge and tools required to successfully integrate sustainability into their businesses (respondents 1 and 5).

Emerging Trends in Green Transformation

Over recent years, SME owners have been becoming more aware of environmental sustainability importance. However, although knowledge about climate change leaves something to be desired, many SMEs have already begun to adapt to environmental friendly practises in their operations. For example, the fashion industry SMEs put in place the implementation of sustainable production methods like using eco-friendly fabrics or decreasing water waste usage in their manufacturing. SME owner Michael Hardie explains that as one grows, 'we are emerging to the fact that sustainable practise is not only best for the planet but is business sense as well.' We need to act responsibly." This trend towards responsible business practises also represents the wider movement towards ecological diversification demonstrating that SMEs are embracing ecological diversification as part of their core strategies (Bassi, Guidolin, 2021; Hossain et al., 2024).

Apart from this, some of the SMEs have also adopted some circular economy methods like the recycle and reuse of materials. Let's take the example of electronics SMEs who are reusing the old devices for electronics repair and refurbishment which helps in reducing e waste. Another entrepreneur mentioned, 'We've begun reusing our packaging materials, and invest in recycling processes; it's a little change, but it makes a big difference when it comes to reducing waste.' These businesses promote practises consistent with circular economy principles, which help to achieve more sustainable long-term environmental ambitions. This presents a trend that SMEs are not only implementing eco-friendly practises but actually making major adjustments to become generally more resource efficient (Hossain et al., 2024; Zorpas, 2024).

Additionally, consumer demand for eco-friendly products has increased resulting in pressures upon SMEs to innovate and supply green market products. SMEs in the food and beverage industry for example, have introduced plant based products and organic food options to cater for the rise in demand for sustainable consumption. "There's definitely been an increased demand for the products that are environmentally conscious; we've adjusted products lines to meet that demand," a product manager noted. In addition to offering SMEs a way to meet continually evolving market needs, this innovation is also helping them cut their environmental footprint. These transitions have been enabled by support from the government and critcal financial institutions, namely Bank Indonesia. Policies, financing, and training programmes that these institutions are patronising are helping SMEs to transition to more sustainable business Heises. "When institutions like Bank Indonesia back us up, it is a game changer for us to be able to implement greener solutions," said one financial expert (Chatzistamoulou, Tyllianakis, 2022; Ling, Wang, 2024).

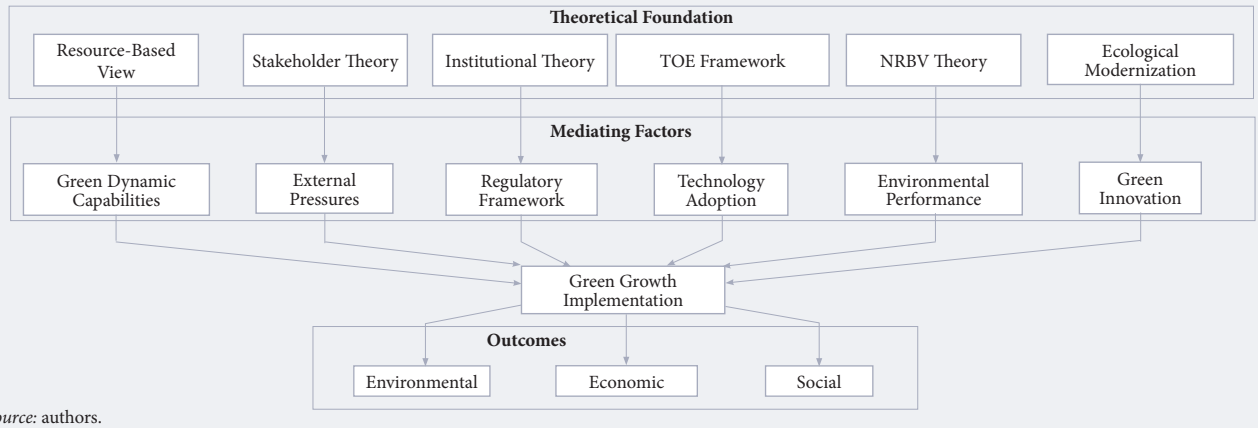
Green Growth Framework for SMEs

This study proposes both theoretical and conceptual frameworks of green growth in SME by the basis of the systematic literature review. The theoretical framework integrates six major theories: Resource Based View (RBV) for how firms utilise internal resources to provide competitive advantage, Stakeholder Theory for external pressures and expectations, Institutional Theory for regulatory and normative pressures, Technology Organisation Environment (TOE) Framework for technology adoption patterns, Natural Resource Based View (NRBV) for the relationship between environmental strategies and performance, and Ecological Modernization Theory for technological advancement in the realm of environmental protection. The conceptual framework aims to offer a more practically oriented perspective, which shows context-dependent relationships between sources of external driver (government policies, market pressures, stakeholder demands), inner capabilities (green innovation, resource efficiency, environmental management), contextual factors (industry type, geographic location, economic development), and implementation stages (from awareness to ecosystem development) resulting in environmental, economic, and social outcomes. Together, these frameworks offer complementary perspectives: studies by Silva et al. (2021), Tian et al. (2023), and Ha et al. (2024) provide evidence of the theoretical framework which provides the academic background for understanding the green growth mechanisms, and the conceptual framework offers a practical road map for the implementation to SMEs (Figure 3).

The green growth framework for SMEs offers a logical way to understand how can small and medium enterprises move towards more sustainable business models. The model of green growth, shown in Figure 4, both delineates the dimensions and contextual factors that enable green growth. Due to their agility and capacity of innovation, SMEs are a crucial component in global economies but they are simply different to larger chains when it comes to embracing sustainability in its operations. The framework deciphers certain critical aspects like environmental innovation and resource efficiency to help SMEs adopt greener practises that drive for long term sustainability, and decrease their environmental footprint (Gandhi et al., 2018).

The framework further shows how global, industry specific and organisational factors are connected though green growth analysis at various levels of analysis. Generally, policies at national and international levels … offer incentives and regulatory measures that encourage environmentally friendly practises (Rennings, 2000). The sector specific trends are influencing more at the industry level, where the adoption of sustainable technologies is being driven by sector specific innovation and competition (Tereshchenko et al., 2023). In the

Figure 3. **Theoretical Framework**



Source: authors.

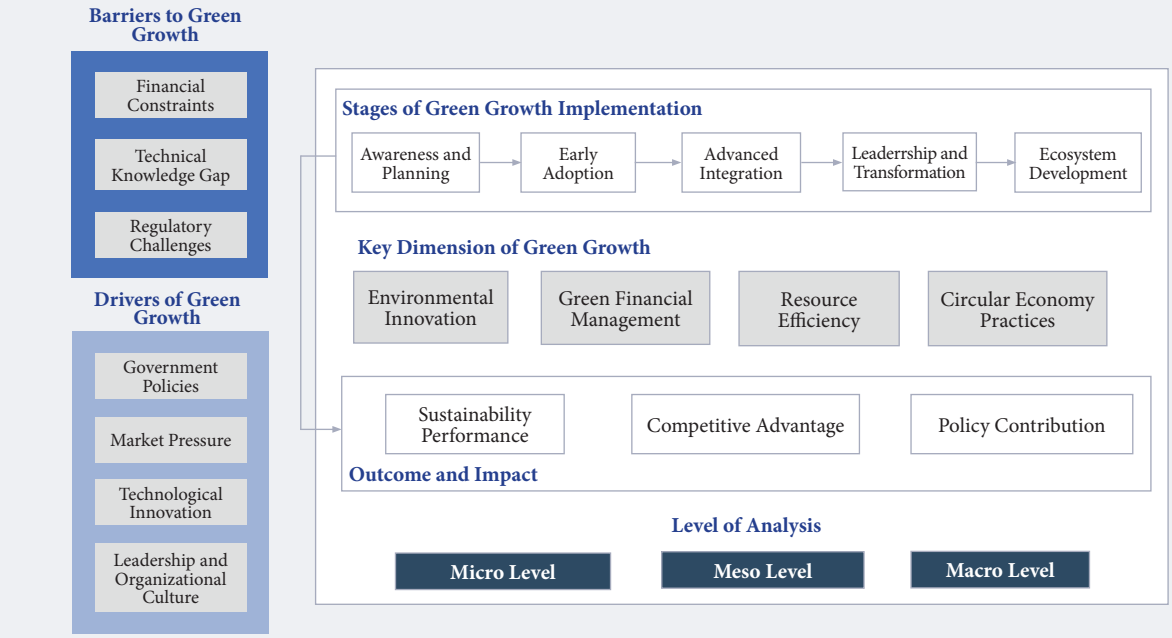
more granular, however, leadership of individual SMEs and organisational culture determine the mode of implementation for green growth strategies (Schaltegger, Wagner, 2011).

More importantly, the framework also lists the drivers and barriers that would likely dictate whether the green growth practise will be adopted. However, essential momentum to help SMEs spar with the depth of green transformation (García-Quevedo et al., 2020) are driven by government policies or technological innovations. However, this process is not without difficulties, since SMEs face difficulties in terms of insufficient financial resources or, quite frequently, lack of technical expertise, and thus slow adoption of green technologies (Del Río et al., 2016). It is important to understand these barriers before we can develop targeted interventions supporting SMEs to overcome these obstacles.

Therefore, the stages of green growth implementation highlighted in the framework understand the iterative nature of sustainability integration. Usually, SME green growth emergence does not follow a linear progression, but is patterned by changing the market forces, leadership decisions, and environmental awareness (Musa et al., 2016). The framework takes this process and frames it as a series of stages that can help guide SMEs from basic resource efficiency to more advanced green strategies and, in turn, towards a comprehensive, ecosystem driven sustainability practise. It indicates the importance of continued support from sectoral stakeholders in fostering and maintaining a conducive environment for sustained green growth of the SME sector (Porter, van der Linde, 1995).

Based on insights drawn from the existing framework, we see how whilst insights into what drives the green growth

Figure 4. **Model of Green Growth**



Source: authors.

Table 8. **Future Research Agenda, by Themes**

a) Digitalization and Green Innovation

Subthemes	• Big data analytics • AI-driven business model innovation • Digital transformation
Research gaps	• Lack of understanding of the impact of digitalization on SMEs' environmental performance • Limited studies on AI use in green innovation for SMEs
Future research avenues	• Investigating the effectiveness of big data analytics in improving SMEs' environmental performance (Anwar et al., 2024) • Exploring the role of AI in driving sustainable business model innovation (Shaik et al., 2024) • Analyzing the impact of digital transformation on green economy implementation in SMEs (Islam et al., 2023; Philbin et al., 2022)
Research Questions (RQ)	**RQ1: How can big data analytics enhance the environmental efficiency of SMEs?** **RQ2: To what extent can AI drive sustainable business model innovation in SMEs?** **RQ3: What is the impact of digital transformation on the implementation of green economy practices in SMEs?**

b) Green Finance and Sustainable Investment

Subthemes	• Green credit systems • Blockchain in green finance • Green investment in SMEs
Research gaps	• Lack of understanding of the effectiveness of green credit for SMEs • Limited research on the role of blockchain in reducing greenwashing
Future research avenues	• Evaluating the impact of green credit systems on SMEs' environmental performance (Ling & Wang, 2024) • Investigating the potential of blockchain to enhance transparency and effectiveness in green finance (Ling & Wang, 2024) • Analyzing the factors influencing green investment decisions in SMEs (Bouchmel et al., 2024)
Research Questions (RQ)	**RQ4: How do green credit systems affect the environmental and financial performance of SMEs?** **RQ5: To what extent can blockchain technology reduce greenwashing in green finance for SMEs?** **RQ6: What factors most influence green investment decisions in SMEs?**

c) Circular Economy and Resource Management

Subthemes	• Circular economy practices in SMEs • Material flow cost accounting • Waste management and recycling
Research gaps	• Lack of studies on circular economy implementation across different SME sectors • Limited research on the effectiveness of material flow accounting in SMEs
Future research avenues	• Developing circular economy models suitable for SMEs in various sectors (Zorpas, 2024) • Investigating the impact of material flow accounting on resource efficiency in SMEs (Aranda-Usón et al., 2024) • Exploring innovations in waste management and recycling for SMEs (Tereshchenko et al., 2023)
Research Questions (RQ)	**RQ7: How can circular economy models be tailored for different SME sectors?** **RQ8: What is the impact of material flow accounting on SMEs' resource efficiency and profitability?** **RQ9: What innovations in waste management are most effective for SMEs?**

d) Post-Pandemic Resilience and Sustainability

Subthemes	• SME adaptation to post-COVID-19 changes • Green innovation as a recovery strategy • Green supply chain resilience
Research gaps	• Lack of understanding of the long-term impacts of COVID-19 on SME sustainability practices • Limited studies on the role of green innovation in economic recovery
Future research avenues	• Investigating SME adaptation strategies to post-pandemic business environment changes (Du et al., 2023) • Analyzing the role of green innovation in improving SMEs' business resilience (Zulkiffli et al., 2022) • Exploring the development of resilient green supply chains for SMEs (Kim et al., 2021)
Research Questions (RQ)	**RQ10: What adaptation strategies are most effective for SMEs in facing post-pandemic business environment changes?** **RQ11: How can green innovation enhance SMEs' business resilience?** **RQ12: What are the key characteristics of resilient green supply chains for SMEs?**

e) Green Policies and Regulations

Subthemes	• Effectiveness of government incentives • Cross-sector policy harmonization • Standardization of green practices for SMEs
Research gaps	• Lack of comprehensive evaluation of the impact of green policies on SMEs • Limited studies on cross-sector policy harmonization
Future research avenues	• Evaluating the effectiveness of various types of government incentives in promoting green practices adoption in SMEs (Qin, Hong, 2023) • Analyzing the challenges and opportunities in cross-sector green policy harmonization (Chatzistamoulou, Tyllianakis, 2022) • Developing a framework for green practice standardization and certification suitable for SMEs (Noranarttakun, Pharino, 2021)
Research Questions (RQ)	**RQ13: What types of government incentives are most effective in promoting green practice adoption in SMEs?** **RQ14: How can green policies be effectively harmonized across sectors to support SMEs?** **RQ15: How can a suitable and implementable standard for green practices be developed for SMEs?**

Source: authors.

has been attained, more work still needs to be done to understand how SME can truly capitalise on digitalization, circular economy models and green finance, so as to promote their own sustainability towards more enhanced levels. Furthermore, as SMEs strive to bounce back from global shocks such as the COVID-19 pandemic, the investigation of the role of resilience in green practises seems to have become more integral to their development. Future work should focus on these emerging trends to develop the tools and concepts needed to overcome barriers and succeed in a green economy from SME.

Table 8 summarizes the key themes, research gaps and proposed future research avenues on the considered topic.

Conclusion

This study provides a comprehensive analysis of the green growth landscape within small and medium-sized enterprises (SMEs), exploring key dimensions such as environmental innovation, circular economy practices, and green financial management. Through a systematic literature review, it highlights the multi-level factors influencing green growth, from national policies at the macro level to organizational dynamics at the micro level. By dissecting drivers such as government policies, market pressures, and technological innovations, as well as identifying barriers such as financial constraints and knowledge gaps, the study presents a nuanced understanding of the complexities SMEs face in adopting sustainable practices. The findings offer significant insights for policymakers, business leaders, and researchers, guiding the development of strategies to foster green innovation and sustainability across the SME sector.

Further research around these key areas will provide invaluable insights to SMEs into both the landscape of green growth and the transition towards more sustainable business practises as the landscape of green growth for SMEs evolves. This systematic literature review follows by presenting the key themes, research gaps and proposed future research avenues (Table 8). This summary provides scholars and practitioners with a clear direction for advancing green growth research, particularly in the case of SMEs. Future research can address the identified gaps and explore new research areas by ensuring that SMEs become effective in adopting, and scaling sustainable practises to contribute to a deeper understanding of how SMEs can be effectively adopted and scaled for sustainable practise and thus build a more sustainable global economy.

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Towards a Sustainable Disruptive Growth Model: Integrating Foresight, Wild Cards and Weak Signals Analysis

Rafael Popper

Director[1], Rafael.Popper@futuresdiamond.com; International Director & Professor of Practice[2], Rafael.Popper@salle.url.edu; Director[3], Rafael.Popper@technologypartners.pl; Adjunct Professor[4], Rafael.Popper@pw.edu.pl; Visiting Professor[5], Rafael.Popper@pb.edu.pl; Adjunct Professor[6], Rafael.Popper@utu.fi; Honorary Senior Lecturer[7], Rafael.Popper@manchester.ac.uk

[1] Futures Diamond Ltd, 9 Bold Street, Warrington, WA1 1DN, Manchester, United Kingdom

[2] Centre for Funding and Innovation (CFI-Barcelona), La Salle - Ramon Llull University, Sant Joan de La Salle, 42 – 08022, Barcelona, Spain

[3] Centre for Foresight and Internationalisation (CFI), Technology Partners Foundation, Bitwy Warszawskiej 1920 r. 7A, 02-366 Warsaw, Poland

[4] Warsaw University of Technology, Plac Politechniki 1, 00-661 Warsaw, Poland

[5] Bialystok University of Technology, Wiejska 45A, 15-351 Białystok, Poland

[6] University of Turku, Rehtorinpellonkatu 3, 20500, Turku, Finland

[7] University of Manchester, Oxford Rd, M13 9PL, Manchester, United Kingdom

Yuli Villarroel

Professor Emerita, yulivilla@yahoo.com

Central University of Venezuela, Ciudad Universitaria, 1051, Caracas, Venezuela

Raimund W. Popper

Professor Emeritus, rwpopper@yahoo.com

Central University of Venezuela, Ciudad Universitaria, 1051, Caracas, Venezuela

Abstract

The paper introduces epistemological and methodological innovations for analyzing non-linear dynamics in sustainability systems, such as deforestation tipping points, exponential renewable adoption, and protests driving global reform. It focuses on adaptive resilience (e.g. decentralized grids stabilizing renewables) and topological models (e.g. network analysis of deforestation or policy diffusion). The study develops metrics to assess four dimensions of evolutionary change – context, people, process, and impact – supporting adaptive resilience and stability. In environmental systems, this may involve tracking early deforestation signals before tipping points, while in economics, it could mean analyzing how small policy shifts trigger market changes. It highlights Wild Cards and Weak Signals Analysis within the Sustainable Disruptive Growth Model (SD-Growth Model), enabling early detection of disruptions – such as AI breakthroughs or geopolitical shifts – so systems can anticipate, reorganize, and adapt effectively to shocks.

The research emphasizes constraints as key to resilience and stability amid disruptions. It integrates advanced analytical approaches to monitor and manage simultaneous information flows, ensuring efficient responses to shocks. The model also explores AI, machine learning, and explainable AI (XAI) in labor market dynamics, where predictive algorithms can identify trends and mitigate systemic risks. By combining quantitative metrics with strategic foresight, the framework equips decision-makers to preserve stability, sustain functionality, and adapt dynamically to change.

Keywords: research methods; forward planning; strategic planning; creative thinking; dimension reduction; horizontal scanning; foresight methods; disruptive dynamic; resilience.

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Introduction

The EEA-Eionet Strategy 2021–2030 highlights the growing role of foresight in the European Environment Agency's (EEA) work[1]. To address this, the Sustainable Disruptive Growth Model (SD-Growth Model) integrates foresight tools, Wild Cards, and Weak Signals Analysis to strengthen sustainability strategies. The model maintains four interdependent subsystems – context, people, process, and impact – to balance sustainable and disruptive growth. It examines disruptive dynamics from two key perspectives: (1) how equilibrium boundaries shift between stability and disruption, influencing system performance and triggering morphological changes (e.g. climate policies accelerating renewable adoption); and (2) the compatibility of metrics, which determines a system's adaptability and transformation (e.g. AI-driven early warning systems for deforestation). By integrating Wild Cards and Weak Signals Analysis, the model anticipates emerging disruptions and addresses deep uncertainties in sustainable systems, enabling more resilient and adaptive decision-making.

Uncertainty in modeling is central to the SD-Growth Model. Der Kiureghian and Ditlevsen (2009) classify uncertainties as epistemic (reducible through improved data or refined models) and random (irreducible). Accurately modeling epistemic uncertainty is crucial, as it can create dependencies among random events, impacting risk assessments (e.g., climate models predicting wildfire intensity). To address this, the model emphasizes Explainable Artificial Intelligence (XAI), ensuring that AI-driven systems remain transparent, interpretable, and trustworthy (e.g., XAI-based forecasts for labor market shifts). By bridging gaps in uncertainty, XAI strengthens reliability, adaptability, and informed decision-making within sustainability strategies.

Building on this, Marchau et al. (2019) describe deep uncertainty as arising when experts lack consensus on models, probability distributions, or desired outcomes (e.g., predicting economic recovery after financial crises). This concept aligns with the comparison of ecological and economic resilience, emphasizing phased recovery mechanisms to navigate uncertain scenarios (Bang et al., 2021). Osband (2023) categorizes indeterminacy across domains: randomness in mathematics, objective risk in economics, and aleatory uncertainty in machine learning (e.g. AI predicting market volatility). His assertion that "the variance of beliefs" reflects the value of new information underscores the SD-Growth Model's emphasis on adaptive management and informed decision-making.

The SD-Growth Model introduces three management frameworks – regular, disruptive, and boundary – linked to four archetypal topological modes: transient, capture, deep transient, and deep capture. These modes illuminate evolutionary phases and stability patterns in sustainable systems, offering insights into adaptive topological resilience. By incorporating stratified axes, the model extends the notions of parallelism, transversality, and concentration, enabling precise measurement of morphological changes and risk areas. These mechanisms facilitate development through foresight-driven scenarios, robust trajectories, and equilibrium boundary detection (Yang et al., 2020).

The SD-Growth Model introduces three management frameworks – *regular*, *disruptive*, and *boundary* – linked to four archetypal topological modes:

- Transient (e.g., short-term policy shifts impacting emissions)
- Capture (e.g., market dominance by a single renewable technology)
- Deep transient (e.g., temporary but severe economic recessions)
- Deep capture (e.g., long-term monopolization of AI infrastructure)

These modes reveal evolutionary phases and stability patterns in sustainable systems, offering insights into adaptive topological resilience. By incorporating stratified axes (e.g. layered socio-economic and environmental data), the model refines parallelism (e.g. simultaneous growth of multiple green industries), transversality (e.g. cross-sector policy interactions), and concentration (e.g. regional clustering of climate adaptation efforts). These mechanisms enhance foresight-driven scenario modeling, enabling robust trajectories and equilibrium boundary detection (Yang et al., 2020).

A comparative analysis of Evolutionary vs. Stable Models highlights the role of theories in understanding complex systems. Karl Popper's "Myth of the Framework" argues that theories help avoid biases and misconceptions, providing a foundation for objective analysis (Popper, 1994). His view on entropy and order – "randomness reflects our lack of knowledge of the prevailing order" – aligns with the SD-Growth Model's approach to managing uncertainty (Popper, 1992). This theoretical grounding strengthens the model's ability to address epistemic (e.g., data gaps in climate projections) and aleatory (e.g., unpredictable market fluctuations) uncertainties, making it a key tool for navigating disruptive dynamics.

The SD-Growth Model is applied through Horizon Scanning and Foresight, identifying emerging technologies and disruptive innovations that drive socio-technical transitions toward sustainability (Popper, 2023). These processes distinguish emerging futures by analyzing contextual drivers of change, enabling adaptive and resilient transformations. For example, Horizon Scanning tracks AI's role in green energy, reinforcing the value of strategic foresight in shaping sustainable futures.

[1] https://eea.europa.eu/en/about/who-we-are/eea-eionet-strategy, accessed 06.12.2024.

The model examines regular and disruptive dynamics using topological resilience to study adaptation and recovery in cyber-physical systems (Yang et al., 2020). It highlights:

- Clusters around behavioral trajectories (e.g., consumer shifts toward electric vehicles)
- Equilibrium boundaries (e.g., carbon pricing thresholds impacting emissions)
- Parallelism (e.g., simultaneous decarbonization of energy and transport sectors)

These insights refine the understanding of topological modes, improving risk detection and management. By linking adaptive topological resilience to real-world challenges, the model enhances sustainability strategies while maintaining systemic balance.

The Four-Dimensional Framework – covering Context, People, Process, and Impact – supports adaptive decision-making and aligns with sustainability, resilience, and foresight goals (Popper et al., 2017). By integrating theories, methodologies, and case studies, the SD-Growth Model provides a robust foundation for managing the complexities of sustainable disruptive growth. Wild Cards and Weak Signals help reveal actionable insights under deep uncertainty, while a multi-dimensional approach fosters cross-sectoral collaboration, essential for tackling interconnected modern challenges.

Overall, the SD-Growth Model strengthens our capacity to navigate uncertainty, promoting resilience and adaptability in the face of disruptive changes. Through foresight tools, theoretical grounding, and practical applications, it offers a comprehensive pathway toward sustainable development – demonstrating how resilience thinking, strategic foresight, and advanced modeling can pave the way for a more sustainable and adaptive future.

Strategic Foresight for Sustainable Innovation

The foresight process integrates reflection, networking, consultation, and discussion to refine visions and co-create strategies (Georghiou et al., 2008). Following the SMART Foresight Framework (Popper, 2011, 2012; Miles, 2013), its five phases – Scoping, Mobilizing, Anticipating, Recommending, and Transforming – help stakeholders navigate uncertainty and align efforts toward sustainable outcomes.

During Action Roadmapping Management, multi-criteria analysis evaluates practices, outcomes, and participants, ensuring strategies are sustainability-oriented. The four dimensions of the framework – Context, People, Process, and Impact – bridge the gap between visioning and actionable plans (Carayannis, Campbell, 2009, 2010; Martin, 2012; Miles et al., 2016; Martini et al., 2020).

The methodology merges the Foresight Diamond (Popper, 2008), topological approaches (e.g. differential systems, local stability), statistical methods (e.g. multivariate factor analysis), and sustainability metrics (e.g., ecological health, human vitality). These tools identify critical issues, including opportunities, risks, and pathways toward sustainable development.

By integrating Comparative Evolutionary Models with global case studies, the foresight process demonstrates its practical value in diverse contexts. This blend of analytical depth and real-world application equips stakeholders to handle uncertainty, boost resilience, and drive sustainable innovation.

Comparative Evolutionary Models

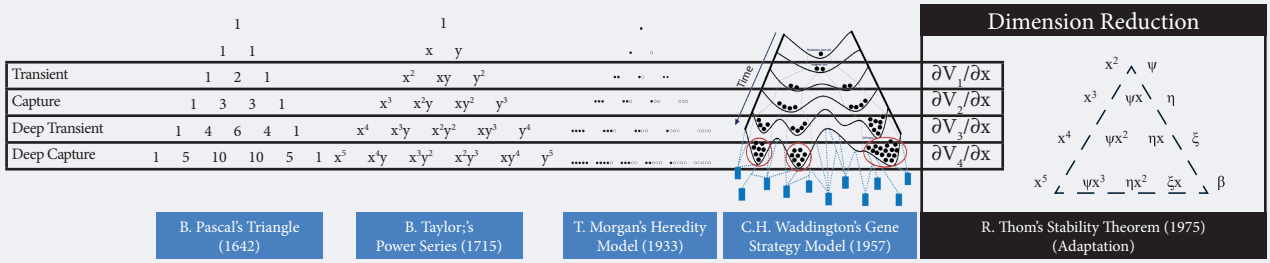
Researchers across disciplines have developed evolutionary models to understand dynamic systems. Notable examples include:

- Pascal's Triangle Model (1642): arranges binomial coefficients to illustrate combinatorial symmetry (e.g., predicting election turnout patterns)
- Taylor's Power Series (1715): uses polynomial approximations for system dynamics (e.g., tracking pandemic spread rates) (Bilodeau et al., 2010)
- Morgan's Heredity Model (1935): reveals chromosomes' roles in inheritance (e.g., tracing disease transmission pathways)
- Waddington's Epigenetic Landscape (1957): shows how environmental interactions shape evolutionary outcomes (e.g., mapping cultural shifts across generations)
- Thom's Catastrophe Theory (1975): focuses on dimension reduction to identify equilibrium zones (e.g., foreseeing economic crash thresholds) (Bilodeau et al., 2010)

These evolutionary models each rely on binary interactions – for instance, Pascal's Triangle with combinatorial pairs (1, 1), Taylor's Series with (x, y), or Morgan's inheritance model using white/black markers (○,●). Figure 1 presents five models, culminating in an extended version of Thom's approach, which introduces a triangular interaction zone (risk or threshold zone) showing how four parametric factors interconnect. The rows represent rates of change in the original catastrophe models, while co-diagonal separations illustrate dimension reduction via principal components. On the diagonal, independent momentum axes emerge along principal directions – shedding light on risk, equilibrium, and stability zones in line with Osband's (2023) indeterminacy framework. This comparative view helps to grasp system dynamics and key transitions across different evolutionary models. They reveal three primary dynamics:

- Horizontal Dynamics: competitiveness and system interactions
- Vertical Dynamics: growth-oriented, focusing on systemic development
- Central Dynamics: interplay of competition, harmony, risk, and stability (Waddington, 1957; Thom, 1975)

Figure 1. **Evolutionary vs Stable Models with Disruptive Dynamics**



Source: authors.

By integrating these perspectives, the SD-Growth Model links theoretical constructs with practical tools – such as foresight and morphological analysis to manage uncertainty, equilibrium boundaries, and system resilience.

Case studies further demonstrate the applicability of these models, showcasing how Wild Cards and Weak Signals Analysis can anticipate risks and seize opportunities, supporting sustainable growth. Together, these frameworks underscore the importance of combining theory and practice to tackle complex global challenges.

Case Studies, Innovative Practices, and the Topological Perspective

By combining topological and statistical methods with the Foresight Diamond, Horizon Scanning, and Foresight Processes, this study identifies constraints, breaking points, and 'weak signals' that hint at potential 'Wild Cards'. These insights feed into a risk-based management strategy addressing when and how systems may experience paralysis or disruption. Four topological modes – transient, capture, deep transient, and deep capture – are linked to the Four Management Dimensions, reflecting varying depths of change:

- *Transient mode* (e.g. temporary shifts in socio-economic preferences, Ahamer, 2020)
- *Capture mode* (e.g. sustainability-focused business models in Sweden's agri-food sector, Dehghannejad, 2021)
- *Deep transient mode*, involving sensitivity analyses of deeper systemic changes
- *Deep capture mode*, representing stable correlations among behavioral modes

This framework clarifies the topological significance of constraints, while 'weak signals' at different stages enable early detection of disruptive events.

Interconnecting Knowledge (iKNOW) for Weak Signals Analysis

The iKNOW Project explored how overlooked issues can shape or disrupt science, technology, and innovation (STI). It advanced Weak Signals research, defining these subtle, ambiguous "seeds of change" as early indicators of potential high-impact developments (e.g., Wild Cards, emerging challenges, or new opportunities). Although interpretation, importance, and impact are often uncertain, systematic monitoring reveals valuable insights for early intervention. In contrast, Wild Cards are low-probability yet high-impact events that can be unexpectedly disruptive (see Appendix). When combined with the SMART Foresight Framework, stakeholders can anticipate, recommend, and transform TEEPSES (technological, economic, environmental, political, social, ethical, and spatial) futures. This integrated approach embeds foresight into policy and strategy cycles, ensuring weak signals and wild cards inform strategic decisions and long-term resilience (Popper, 2011).

Figure 2 illustrates how Topological Analysis connects to the Policy & Strategy Cycle (Formulation, Realization, Learning) and the Issues Analysis Framework. A stratified behavioral function in a production-line scenario highlights four dynamic modes, from maximum output (A) to minimum arrival (C), with an inflection point (B). Decomposing equilibrium points isolates regular dynamics, showing how systems absorb shocks and maintain resilience (Yang et al., 2020). On the right, Figure 2 showcases the Issues Analysis Framework, emphasizing how different levels of uncertainty and interpretative biases influence Weak Signals Analysis, which is context dependent or situation-bounded (Popper et al., 2011; Ravetz et al., 2011). Four Wild Card trajectories emerge:

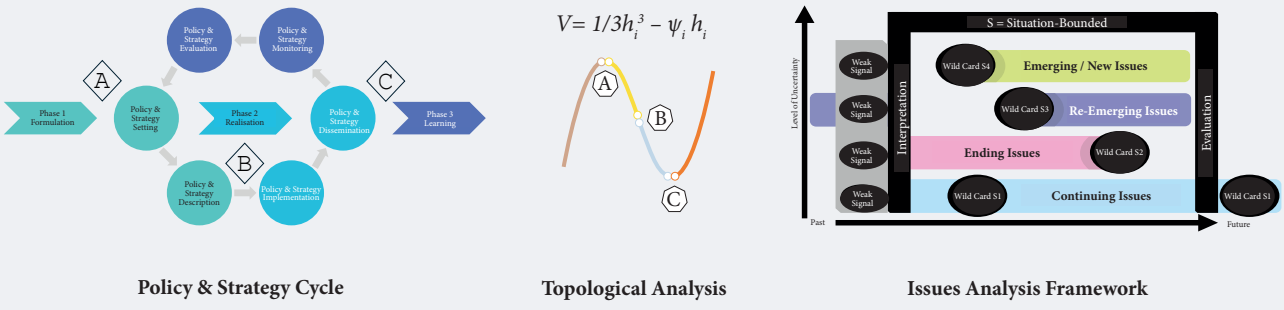
- Continuing Issues (e.g., cyber attacks)
- Ending Issues (e.g., market exit)
- Re-emerging Issues (e.g., global pandemic)
- Emerging Issues (e.g., new paradigm)

Evaluating process, people, and impact dimensions supports co-created action roadmaps, ultimately strengthening foresight and resilience in complex systems.

CASI Framework for Sustainable Innovation

The CASI Framework (CASI-F) – A Common Framework for Assessment and Management of Sustainable Innovation (SI) – has been applied across all EU Mem-

Figure 2. **Linking Weak Signals Analysis Framework with Disruptive Dynamics**



Policy & Strategy Cycle **Topological Analysis** **Issues Analysis Framework**

Source: authors.

ber States and in regions like Latin America (e.g. Uruguay) and the Middle East (e.g. United Arab Emirates). Figure 3 presents the CASI-F approach, an inductive method for SI assessment and management (top), alongside a network analysis of research and innovation (R&I) priorities distilled from 1,852 SI goals into 10 SI agendas (bottom) (Popper et al., 2017).

The CASI-F framework uses five steps to map innovations, prioritize cases, analyze issues, identify STI actions, and co-create roadmaps. In Step 5, these roadmaps span four dimensions – Context, People, Process, and Impact – across short-, medium-, and long-term timelines (Martini et al., 2020). By aligning these four CASI-F dimensions with four locally stable topological models, the study reveals topological constraints tied to equilibrium and depth. For instance:

- Transient (e.g. AI-driven climate adaptation pilots)
- Capture (e.g. local carbon sequestration projects)
- Deep transient (e.g. global circular economy expansions)
- Deep capture (e.g. region-wide decarbonization frameworks)

These perspectives guide STI foresight, revealing emerging trends, uncertainties, and prudent preparedness.

Four properties: Management Framework and Topological Modes

- *Intrinsic Property* focuses on transient context dynamics, influencing all process stages as systems shift from one state to another. Examples include nanotech safety alerts, e.g. coral reef conservation efforts (Bang et al., 2021), and iKnow Policy Alert (Popper et al., 2011).
- *Evolutionary Property* relates to capture topological modes, where stable attractors (basins) join two states at a shared boundary. This involves structure sensitivity, in which morphological constructs share internal properties, e.g. iKnow Policy Alert A39 on 'Nanotech robots caring for the elderly' (ibid). Contrasting scenarios highlight humility, adaptability, and persistence.
- *Transmuting Property* is defined by deep transient modes, emphasizing unexpected biases in impact and development pathways, e.g. iKnow Policy Alert A06 on food safety (ibid).
- *Imprinting Property* involves deep capture-emission dynamics, creating lasting impacts during sensitive periods. Examples include the global spread of a killer virus, e.g. iKnow Policy Alert 01 (ibid), illustrating how deep capture affects ecological systems (Hastings, 2004).

Summary

Analyzing the Specific Dynamics behind evolutionary processes is vital for managing uncertainties in both policy and business. By integrating Foresight, Wild Cards, and Weak Signals Analysis, we refine risk management (e.g. anticipating market volatility) and reliability (e.g. strengthening supply chains) through precise uncertainty categorization, paving the way for local sustainable disruptive growth.

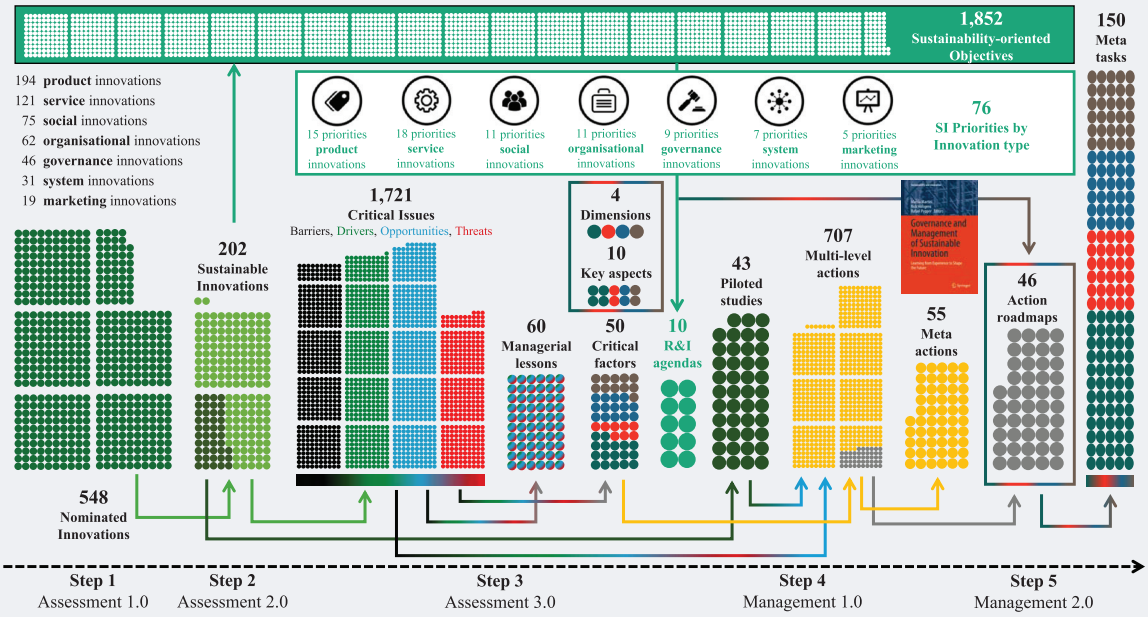
We identify four levels of growth, each linked to a topological mode – transient, capture, deep transient, and deep capture – and three types of dynamics: regular, disruptive, and boundary. For instance, transient growth may involve brief policy changes that shift consumer demand, while capture might describe a new platform dominating a local market. A threshold zone separates macro (e.g. rapid currency devaluation affecting entire economies) from micro (e.g. DeepSeek's sudden disruption of the AI sector) disruptive behaviors. Finally, boundary dynamics concentrate critical information – such as system breakpoints or adjacency in complex networks – revealing where and when policymakers or businesses should intervene.

Dimension Reduction

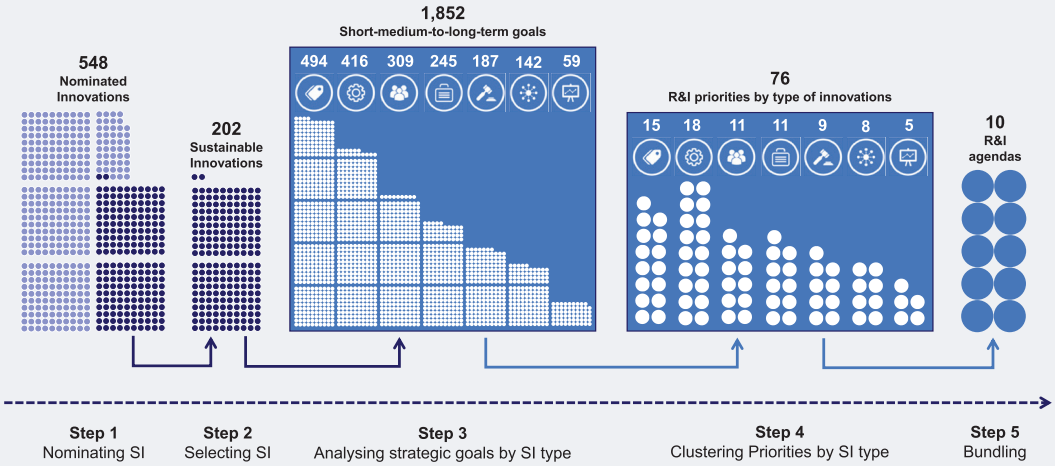
We propose new methods for analyzing non-linear dynamics in sustainability systems, focusing on adaptive resilience and topological models. By applying dimension reduction techniques – including singular value decomposition (SVD), factor analysis, clustering, and policy bundling – we simplify large datasets into man-

Figure 3. **The CASI-F Framework and Network Analysis**

a) The CASI-F to Sustainable Innovation Assessment and Management



b) Network Analysis for R&I Agendas on Sustainable Innovation



Source: authors.

ageable frameworks, eliminating noise and highlighting critical signals. This process clarifies four correlated subsystems linked to local stability, while revealing essential variables for understanding four stages of evolutionary change.

The SD-Growth Model integrates Wild Cards and Weak Signals Analysis to preserve local stability amid disruptive events, emphasizing constraints as a path to resilience. A practical example is the dimension reduction from 1,852 short-to-long-term goals to 76 R&I priorities and 10 R&I agendas, showing how quantitative, semi-quantitative, and qualitative methods can streamline complex data in sustainable innovation management. Arriving at the 10 SI R&I agendas involves aligning Context, People, Process, and Impact with the four locally stable topological models – Transient, Capture, Deep Transient, and Deep Capture. For instance, AI-driven climate adaptation pilots (Transient) emphasize shifting contexts; local carbon sequestration projects (Capture) highlight collaborative processes; global circular economy expansions (Deep Transient) affect long-term societal impacts; and region-wide decarbonization frameworks (Deep Capture) demonstrate embedded systemic change. This integrated viewpoint helps decision-makers balance resilience, innovation, and stability when designing R&I roadmaps.

Integrated Analytical Perspectives

Our analysis includes monitoring and transmitting simultaneous information, creating opportunities for artificial intelligence (AI), machine learning, explainable AI (XAI), and relatedness metrics (e.g., cosine similar-

ity for job skill matching). These tools address labor market shifts and motivate the SD-Growth Model.

Achieving High Accuracy and Preserving Essential Information

Dimension Reduction is crucial for simplifying complex datasets while preserving key insights needed for sustainable innovation assessment and management. Techniques like singular value decomposition enable efficient data compression, ensuring that environmental, economic, and social variables can be analyzed together without information overload. In communication theory, reducing noise (Wiener, 1948) addresses the entropy problem (Shannon & Weaver, 1949) – the tendency toward disorder – so decision-makers can focus on relevant signals. Meanwhile, Deng entropy (Deng, 2016), based on Pascal's Triangle, measures uncertainty in basic probability assignments, and quantum computing merges physics, math, and computer science for more advanced information processing. Collectively, these methods enhance risk analysis, strategic foresight, and resource allocation, enabling policymakers and innovators to anticipate challenges and bolster resilience within sustainability systems.

In statistics, dimension reduction (e.g. factor analysis for specific variance) aims to maintain accuracy when analyzing high-dimensional data (Pearson, 2022; Spearman, 1904; Johnson & Wichern, 2014). In topology, it involves using canonical models to highlight independent main directions, clarifying complex interactions (Yang et al., 2020) and showcasing topological resilience (e.g. homeomorphisms for stability analysis).

Critical Discourse Analysis (CDA) and Action Research support the SMART Foresight Framework, employing dimension reduction to reassess advisors' mindsets about balanced preservation across all levels (Velasco, 2017). In linguistics, dimension reduction supports depth-based classification – covering lexical, semantic, morphological, and compositional effects (Pinker, 2007; Huang & Pinker, 2010).

Overall, these approaches integrate economics, topological methods, statistical analyses, and morphological insights, illuminating complex evolutionary frameworks for sustainable behavior change.

Towards a Sustainable Disruptive Growth Model (SD-Growth Model)

In the Four-Dimensional Management Framework, we combine Weak Signals and Wild Cards (WIWE) analysis across four phases:

1. *Stratified Dynamics* (e.g. equilibrium sets mapping tipping points)

2. *Behavioral Convergence* (e.g. eigenvalue shifts indicating system alignment)

3. *Equilibrium Stability Analysis* (e.g. boundary detection using potential functions)

4. *Sustainable Disruptive Growth* (e.g. dynamic change modeling using nonlinear differential equations)

Using topological modes, we link unexpected realities (seen as constraints) with abstract sensitivity levels. Each mode – transient, capture, deep transient, and deep capture – can be visualized as function graphs displaying varying degrees of singularity, shown through rates of change. This approach highlights how small signals or shocks can trigger significant transitions, guiding innovators and policymakers to manage and adapt their sustainability strategies effectively.

$$v_1 = 1/3h_i^3, v_2 = 1/4h_i^4, v_3 = 1/5h_i^5, v_4 = 1/6h_i^6;$$
$$s_1 = h_i^2, s_2 = h_i^3, s_3 = h_i^4, s_4 = h_i^5.$$

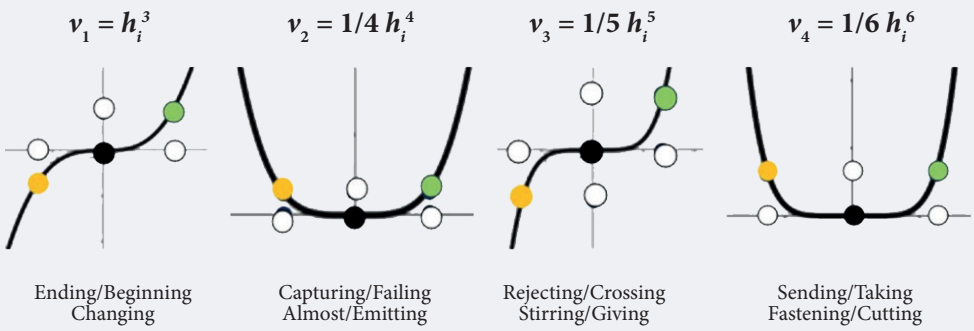
A stratified version of topological modes (e.g. layered phase transitions in markets) is introduced here. This approach treats each one-dimensional stratum of the mode's graph as a solution of a regular dynamical system, effectively splitting an initially singular, structurally stable system into two regular subsystems with unique, complete solutions. By applying differential systems in contact theory (e.g. modeling how supply and demand curves dynamically adjust in competitive markets), we can detect robust connections among stable solutions converging to the same closure point – an insight that proves useful in mapping innovation ecosystems and identifying dominant market strategies.

For transient topological modes in their canonical environments (e.g. unexpected shifts in economic equilibria), such robust connections emerge when multiple rates of change (1st, 2nd, 3rd derivatives) converge to their closure point from both sides. This implies curvature may switch concavity yet preserve slope and radius – with downward concavity (past dynamics) on one side and upward concavity (future outlook) on the other.

Figure 4 shows a stratified representation using analytical expressions v_k and rates of change s_k, for k=1 to 4. Each behavioral mode – *transient, capture, deep transient, deep capture* – is partitioned into two one-dimensional strata plus a zero-stratum (the closure point). Link points (yellow or green) lie near the zero stratum, indicating where behavioral dynamics shift. Two white link points reveal disruptive transitions (e.g. supply-chain breakdown leading to a new market normal). The i-th slope function (i-th derivative) is calculated at these points, and if left and right limits coincide, it signals a robust connection – key for systemic stability. Finally, the deep transient mode is more fragile, since rates of change vanish at zero up to the fourth order, showing non-zero behavior only at the fifth – underlining long-term vulnerabilities in complex innovation ecosystems..

In the Appendix, you can find details about the stratified axis ψ_i (e.g. layered policy thresholds) – also known as the Context Dimension Management Axis, which includes elements such as '*Momentum*', '*Foresight*', '*Resources*', and '*Mobilization*', all crucial for in-

Figure 4. **Topological Modes Graphics & Neighbourhood Dynamics**



Source: authors.

novation and strategic planning (Martini et al., 2020). The ψ_i -parametric family is represented by V_1. When the parameter is positive, the rate of change of the topological transient mode (e.g. quick shifts in markets) is linked to specific variance. This link highlights how shifts in a representative mode mirror key variation, essential for understanding disruptive dynamics in sustainable systems.

The relationship between specific variance and the transient topological mode is shown analytically in the Appendix. The singular set (e.g. boundary points of transformations), (Sv_1), representing the equilibrium set of the transient mode behavior, defines a nearby threshold zone, allowing concepts like parallelism, transversality, and concentration to explain transitions within this zone. Inside, the behavior compresses and reflects; outside, it expands and reflects. This duality illustrates how constraints affect the stability and evolution of complex systems, offering a framework to analyze and manage them in sustainable contexts.

The risk zone, bordered by singular points, holds the critical changes in behavior. Transversal transit through this risk zone, connects different behavioral states, aiding in identifying and managing potential risks and disruptive behaviors. Figure 5 (left) shows the threshold zone, defined by two symmetric curves γ_i, denoted by $G(\gamma_i^{\pm})$, as explained further in the Appendix.

There are three transversality types – Regular (R), Disruptive (D), and Boundary (B) – which define transversal lines to the axis ψ_i. Specifically, $L_1(R)$, $L_{-1}(D)$, and $L_0(B)$ intersect the Regular (ψ_i=1), Disruptive (ψ_i=−1), and Boundary (ψ_i=0) points respectively. For instance, Regular transversality might reflect standard supply-demand adjustments, Disruptive transversality could manifest as abrupt AI-driven policy shifts, and Boundary transversality can denote cross-sector trade negotiations.

Figure 5 (middle) illustrates parallelism, concentration, and multi-fibration (e.g. parallel AI deployments, concentration of green investments, multi-fibration linking economic sectors). On the right, the figure shows parallel lines traversing the negative ψ_i axis – indicating disruptive dynamics. Three notable closure points capture *Momentum* (a maximal or unstable attractor), *Foresight* (a minimal or stable attractor), and an inflection point (tied to *Resources* and *Mobilization*). These points highlight how behavioral trajectories with robust connections tend to converge on shared destinations, emphasizing the need for higher-order contact coordinates to enable or reject connections across behavioral dynamics.

Five operations guide these transitions:

1. Symmetries (input/output vs. equilibrium) around a parametric neutral axis (ψ_i) (e.g. average CO_2 footprints), which measures variance (distance to a mean).
2. Expansion & symmetry away from equilibrium.
3. Compression & symmetry inside the threshold zone.
4. Robust connections aiding transmission of behavior.
5. Resilient trajectories with a quadratic rate of change.

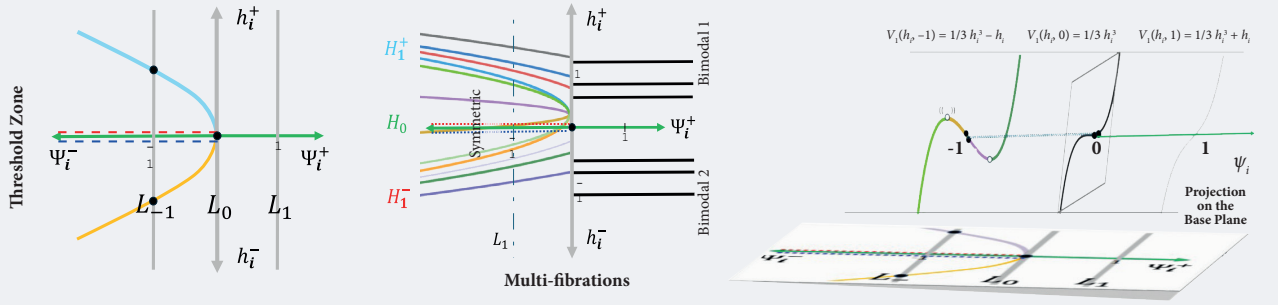
The SD-Growth Model helps form evolutionary clusters, tracing parts of behavioral trajectories to visualize potential arrival connections and spot synergy gaps (e.g. mismatched AI–climate policies). Laurett et al. (2021) used exploratory factor analysis in Brazil to gauge local views on sustainable development, focusing on natural agriculture variables. They found two main barriers – lack of information/knowledge and lack of planning/support, both echoing common obstacles to sustainability and synergy in complex systems.

Applications

Context Dimension Management and the Transient Mode

Transient Mode: A Key to Context Dimension Management. A stratified transient mode (see Figs. 4, 5) illustrates how dynamic systems undergo layered, multi-scale changes. This process comprises four phases – two macro (e.g., production and distribution) and two intangibles (e.g., management and optimization). Within this framework, three key transition points emerge – a maximum, a minimum, and an inflection

Figure 5. **Transient Mode & Stratification by Equilibrium**



Source: authors.

point (see Fig. 2) – that act as connection layers between phases. Recognizing these critical elements is fundamental for sustainable innovation management, as it reveals how systems shift between stable and risky conditions. This insight enables policymakers and innovators to detect weak signals of disruption early, implement targeted interventions, and adapt strategies to maintain local resilience and stability.

Energy Applications: Harnessing Stratified Efficiency. In wind energy studies, the potential function measures average change over time (P = E/t). For example, a cylindrical mass of air (density ρ, radius R) passing through a vertical disc generates an average power of $P = 1/2\rho\pi R^2 v_w^3$. This concept extends beyond physical scales to processes like diffusion, conduction, and transport in energy networks, where an "efficiency diameter" defines the largest cluster in fragmented systems (Aliprantis, 2011). We propose linking a local state variable, v_{rel} (velocity relative to mass density), to model a transient mode of behavior as $v_1(v_{rel}) = 1/3 v_{rel}^3$ – matching the average local power and integrating environmental analysis via specific variance (ψ_i). The function $V_1(\psi_i, v_{rel})$ reveals singular points and the topological resilience of behavior. In terms of sustainable innovation, this framework helps energy planners manage both stable and risky areas, ensuring robust connections (e.g. wind farm networks).

Communication Applications: Ensuring Robust Signaling. A maximum behavioral trajectory (e.g. peak user participation in digital systems) guides signal transmission between a source and a receiver. Figure 5 (right) illustrates a prototype of L_{-1} disruptive behavior in the variance-variable plane, generating four one-dimensional layers: two external (for source and destination messaging) and two internal (for operational systems). Topological resilience visualizes the zero-strata – key connection points – as stable links between phases. Equation (4) shows that the transient mode maintains robust contacts across phases, thereby enhancing communication reliability (e.g. in network traffic management for smart city projects).

AI Applications: Managing Complex Behaviors. The canonical environment of the layered transient mode provides detailed precision for AI systems (e.g., robotic coordination and recommendation algorithms). It robustly connects different behavioral phases around an equilibrium point (Figs. 4, 6), where the weaknesses of one phase are offset by the strengths of another, creating a dynamic capturing/emitting process. As shown in Fig. 6 (left, step 4), both parameters act as stable attractors that regulate the machine learning process, enabling adaptation or failure under stress (e.g., compression or distension in the model's variance and covariance parameters).

Quantum Applications: Leveraging Parallel Frameworks

Topological modes of behavior exhibit a twofold parallelism: within the threshold zone, they enable concurrency (e.g., multiple qubits operating simultaneously), and outside the threshold zone, they support task decomposition and simultaneous execution of smaller sub-tasks. This dual approach is crucial for managing complex sustainability initiatives, such as coordinated greenhouse gas reductions across multiple sectors, highlighting the value of topological modes for seamlessly orchestrating operations across diverse contexts.

Startup Ecosystem Applications: Orchestrating Growth Dynamics. Stratified transient modes help pinpoint constraints shaping early-stage venture cycles (e.g. pivot signals from founders, synergy cues among investors). By analyzing short bursts of innovation, we see how disruptive factors (e.g., new competitor entries or shifts in venture capital) escalate or stabilize. This approach fosters a robust ecosystem, ensuring sustainable expansions and long-term resilience in startup networks.

Data Requirements for Stratified Transient Mode Analysis. Effective application of stratified transient modes involves multifaceted datasets. In startup ecosystems, for example, funding data (e.g. investment rounds, valuations), accelerator or incubator metrics (e.g. applicant acceptance rates), and pitch-deck analytics (e.g. traction and user growth) provide quantitative indicators. Qualitative inputs (e.g. mentor feedback, founder surveys) capture contextual nuances, while hybrid data streams (e.g. regional policy changes, co-working

space usage) further enrich analysis. By combining these diverse sources, organizations can detect hidden constraints, track evolving behaviors, and develop resilient strategies for sustainable growth.

Synthesis and Multi-Level Analysis. Overall, these application examples – spanning energy, communication systems, AI, quantum computing, and startup ecosystems – show how topological constraints and stratified transient modes guide sustainable innovation management. At the micro level, the SD-Growth Model pinpoints disruptive dynamics within threshold zones, highlighting wave-like behaviors tied to system depth. Beyond these zones, regular behaviors dominate at the macro level. Identifying equilibrium sets and topological constraints supports in-depth exploration of behavioral shifts.

When behavioral trajectories converge on a common closure point, their topological resilience drives collaborative innovation, vital for sustainable outcomes in complex systems. The Context Dimension is paramount, shaping how local environments – from community energy programs to startup hubs – can nurture robust clusters for long-term success. This approach depends on diverse data sources (e.g. sensor readings, financial metrics, mentor surveys) to detect hidden constraints, track evolving behaviors, and adapt strategies effectively for resilient, multi-scale growth.

People Dimension Management and Capture Mode of Behaviour

The People Dimension Management involves aspects such as 'aptitude' (current skill sets) and 'attitude' (behaviour and motivation) linked to innovation. These factors are essential in the foresight process, particularly during the mobilizing phase, which encompasses activities like contract negotiations and engaging target groups, helping to locate equilibrium points where cooperation and networking can stabilize.

Mobilizing represents the second phase of Foresight. identifying three key topological moments, two competing attractors which are minimum points (mP), namely: the ´aptitude´ a locally stable mP- attractor, the attitude a simultaneous mP-attractor; and, a neutral point (NP), together with a balance point between these two attractors (within the scoping phase, where cooperation and networking can stabilize). Near the center of balance, the two competing attractors (aptitude and attitude) have the opportunity to jump from one level to another, leading to a possible detection of those 'key moments' for leaps in development or disruptive innovation; connected by two fundamental aspects: financing and foresight mobilization, where ´cooperation and networking´ could attain a locally stable cluster equilibrium.

The capture topological mode represented by Figure 6 (the second function, Appendix, Table A1), exhibits its behavior inside a parametric family of behavioral functions; depending on two parametric factors representing. The figure right shows its complexity and restrictions through the equilibrium analysis. The left figure is divided into two zones: non-disruptive behavior, represented by the line L_1, and disruptive behavior, represented by the line L_{-1} transverse to a cusp curve; and the line L_0, the boundary between two types of behavior.

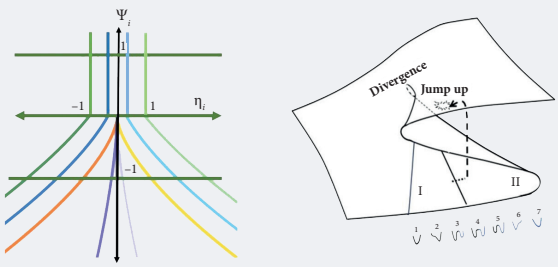
An equilibrium analysis similar to the Context Management Dimension, allows defining the set of the singular points which are distributed in the form of a curved cusp with bifurcation pont at zero. The transversal factor, η_i, incorporates a new measure, which shows how the trajectories of behavior can preserve harmonious parallelism of the ψ_i axis, which exhibits a bimodality in its transversal transit through the η_i axis. This bimodality illustrates how constraints (the cusp curve as boundary of a 'threshold zone' or risk zone) impact the stability and evolution of complex systems with a parallelism induced by a threshold zone.

The Figure 6 right, show the lifting of the bimodal plane; at the bottom the image shows seven waves numbered from one to seven, representing a strategic cycle that allow crossing the area through a resilient path, monitoring the Weak Signals of the behavior function, as in the case of 2. The cicle shows how two behaviour attractors (the attractor (1) and the attractor (7), when the function V_2 take minimum value, change progressively from one mode to another, passing for stability (4), in whose proximity the occurrence of a jump to the top layer, could be favorable, for possible innovation (and after, going to the right), or catastrophic shock (returning to the left and generating a cycle falling down and jump up again.

A natural jump up occurs on the seventh step, hence the importance of identifying the proximity of the equilibrium sets; also, the parallelisms analysis, concentration analysis and the visualization of trajectory linked to robust connections and risk analysis. Barunik and Vosvrda (2009) adapted representative of the capture topological mode to stock market data, explaining the fall of the stock markets, using data from the US stock markets.

The Dimension People equilibrium dynamics is linked to stable attractor points and jumps between different behaviour modes. The "jump up-capturing" archetype (Figure 6 emphasizes conditions for disruptive innovation, balancing aptitude (knowledge and research) with attitude (experience and tradition) then, enhancing the depth of morphological change processes is encouraged by the emergence of Cluster Grouping and Cooperation, on the (context, people) plane, with (ψ_i, η_i), parametric coordinates references (Masini, Vasquez, 2000). There can be grouping alignations with the spectrum of knowledge states (certainty-risk-uncertainty-ambiguity), consistent in the cooperative behaviour emerging at the bifurcation point (0, 0); cooperative cluster with recognise specific properties and risk dynamic (Vasquez, Ortegón, 2006).

Figure 6. **Capture Topological Mode. Stratification & Outlier Points**



Source: authors.

Process Dimension Management and the Deep Transient Mode

Deep Transient Mode: A Key to Process Dimension Management. A *deep transient mode* emerges when systems experience longer-lasting transitions – often involving complex changes that unfold gradually before stabilizing. Recognizing this mode is crucial in Process Dimension Management, which addresses *Catalysts* (factors initiating and implementing innovation) and *Fosterers* (elements consolidating and diffusing innovation). By identifying deep transient behaviors, managers can guide innovation processes through prolonged shifts, ensuring resilient and sustainable transformation over time.

Process Dimension Management. In this dimension, function V_3 defines a canonical neighborhood of the deep transient mode, while its slope function $s_3(h_i)$ (linked to the fourth statistical moment) captures innovation's rate of change. A bias factor ξ_i introduces a third parametric axis – in addition to ψ_i and η_i – allowing growth within an equilibrium zone. Figure 7 illustrates these parametric axes at the center, showing a curvilinear polygon sliding along ψ_i and displaying two behaviors:

- Regular ($\psi_i>0$, e.g. $\psi_i=1$)
- Non-regular ($\psi_i<0$, e.g. $\psi_i=-1$)

The resulting stratified surface contracts near zero, revealing two symmetric cusps influenced by ξ_i. When ξ_i shifts, the system can undergo a behavioral change, marking critical thresholds for process-driven innovations.

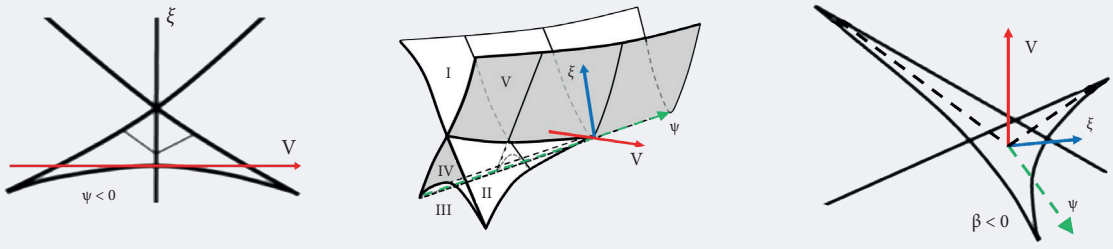
Case Study on Aphid Population (Wu et al., 2014). An example from ecological management highlights how monitoring equilibrium zones is essential in dynamic systems. Let h_i be Aphid population density, ψ_i an environmental control factor, η_i the crop condition (carrying capacity), and ξ_i a predator factor. A representative unfolding function captures how state variable h_i behaves under control conditions, influencing morphological changes in pest management – much like deep transient modes in innovation processes.

Applications in Startup Ecosystem Orchestration. For startups, the deep transient mode spotlights prolonged shifts in processes – for example, a multi-stage pivot driven by new market insights. *Catalysts* might be accelerator programs and angel investments, while *Fosterers* could be industry partnerships and user community growth. By tracking parametric shifts (ψ_i,η_i,ξ_i), founders can spot cusp points that signal slow-building transitions, helping them fine-tune product rollouts or scale more sustainably.

Data Requirements for Deep Transient Mode Analysis. To understand deep transient modes in process management, mixed data are crucial: *Quantitative*: Longitudinal metrics (e.g., implementation timelines, R&D spending, customer retention rates); *Qualitative*: Stakeholder feedback, expert interviews, field observations capturing persistent challenges or gradual cultural shifts; and *Hybrid*: Policy updates, organizational network measures, pilot project outcomes that help correlate slow-moving changes with faster pivots. Such integrated datasets reveal extended transitions and underlying biases, enabling adaptation in sustainability-driven innovation processes.

Synthesis and Multi-Level Analysis. In deep transient mode scenarios, prolonged shifts can either strengthen or disrupt innovation trajectories. At the micro level, analyzing catalysts and fosterers pinpoints local changes (e.g. team reorganization, ongoing pilot ex-

Figure 7. **Depth Transient and Capture Modes & Dynamic**



Stratified 3-depth curve | 3-depth curve moving on axis Ψ | Stratified 4-depth curve

Source: authors.

periments) that slowly reshape process outcomes. At the macro level, cusp analyses and contracting surfaces guide policy interventions, financial backing, or ecosystem partnerships aimed at sustaining long-term innovation growth. Recognizing these deep transient patterns bolsters Process Dimension Management, ensuring continuous adaptation and resilience across complex innovation landscapes.

Capture Mode and High-Precision Monitoring

Deep Capture Mode: A Key to Impact Dimension Management. A deep capture mode emerges when long-term, transformative change takes root in a system, culminating in significant, stable shifts across multiple parameters. Recognizing deep capture is critical in Impact Dimension Management, which addresses '*Transformation*' (positive changes in the quadruple helix of science, innovation, and society) and '*Sustainability*' (environmental, societal, economic, governance, and infrastructural advancements). By spotting deep capture patterns, decision-makers can direct high-precision monitoring toward long-lasting impacts in complex socio-technical systems.

Impact Dimension Management. In this dimension, function V_4 defines a canonical neighborhood of the deep capture mode, while its slope function, $s_4(h_i)$ (related to the fifth statistical moment), measures the rate of change in agreeing and impacting processes. A new butterfly factor (β_i) introduces a fourth axis alongside ψ_i, η_i, and ξ_i, generating stability in an equilibrium zone. For $\beta_i<0$, the maximal trajectory passing transversally to ψ_i marks the boundary of the shock wave – sometimes termed a "pocket organization" in semantic interpretations.

Case Study – Risk Analysis and Policy Recommendations. Zhu et al. (2023) applied a capture topological mode to investigate China's zirconium industry (2005–2021), revealing an "early warning" state tied to political turbulence and technological advances. Their work illustrates how deep capture insights can inform policy proposals that strengthen sustainability in vulnerable industries.

Applications in Startup Ecosystem Management. For startups, a deep capture mode highlights long-term impact (e.g. systemic shifts in market positioning or industry-wide alliances). When transformation occurs – encompassing quadruple helix actors such as universities, industry, government, and society – founders and investors can analyze β_i to detect shock wave boundaries. Identifying pocket organizations or hidden networks may guide sustained growth strategies (e.g. global expansions or circular economy initiatives).

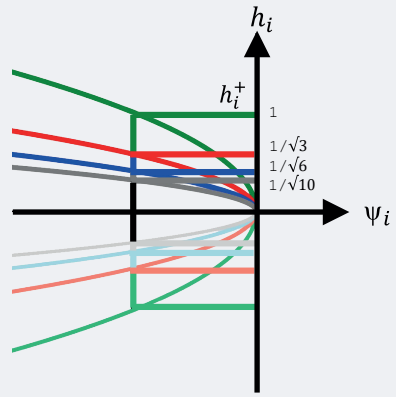
Data Requirements for Deep Capture Mode Analysis. Effective deep capture assessment demands comprehensive datasets: *Quantitative*: Longitudinal policy metrics, macro-level market data, environmental impact scores; *Qualitative*: Stakeholder interviews (society, government), expert panels on technological adoption; and *Hybrid*: Cross-sector collaborations (e.g. academia-industry partnerships), funding flows that reflect multi-helix engagement. These inputs pinpoint equilibrium sets, shock wave boundaries, and butterfly factor dynamics, ensuring risk analysis and policy adaptation align with deep, transformative change.

Synthesis and Multi-Level Analysis. In deep capture mode scenarios, long-term transformations become anchored in impact-oriented dimensions, driving substantial shifts across entire sectors or regions. At the micro level, analyzing butterfly factor (β_i) and equilibrium zones reveals organizational readiness (e.g. pocket organizations fostering breakthrough innovations). At the macro level, shock wave boundaries outline where policy interventions or stakeholder cooperation can secure sustainable advantages. Recognizing deep capture patterns fortifies Impact Dimension Management, enabling high-precision monitoring and systemic resilience in complex, ever-evolving innovation ecosystems.

Energy: A Key Driver for Sustainable Disruptive Growth

Within the four Management Dimensions – *Context*, *People*, *Process*, and *Impact* – energy systems provide a powerful example of how topological modes shape sustainable innovation management. As illustrated earlier with wind power (mass of air at average velocity), energy-related contexts highlight key risk exposures and resilience strategies, echoing Cherp and Jewell's (2014) "four A's of energy security" (availability, accessibility, affordability, acceptability) and the vulnerability arising when vital energy systems intersect with critical social functions. According to Americo et al. (2023), clean technologies (wind, solar, electric vehicles) pose

Figure 8. **The (h_i, ψ_i)-plane Stratified by Depth of Change**



Source: authors.

opportunities and challenges for fossil-fuel producers and metals/minerals suppliers, demanding long-term adaptation across local and global networks.

Figure 8 demonstrates how the four dimensions interact – *Context* frames resource availability, *People* drive skills and motivation, *Process* underpins system development, and *Impact* reflects transformation. This stratification reveals zones of energy change where threshold overlaps define stable or disruptive behavior. Behavioral clustering at close distances (e.g. regional cooperatives or innovation alliances) fosters cooperative pathways, parallelism in roles, and concentration of efforts. The four structurally stable behavioral models (depicted in Figure 8 at $\psi=-1$) each link to a distinct dimension; together, they enable anticipation of system requirements for scalable or disruptive growth.

Moreover, these dynamics mirror market liquidity and resilience principles. Effective energy markets share traits with well-functioning financial markets – they involve diverse participants, reliable price discovery, and robust trading mechanisms (Markets Committee, 2019). Adequate liquidity – or energy supply flexibility – supports timely transactions and efficient adaptation under uncertainty (Logan, Bindseil, 2019). This parallel extends to startup or innovation ecosystems investing in renewable projects, where stakeholders with varied commercial interests must coordinate to ensure both resilience and disruptive potential, thereby advancing sustainable and transformational energy solutions.

Measuring Behavioral Relationships and Economic Complexity

Building on the Context Dimension Management discussed earlier (momentum and foresight points), a system's future arises from its current momentum and management negotiations across threshold zones, bridging two distinct states to reach foresight visions. One context measure calculates the distance between two canonical behavioral trajectories – for instance, $(h_i,\psi_i) \mid \psi_i=a$ and $(h_i,\psi_i) \mid \psi_i=b$ – where the rate of change might be $h^2+\psi$. The difference in rates of change is $|a - b|$, yielding a behavior-specific distance for Context, People, Process, or Impact strata.

Hidalgo and Hausmann (2009) introduce an economic complexity framework linking countries, their capabilities, and the products requiring those capabilities. Under the SD-Growth Model, these could represent a source (ψ_i,η_i,ξ_i) and target (ψ_i,η_i,ξ_i), reflecting ideal connections. The distance between two behaviors is then the mean difference of these ideal points. Axis ψ_i can signify momentum-foresight (Context), η_i captures skill or attitudinal leaps (People), and ξ_i reflects innovation bias (Process), influencing the overall impact on production or growth. In a startup ecosystem, these dimensions help entrepreneurs identify capability gaps and potential pivots – bridging the gap between localized production and scalable solutions. Future work will explore how these ideal model connections inform synergies and cluster formation across context, people, process, and impact dimensions.

Key Outputs

The SD-Growth Model offers a structured framework for analyzing non-linear dynamics in sustainability. Integrating topological, statistical, and morphological analysis, it addresses disruptive, regular, and boundary behaviors. By focusing on context, people, process, and impact dimensions, it enables more resilient, adaptive, and innovative strategies across complex systems, ensuring sustainable long-term transformations.

Dimension Reduction and Topological Frameworks

TThe SD-Growth Model employs four stratified measurement axes – linked to the *transient*, *capture*, *deep transient*, and *deep capture* modes – to track morphological changes by depth. Each axis detects regular, disruptive, or boundary behavior, linking back to *Context*, *People*, *Process*, and *Impact* dimensions. By reducing complexity, the model pinpoints essential behavioral shifts for sustainable innovation management (e.g. identifying sudden AI disruptions or pivot moments in startup ecosystems).

Behavioral Convergence Across Dimensions. Through diverse case analyses, the SD-Growth Model highlights converging trajectories that share robust connections and display adaptive or recovery capabilities, eventually approaching a common focal point. Recognizing these higher-order contact coordinates is crucial for aligning resources and fostering collaboration across the *People* (skills, motivation) and *Process* (catalysts, fosterers) dimensions, thereby enabling or rejecting specific behavioral connections.

Stratified Dynamics: Macro and Micro. The SD-Growth Model differentiates macro-dynamics (outside threshold zones) from micro-dynamics (within threshold zones). Macro-dynamics often reflect stable developments (e.g. steady market growth), while micro-dynamics capture disruptive or wave-like changes (e.g. small-scale energy cooperatives confronting local risks). This stratification supports policymakers and innovators in targeting interventions precisely where volatility or opportunity is greatest.

Equilibrium Stability and Threshold Zones. At the micro level, the model reveals disruptive dynamics emerging in risk zones, with varying amplitudes tied to system depth. Macro-level behaviors outside these zones remain regular. By identifying equilibrium sets and topological constraints, the SD-Growth Model offers methodological guidance for analyzing behavioral shifts in fields like data analytics, artificial intelligence, astrophysics, and startup ecosystem management. Recognizing these threshold zones is vital for preventing instability or capitalizing on disruptive innovation.

Advancing Sustainable Growth. By blending management frameworks (human-society and foresight processes) with morphological, statistical, and topological analyses, the SD-Growth Model underscores the importance of *Context* in defining local environments that foster cooperative relationships. This facilitates sustainable growth and local stability, effectively bridging morphological changes with potentially disruptive yet transformative innovations.

These five features demonstrate the analytical depth and strategic insights provided by the SD-Growth Model in understanding resilient systems, behavioral dynamics, and their implications for sustainability and innovation theory.

Methodological Contributions of the SD-Growth Model

The SD-Growth Model presents a multidimensional framework analyzing *context*, *people*, *process*, and *impact* together, enabling a holistic understanding of how sustainability and innovations evolve over time and space. By stratifying behavioral trajectories into depth-based phases (e.g. *transient*, *capture*, *deep transient*, *deep capture*), it pinpoints critical transformation points and reveals resilience dynamics in complex systems. Using topological and statistical tools, the model examines morphological changes, identifies equilibrium states, and detects disruptive behaviors linked to sustainability goals. Its dimension reduction techniques simplify high-dimensional data, focusing on essential parameters that influence socio-sustainable processes – a crucial asset for startup or innovation ecosystems exploring new markets or technological breakthroughs. By bridging biological, statistical, and epidemiological frameworks, the model broadens sustainability analysis and offers fresh perspectives on topological resilience and emerging disruptive innovations.

Epistemological Contributions of the SD-Growth Model

Adopting a four-dimensional perspective (*Context*, *People*, *Process*, *Impact*), the model underscores the interconnectedness of factors shaping sustainable disruptive growth. Its depth-based approach moves beyond surface-level observations, uncovering underlying forces and emergent properties within adaptive systems. By stratifying the evolution of sustainable behaviors, the model clarifies how these systems maintain topological resilience and stability in the face of external shocks – an insight especially relevant for innovators managing long-term change. Integrating biological, statistical, and topological concepts strengthens this interdisciplinary stance, revealing the mechanisms by which disruptive innovations arise in sustainable contexts. In doing so, the SD-Growth Model expands the theoretical foundations of sustainability studies, promoting a forward-looking view on transformation and evolution that deepens our understanding of systemic behaviors and the drivers behind radical innovation.

Conclusions and Practical Implications

By incorporating Context, People, Process, and Impact dimensions, this paper's insights offer policymakers and innovators a multi-dimensional lens to shape sustainable innovation ecosystems and enhance resilience. Understanding depth analysis and stratified behavioral dynamics enables targeted management of innovation processes, identifying key transformation points, optimizing resource allocation, and creating environments conducive to disruptive growth.

Integrating biological, statistical, and topological frameworks supports network analysis and strategic planning in socio-technical systems, revealing key actors, network dependencies, and systemic shifts central to ecosystem resilience (e.g., adaptation in renewable energy cooperatives or cross-sector startup collaborations). Recognizing risk zones and robust connections enhances risk management, helping stakeholders anticipate disruptions and devise adaptive strategies. Likewise, AI-driven analytics can leverage these insights for scenario simulations, sustainability planning, and evidence-based decision-making aligned with sustainable innovation principles.

Imagine you are piecing together a huge jigsaw puzzle where each piece keeps changing shape and size every time you try to fit it in. The four dimensions – *Context*, *People*, *Process*, and *Impact* – act like the puzzle's edges, giving you a sense of where to start and how everything might link up. Meanwhile, the four topological modes – *transient*, *capture*, *deep transient*, and *deep capture* – are special pieces that unlock new connections, revealing unexpected patterns or hidden shortcuts in the bigger picture. Even when it seems impossible, this paper shows which pieces fit, which to rotate, and which to save for later, making the puzzle manageable and exciting. In doing so, it provides a groundbreaking blueprint for navigating the ever-evolving jigsaw of sustainability, innovation, and disruptive transformation – applicable to all fields, from science and technology to the humanities.

Further Research Areas

Dynamic Network Analysis. Future work could integrate depth analysis and stratified dynamics into network-oriented methods, examining how topological changes over time influence sustainability outcomes. This might involve studying behavioral patterns in innovation clusters, tracking persistence of stratified states, and gauging long-term resilience against disruptions.

Multi-Level Governance and Complexity. Applying the SD-Growth Model to multi-level governance structures can clarify how local, national, and global poli-

cies interact in driving innovation diffusion and policy effectiveness. Research might explore vertical (national–local) and horizontal (cross-sector) integration, revealing synergies or tensions that affect ecosystem resilience.

Integration of Sustainable Behavioral Strategies. Investigating how social norms and individual choices shape innovation adoption can deepen our understanding of sustainable behavior. This includes identifying decision-making biases, mapping collective behavior shifts, and tailoring interventions for increased uptake of green technologies, ethical entrepreneurship, or circular economy models.

Futures Prosperity Index (FPI) or Model (FPM). Building on the SD-Growth Model's multidimensional focus (context, people, processes, impact), future work could develop a Futures Prosperity Index (FPI) or Futures Prosperity Model (FPM). This would integrate the following four factors – environmental sustainability, social and health wellbeing, innovation competitiveness, and fiscal/governance resilience – into a composite measure.

Extreme-Scenario Testing and Foresight. Employing future-proof methods (Popper, Towpik, 2024; Popper, Popper, 2024) within the SD-Growth Model allows strategies to be tested against uncertain and disruptive scenarios, particularly those affecting public funding for research and innovation. This approach strengthens policy robustness and refines innovation design, equipping decision-makers to meet frontier challenges in rapidly evolving fields.

Finally, extending these methodologies beyond sustainability – to fields like ecology, sociology, political science, and economics – can help validate and refine their applicability, fostering greater coherence and synergy in tackling complex global challenges.

Limitations

A key limitation is the availability and quality of data for depth analysis and stratified behavioral dynamics. Overcoming this may require new data collection methods or leveraging AI and machine learning for robust synthesis. Similarly, the sustainability and practicality of the models can be challenging, especially when interpreting and applying results to real-world scenarios. Researchers might develop simplified frameworks or visualization tools to help stakeholders grasp ecological dynamics.

Another limitation is generalizing findings across diverse ecological contexts and regions. Validating these methodologies in varied socio-ecological environments and institutional settings is essential to confirm robustness. Ethical and policy issues also arise when predictive analytics and algorithmic models influence governance – fairness, transparency, and unintended consequences must be assessed. Interdisciplinary collaboration is vital; bridging disciplinary gaps and harmonizing methodologies can significantly advance sustainability research.

Moreover, the complex topological modes (transient, capture, deep transient, deep capture) may hinder adoption if stakeholders lack technical expertise. Overlapping threshold zones can create ambiguous signals, complicating decision-making. While Wild Cards (low-probability, high-impact events) are partly addressed by Weak Signals Analysis, true Black Swans (rare, unforeseeable disruptions) may exceed the model's scope. Sector-specific nuances – from quantum computing to startup ecosystems – might require tailored adaptations. Finally, longitudinal datasets capturing shifts in Context, People, Process, and Impact are essential to maintain the model's accuracy in fast-changing environments.

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Appendix 1. Topological Stability & Non-Regular Dynamic

The Stratified Axes

The stratified axes, e.g., ψ_i, represents each stratum, the positive (resp. negative) as image of the real line using exponential function. Similarly, the real axis of potential function.

$Axis(h_i) = \{-e^{\lambda_h}\} \cup \{(0,0)\} \cup \{e^{\lambda_h \cdot}\}$

The Local Stability Theorem

Using a stratified version of the theorem, we decompose the behavioural functions into strata. The analytical expression of the equations allows demonstrating the relationship between the statistical moments, especially the specific variance with the equations shown in the table A1.

Theorem. If a process, controlled by no more than four real factors or parameters, can be described by minimizing or maximizing a function with one explanatory variable, then any singularities will be like those appearing in any of the following archetypal models, where h_i represent a density variable in a *i* locality and ψ_i, η_i, ξ_i and β_i are real parameters (Thom, 1975).

Table A1: Germs of Functions and their Unfolding

Germ of function	Universal unfolding of function
$v_1 = 1/3h_i^3$	$\mathcal{V}_1 = 1/3h_i^3 + \psi_i h_i$
$v_2 = 1/4h_i^4$	$\mathcal{V}_2 = 1/4h_i^4 + 1/2\psi_i h_i^2 + \eta_i h_i$
$v_3 = 1/5h_i^5$	$\mathcal{V}_3 = 1/5h_i^5 + 1/3\psi_i h_i^3 + 1/2\eta_i h_i^2 + \xi_i h_i$
$v_4 = 1/6h_i^6$	$\mathcal{V}_4 = 1/6h_i^6 + 1/4\psi_i h_i^4 + 1/3\eta_i h_i^3 + 1/2\xi_i h_i^2 + \beta_i h_i$

The first function is solution of a differential equation defined by the specific variance, since the rate of change of the behavioral functions coincides with the specific variance. The diagram relates the behaviors in the zero environment. The following diagram shows the relation The specific variance as the rate of change of the first function defined in the stability theorem, for the case of a positive parameter.

$$\begin{array}{ccc} \mathrm{G}(\tilde{v_1}) = \{(h_i, 1/3h_i^3), h_i \in \Re^*\} & \xrightarrow{H_\epsilon} & \mathrm{G}(\tilde{\mathcal{V}_1}) = \{(h_i, 1/3h_i^3 + \epsilon h_i), h_i \in \Re^*\} \\ \downarrow{\scriptstyle \frac{\partial}{\partial h_i}} & & \downarrow{\scriptstyle \frac{\partial}{\partial h_i}} \\ \mathrm{G}(\tilde{s_1}) = \{(h_i, h_i^2), h_i \in \Re^*\} & \xrightarrow{\tau_\epsilon} & \mathrm{G}(\tilde{S_1}) = \{(h_i, h_i^2 + \epsilon), h_i \in \Re^*\} \end{array} \quad (1)$$

Transient model & non-regular points

The threshold zone, defined by two graph, and the bifurcation point (0, 0):

$$G(\gamma_i^+): \quad \gamma_i^+ = (\sqrt{-\psi_i}, \psi_i), \psi_i < 0; \quad G(\gamma_i^-): \quad \gamma_i^- = (\sqrt{-\psi_i}, \psi_i), \psi_i < 0 \qquad (2)$$

Parallelism in the Risk Zone: compression & expansion

The threshold zone opens up space, like the basing of a river, and induces new notions of parallelism and transversality in the variable-parameter plane. New parallelism we defined using a δ compression, for $0 < \delta < 1$, denoted by c_δ, and δ expansion for δ greater than zero, denoted by e_δ, and given by:

Table A2: Transient Topological Mode. Morphological Changes and Key Information.

Slope function: $s_1 = h_i^2$ **Behaviour:** $v_1 = 1/3h_i^3$ **Unfolding:** $\mathcal{V}_1 = 1/3h_i^3 + \psi_i h_i$			
Singular set (Sv_1)	**Bifurcation set** (v_1)	**Outlier set** (Ov_1)	**Code marks on** $\{\psi_i\}$
$\frac{\partial \mathcal{V}_1}{\partial h_i} = h_i^2 + \psi_i = 0$	$\{\frac{\partial^2 \mathcal{V}_1}{\partial h_i^2} = 0\} \cap S_{\mathcal{V}_1}$	$\pi_{\psi_i} : p \in S_{\mathcal{V}_1} \mapsto \psi_i$	$(-\sqrt{-\psi_i}, \psi_i), \quad \psi_i < 0$
$\{(\mp\sqrt{-\psi_i}, \psi_i)\}$	{(0, 0)}	$h_{\psi_i} = \pm\sqrt{-\psi_i}$	$(0, \psi_i), \quad (\sqrt{-\psi_i}, \psi_i)$

$$c_\delta \gamma_i(\psi_i) = (\sqrt{-\psi_i \delta}, \psi_i); \quad e_\delta \gamma_i(\psi_i) = (\sqrt{-\psi_i + \delta}, \psi_i). \qquad (3)$$

The Maximal Stratified Trajectory of Behaviour & Robust Connection

The plane (stratified by non-regular points) is lifted without non-regular points, denoted E^2, to its natural extension to the 3-space, $E^3 = E^2 \times \Re$. The natural projection of each point on its base allows to define a fibered manifold $M = (E^3, \tilde{\pi}_i, E^2)$, and a lifting of E^2 using the function v_1, i.e., a section η, of the bundle M: given by:

$$c^3\eta : (h_i, \psi_i) \in E^2 \mapsto (h_i, \psi_i), 1/3h_i^3 + \psi_i h_i, h_i^2 + \psi_i, 2, 0) \in C^{3,1}M). \qquad (4)$$

We define an integrable differential system of order three, using a a regular submanifold $W \subset C^{(3,1)}M$ of the contact manifold of order 3 and dimension 1 of the bundle M. (Villarroel, 1995). Then, robustness connection can be defined, introduced, converting the behavioral trajectories,namely the ´R-pseudomanifolds´, where R is a parametric group defined by a maximal solution of a differential equation; the notion is related with G-pseudomanifold, introduced by R. W. Popper in the case of G being a compact Lie group acting on pseudomanifolds (Popper, 2000).

Capture Mode & Parallelism

Similarly, the parallelism in the 'capture mode' linked to 'people' is defined by virtue of the coexistence of two modes of behavior, analyzed in the 'capture mode' section.

$$\gamma_1^+(\psi_i) = (\psi, \sqrt{-4/27\psi_i^3}), \quad \gamma_1^-(\psi_i) = (\psi_i, -\sqrt{-4/27\psi_i^3}), \quad \psi_i < 0.$$

The depth transient and capture behavior modes are analyzed by decomposing the respective plane by singularities. The notions of parallelism and transversality modes of behavior depth transient and capture are more complex since as the depth increases the dimensions involved increase.

Appendix 2. Key Concepts

Critical Issues Analysis (CIA) is a multidisciplinary, systematic method for identifying, evaluating, and prioritizing issues that significantly influence the technological, economic, environmental, political, social, ethical, and spatial (TEEPSES) dimensions of a given context, particularly in relation to sustainable innovations. This approach integrates diverse inputs from creativity-based, interaction-based, evidence-based, and expertise-based methods to assess, in a structured manner, the potential impact and uncertainty of key drivers of change. By doing so, CIA offers a comprehensive framework for tackling complex, multifaceted challenges, enabling decision-makers to prioritize issues that demand immediate attention for effective management and strategic action.

SMART Foresight is a structured, participatory, forward-looking, and policy-driven process designed to actively engage key stakeholders in a comprehensive set of activities. These activities encompass Scoping, Mobilizing, Anticipating, Recommending, and Transforming (SMART) potential futures across technological, economic, environmental, political, social, and ethical (TEEPSE) dimensions.

Horizon Scanning (HS) is a structured, ongoing activity designed to "monitor, analyse, and position" (MAP) emerging and frontier issues that are relevant to policy, research, and strategic agendas. The issues identified through HS include new or emerging trends, policies, practices, stakeholders, services, products, technologies, behaviours, attitudes, as well as unexpected events (Wild Cards) and early indicators of change (Weak Signals).

Wild Cards are low-probability, high-impact events that are both unexpected and disruptive (e.g., the 9/11 attacks, environmental catastrophes, or technological failures). These events may also emerge through serendipitous discoveries in scientific research (e.g., Penicillin, Dynamite, Viagra, Graphene). Wild Cards can be classified into three categories: nature-related surprises, unintentional human-induced events, and intentional human-induced events. In foresight and forward-looking research, Wild Cards are increasingly recognized as critical factors for understanding future uncertainties.

Weak Signals are subtle, ambiguous indicators or "seeds of change" that offer early insights or "hints" about potential future developments, such as Wild Cards, emerging challenges, or opportunities. These signals are inherently subjective, often shaped by the mental frameworks and interpretations of individuals working with limited information on emerging trends, developments, or issues within a specific temporal and contextual setting. The "weakness" of these signals corresponds to the degree of uncertainty surrounding their interpretation, importance, and potential impacts over the short, medium, or long term. Weak Signals are often indistinct observations that serve as early warnings of possible future events with the potential to be highly transformative or "game-changing".

Scenarios are structured narratives that systematically explore potential future developments by analysing trends, uncertainties, and expert insights. Constructed through methodologies such as desk research, workshops, and computational modelling, scenarios generate plausible and internally consistent future states. They may integrate expert opinions or reflect the collective perspectives of stakeholder groups, facilitating the mapping of alternative futures and guiding decision-making by elucidating potential risks, opportunities, and pathways for action. Classic approaches to scenario development include the 2x2 Approach, which uses a matrix based on two critical drivers; the Archetype Approach, which examines scenarios characterized as "better than expected", "worse than expected", and "different than expected"; and the Success Scenarios Approach, which delineates a credible and desirable future. Additionally, semi-quantitative techniques that leverage artificial intelligence, data analytics, cross-impact analysis, and morphological modelling are gaining importance in scenario development, providing innovative frameworks for addressing complexity and uncertainty in strategic foresight and planning.

Action Roadmapping (AR) is a structured methodology for coordinating and executing actions at the strategic, tactical, and operational levels to achieve innovation objectives. It aligns stakeholders and systematically addresses four key dimensions: Context, People, Process, and Impact, each comprising ten critical aspects that drive sustainable innovation. At the strategic level, AR guides top decision-makers from government, industry, civil society, and academia (the quadruple helix) to establish momentum, build foresight, and mobilize resources. Tactical actions translate these objectives into specific interventions, such as funding programs and partnerships, equipping stakeholders with the necessary skills and resources. Operational actions, led by front-line actors like policymakers and researchers, focus on executing tasks that drive innovation and its diffusion. AR ultimately emphasizes long-term impact, fostering systemic transformation and ensuring sustainability across environmental, social, and economic dimensions. By integrating actions across all levels, AR supports a cohesive and adaptive approach to innovation (Popper, 2008).

Strategies of Financial Inclusion for Enriching Sustainable Development Goals in BRICS Economies

Manoj Kumar[a]
Professor, Department of Information Science and Engineering, manojmv24@gmail.com

Nasser Al Muraqab[b]
Associate Professor, Dubai Business School, nasser@ud.ac.ae

Prashanth Bshivanna[a]
Assistant Professor, Department of Information Science and Engineering, prashanth.bshivanna@gmail.com

Immanuel Azaad Moonesar
Professor, Department of Academic Affairs - Health Policy & Systems Researchc, & Scientific Policy Advisore, immanuel.moonesar@mbrsg.ac.ae

Udo Christian Braendle[d]
Professor, CEO and University Management Research & Innovation, udo.braendle@imc.ac.at

Ananth Rao
Emeritus Professor — Finance, University of Dubai, Dubai Business Schoolb, and Non-resident Fellow (NRF)c, arao@ud.ac.ae

[a] Nitte Meenakshi Institute of Technology, Nitte Deemed to be University, NITTE Campus, 6429, Yelahanka, Bengaluru, Govindapura, Karnataka 560064, India
[b] University of Dubai, Academic City Emirates Road—Exit 49, Dubai, United Arab Emirates
[c] Mohammed Bin Rashid School of Government, Level 13 Convention Tower DWTC, Sheikh Zayed Rd, Dubai, United Arab Emirates
[d] IMC Krems University of Applied Sciences, A-3500 Krems an der Donau, Austria
[e] International Vaccine Institute, 1 Gwanak-ro, Nagseongdae-dong, Gwanak-gu, Seoul, South Korea

Abstract

Most of the challenges to sustainable development are interconnected and systemic in nature, which makes achieving this goal particularly challenging. Research on these barriers and their solutions revealed that neither technological nor social innovation hinders the adoption of this development model. The main reason lies in the specific mechanisms for overcoming inertia, resistance to change, path dependency, and entering a new trajectory. One of the key spaces where the widest circles of the population are in close contact with new technologies is the financial sector. Fintech has significant potential to overcome these limitations, change behavioral patterns, reduce path dependence, and launch development on a new trajectory.

The article provides a comprehensive analysis of these processes using the example of the expanded BRICS countries. It compares heterogeneous socioeconomic landscapes and assesses the readiness of the countries in question to master more complex development models, using digital banking as an example. The study identifies the blocking factors and suggests ways to overcome them. An interdisciplinary synthesis of the theories of narrative persuasion, evolutionary governance, and path dependence provides a new understanding of the interaction of financial systems, governance structures, and social behavior, upon which financial inclusiveness depends as a cornerstone for achieving balanced economic growth.

Keywords: openness to change; financial inclusion; digital financial technologies; BRICS countries; sustainable development goals; path dependence; economic flexibility; digital platforms; fintech; behavioral patterns

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Introduction

The development of financial inclusion (FI), i.e., providing citizens with broad access to financial services using digital technologies, is actively discussed among experts and politicians. In leading countries, universal access to such technological solutions has long been the norm. Meanwhile, in developing countries, with the adoption of new technologies that improve the quality of life, certain problems remain, the elimination of which is a priority socio-economic task for development institutions such as the World Bank and the UN (World Bank, 2022; UN, 2017). In most BRICS countries, the share of the population not covered by digital technologies remains significant. However, the spread of these technologies can stimulate a transformative transition to a new development trajectory (Purva et al., 2021). Embracing banking innovations expands the possibilities of managing available funds for different purposes – current expenses, emergency response, investment in education, health support, entrepreneurship, and so on. (OECD, 2020, 2022, 2023). As BRICS countries strive to increase welfare, FI can play a crucial role in achieving this goal (Umar et al., 2021). Mobile banking, digital wallets, online payment systems, and other tools, have increased the space for operating available financial resources and have created the preconditions for smoothing out social inequality (Pradhan et al., 2021; Abdu, Adem, 2021; Tian, Xiang, 2023). The spread of digital technologies is a priority for international development institutions, financial institutions, and government agencies. Specialized associations have emerged, such as the Alliance for FI (AFI) and the Global Partnership for FI (GPFI). Although this topic has only recently entered the academic discourse (Yang, Masron, 2023), a significant cluster of studies has formed around it. When talking about FI measurements, the most common indicators are the number of bank accounts or ATMs per capita. However, they reflect only one aspect of FI, namely access to finance (AF). According to the public goods theory, FI should benefit everyone, regardless of status or income (Kumar Vaid et al., 2020). The value of access to financial services directly impacts all areas of life, including investments in the future, making this area a priority in terms of including the entire population in a single financial system (Allen et al., 2016).

The positive contribution of FI to economic growth has been confirmed by numerous studies in different regions of the world (Mitchell, Scott, 2019; Zins, Weill, 2016; Evans, 2018; Tsai, 2017). For the BRICS countries, FI is one of the priorities for achieving inclusive growth and improving the population's well-being through a wide range of instruments (Umar et al., 2021). For financial system reforms to be effective, it is important to understand the diversity of microeconomic factors that influence FI. Digital platforms accelerate the spread of financial services, reduce costs, increase customer needs adaptability, and provide economic opportunities (Lauer, Lyman, 2015). The volume of non-cash transactions is projected to reach $1.9 trillion this year and the amount of per capita digital payments will triple by 2030 (PwC, 2021). However, for FI to spread everywhere, digital financial technologies alone are not enough since another deep-seated challenge is to overcome the population's unwillingness to accept them (Chatterjee 2020). A transformation of collective thinking and a rejection of established stereotypes are required.

The topic of societal acceptance of innovations is also widely covered in the literature, where a notable constellation of concepts related to this problem is used: the theory of evolution (Beinhocker, 2006), community planning (Albrechts, 2004), spatial development (Stöhr et al., 1981), evolutionary economics (Pike et al., 2010; Martin, 2012), futures studies (Inayatullah, Sweeney, 2021; Donnelly, 2023; Di Zio et al., 2023), cognitive biases (Tversky, Kahneman, 1974), path dependence (Arthur, 1994; Garud et al., 2010), resistance to novelty (Oreg, 2003), and observational learning (Walden, Browne, 2009), etc. All of them, to one degree or another, shed light on the mechanisms that allow us to overcome the low sensitivity of the population to new technologies, in our case, fintech and FI.

This paper uses Bayesian and Markov decision models to identify entry points for path rethinking and openness to new technologies. We synthesize the concepts of "path dependence" (Liu et al., 2024), "observational learning" (Walden, Browne, 2009), "narrative theories" (Puckett, 2016), "financial inclusion " (World Bank, 2022; UN, 2017), and "vision of the future" (Polack, 1972). The reasons for resistance to innovation and ways to overcome it are analyzed. It shows how a combination of these concepts can "grow" into a proposal for effective ways to ensure the financial inclusion of the population in the BRICS countries.

This article begins with a review of the literature on FI and concepts that encourage rethinking of emerging opportunities. It then provides examples of both successful implementation and problematic situations, as well as possible future scenarios. A classification of BRICS countries by their level of FI achievement and targeted recommendations for their transition to higher positions are proposed.

Literature Review

According to numerous studies, a narrative approach can stimulate change and motivate people to choose more complex, sustainable development paths, the reliability of which has been proven by the experience of those who have previously applied

such a strategy (Talbi, 2024). Narratives are structured assumptions about cause-and-effect relationships. Combined with analytical data, they reveal a holistic perspective, allow us to interpret events realistically, and make choices in conditions of deep uncertainty (Johnson et al., 2022). The structured delivery of narratives serves to solve such problems as rethinking the past, coordinating behavioral patterns and actions, and shaping a preferred future. Given that public narratives can be embodied in individual strategies and, under certain conditions, the likelihood of making bolder and more radical decisions to overcome path dependence increases, Conviction Narrative Theory (CNT) appears to be a relevant conceptual framework for our study. Countries still have barriers to accessing "digital finance," which have a destructive impact on development. The diagram in Figure 1 reflects the "dependence on the past" structure.

Existing ideas are transformed under the influence of two channels. On the one hand, "shot" fragments of the narrative transform the social context, and on the other, the actions taken can lead to the emergence of new events. Narratives combine the cause-and-effect, time, analog, and valence components of the information underlying decision-making. In other words, four processes are integrated:

- Explanation (structuring facts to make sense of the past and present).
- Modeling (creating a new path by extrapolating the narrative over time).
- Perception (assessment of the preferred scenario).
- Communications.

Relying solely on facts does not provide a holistic view of reality and must be supported by deeper knowledge that takes into account components that are not always measurable (Tuckett et al., 2020). The Bayesian process involves synthesizing knowledge about the past with new events. Taking these aspects into account becomes the basis for developing effective strategies to achieve FI, coordinating the efforts of different players to promote relevant instruments while increasing the population's readiness to accept them (Falaiye et al., 2024).

Evolutionary governance theory (EGT) considers, among other things, the influence of limiting conditions and collective behavioral patterns on the trajectories of socio-ecological development (Goldstein et al. 2023). Fairbairn (2020) provides an example of how this mechanism operates. The concept of "inevitable effects" derived from EGT helps identify important events that cause radical transformational shifts. However, it is not applicable to a broader spatio-temporal identification of future trajectories, since complex socioeconomic systems behave unpredictably. To describe them, evolutionary models of change, including "path dependence" (Gowdy, Baveye, 2019), are increasingly used in interdisciplinary sciences. According to the EGT, evolution is not always linear, allowing for locks that keep us in inertial scenarios from which it is very difficult to exit. The transition to a new, dynamic trajectory requires the ability to finely and complexly orchestrate interactions between different stakeholders and collective learning to adapt to more complex development models (Goldstein et al. 2023). Thus, the combination of CNT and PDM is a suitable tool to achieve the objectives of our study on the factors hindering the adoption of new technologies as a basis for ensuring FI in the BRICS countries.

BRICS Countries

With the accession of five new members to BRICS in 2024[1], the alliance's combined GDP reached $30.76 trillion (30% of the global total), and its share of the world's population is 40%. Its members have expressed their commitment to achieving the Sustainable Development Goals (SDGs), one of the key conditions that are seen as stimulating economic growth and reducing inequality. Digitalization and FI can significantly contribute to this process (Iammarino et al., 2019). Table 1 shows the main macroeconomic indicators of the BRICS countries in 2023.

Austria was chosen as a benchmark for assessing the current level of FI in the BRICS countries, whose relations with the alliance members can be called

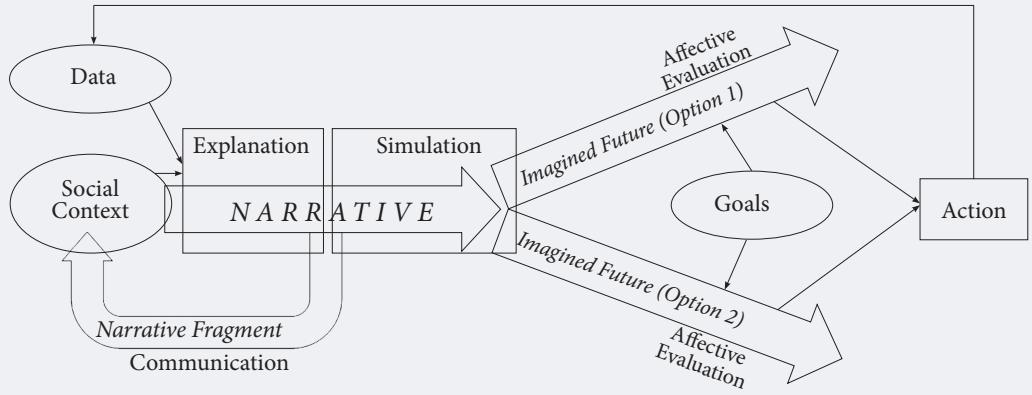
Table 1. **Macroeconomic Indicators of BRICS Countries Compared to Austria (2023)**

Country	GDP (share of world, %)	GDP growth rate (annual, %)	Inflation, consumer prices (annually, %)
Brazil	2.1058	2.9084805	4.5935628
China	18.50106	5.2	0.2348368
Egypt	0.507273	3.7590054	33.884776
Ethiopia	0.121358	6.4981346	30.218828
India	3.446253	7.5839711	5.6491432
Iran	0.551398	4.9521632	44.579186
Russia	1.642323	3.6	..
Saudi Arabia	0.836087	–0.754915	2.3270852
South Africa	0.390917	0.6016623	6.0739085
UAE	0.4806	3.4038572	..
Austria	1.760292	3.0169881	5.5970149

Source: authors.

1 On January 1, 2024, the BRICS alliance expanded to 10 countries: the original members, Brazil, Russia, India, China, and South Africa, were joined by Egypt, Ethiopia, Saudi Arabia, Iran, and the UAE.

Figure 1. **Representations and Processes in Conviction Narrative Theory (CNT chart)**



Note: Components are represented by block arrows, processes by rectangles, and beliefs and values that the thin arrows bring to the table by ovals.

Source: (Johnson et al., 2022).

partnerships, with a focus on the economic component. The country is a good benchmark for BRICS members due to its high level of FI and the development of digital technologies. Developed digital infrastructure and strong social support systems have provided the population with almost universal access to financial services.

India demonstrates the highest GDP growth rate (7.58%). It is noteworthy that Ethiopia, with a rate of 6.5%, is ahead of China (5.2%). In Saudi Arabia, a decrease in GDP of -0.75% was noted. These figures give an initial idea of the heterogeneity of the BRICS economic landscape, the variety of existing problems, and differences in development dynamics.

One of the key concepts used in our study is "unbanked," which means that an individual does not have an account with a financial institution. This status is seen as an obstacle to wealth. Most of its holders live in developing countries and have severely limited opportunities to perform banking transactions. Concentrating efforts on the digitalization of financial technologies will significantly increase the level of FI. The data presented below illustrate the problems of the countries under consideration, caused by the following factors: access to finance (AF), use of finance (UF), digital access to finance (DAF), and the level of wealth (LW). The analysis is based on data from the FINDEX 2021 survey (Demirgüç-Kunt et al., 2022).

A multi-level approach can improve the effectiveness of strategies to achieve FI. Table 2 lists the barriers to FI development in each country, according to the relevant characteristics, and outlines the general measures to overcome them. Table 4 pres-

Table 2. **Principal Component Loadings of FI Dimensions in BRICS Countries Compared to Austria**

Country	Component	Factor loading	Contribution to explanation of statistical dispersion (%)
Austria	AF	0.92	82.5
	BS	0.38	17.5
Brazil	AF	0.85	72.4
	WB	0.53	27.6
China	AF	0.92	82.5
	WB	0.38	17.5
Egypt	AF	0.92	82.5
	WB	0.38	17.5
Ethiopia	AF	0.92	82.50
	WB	0.38	17.50
India	AF	0.85	59.2
	WB	0.52	33.5
	UF	0.02	7.3
Iran	AF	0.92	82.3
	WB	0.38	17.7
Russia	AF	0.92	82.5
	WB	0.38	17.5
Saudi Arabia	AF	0.91	82.3
	WB	0.40	17.7
South Africa	AF	0.90	74.6
	WB	0.44	21.3
	DAF	0.12	4.1
UAE	AF	0.88	77.9
	WB	0.47	22.1

Legend: AF - access to finance, WB - well-being, UF - use of finance; DAF – digital access to finance.

Source: authors.

Table 3. **Analysis of The FI Index and Its Components by Country Using the Principal Component Method**

Country	AF	WB	UF	DAF	FI
Austria	0.95	0.90	-	-	0.92
Brazil	0.60	0.65	-	-	0.62
China	0.80	0.75	-	-	0.78
Egypt	0.50	0.55	-	-	0.52
Ethiopia	0.30	0.40	-	-	0.38
India	0.70	0.60	0.02	-	0.72
Iran	0.55	0.50	-	-	0.54
Russia	0.75	0.70	-	-	0.74
Saudi Arabia	0.85	0.80	-	-	0.82
South Africa	0.65	0.60	-	0.12	0.64
UAE	0.90	0.85	-	-	0.88

Source: authors.

Table 4. **Levels of Development of FI**

Country	AF	UF	DAF	WB	FI
L_1 — countries with developed financial sector					
Austria	0.95	–	–	0.90	0.92
UAE	0.90	–	–	0.85	0.88
Saudi Arabia	0.85	–	–	0.80	0.82
China	0.80	–	–	0.75	0.78
Russia	0.75	–	–	0.70	0.74
L_2 — countries at the stage of rapid transition to FI					
India	0.70	0.02	–	0.60	0.72
South Africa	0.65	–	0.12	0.60	0.64
Brazil	0.60	–	–	0.65	0.62
Iran	0.55	–	–	0.50	0.54
L_3 — countries with weak FI					
Egypt	0.50	–	–	0.55	0.52
Ethiopia	0.30	–	–	0.40	0.38

Source: authors.

ents the results of the principal component analysis (PCA) of the FI index and its dimensions by country.

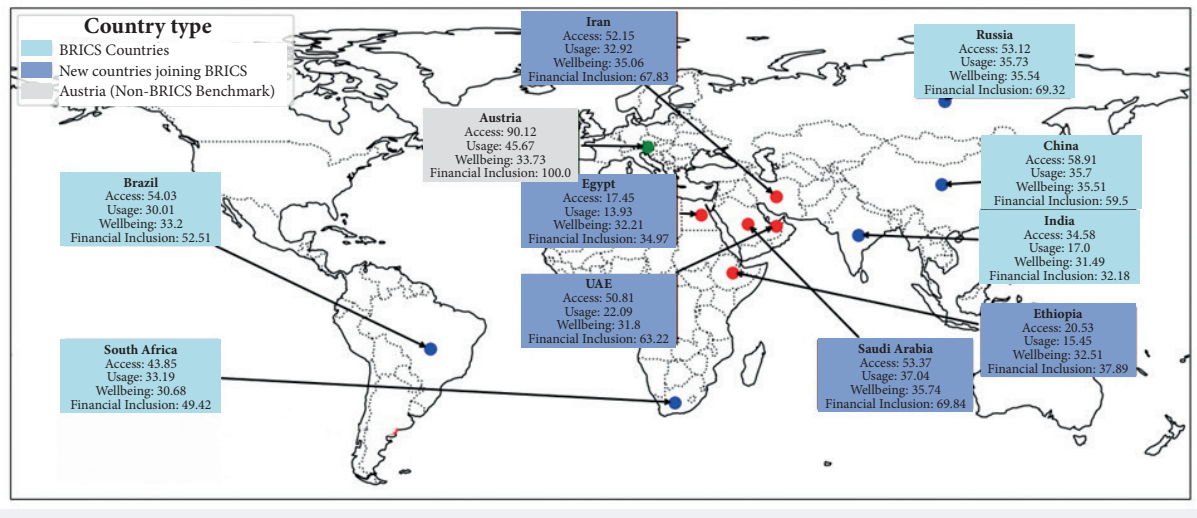
For most countries, the measures involve raising the level of education, smoothing out the "contrasts" between rural and urban areas, and adjusting mental and cultural patterns.

The data in Table 3 allow us to draw the following conclusions. Austria and the UAE dominate in all dimensions of FI. The remaining countries demonstrate noticeable differences in the values of AF and UF. In China, India, Russia, and Saudi Arabia, these indicators are balanced, indicating continued dynamism, while in Ethiopia and Egypt their values are low, indicating the need for targeted policy interventions.

In Table 4 and Figure 2, countries are divided into three levels according to their degree of FI development: L_1 (developed FI), L_2 (stage of rapid transition to FI) and L_3 (weak FI development).

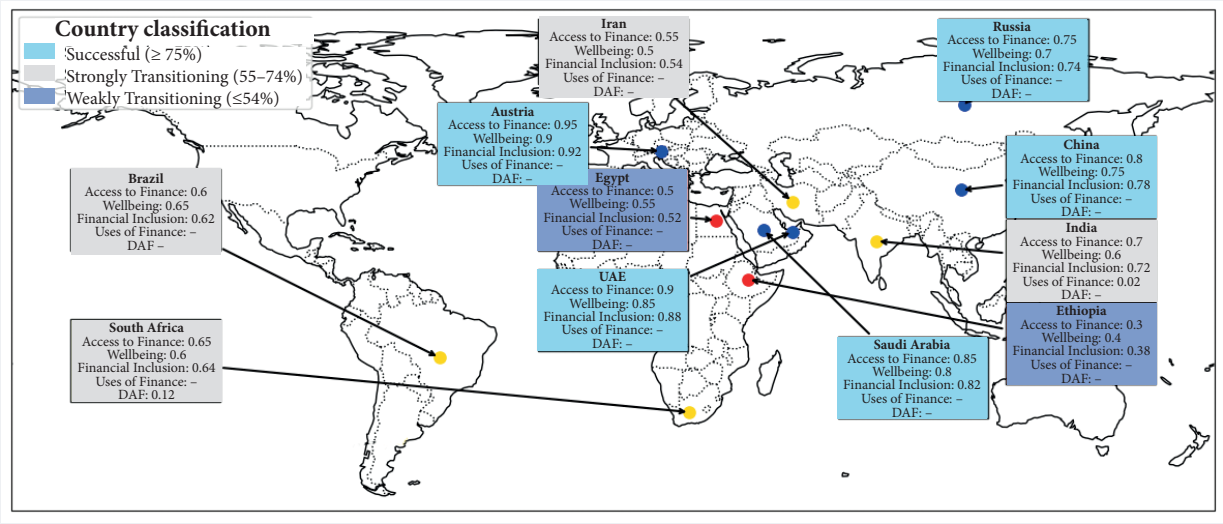
The distribution of the countries is based on their level of financial ecosystem development. The first-level "residents" are characterized by high values of all financial ecosystem indicators and a developed financial ecosystem. Austria is in the lead, followed by the UAE, Saudi Arabia, China, and Russia. The second tier includes India, South Africa, and Brazil, demonstrating a slower pace. Egypt and Ethiopia are located at the lower level and will have to take enhanced measures to expand access to financial services. The presented classification serves as a

Figure 2. **Current Situation with FI Parameters in the BRICS Countries and Austria**



Source: authors.

Figure 3. **The Degree of Progress of BRICS Countries Towards an Inclusive Financial System Compared to Austria**



Source: authors.

guide for determining the strategic focus for countries with different adoption levels, which would allow them to move from L_3 to L_2 and from L_2 to L_1.

Figure 3 divides the BRICS members into three categories based on the range of percentage values of their FI indicators relative to the benchmark, Austria. For the first of these ('successful,' ≥ 74%), the transition to an inclusive financial system should not pose any particular difficulties.

The second category (50-74%) is in the process of dynamic transition to building such a system. South Africa, Brazil, India, and Iran provide relatively high availability of finance in emergency situations (for a month), and the first two - also for a week. India, along with South Africa, leads in the distribution of mobile financial applications among the most economically active 60% of the population and, together with Brazil, is ahead of other countries in the volume of transfers of public funds to the accounts of such users. This demographic group, compared to the rest, expresses the least concern about their ability to meet current expenses and deal with the costs of medicine and education.

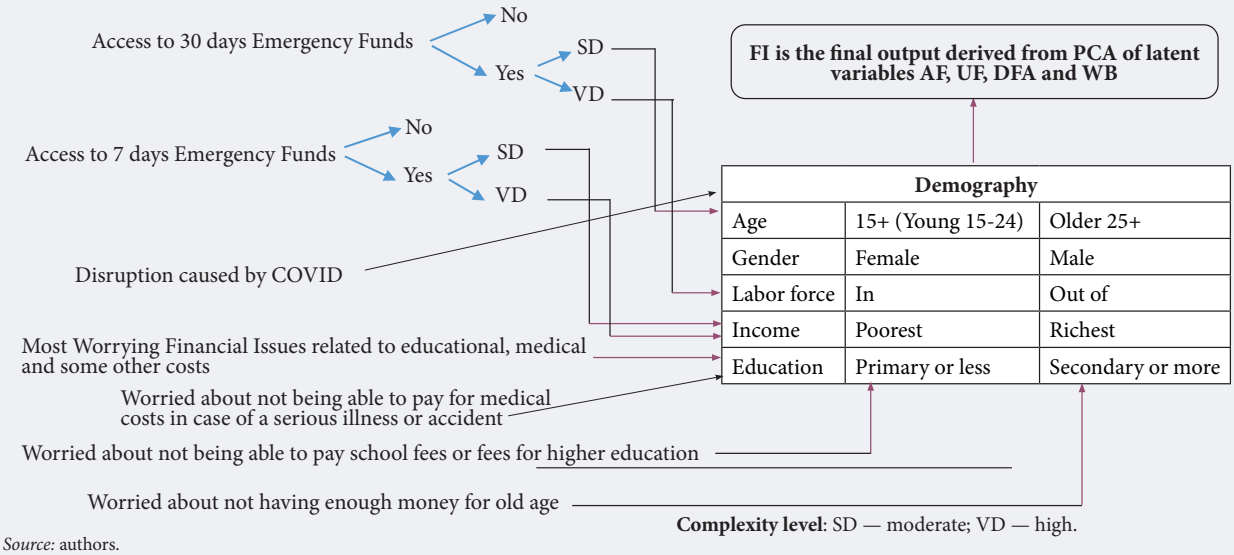
The third category of countries (less than 50%) is characterized by high barriers that impede the transition to an inclusive financial system. Ethiopia and Egypt, which are included here, have the poorest ability to provide access to finance in emergencies, regardless of the demographic group. These countries are characterized by the highest rates of vulnerable groups, the share of inactive accounts, and the minimum provision of digital infrastructure. In turn, the UAE, Austria, and Brazil are the top three countries when it comes to financial inclusion and the flexibility of their governance systems. This is shown by the fact that more people have bank accounts, use digital payment tools, and have better access to money in an emergency. In all BRICS countries, access to finance is highly dependent on employment status, income, age, and gender. Mature individuals with high incomes enjoy the greatest advantages.

Figure 4 shows a path dependence matrix that visualizes the cause-and-effect relationships that influence FI. Table 5 provides detailed characteristics of its elements. Finding the link between the things that affect the level of FI and demographic details helps us understand the problems that different groups of people face, taking into account the rules and technology available at the time. Understanding these relationships allows us to outline key areas of action to eliminate barriers to FI.

The Relationship between the Concept of FI and the Theories of Narrative, Public good and evolutionary control

According to ***Narrative Theory***, individual and social perceptions are reinforced by the transmission of success stories or failures, experiences, and discourses. Narratives influence decision-making, behavior patterns, the reproduction of patterns and barriers. Path dependence often arises from dominant blocking narratives that constantly generate and feed resistance to change in a self-reproducing cycle. Certain segments of the population lack access to financial services due to predetermined historical and cultural contexts. They express biased attitudes toward financial systems, perceiving them as complex, inaccessible, and questionable. Seeing financial services as "too expensive" perpetuates the narrative of exclusion through a rejection of complexity or the availability of "digital money" for ev-

Figure 4. **The "Path Dependence Matrix" Model for Analyzing Factors that Hinder FI**



Source: authors.

eryone. Such limiting patterns are displaced by new, alternative, and creative narratives.

Public Good Theory sees FI as a driver of collective well-being. From this perspective, regular financial literacy campaigns and other tools can break limiting narratives. Mechanisms that can help expand digital access to finance include subsidizing mobile devices and tariff plans for low-income groups and e-KYC (Know Your Customer). Concerns about not being able to pay for health care or education are addressed through microinsurance or public savings schemes that provide "safety nets" and mitigate systemic risks.

From an ***Evolutionary Governance Theory*** perspective, it is necessary to continually adapt to changing population needs and the emergence of new technologies, which implies a proactive response to waves of change.

Comparison of Approaches

Each theory offers unique but complementary approaches to overcoming the barriers discussed. The first of them (narrative) focuses on changing perceptions and behavioral patterns through stories and collective discourses [2]. The second emphasizes structural reforms and the democratization of financial services. The third suggests overcoming entrenched constraints through adaptability and institutional transformation. Table 6 presents measures for FI development based on the application of these theories. In general, they come down to adjusting narratives through information campaigns for L countries, shaping the perception of FI as a public good through infrastructure development, and regularly revising policies in light of emerging social and technological changes that determine changing public needs.

Comparison of the Conviction Narrative Theory and Path Dependence Model

Figures 1 and 4 present analytical frameworks for studying decision-making processes and system challenges from different perspectives.

Narratives are defined by the social context. They allow us to interpret events and facts, anticipate the future, and redefine the vector of development. Successful fragments of a narrative transform collective perception and generate new narratives to update individual narratives. According to the Path Dependence Model (PDM), mistrust of financial institutions and fears of the consequences of pandemics are deeply rooted in cultural narratives, determine behavior, reinforce path dependence, and hinder change. In both models, narratives play a key role in influencing decision-making, which in the CNT view is carried out through feedback loops, and in the logic of the PDM, underlies systemic barriers and behavior determined by path dependence.

Feedback loops connect narrative fragments in different combinations. Creative narratives reshape

2 In terms of approaches to adjusting narratives, a striking illustrative example is the comparison of the cases of three settlements on the Canadian island of Newfoundland, presented in the work (Van Assche et al., 2021). By following their own tracks, their populations eventually managed to achieve a profound transformation of collective thinking, successfully overcome "path dependence," identify and implement emerging opportunities in order to move to more complex, innovative business practices and adapt to new development models.

Table 5. **Factors Determining Path Dependence (by Components of the FI)**

Access to finance
Availability of funds in an emergency situation within 7/30 days
Reasons for not having a personal bank account • Distance to the banking institution • High cost of financial services • Lack of necessary documents • Distrust of financial institutions • Insufficient funds to replenish the account • Religious motives • Having an account with a family member
Welfare
Degree of concern about the inability to meet the following expenditure items (on a scale: Moderate / High) • Treatment of a serious illness or injury • Education • Current expenses, payment of utility bills • Life in the «third age»
Degree of concern about the consequences of global crises (e.g. pandemics) (on a scale: Low / Medium / Strong)
Use of finances
Reasons for not using a registered bank account • Distance to the banking institution • Discomfort when using the account independently • Insufficient funds to replenish the account • Lack of trust in financial institutions • No need to use an account
Digital access to finance
Reasons for the absence of a mobile money account • High cost of using mobile payment instruments • Insufficient funds to replenish the account • Lack of necessary documents • Remoteness of service providers • Access to an account provided by another person
Source: authors.

collective perception. Feedback transforms both systemic structures and determinants of FI. For example, concern about money problems is in a mutually reinforcing relationship with isolationist behavior. In CNT, feedback loops are explicitly present, while in the rut effect model they are implicitly embedded in the cyclical nature of barriers that reinforce path dependence.

Decision-Making involves assessing narratives in relation to goals and strategies based on personal and collective beliefs and values. The degree of achievement of FI is determined by the removal of barriers that reflect collective behavior and systemic inertia and are expressed in the absence of funds and inactive accounts.

Adaptation occurs when creative narratives change the collective social context and influence strategic decisions. It is a condition for overcoming path dependence. Removing barriers such as the lack of documentation and remoteness of service providers requires systemic reforms. Both models focus on the dynamic interaction of systemic structures and individual behavior. Both adaptive social narratives and reforms are aimed at breaking the rut.

Similar Information is considered the basis of narratives, which in turn become a tool for their assessment and interpretation. The arrows in Figure 1 reflect the interaction of information with narratives in the decision-making process. In the PDM, data are indirectly used to identify and assess barriers without narrative interpretation. Thus, in both models, information becomes the starting point for analyzing the system's state and its processes. However, in the CNT model, unlike the PDM, the use of data to select methods for eliminating FI barriers is supported by their narrative interpretation.

Summarizing the observations on the five considered dimensions, it can be concluded that the CNT focuses on the role of narratives and decision-making in a social context, and the PDM focuses on the structural barriers that accompany financial systems. The emphasis on the relationship between individual choice and systemic evolution will allow them to perform complementary functions for the analysis of complex processes, such as the achievement of FI.

Recommendations for BRICS Members

Significant progress in digitalization is observed in most BRICS countries – money transfers and payments are carried out using e-wallets, digital savings accounts are offered to manage finances online, and digital ID cards are being introduced. Examples of successful initiatives are given in Table 7.

Table 6. **Strategies for Achieving FI Based on the Theories under Consideration**

Theory	Measures
Narrative theory	• Presenting financial opportunities through creative, inspiring narratives • Media campaigns presenting alternative narratives
Public Good Theory	• State subsidies for relevant offers (low-rate insurance) • Expanding financial and digital infrastructure in underserved areas • Encouraging banks and fintech to innovate for underserved groups
Evolutionary control theory	• Adaptation to technological development taking into account feedback from the population (implementation of financial innovations in management) • Developing cooperation between government, business, and society to develop inclusive solutions. • Creating platforms for building resilience (preparing for economic shocks or technological disruptions).
Source: authors.	

Table 7. **Cases of National Programs**

Country	Program
Brazil	In 2020, an application was developed that integrates the social security card (Cadastro de Pessoas Phísicas) and driving licenses for digital identification of the individual.
Russia	In 2020, the Digital Profile system was introduced, allowing the management of the transfer of personal data to companies in real time. Access to data has improved, transparency has increased, and the quality of services in general has improved. It has become easier to process loans and insurance contracts.
India	The world's largest digital identity platform, Aadhaar (over a billion users), launched [1], allowing identification of a person anywhere.
China	Since 2019, the Zhen system has been in effect Ni, which identifies users by checking their faces against a database of digital IDs. By synchronizing the ID with the WeChat app, it allows users to pay for travel and accommodation through their phone.
Austria	Project Digital Austria aims to facilitate the transition of young entrepreneurs to digital financial technologies, thereby expanding market access and increasing competitiveness.

[1] https://www.digitalindia.gov.in/ebook/deity/page4.php, accessed 18.11.2024.

Source: authors.

Summarizing the current situation in countries with different levels of FI and possible measures to move to higher positions or maintain them, the following can be noted. To remain at the top level, L_1 countries (Austria, UAE, Saudi Arabia, China, and Russia) should invest in the creation of innovations and the development of partnerships.

L_2 countries (India, South Africa, Brazil, and Iran) have moderate FI performance. Significant potential can be unlocked through individual strategies.

India faces the challenge of reaching new population groups. This can be achieved by focusing on rural banking and improving financial literacy. In South Africa, the priority is to expand access to basic financial services. Brazil can improve the situation by investing in education and health. Iran needs to stabilize its economy and develop trade relations to reduce barriers and expand access to financial resources.

L_3 countries (Egypt and Ethiopia) face the most acute challenges. Egypt sees mobile banking and microfinance as a priority. Ethiopia needs comprehensive measures to build financial and medical infrastructure. They need targeted international aid and development partnerships to begin moving toward L_2.

The transition matrix can be viewed as a roadmap for different countries to increase their FI level. By eliminating key barriers, L_3 residents will increase their chances of moving to L_2, and likewise, L_2 residents will accelerate their ascent to L_1.

We developed proposals for appropriate strategies using the logic of the Bayesian and Markov decision models. Our methodology is described in detail in Appendices 1 and 2.[3] Table 8 provides an interpretation of the results of the Bayesian analysis and Table 9 provides country-specific recommendations.

Table 8. **Interpretation of Bayesian Analysis Results by Country Level**

Level	Brief Description
L_1	Austria, the UAE, Saudi Arabia, China, and Russia retain every chance of remaining at the L_1 level, which is due to consistently high indicators in all parameters.
L_2	India, South Africa, Brazil, and Iran have a 50% chance of moving to level L_1, especially if access to finance improves.
L_3	Ethiopia and Egypt have good prospects of moving to L_2, mainly due to the increase in AF and WB. However, without effective measures, they are likely to remain at the L_3 level.

Source: authors.

Conclusion

Increasing financial inclusion is seen as one of the priority conditions for stimulating economic development and reducing inequality. Digital technologies (mobile banking, payment platforms, etc.) are a cost-effective way of providing financial services, involving the population in the transition to a new quality of life.

They have played an important role in bridging the FI gap, especially in underbanked regions. However, increasing access to finance alone cannot drive change, as there will be resistance to new technologies and the effects they produce. To overcome this resistance, innovative strategies are needed, including the development of measures to overcome entrenched behavioral stereotypes and improve financial literacy.

[3] The Methodology is described in details in Appendices 1 and 2 (see Supplementary file: https://foresight-journal.hse.ru/article/view/22273).

Table 9. **Address Recommendations by Country**

Country	Focus	Measures
	L_1 countries	
Austria, UAE, Saudi Arabia, China, Russia	Maintaining a high level of development through innovation and global partnerships	L2 and L3 countries to promote regional development and stability
	L_2 countries	
India	Increasing the supply of banking services and simplifying the process of obtaining loans for SMEs in rural areas	Mastering new technologies to expand service coverage and improve financial literacy
South Africa	Promoting equal access to finance	Forming public-private partnerships to increase the number of jobs and reduce social inequality
Brazil	Improving education and health systems	Development of credit programs to support SMEs and agriculture
Iran	Expanding access to finance through international trading partnerships	Investing in infrastructure for a sound financial system
	L_3 countries	
Ethiopia	Improving financial inclusion through the development of microfinance and the creation of banking networks in rural areas	Modernization of basic infrastructure for health and education
Egypt	Development of mobile banking and digital payment systems	Stimulating entrepreneurship in regions underserved by banking services

Source: authors.

The BRICS countries, with their diverse economic landscapes, are interested in exploring the potential of digitalization to bridge the gap between financially underserved and financially affluent regions. China and India have demonstrated robust growth and high levels of digital innovation, while other members of the alliance face different challenges that limit their access to technology. This heterogeneity points to the need for tailored approaches to FI policy for each specific country.

Our analysis, based on data from the FINDEX 2021 survey, reveals differences in financial inclusion across demographic groups. The highest barriers are faced by young people, women, and the lower 40%. The lack of access to immediate financial support in emergency situations, fears of not being able to pay for healthcare and education, and a lack of interest in digital banking services stem from a lack of awareness and education, which manifests itself in path dependence effects. Persistent destructive narrative factors, such as the mistrust of financial institutions, also play a blocking role. Freeing yourself from such mental patterns will help you identify emerging opportunities and create a new path. Brazil, China, and India have succeeded in this, with government-supported digital financial ecosystems with effective tools. Of all the BRICS members, they are the closest to the conventional benchmark, Austria, which has provided almost full FI through advanced digital infrastructure and public-private partnerships.

We categorize countries based on their FI index values: L_1 (advanced FI), L_2 (rapid transition to FI), and L_3 (low FI). Transition strategies include reducing the cost of using accounts, improving financial literacy, subsidizing digital access, and implementing co-evolutionary policies tailored to societal needs. We propose a probabilistic model of FI development based on a gradual transition from the lowest level ($L_{3)}$ to the highest ($L_{1).}$ For L_3 countries, the fundamental expansion of access and the improvement of literacy are necessary prerequisites for progress.

The policy recommendations fall into the following categories:

- *Narrative interventions* are the dissemination of creative narratives that strengthen trust in financial systems and technologies in general.
- *The public good approach* is to subsidize the development of infrastructure and individual financial products based on the perception of FI as an asset, the access to which by each user does not reduce the benefits for everyone.
- *Adaptive management* is the development of flexible policies that ensure dynamic adaptation to changing technological and demographic realities.

Based on the transformative potential of FIs to stimulate "proportionate" growth, it is proposed to integrate the latest fintech solutions into localized policy frameworks to achieve sustainable and inclusive development of BRICS countries.

Limitations of the Study

First of all, it should be noted that there is insufficient analysis of specific regional or demographic nuances of the BRICS countries, since the analytical base was built on aggregated macroeconomic data from the FINDEX 2021 statistical survey. Principal component analysis appears to be a useful method for measuring FI, but it nevertheless presents an

overly simplified picture of the complex interaction of variables affecting FI in different contexts.

The economic, cultural, and infrastructural diversity of countries makes it difficult to draw general conclusions. The socioeconomic conditions in countries such as Austria (used as a benchmark) differ significantly from those in less developed BRICS countries such as Ethiopia or Egypt, making direct comparisons and extrapolations difficult. Systemic barriers to digital FI, such as lack of technological literacy and low internet access, have been understudied. Unintended consequences of digitalization, such as increased income inequality and cybersecurity risks, have not been addressed. Focusing on socio-cultural narratives and theoretical frameworks (the CNT and PDM models) may have overlooked practical issues such as policy resistance, the legal and regulatory environment, institutional frameworks, and private sector engagement. These problems show that the proposed frameworks need to be analyzed in more depth, taking into account the specific situation, and tested in real life in order to be used in more situations and have a greater impact.

Theoretical Conclusions

The application of the CNT model allowed us to determine how narratives influence decision-making regarding technologies and systems and determine the degree of resistance to them. The presented analysis enriches the theoretical understanding of the role of behavioral barriers in economic activity. Creative narratives and the rethinking of public perceptions help overcome path dependence and contribute to the increase of FI. Using the Evolutionary Governance Theory, the coevolutionary relationship between technological advances, institutional reforms, and public behavior was revealed. This contributes to the discourse on the adaptation of governance structures to overcome entrenched systemic barriers in a transition economy.

The perception of FI as a public good expands its theoretical understanding, highlights its importance and benefits for the entire population, and contributes to reducing inequality and achieving sustainable development. The study presents a path dependence framework that takes into account the interdependence of AF, UF, DAF, and WB.

It enriches the theoretical understanding of how historical and systemic factors perpetuate financial exclusion and offers a structured approach to identifying and mitigating these barriers. A probabilistic Markov model of how countries move between FI levels (L_1, L_2, and L_3) has been created. This model gives us a way to think about how policy outcomes change over time. The framework links theoretical ideas with their practical application by quantifying the likelihood of FI development through comparisons of socioeconomic indicators and development outcomes.

The study highlights the transformative potential of digital financial technologies (mobile banking, digital IDs) to reimagine economic systems and achieve financial inclusion. It provides a theoretical rationale for the idea that technology adoption can lead to systemic change if socio-cultural and infrastructural barriers are removed. Considering society's openness to technological solutions for their problems brings a behavioral dimension to FI theories, complementing the existing literature by analyzing the cognitive and cultural factors of FI adoption, in addition to the structural and technological determinants.

This study positions FI as a cornerstone for achieving equitable economic growth by directly linking FI to the SDGs. It advances the scholarly understanding of FI as a multidimensional phenomenon with broad health, education, and economic stability implications. The interdisciplinary synthesis of narrative persuasion, public good, and evolutionary governance theories provides new insights into the interactions between financial systems, governance structures, and social behavior that support FI and identifies directions for future research in similar contexts.

Practical Conclusions

The categorization of BRICS countries by FI levels (L_1: advanced FI, L_2: rapid transition to FI, L_3: weak FI) provides policymakers with a clear framework to tailor interventions to national circumstances and capabilities. For L_3 countries (Ethiopia and Egypt), fundamental financial infrastructure development and targeted initiatives for vulnerable groups are crucial. Successful examples from India (Aadhaar) and China (WeChat-integrated ID cards) highlight the importance of digital identities and mobile payment platforms for FI development.

Practical interventions include subsidizing mobile devices, facilitating digital access, and expanding mobile payment networks to cover more areas. Financial literacy campaigns are important to address barriers such as inactive accounts and mistrust of financial institutions. Programs targeting specific demographic groups (women and rural populations) can increase financial inclusion. Governments should reduce account fees, simplify account opening procedures, and provide low-income groups with subsidized financial products.

Public-private partnerships can increase access to financial products that meet customer needs. An analysis of narrative-driven resistance shows that creative narratives and policies can change public attitudes toward technologies, including those that enable FI. Recommendations to support vulnerable groups include expanding access to emergency finance, providing microinsurance, and creating opportunities to participate in government savings programs. Focusing on youth, women, and the lower 40% of the population can reduce their concerns about healthcare, education, and daily living expenses. Adaptive governance strategies, such as integrating fintech innovations into policy frameworks and digitizing identity documents (e.g., e-KYC), can remove barriers related to undocumented status. Overall, inclusive financial systems emerge from collaborative governance between governments, financial institutions, and technology providers. Identifying "blockers" (mistrust, price barriers, lack of digital literacy) allows us to develop measures to overcome systemic inertia.

Governments can use tools such as the Bayesian and Markov probability models to monitor and manage the transition to the next FI level, ensuring iterative and measurable progress. The perception of FI as a public good confirms the need to develop (with government participation) financial infrastructure, including banking networks in unserved areas, digital platforms, and subsidized services for low-income groups. Investments will ensure equal access to financial services.

This way, FI strategies will be linked to the SDGs (reducing inequalities and promoting inclusive economic growth). The findings apply to the design of policies aimed at closing the gap between FI and broader development goals.

Our study's findings offer practical recommendations for closing FI gaps, especially in less developed and transitioning countries. A multidimensional and adaptive approach will help stakeholders stimulate inclusive growth and enhance financial sustainability.

Further Research

We propose continuing research into the following areas:

- Principles for designing effective digital platforms that facilitate user adoption of financial services
- Policy frameworks for stimulating innovation in fintech.
- The role of narratives in shaping programs for teaching responsible strategic decision-making.

Addressing these issues will help shape a more inclusive future for the BRICS countries. Micro-level data could be used in future research to learn more about the regional, demographic, and sectoral differences in FI in these countries. This would also help researchers learn more about the things that help and hinder the growth of FI at the local level. It would be useful to focus on the growing role of new technologies in advancing FI, such as blockchain, AI, and decentralized finance, and to analyze their adoption and scalability. Assessing the effectiveness of narrative strategies to overcome public resistance to fintech could provide useful insights. In particular, this could include examining the role of local leaders, narratives, and cultural adaptation in shaping attitudes toward new technologies.

A comparative analysis of FI policies in the BRICS countries and benchmark countries such as Austria helps identify good practices and valuable strategies for improving regulatory frameworks, developing public-private partnerships, and integrating digital IDs into financial systems. Longitudinal studies assessing the socioeconomic impacts of FI development, including income inequality reduction and economic growth, will help quantify its broader impact. The analysis of the practical use of evolutionary governance structures in other regions or sectors will inform better adaptive policymaking strategies to address systemic barriers.

Research in these areas will help advance the scientific and practical understanding of FI, fill existing gaps, and leverage technological advances to advance inclusivity.

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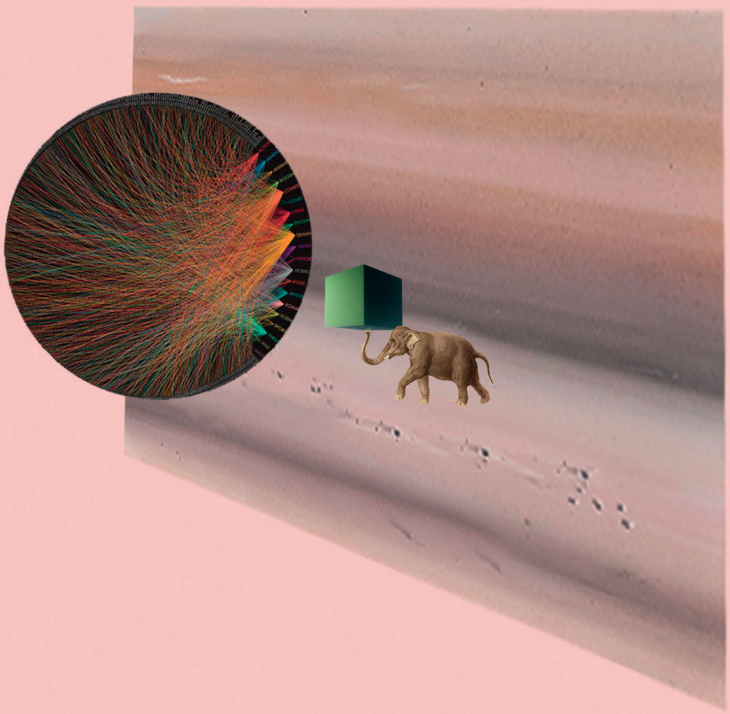

Accounting for Oslo Manual: Reflecting on the Past and Setting the Stage for Future Research

Alexandre Paredes

PhD Candidate, alexandre.paredes@dgeec.medu.pt

NOVA Information Management School (NOVA IMS), Universidade NOVA de Lisboa, Campus de Campolide, 1070-312, Lisboa, Portugal

Bruno Damásio

Assistant Professor, bdamasio@novaims.unl.pt

NOVA Information Management School (NOVA IMS), Universidade NOVA de Lisboa, Campus de Campolide, 1070-312, Lisboa, Portugal

Sandro Mendonça

Professor [a] and Faculty [b], sfm@iscte-iul.pt

[a] ISCTE Business School, Business Research Unit (BRU-IUL), Avenida das Forças Armadas, 1649-026 Lisboa, Portugal; UECE/REM — ISEG/ University of Lisbon, Rua do Quelhas 6, 1200-781 Lisboa, Portugal;

[b] SPRU, University of Sussex, Falmer, Brighton, UK

Abstract

The Oslo Manual is the internationally recognized reference for guiding the collection and interpretation of evidence on innovation. This research explores its three-decade-long implementation and influence, emphasizing its role within the research community. We assess the content's quantity and quality through an advanced bibliometric and textmetric analysis of over 1300 research papers published in internationally indexed journals. Our study offers an evidence-based understanding of the Oslo Manual's adoption and impact, elucidating disciplinary integration, geographical interest, and reception phases. Notably, the findings unveil the increasing significance of innovation-related topics since its inaugural edition in 1992, with a pronounced surge gaining momentum after 2008. Furthermore, the consistently cited references underscore the researchers' focus, highlighting the rising importance of innovation and interconnected domains like entrepreneurship, performance, knowledge, and management. This study enhances our understanding of the Oslo Manual's use and influence, revealing its enduring relevance and its broader impact on shaping innovation research.

Keywords: Oslo Manual; innovation; bibliometrics; policy

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Introduction

Innovation is a practical topic that holds significant importance for individuals, institutions, productive sectors, and countries, as it enhances living standards and economic growth (OECD, Eurostat, 2018). Nevertheless, it is also an object of research in itself. Indeed, the study of innovation has recently developed into a vibrant field in its own right (Castellaci et al., 2005; Santos, Mendonça, 2022a). A valuable resource bridges these two worlds: the tool known as the Oslo Manual. The Oslo Manual is an internationally recognized reference that provides guidelines for collecting and interpreting evidence on innovation (Smith, 1992).

In innovation studies, researchers delve into key topics from existing literature or uncover their dynamics (Rossetto et al., 2018; Sun, Zhai, 2018). Some works, like those by Nelson and Winter (1977) and Abernathy and Clark (1985), provide comprehensive literature reviews on innovation. Additionally, Merigó et al. (2016) and Cancino et al. (2017a) conducted literature reviews on innovation. Other research utilises bibliometric and textmetric analyses to examine innovation literature (Rakas, Hain, 2019; Santos, Mendonça, 2022a), scientific journals (Kajikawa et al., 2022), and authors (Mendonça, 2017) in the field of science, technology, and innovation.[1] This paper employs advanced analytical techniques, including text mining, to evaluate the review process of a technical report called the Oslo Manual.

This paper aims to compare changes in different editions of the Oslo Manual over the years and present a comprehensive and evidence-based analysis of its development. Using text mining techniques, we examine a collection of internationally peer-reviewed publications, conducting a content analysis of research articles that assess the evolution of the Oslo Manual's structure and content (primary areas of analysis).

In this study, we apply a comprehensive approach, combining bibliometric and textmetric analytical dimensions, to evaluate 1,388 scientific papers that cite the Oslo Manual. These papers are authored by individuals affiliated with various entities from every country, spanning 30 years from 1992 to 2021. The methodological shifts (do economic and social changes impact innovation definitions?) and the increasing interest in the Oslo Manual (are emergent economies more engaged to use metrics for measuring innovation?) are discussed. This study can provide helpful evidence for those interested in innovation studies. Policymakers can gain insights into key stakeholders and potential partners for collaboration in innovation-related initiatives. On the other hand, researchers can understand the trends, gaps, and emerging areas related to innovation. They can identify potential research collaborations and knowledge-sharing opportunities, as well as gauge the visibility and influence of their work in the context of innovation.

The Oslo Manual

Genealogy of the Oslo Manual

Before the 1970s, innovation was primarily measured using proxies such as patents and industrial expenditures on R&D (Freeman, 1987). Jacob Schmookler pioneered the extensive use of patents as an indicator of innovation in the 1950s (Schmookler, 1950, 1954). Industrial R&D data was relatively easier to collect and measure than other aspects of innovation (Godin, 2005). However, these early measures were limited in providing a comprehensive view of innovation (OECD, 1976).

OECD members' interest in direct measures of innovation dates back to the late 1970s when their work on direct or proxy output indicators led to seminars at the end of the decade (OECD, 1992). However, systematic innovation surveys were only widely conducted in the 1980s. Before then, there had been some sporadic data collection by government departments (e.g., US Department of Commerce), statistical institutes (e.g., Statistics Canada), and research units (e.g., SPRU, University of Sussex, UK), but rarely in a standardized way (Freeman, 1971; Rothwell et al., 1974; Pavitt, 1983).

In 1980, the OECD arranged a conference to explore output indicators and discuss national innovation surveys and indicators. Subsequently, workshops dedicated to innovation took place in 1982 and 1986, recognizing that patents were a poor indicator of a country's technological position (OECD, 1980, 1982, 1986).

The OECD's involvement in innovation surveys began with the Nordic Fund for Industrial Development's initiative to collect data on innovation activities in Scandinavian countries (Nordic Industrial Fund, 1991). In 1988, a workshop organized by the Nordic Fund invited the OECD and its member countries to participate (OECD, 1988). The workshop introduced a conceptual framework for developing innovation indicators (Smith, 1989). This framework underwent revisions in a subsequent workshop and was presented to the OECD Group of National Experts on Science and Technology Indicators (NESTI) in 1989, which recommended that the Nordic Fund prepare a draft Manual (OECD, 1990).

The draft Manual, prepared by Keith Smith and Mikael Akerblom, was discussed and amended by OECD member countries between 1990 and 1991 (OECD, 1991a). The first edition, named after the city of Oslo, was officially adopted in 1992 (OECD, 1991b).

[1] Fagerberg et al. (2012) analysed the development of innovation research and used an empirical approach based on the analysis of chapters in authoritative innovation research handbooks to determine which original publications had the most significant influence (see also: Fagerberg, Verspagen, 2009).

In 1993, a significant milestone was achieved when delegates from twelve European countries collaborated to carry out the first-ever coordinated survey of innovation activities based on the Oslo Manual (Godin, 2005). After completing the initial round of surveys in member countries, the Manual was reviewed and further developed based on the valuable experience gained during the process (OECD, 1992). As a result, the Oslo Manual underwent its first review in 1996 and was subsequently published in collaboration with the European Commission (Eurostat) in 1997 as the second edition.

While the Oslo Manual's initial focus was primarily on technological innovations within manufacturing industries (OECD, 1992), the concept of innovation and the need for comprehensive measurements started to evolve. Recognizing these shifts, the Manual expanded its scope to include additional dimensions of innovation beyond technology. This expansion encompassed non-technological innovations and services, acknowledging their growing significance in innovation (OECD, Eurostat, 1997). The second edition's publication in the same year marked a crucial shift in perspective, reflecting a broader conceptual framework that embraced the evolving nature of innovation measurement and its applications.

The subsequent editions of the Oslo Manual continued to adapt and respond to changing perspectives and demands in the field of innovation. There was a noticeable increase in emphasis on services, reflecting the growing recognition of their role in fostering innovation. With each new edition, the Manual's genealogy mirrored the dynamic evolution of innovation measurement. It illustrates the ongoing efforts to refine and update the framework, ensuring its relevance in capturing the multifaceted nature of innovation in an ever-changing global landscape. The Oslo Manual's journey exemplifies the commitment to staying abreast of emerging trends and methodologies, ultimately contributing to a more comprehensive understanding of innovation and its impact.

Oslo Manual comes of age

Between the first and fourth editions, the Oslo Manual experienced an increase of 50% or more in the number of pages, starting with 62 pages and reaching 258 in the fourth edition. Figure 1 displays the evolution of the Oslo Manual concerning its contents. Notably, the first three editions shared four common topics: "Objectives and scope of the Manual", "Basic definitions", "Innovation process", and "Survey procedures". Furthermore, upon comparing only the first two editions, we observed another shared chapter: measuring the cost/expenditure on innovation.

The first edition of the Oslo Manual, published in 1992, laid the foundation for measuring and analysing innovation. This first edition had two primary objectives: to establish a framework that enables existing surveys to evolve towards comparability and to assist researchers in innovation. According to the OECD (1992, p. 35), "From the policy viewpoint, indicators of the outcomes of the innovation process are perhaps the most important results of innovation surveys".

Regarding the methodological change from the first to second editions, the second edition of the Oslo Manual expanded the scope of innovation measurement beyond R&D to include non-technological areas such as marketing, organizational changes, and design (OECD, Eurostat, 1997). The second edition emphasized capturing the innovation process's inputs, activities, and outputs. It highlighted the need to measure innovation inputs (e.g., R&D expenditures, human resources dedicated to innovation) and outputs (e.g., new products, improved processes, market success). The guidelines covered various aspects, including measuring expenditures on innovation, identifying innovation sources, assessing innovation's impact on firm performance, and introducing a new chapter related to "Institutional classifications" (Chapter 4), as shown in Figure 1.

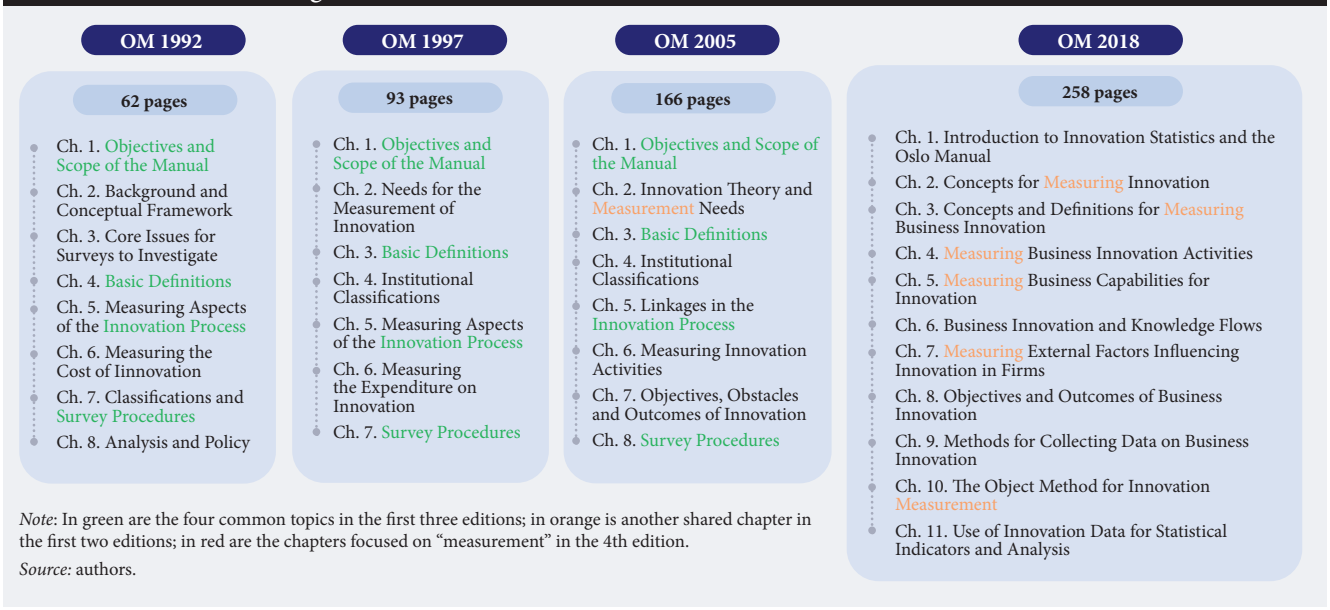
The Manual has progressively expanded its coverage and definitions to accommodate a broader range of industries and capture the complexity and heterogeneity of innovation, reflecting the maturation and growing significance of innovation research as a multidisciplinary field (Castellaci et al., 2005).

Regarding the methodological change from the second to third editions, the third edition of the Oslo Manual provided more explicit guidelines on capturing and measuring non-technological innovations, such as organizational and marketing innovations (OECD, Eurostat, 2005). It recognized that innovation is not limited to technological advances and that firms can innovate in various dimensions.

The Manual expanded the discussion on measuring intangible assets, such as intellectual property and human capital. Moreover, the third edition introduced the concept of "innovation cooperation". It recognized that innovation often involves partnerships, alliances, and networks among different actors and provided guidance on measuring and assessing these collaborative efforts. It emphasized the role of innovation systems in fostering organizational innovation. In addition to the four chapters common with the first edition, the third edition retained the new chapter introduced in the second edition, the "Institutional Classifications", and included a new chapter dedicated to "objectives, obstacles and outcomes of innovation" (OECD, Eurostat 2005, Chapter 7).

The fourth edition of the Oslo Manual incorporates methodological changes from the third edition, including advances in data collection methods, such as new data sources and techniques for measuring innovation (OECD, Eurostat, 2018). It guides the use of new data collection tools, such as web-based surveys

Figure 1. **Table of Contents of the Four Oslo Manual Editions**



Note: In green are the four common topics in the first three editions; in orange is another shared chapter in the first two editions; in red are the chapters focused on "measurement" in the 4th edition.

Source: authors.

and big data analytics. The fourth edition introduces the concept of «open innovation», emphasising the importance of collaboration and knowledge sharing between organizations.

Comparing the fourth edition with the previous editions, in addition to the increase in the number of pages and chapters, we can also observe a new chapter (Chapter 11) dedicated to the "Use of innovation data for statistical indicators and analysis". Moreover, more than half of the chapters (six out of eleven) focus on "measurement" (see Figure 2): "measuring innovation", "measuring business innovation", "measuring business innovation activities", "measuring business capabilities for innovation", "measuring external factors influencing innovation in firms", and "the object method for innovation measurement".

The Oslo Manual evolved over the four editions to capture a more comprehensive understanding of innovation. It expanded from a focus on R&D-related activities to encompass various dimensions of innovation, including non-technological, organizational, marketing, and business innovation. The different editions also incorporated advances in data collection methods and highlighted the importance of measuring innovation impacts and outcomes. Open innovation, innovation cooperation, and systemic innovation were introduced to reflect innovation processes' collaborative and interconnected nature.

Materials and Methods

Article subject matching system

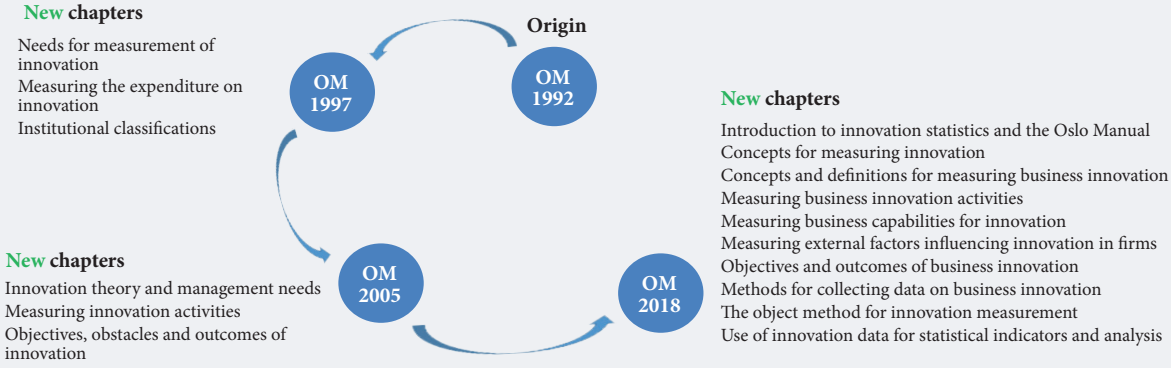
The field of innovation embraces diverse methodologies and approaches, drawing upon disciplines such as economics, management, and sociology. Researchers have utilized a range of quantitative and qualitative research methods to explore innovation processes, employing surveys, case studies, interviews, and various data analysis techniques. For instance, Nelson (1959) pioneered the application of economic theories to the study of innovation, while Burns and Stalker (1961) introduced organizational and management perspectives. Furthermore, Rogers (1962) made significant contributions by examining how innovation diffuses through social networks. As time passed, the field of innovation developed into a global research community, promoting collaboration and knowledge exchange among researchers worldwide (Martin, 2012).

The exponential growth in the number of scientific platforms and their online journals, coupled with the massive increase in research outputs, has made it challenging for researchers to select the appropriate journal to publish their work, as these platforms represent the privileged channel for disseminating their research (Bornmann, Mutz, 2015; Confraria, Godinho, 2015; Gu, Blackmore, 2016; Ioannidis et al., 2018; Santos, Mendonça, 2022a; Shifrin et al., 2018; Ware, Mabe, 2015).

The first attempt to describe authors' motivations for submitting an article to a particular journal dates back to the 1950s and 1960s, when de Solla Price (1965) treated science as a measurable entity, developed some quantitative techniques and introduced the concept of scientometrics (see also Rousseau, 2021). Later, Kochen and Tagliacozzo (1974) identified five fundamental factors influencing journal selection: relevance, acceptance rate, circulation, prestige and publication lag.

Until now, we can observe bibliometric and textmetric materials on innovation literature (Klarin, 2019; Santos, Mendonça, 2022b), scientific journals (Singh

Figure 2. **Oslo Manual timeline**



Note: For each new edition, the new chapters are identified. Regarding the 4th edition, the chapters related to the "measurement" are highlighted in red.

Source: authors.

et al., 2020) and authors (Meyer et al., 2004) with contributions to the study of science, technology and innovation. This paper assesses the review process of a technical report – The Oslo Manual. For this purpose, we assemble a set of observations to compose a meaningful understanding of the Oslo Manual review.

The raw observations for the analysis are scientometric data, that is, the publication (bibliometric) and content (textmetric) materials on scientific-level types of knowledge (Saheb et al., 2021; Eom, 2009). The scientometric toolbox is usually deployed to understand the scientific enterprise (Mendonça et al., 2022). We extracted and tabulated all the relevant academic publications that focus on or refer to the Oslo Manual. A supervised machine learning algorithm was developed to enable textmetric analysis.

However, despite its complex nature, this methodology offers a high level of granularity, comparability, and adaptability to effectively address the changing demands of analytical and policy requirements (Glänzel et al., 2019)[2]. What sets our integrated approach, combining bibliometric and textmetric analyses, apart is its ability to reveal the underlying processes that drive the review of the Oslo Manual.

This paper extends our analysis to incorporate social network analysis techniques, specifically focusing on centrality measures such as degree, betweenness, and closeness. We investigate the network's most influential journals and authors, exploring their pivotal role.

Analysing the Oslo Manual review: a comprehensive scientometric approach

Scientific publication data have been used in many econometric analyses (Griliches, 1990; Hall et al., 2001; Jaffe, Trajtenberg, 2002). Three fields – bibliometrics, technometrics and econometrics – converged as publication statistics started to be used in economic and policy analysis (Meyer et al., 2004). By conducting bibliometric analysis, the evolution of a topic can be analysed. The bibliometric analysis employs a quantitative approach to describe, evaluate, and monitor published research (Dzikowski, 2018; Small, 1973). This study employs quantitative bibliometric analysis in reviewing a technical report – The Oslo Manual.

Bibliometric methods are effective approaches to support a comprehensive understanding of the journal because they use tools and statistical methods for publications, including research articles (Thelwall, 2008). They facilitate the comprehension of large amounts of data and enable the discovery of hidden patterns. Bibliometrics is applied to studying academic disciplines, topics, or journals (Mejia et al., 2021).

Bibliographic items are appealing because they span time, space, and institutional and thematic categories. They can be examined individually, aggregated or put into a relational perspective. As indicators of creative enterprise, formal publications in scientific peer-reviewed journals provide a robust data pool (Mendonça et al., 2022).

To process the substantial amount of data, specialized software like R, VOSviewer, and Gephi (Manoj Kumar et al., 2022) was employed. A comprehensive computer-assisted literature exploration was conducted on the Web of Science (WoS) database to capitalize on this potential.[3] The following citation indexes were queried: SSCI, ESCI, SCI-EXPANDED, CPCI-SSH, CPCI-S, and A&HCI. The Scopus database supplies authors' identification since retrieval could be automated through an Application Programming Interface (API). Bibliometrix (an R package) was used since it automatically adds affiliation dates to authors' identifications. Descriptors regarding the standing and prestige of periodicals were gleaned from Scimago Journal Rank (SJR), the public repository of journal metrics. Finally, a search for academic journal articles only was performed for the complete database with no date restrictions to ensure completeness.

Research findings can be represented in different formats, such as tables, charts, citation maps and net-

work displays. Many indicators can be identified from bibliometric analysis, offering valuable insights into the research landscape. These include the top journals and articles, the most active authors, institutions and countries, the most popular research subjects or keywords, and patterns of collaboration and citation among researchers, institutions and countries. It can also facilitate the identification of research gaps and contribute to formulating research objectives or policies in a specific subject (Cancino et al., 2017b; Ellegaard, Wallin, 2015). The bibliometric indicators also measure the quantity and quality of publications, where quantity is measured in terms of the number of publications, whereas the impact of received total number of citations by a publication measures quality.

In this study, the final sample includes 1388 articles that cited the Oslo Manual in the above citation indexes. Each article can be classified in more than one index. Items were published in 403 journals (unique ISSNs) and classified into 94 different categories, where five (Management, Business, Economics, Environmental Studies/Sciences, and Regional & Urban Planning/Geography) out of 94 different categories aggregate two-thirds of the articles and containing 56,600 references to other documents.

The publication records and their characteristics were processed from a descriptive perspective. In addition, summary statistics were computed (namely, the conventional concentration index), and network analysis was carried out (graph representations and the usual network metrics). Finally, we incorporated WoS's subject and disciplinary framework without any limitations. However, it is widely acknowledged that it may not always offer an optimized bibliometric classification for every research endeavor. The identification of individuals is challenging, and their identities are retrieved via Scopus ("rscopus" package)[4].

A Bibliometric Account of Oslo Manual-related Research

An overview of the studies published about the Oslo Manual until 2021

Trends in Oslo Manual citations. The total entries related to the Oslo Manual are shown in Figure 3. The 1388 articles that cited the Oslo Manual were authored by 1735 individuals (estimated) from 87 countries between 1997 and 2021. The first publication was in 1997, the same year as the second edition. From 2006 onwards, after the publication of the third edition, we can observe a persistent and rising production ensues until 2018. The peak in the number of published articles coincides with the year of the publication of the fourth edition, 2018. We can also observe an identical number of publications in the three years before and three years after the publication of the fourth edition. Between 2015 and 2021, this period concentrates on two-thirds of all publications.

The geography of authorship. It is possible to picture the international distribution of knowledge production by processing authorship information. Figure 4 presents the number of articles by region published in the time series per year. We can observe that most of the authors are established in Europe, East Asia & Pacific, and Latin America & Caribbean. The distribution of the publications in Europe can explain the distribution observed in Figure 3. As can be observed in Europe, the peak of the number of publications coincides with the year of the publication of the fourth edition, and the distribution of the number of publications in the three years before and three years after the publication of the fourth edition is very similar, representing almost half of the total of publications.

In analyzing the geography of authorship, we focused on the peak of the distribution, which aligns with the year of publication of the fourth edition of the Oslo Manual, along with the three years preceding and following it. This period accounts for approximately two-thirds of the total publications we examined. To gain a comprehensive understanding, we further explored the trends before and after the publication of the last edition, 2018. The figures below (Figure 5 for the period before 2018 and Figure 6 for the period after 2018) depict the distribution of knowledge production during these distinct timeframes.

Despite the evidence that the number of published articles is spread among different countries across all regions (mainly Europe, East Asia & Pacific, and Latin America & Caribbean) after the publication of the fourth edition of the Oslo Manual, the share of the publications among the non-OECD countries, in the total of the publications increased from 11% to 18% of total publications. This fact is even more significant since 24 out of the top 25 scientific journals (see Figure 10) from the different indexes of the Web of Science are from the OECD countries.

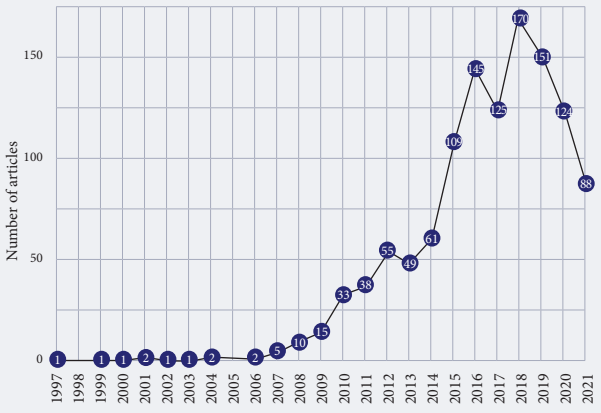
International diffusion of Oslo Manual-related research. Figure 7 accounts for the spread of research around the Oslo Manual over time. The period in which the Oslo Manual comes alive as the research topic is after the publication of the third edition of the Oslo Manual. Before the third edition, only a few countries were engaged in the topics related to the Oslo Manual. However, during the last decade, before

[2] Other indicators could have been used, from the most conventional like patents (e.g. Mendonça et al., 2019) to less conventional ones, like trademarks (Castaldi, 2020; Mendonça et al., 2004; Mendonça 2012, 2014) and standards (Foucart, Li, 2021; Laer et al., 2021; Teubner et al., 2021).

[3] This source is well-known and has extended coverage, and its findings are highly correlated with other databases (Archambault et al., 2009).

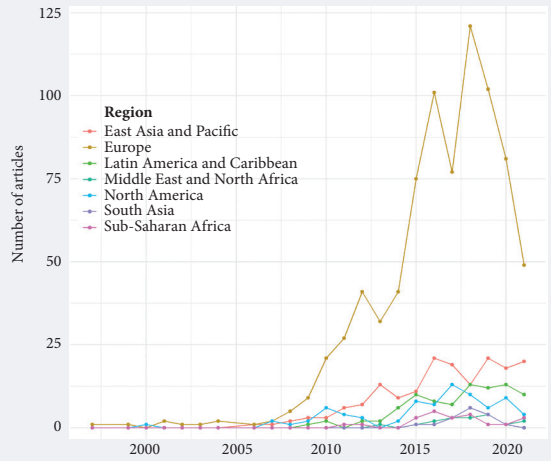
[4] Authors may have changed affiliations throughout their careers. This implies making decisions: papers were counted for the affiliation at the year of the publication, and where the change happened, all those papers were assigned to the institution and country of the authors' last paper in the database.

Figure 3. **Number of Published Articles, by year**



Source: authors.

Figure 4. **Number of Articles per Region, by year**



Source: authors.

(as a result of the increasing interest that the review of the Manual implied) and after (as a result of the new structure of the Manual) the publication of the fourth edition in 2018, there was a significant increase in the number of countries active in the Oslo Manual agenda, particularly the BRICs. Compared with the third edition's dissemination period, by the fourth, approximately ten times more countries participated in research activities related to the Oslo Manual.

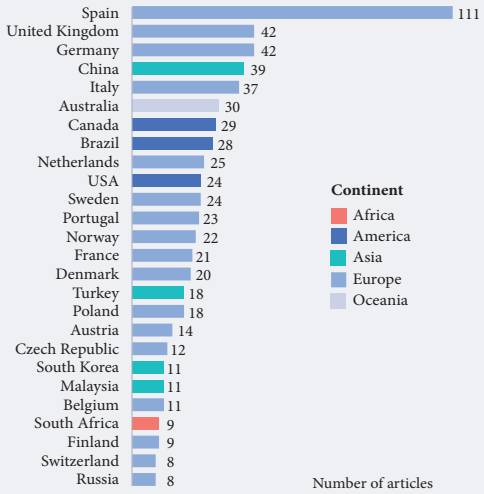
A consequence was the steady decline in the country's concentration of research in publication shares, as can be gleaned from the Hirschman-Herfindahl index in Figure 7. That is to say, over the years, but mainly after the second edition's publication, the interest in the Oslo Manual has become increasingly distributed, opened up, and more participated.

Institutions, journal platforms and thematic profile

Major research actors. Regarding research volume (number of articles), in Figure 8, we can observe that the top places are occupied by European Institutions, namely the ZEW (Zentrum für Europäische Wirtschaftsforschung), the United Nations University Maastricht and the Universidad Complutense de Madrid. Of the top 10 institutions more active, only one is from outside Europe: Universidade de Sao Paulo.

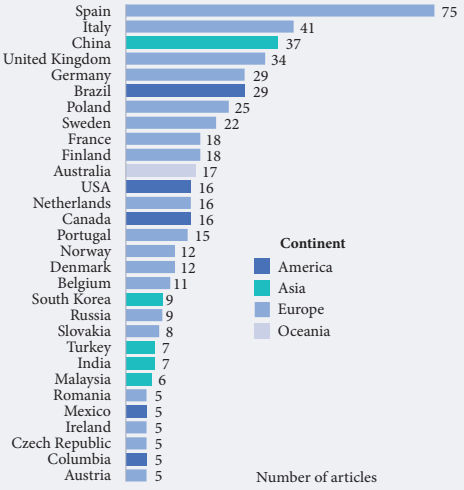
However, regarding the average number of citations, Figure 9 shows that the top higher scores were observed in the Universiteit Hasselt, the EIM Group, the Technische Universiteit Eindhoven, and the Ecole Polytechnique Federale de Lausanne. The European institutions are the most active and present a relevant average number of citations. Figure 9, presenting the top 25 institutions with the higher average number of citations, also allows us to see the discrepancies between institutions – the first institution has more than five times more citations than the 25th, on average.

Figure 5. **Number of Published Articles before 2018, by region and country**



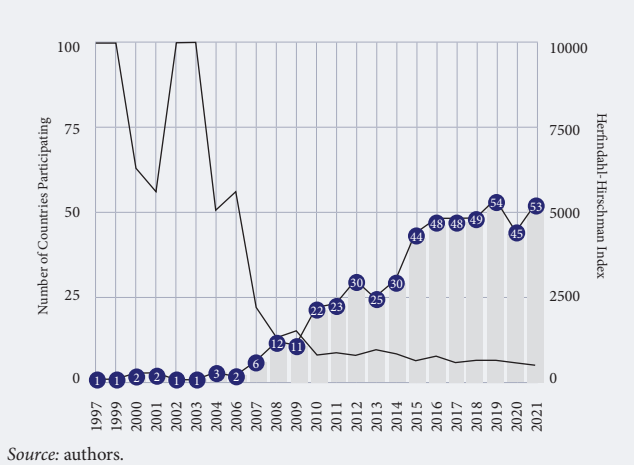
Source: authors.

Figure 6. **Number of Published Articles after the Publication of the 4th Edition of the Oslo Manual**



Source: authors.

Figure 7. **Increasing Participation in Oslo Manual – Related Publications per year**



Source: authors.

Main publishing outlets. Figure 10 shows the major journals in which the research appears. *Research Policy* is dominant among the top venues for Oslo Manual–related research. We can see that the first journal (*Research Policy*) has more than twice as many publications as the second journal (*Technological Forecasting and Social Change*). These results confirm previous research (Chesbrough, 2003; Dahlander, 2010; Rossetto et al., 2018). Regarding the major journals in which the research appears, 9out of 25 were among the 20 most influential journals in Innovation Studies[5] identified by Fagerberg et al. (2012).

During the second half of the last decade, there was a significant shift in the number of scientific journals publishing articles related to the Oslo Manual, with an increase from just a few journals prior to the publication of the third edition to dozens of diverse scientific journals coinciding with the release of the latest edition of the Manual. This statistic is not just about growth in the distribution capacity of research; it should also be understood as indicating the increase in the branching out of thematic strands. Different journals position themselves differently, tackling other topics and angles of analysis and addressing distinct audiences.

According to the Scimago Journal Rank, the journals are classified in a specific subject and within each subject in a specific category. Table 1 shows how each journal out of the top 25 from Figure 10 is classified in subject and category terms. Table 1 shows that 17 out of 25 journals are classified as "Business, Management and Accounting". On the top 25 journals, the other subjects more representative are "Social science" (#7), "Environmental science" (#6), and "Engineering" (#6). Regarding the categories, within the "Business, Management and Accounting", the most representative is the "Management of Technology and Innovation" (8 out of 17).

In Figure 11, some well-known domains related to innovation are singled out: the rising trends highlight their differential dynamics. In particular, we confirm how relevant and linked to innovation are or have become domains like Management, Business and Economics.

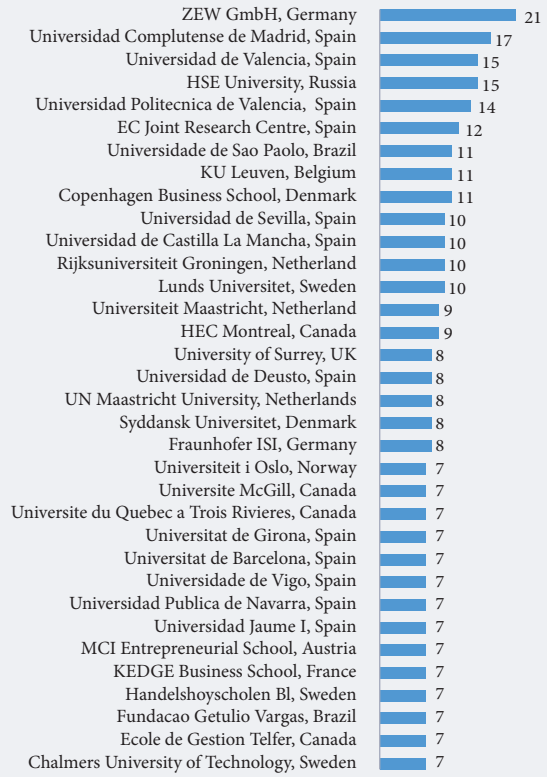
Figure 11 also shows that the persistent and rising production that ensues from 2006 and 2007 is mainly explained by three main domains: Management, Business and Economics. More recently, a significant increase was observed in Environment Studies/Sciences and Regional & Urban Planning/Geography domains in the last five years.

Evidence on performance and impact. Influence can be unpacked by investigating leadership in terms of authorship but also in terms of consequences. Here we look at outputs (publications) and outcomes (number of citations). In Figure 12, we can observe the top 15 influential authors based on the number of citations and that the author with more citations has more than twice the second author with more citations.

Research networks

Figure 13 expands the analysis by offering a representation of the authorship network – a graph with 74

Figure 8. **Most Active Institutions (number of articles)**



Source: authors.

[5] *Research Policy, Technological Forecasting and Social Change, Technovation, Industrial and Corporate Change, Regional Studies, Technology Analysis & Strategic Management, Small Business Economics, R&D Management, International Journal of Technology Management.*

Table 1. **Top 25 Journals by Subject and Category**

Rank	Journal	Subject	Category
1	Research Policy	Business, Management and Accounting; Decision Sciences; Engineering	Management of Technology and Innovation; Strategy and Management; Management Science and Operations Research; Engineering (miscellaneous)
2	Technological Forecasting & Social Change	Business, Management and Accounting; Psychology	Business and International Management; Management of Technology and Innovation; Applied Psychology
3	Sustainability	Computer Science; Energy; Environmental Science; Social Sciences	Computer Networks and Communications; Hardware and Architecture; Energy Eng. And Power Tech.; Renewable Energy, Sustainability and the Environment; Environ. Science; Management, Monitoring, Policy and Law; Geography, Planning and Development
4	Journal of Business Research	Business, Management and Accounting	Marketing
5	International Journal of Innovation Management	Business, Management and Accounting	Business and International Management; Management of Technology and Innovation; Strategy and Management
6	Journal of Cleaner Production	Business, Management and Accounting; Energy; Engineering; Environmental Science	Strategy and Management; Renewable Energy, Sustainability and the Environment; Industrial and Manufacturing Engineering; Environmental Science
7	Industrial and Corporate Change	Economics, Econometrics and Finance	Economics and Econometrics
8	Technovation	Business, Management and Accounting; Engineering	Management of Technology and Innovation; ; Engineering (miscellaneous)
9	Economics of Innovation and New Technology	Business, Management and Accounting; Economics, Econometrics and Finance	Management of Technology and Innovation; Economics, Econometrics and Finance
10	Industry and Innovation	Business, Management and Accounting;	Business, Management and Accounting; Management of Technology and Innovation
11	Regional Studies	Environmental Science; Social Sciences	Environmental Science; Social Sciences
12	Technology Analysis & Strategic Management	Business, Management and Accounting; Decision Sciences	Strategy and Management; Management Science and Operations Research
13	Science and Public Policy	Environmental Science; Social Sciences	Management, Monitoring, Policy and Law; Geography, Planning and Development; Public Administration
14	Small Business Economics	Business, Management and Accounting; Economics, Econometrics and Finance	Business, Management and Accounting; Economics and Econometrics
15	International Journal of Technology Management	Business, Management and Accounting; Computer Science; Engineering ; Social Sciences	Industrial Relations; Strategy and Management; Computer Science Applications; Engineering; Law
16	Journal of Technology Transfer	Business, Management and Accounting; Engineering	Accounting; Business and International Management; Engineering
17	Industrial Marketing Management	Business, Management and Accounting	Marketing
18	R&D Management	Business, Management and Accounting	Business and International Management; Business, Management and Accounting; Management of Technology and Innovation; Strategy and Management
19	Innovation-Organization & Management	N/A	N/A
20	Forest Policy and Economics	Agricultural and Biological Sciences; Economics, Econometrics and Finance; Environmental Science; Social Sciences	Forestry; Economics and Econometrics; Management, Monitoring, Policy and Law; Sociology and Political Science
21	Annals of Regional Science	Environmental Science; Social Sciences	Environmental Science; Social Sciences
22	Journal of Engineering and Technology Management	Business, Management and Accounting; Decision Sciences; Engineering	Industrial Relations; Strategy and Management; Information Systems and Management; Management Science and Operations Research; Engineering (miscellaneous)
23	European Planning Studies	Social Sciences	Geography, Planning and Development
24	European Journal of Innovation Management	Business, Management and Accounting	Management of Technology and Innovation
25	Applied Economics	Economics, Econometrics and Finance	Economics and Econometrics

Source: authors.

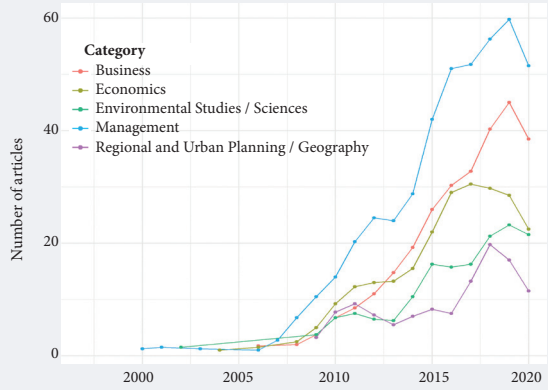
Figure 9. **Average Number of Citations, per institution**

Source: authors.

Figure 10. **Top 25 Journals, number of total articles published**

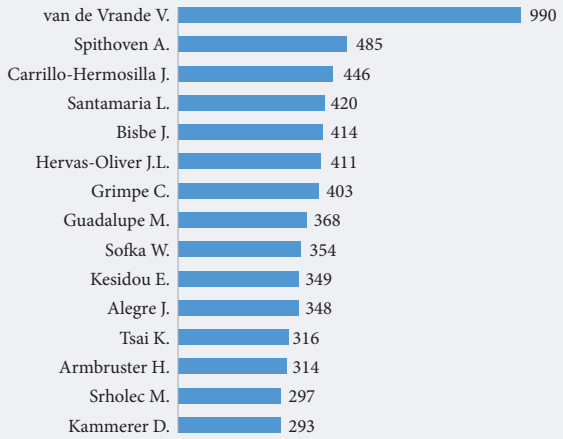
Source: authors.

Figure 11. **Number of Published Articles by scientific domain, 2000-2021**



Source: authors.

Figure 12. **Impactful Contributors, Top 15, in number of citations**

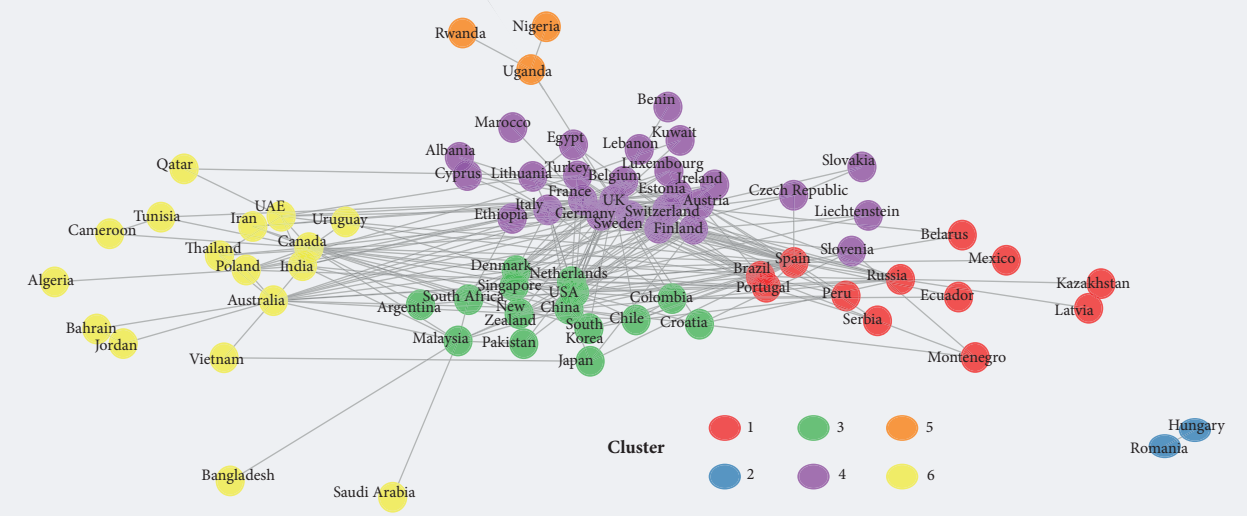


Source: authors.

nodes (countries). This visualization highlights the connections and clusters among countries. The distance between each pair of nodes on the map indicates their similarity and connection. The proximity of two nodes on the map reflects the similarity and correlation of their bibliometric attributes (McAllister et al., 2022). Different colours on the map represent distinct clusters, which are groups of countries more strongly connected than others on the map. The map shows unexpected connections due to the geographical distances of some countries in the same cluster. These unexpected connections, however, represent opportunities for further collaboration among these countries. The network has a density of 0.11, the proportion of existing links relative to the possible number.

Furthermore, the diameter is 5, the shortest distance between the two farthest nodes, and the average path length is 7.2. These metrics jointly underscore a significant level of interaction, indicating that there is diversity and a role for positive effects from the periphery to the centre that cannot be ignored (Gilsing *et al.,* 2008). Additionally, the network is not homogeneous, and six clusters of countries can be identified. Cluster 1 includes countries that share Spanish (e.g., Mexico, Spain, Peru, Ecuador), Portuguese (e.g., Brazil, Portugal), and Russian (e.g., Russia, Belarus) as their mother tongues. The common language facilitates communication and collaboration in re-

Figure 13. **Country Collaboration**



Source: authors.

search and authorship. Cluster 3 includes countries with English as their mother tongue (e.g., USA, New Zealand, South Africa). The common language and historical ties promote strong collaboration among these countries). Cluster 4 mainly consists of European countries (e.g., the UK, Germany, France, Italy). These countries' scientific solid and research infrastructure likely fosters robust collaborative networks. Clusters 2, 5 and 6 gathers countries close geographically, respectively, from Central Europe, Africa and the Middle East.

The clustering and the overall network structure may reflect the degree to which different countries have adopted and utilized the Oslo Manual's guidelines for innovation data collection and reporting. Countries within the same cluster may exhibit similar approaches to innovation practices and research methodologies, as defined by the Oslo Manual, thus fostering stronger collaborations among them.

Table 2 presents measures of the influence and position of countries in the network. The UK has the highest "pagerank" and "betweenness" centrality. In a statistical sense, it is the country with the most direct and indirect connections to other countries. It is also the most central by the shortest paths that flow through it, making it an information intermediary (Wasserman, Faust, 1994).

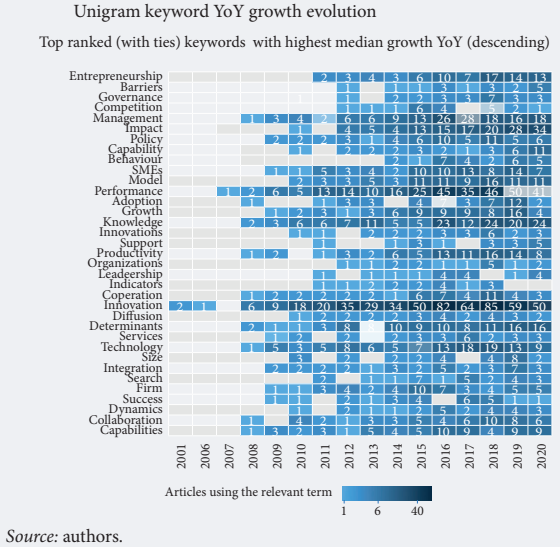
Research directions

In order to understand the dynamics of content over time, we employed keyword processing, mainly focusing on term extraction and textmetric analysis related to Oslo Manual publications. Our approach is based on analysing single words or unigrams.

Figure 14 visually represents the presence and growth of specific themes. Dark colours indicate a heavy relative presence, while the numbers in the tiles represent the frequencies of these themes in abstracts for each year. The Y-axis displays the terms with the highest growth rates (year-on-year) in descending order. Notably, we observe a rapid rise in mentions of «Entrepreneurship.» Furthermore, this analysis highlights the distinctive importance of key features of the Oslo Manual, including «Innovation,» «Performance,» «Knowledge,» and «Management.»

These straightforward observations demonstrate textmetric approaches' effectiveness in capturing the Oslo Manual's underlying characteristics and developments. Additionally, the content analysis provides insights into central thematic and sub-thematic categories directly associated with the manual and potential future developments.

Figure 14. **Thematic Keywords (unigrams)**



Source: authors.

Table 2. **Country Network Statistics, ranked**

Country rank	Cluster	Pagerank Centrality	Country rank	Betweenness Centrality	Country rank	Closeness Centrality
UK	4	0.0455	UK	790.92	Romania	0.10000000
USA	3	0.0333	Spain	664.57	Hungary	0.10000000
China	3	0.0328	The Netherlands	316.97	Spain	0.00336700
France	4	0.0305	Australia	267.56	UK	0.00335570
Spain	1	0.0305	Canada	263.98	The Netherlands	0.00321543
Canada	6	0.0305	France	242.19	USA	0.00320513
Germany	4	0.0293	USA	215.31	China	0.00313480
Sweden	4	0.0286	Russia	215.08	Denmark	0.00313480
Italy	4	0.0269	Malaysia	152.79	Germany	0.00311526
Austria	4	0.0265	Italy	146.27	France	0.00309598
Belgium	4	0.0260	Uganda	143.00	Australia	0.00309598
Australia	6	0.0240	Croatia	142.00	Canada	0.00309598
Norway	4	0.0237	Austria	129.40	Russia	0.00306748
The Netherlands	3	0.0223	Germany	112.26	Italy	0.00304878
Finland	4	0.0219	Belgium	95.46	Brazil	0.00303951
Russia	1	0.0201	Denmark	89.13	Portugal	0.00303951
Malaysia	3	0.0190	China	88.09	Colombia	0.00298507
Estonia	4	0.0187	Poland	86.60	New Zealand	0.00297619
Brazil	1	0.0185	South Africa	85.53	South Korea	0.00295858
Poland	6	0.0182	Brazil	82.29	Finland	0.00295858

Source: authors.

Framing factors and rising themes around Oslo Manual

In Figure 15, distinct domains associated with the Oslo Manual have been identified through the identification and assessment of specific keywords. These domains are recognized for their unique dynamics, reflected in emerging trends. Notably, trends observed in Figure 15 confirm the significance of dimensions such as innovation and performance in the context of the Oslo Manual. Furthermore, other aspects such as knowledge, management, and firms are also evident, although they appear less frequently.

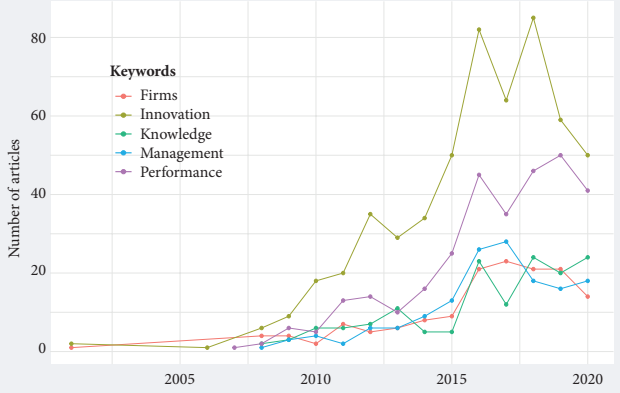
Conclusions

Innovation is vital in enhancing living standards and has far-reaching impacts on individuals, institutions, economic sectors, and countries. As a guide for collecting and interpreting evidence of innovation, the Oslo Manual has evolved through three revisions, reflecting the need to adapt to the changing landscape of innovation and accommodate new practices. This research article employs an enhanced bibliometric and text-mining approach, analysing a comprehensive dataset from 1992 to 2021 to gain insights into the quantitative and qualitative aspects of the Oslo Manual's review. The findings offer valuable contributions to innovation research and serve as an orientation for future theoretical developments.

The longitudinal analysis revealed significant streams of thought underpinning current innovation research. By studying a substantial database comprising 1,388 research articles, this study demonstrates an increased interest among researchers and policymakers in innovation-related topics, including entrepreneurship, performance, knowledge, and management. This growing interest aligns with previous studies (Chesbrough, 2003; Dahlander, 2010; Rossetto et al., 2018), affirming the integration of innovation with established management and economic theories (Van de Vrande et al., 2010).

This research stands out by focusing on the interpretation of innovation within the context of the Oslo Manual, utilizing network analysis methodology. It complements previous works (e.g. Rossetto et

Figure 15. **Main Categories (Keywords) Related to the Oslo Manual**



Source: authors.

al., 2018; Cancino et al., 2017a; Merigó et al., 2016; Shafique, 2013), offering a more comprehensive understanding of the theoretical basis of innovation research and providing valuable insights for future theoretical developments in the field.

By examining the references cited in the analyzed papers, the study provided insights into how this literature connects with broader management and innovation studies, further contributing to understanding innovation research's theoretical foundation.

However, challenges such as changes in definitions and methodologies across different editions of the Oslo Manual and comparability issues across countries need careful consideration when interpreting trends. Future research can explore specific themes, authors, and relationships and employ innovative methodologies to illuminate emerging areas within innovation research (Sharma, Lenka, 2022; Silva et al., 2023; Wulff et al., 2023; Rahman et al., 2024). This study offers valuable insights into the evolution and practical implications of the Oslo Manual, highlighting its critical adaptability to capture the dynamic innovation landscape and foster global cooperation.

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Shaping Innovation Capabilities to Enable Transformative Sustainability Transitions in Agriculture

Mohd Arif Adenan
PhD Candidate, arif.mohe@gmail.com

Lily Julienti Abu Bakar
Associate Professor, julienti@uum.edu.my

Sabariah Yaakub
Associate Professor, y.sabariah@uum.edu.my

College of Business, Universiti Utara Malaysia, Sintok, 06010 Bukit Kayu Hitam, Kedah, Malaysia

Abstract

The agro-industrial sector is one of the largest socio-technical systems upon which the prospects of transition to sustainable development critically depend. To meet the food needs of a growing population, it requires profound transformation, new knowledge, advanced technologies, and highly qualified specialists. The agro-industry is moving from traditional schemes to fourth and fifth generation smart models that have innovative potential to ensure food security, heal natural systems, and stimulate economic growth. This potential will be able to be realized only if provided with an appropriate human resource base.

The article uses the example of young agri-preneurs in Malaysia to assess the key components of human capital that determine the performance of modern agro-industry, as well as the potential contribution of the government interventions in strengthening their effects. Three factors are considered - innovativeness, willingness to take reasonable risks, and proactivity. It is found that the presence of targeted governmental support, significantly enhances the influence of the first two on business performance. As for proactivity, its presence does not produce an operational tangible impact on performance, regardless of the context, including the presence of external support. The outcomes from proactivity manifest rather in the distant perspective. The latter circumstance is due to the high uncertainty and turbulence that accompany the activities of the studied sector, caused by uncontrollable, hardly predictable natural and social processes and their consequences. An in-depth understanding of the interrelationship of the factors under consideration can contribute to the development of more effective policies and support systems to foster sustainable growth in the agribusiness sector.

Keywords: agricultural innovations; transitions to new technological modes; highly qualified personnel; agro-entrepreneurs; entrepreneurial orientation; proactivity; government interventions; business performance; Malaysia

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Introduction

Over the last decade, there has been growing interest in academic and political discourses 0n the issues of transformation of large socio-technical systems, upon which the prospects for the transition to sustainable development critically depend (Polzin, 2024; HLPE, 2019; Herren, Herlin, 2020). Basic sectors are studied, the task of which is to ensure survival, the basics of life, and, in the long term, prosperity. Among them is the agro-industrial ecosystem responsible for the food supply. It is expected that by 2050 the world population will reach approximately 10.1 billion people, therefore, the global demand for food will grow by 70% (Rudrakar, Rughani, 2023). In this regard, the agricultural sector is faced with unprecedented production challenges, since it will be necessary to produce more than in all previous history (Fraser, Campbell, 2019). To meet such a demand, the agricultural industry needs a profound transformation with the help of new knowledge and advanced technologies, allowing it to adapt to more complex development models (Bissadu et al., 2024; Naikwade et al., 2023). There has been a shift from the traditional paradigm to a high-tech model, which is manifested in such concepts as fourth- (AG 4.0) and fifth-generation (AaG 5.0) agriculture. The latter takes on the solutions of the problems that the previous version is unable to solve. "Smart agriculture" has enormous potential to contribute to solving complex large-scale problems, such as ensuring food security, improving natural systems, stimulating economic growth, smoothing out inequality, and so on. All this can affect other sectors, create new market niches, and give impetus to their accelerated development.

So far, the implementation of such a "smart model" has been hampered by high entry costs and a certain inertia, which manifests itself in the acute shortage of highly skilled labor and low ability to break path dependence. It is noteworthy that developed countries also face these challenges. Thus, in the United States and Canada, there are noticeable gaps in the supply of skilled labor in the context of the sector in question (Saiz-Rubio, Rovira-Más, 2020; Contreras-Medina et al., 2022). Similar difficulties are typical for Germany, which, despite its solid industrial and technological background, nevertheless has difficulties with the transition of agriculture to a smart model. There is a conceptual contradiction: the ingrained dominant narrative does not allow new alternative approaches to emerge that are capable of balancing economic, environmental, and social components (Polzin, 2024). Many researchers point out that emerging opportunities for a new level cannot be realized, since they are not provided with an appropriate personnel base (Bissadu et al., 2024). Despite this, a number of countries are still dynamically increasing their potential for such a transition.

In the Netherlands, for example, Shell has teamed up with Erasmus University of Rotterdam to launch an innovative education program where students search for innovative, cyclical solutions for agriculture, climate change, biodiversity restoration and improving water availability. It has also developed and practiced technologies to eliminate chemical fertilizers altogether, while increasing crop yields.[1] In other words, research at universities goes beyond previous knowledge into completely new areas and is attempting to unlock the previously unperceived potential of agriculture. This can be seen in the growing and processing of certain crops for use in areas where they have never been used before, including in the construction and chemical industries.

The aim of our study is to assess the key factors that determine the prospects for the agricultural sector to transition to a sustainable, smart model that relies on young, highly skilled entrepreneurs. We study the relationship between their entrepreneurial orientation, innovativeness, proactivity, and ability to take reasonable risks. The results obtained form the information basis for policy in terms of developing measures to support this promising segment of the human resource base in order to accelerate the transition to Model 5.0.

Literature Review

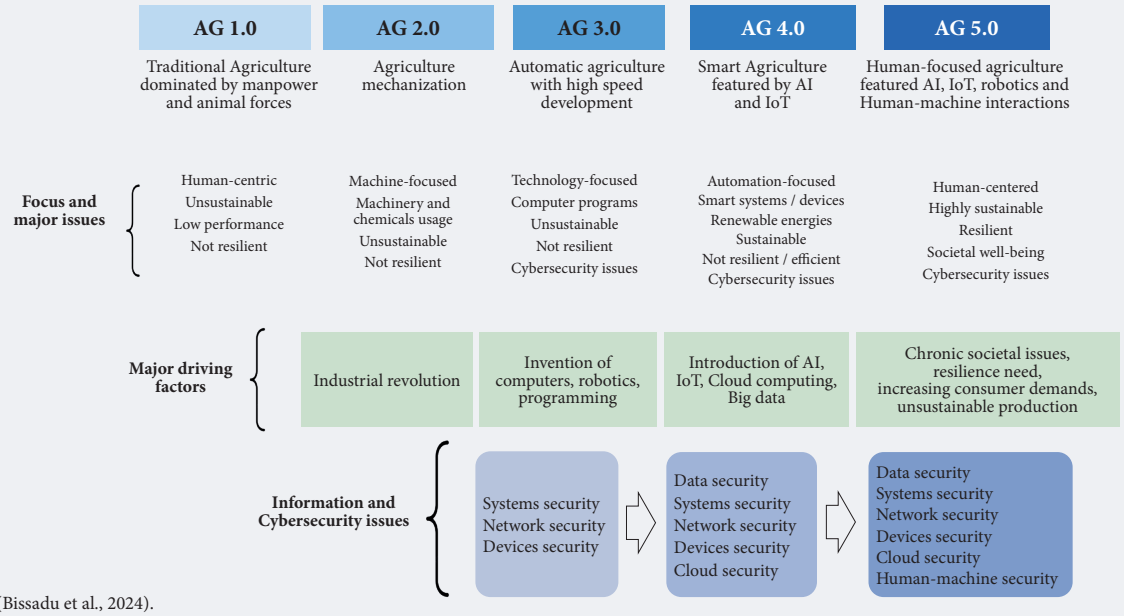
Technological Potential

Based on the scheme of the technological evolution of the agricultural sector, presented in Figure 1, the mainstream topic in the current industry discourse is Agriculture 4.0. In addition, discussions are emerging and gaining momentum about moving toward a more advanced and balanced model – Agriculture 5.0.

The concept of AG 4.0 has brought to the fore a number of competitive advantages, including a new type of management, the efficient use of resources, sustainable production, and the introduction of renewable energy sources (Mourtzis et al., 2022). Their implementation depends on the degree of development of technologies such as artificial intelligence (AI), 5G, big data, robotics, cloud computing, the Internet of Things, robotics, and so on. (Bechar, Vigneault, 2016; Bergerman et al., 2016; Pandrea et al., 2023; Yuniarto et al., 2023) (Figure 1). Here, the emphasis is on the efficiency of production and marketing chains through the internal integration of technologies, which, among other things, will

[1] https://managementscope.nl/en/interview/jan-rotmans-green-industrial-policy, accessed 14.01.2025.

Figure 1. **Evolution of Agriculture from Traditional to Smart Model**



Source: (Bissadu et al., 2024).

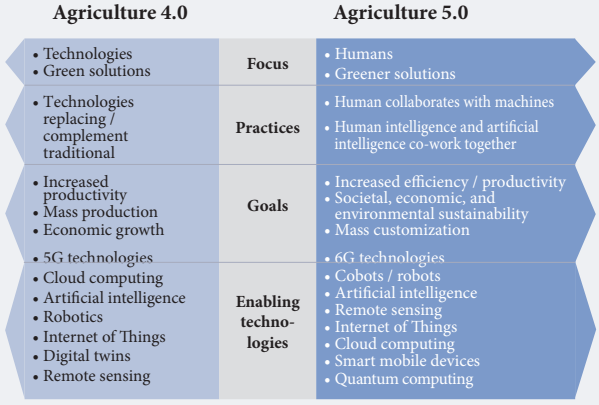
increase the efficiency of processes and reduce the burden on the environment (Martos et al., 2021; Ragazou et al., 2022; Tulungen, 2022).

In turn, the AG 5.0 model describes a fundamentally new paradigm of agriculture, which gives priority first of all to people and only then to technological solutions that integrate not only with each other, but also with cultural values (Baryshnikova et al., 2022; Contreras-Medina et al., 2022; Sindhwani et al., 2022). Sustainability in this sense is an imperative for the implementation of bio-based agricultural practices (Sindhwani et al., 2022). While AG 5.0 may use technologies from the AG 4.0 model, their focus, methods, and goals differ significantly (Figure 2). Thus, one of the key objectives of the 5.0 model is to produce the required amount of clean and affordable food in a healthy and protected ecosystem (Fraser, Campbell, 2019).

From a technology perspective, the four main areas that have the potential to transform the sector are AI, cloud computing, robotics, and the Internet of Things (IoT). As of 2023, the AI sector has reached $241.8 billion in annual turnover. It is projected to grow at a compound annual growth rate (CAGR) of 17.3%, which could result in the AI market reaching $738.8 billion by 2030. In the cloud segment, the market will grow at a compound annual growth rate of 12.27% and could reach $1.062 trillion by 2028 (Bissadu et al., 2024). Other emerging technologies include: collaborative robots (cobots), 6G, digital twins, big data analytics, blockchain, edge, cloud, and quantum computing (Table 1).

IoT-enabled devices are expected to increase significantly across all countries by 2030 compared to today's levels. For example, Sub-Saharan Africa has the lowest adoption rates, but even there, the number of IoT devices is projected to reach over 0.26 billion by 2030. The robotics market is not as large but is also growing rapidly, at about 3.83% CAGR, to reach $45.09 billion by 2028. Cobots are seen as disruptive solutions as they can enable the migration of young, promising talent from unproductive and oversaturated sectors to the agricultural sector. 6G technologies, which expand bandwidth to 1 Tbps, will serve as the catalyst for improved IoT sensor connectivity and other innovations. One of the key features of AG 5.0 is the integration of large data sets from different sources, offering holistic knowledge for decision-making leading to the optimal use

Figure 2. **Main Differences between the AG 4.0 and AG 5.0 Models**



Source: (Bissadu et al., 2024).

Table 1. **Enabling Technologies for the Adoption and Implementation of Agriculture 5.0**

Enabling technologie	Descriptions/benefits
Cobot	A collaborative robot designed for direct interactions and collaboration with humans within a shared space, enabling close proximity and collaboration between humans and robots
6G technologies	The 6G network will provide the technological advancements for realizing the full potentials of Agriculture 5.0 through high throughput IoT networks
Artificial intelligence	Provides quick decision making, promotes greater efficiency in operations, high-quality assurance, intelligent automation
Digital twins	Minimize production costs, predicts future actions
Internet of Things	Increased and timely agricultural data collection, intelligent network, efficient supply chain, reduced loss of products and yields
Big data analytics	Enable customization, quick and better decision making, real-time monitoring and predictions
Blockchain technologies	Enhance decentralized management of agriculture IoT, ensure transparency, and security
Edge computing	Improve low latency, increase cybersecurity, reduced data storage costs, boost interoperability
Cloud computing	Offer low-cost operations, increased collaboration, better data management, and shared responsibility economy model, knowledge transfer
Quantum technologies	Offer super-high data transmission and enhanced security capabilities

Source: authors based on (Bissadu et al., 2024).

of resources, the reduction of waste, and increased productivity (Fraser, Campbell, 2019; Chamara et al., 2022). Digital twins provide monitoring of the environmental, social, and economic sustainability of agricultural systems and allow for forecasting their changes (Cesco et al., 2023).

Thus, the entire emerging complex and multidimensional context is reformatting ideas about what the provision of human resources for agriculture should be. New methods of its management involve reliance on highly qualified specialists (Humayun, 2021).

Human and Innovative Potential

In all countries, the agro-industry is experiencing an acute shortage of labor (Naikwade et al., 2023; Rotz et al., 2019; Ragazou et al., 2022). For example, Canada was previously projected to face a critical labor shortage of 113,000 workers this year (Rotz et al., 2019). Changing skill requirements create huge demand for continuous learning, retraining, and the development of dynamic capabilities (Humayun, 2021; European Commission, 2021). They are associated with the ability to create innovations, flexibly adapt to change, break path dependence, and balance the use of existing resources and the search for new assets (Turner et al., 2017). Managing such multi-level processes requires the ability to coordinate the actions of various actors: farmers, agricultural and processing industries, land use planners, environmental, financial and regulatory organizations, markets, specialized educational and design centers, and so on. (Brown et al., 2016; Läpple et al., 2016; Sutherland et al., 2017; Vanclay et al., 2013). It can be said that an agricultural innovation system (AIS) is being formed (Knierim et al., 2015; McDonald, Macken – Walsh, 2016), which integrates agribusiness companies with other stakeholders in extended processes of learning, coordination, and policy improvement (Läpple et al., 2016; Phillipson et al., 2016; Vanclay et al., 2013).

From the perspective of this concept, innovations emerge from a co-evolutionary process of the interactive development of technologies, artifacts, practices, markets, procedures, and socio-institutional mechanisms (Hall, Clark, 2010; Klerkx et al., 2012). It involves actors from different fields: industry representatives, politicians, traders, processors, standard developers, NGOs, and regulatory organizations. Agribusinesses gain a platform upon which to build their innovative and adaptive potential and to form networks for the exchange of knowledge and other resources (Hall, 2005; Leeuwis et al., 2014). Promising models of agricultural production and land use are listed in Table 2.

Three categories of innovative potential are distinguished (Boly et al., 2014; Wang, Ahmed, 2007): (i) scanning for innovative opportunities (Wang, Ahmed, 2007); (ii) adaptability to a dynamic, changing environment (Wang, Ahmed, 2007); and (iii) absorptive capabilities - the acquisition, assimilation, and transformation of external knowledge and resources (Boly et al., 2014; Wang, Ahmed, 2007). The mobilization and reconfiguration of capabilities to shape it occurs at different levels, and implementation requires that agents and resources come together in the right combinations at the right time (Engel, 1995, Klerkx et al., 2010).

Table 2. **Prospective Models of Agricultural Production and Land Use**

Models	Literature
Sustainable or ecological intensification	Petersen, Snapp, 2015; Pretty et al., 2011; Tittonell et al., 2016
Smart agriculture adapted to climate change	Kpadonou et al., 2017; Long et al., 2016
Circular Economy and Bioeconomy	Kristensen et al., 2016; O'Brien et al., 2017
Urban farming	Huang, Drescher, 2015; Pölling et al., 2016
High-tech agriculture based on precision manufacturing, the Internet of Things and Big Data	Eastwood et al., 2017; Poppe et al., 2013; Wolfert et al., 2017

Source: authors based on (Turner et al., 2017).

For the purposes of our study, we will consider how the above processes are implemented in the context of the Malaysian agro-industry.

Dynamics of the Agro-Industry in Malaysia

Along with mining, the agricultural sector has been a cornerstone of the national economy since before independence (Yusoff, 2019). It received a new impetus with the introduction of the National Agricultural Policy (NAP) (Lim et al., 2012; Yusoff, 2019). Small and medium enterprises (SMEs) are the backbone of this industry, accounting for about 90% of all agricultural companies in the country.[2] They play a key role in rural development, employment, and economic growth. The adaptability and innovation of SMEs are vital to improving food security, diversifying agricultural production, and increasing resilience in the context of climate change and global competition (Zainol, Yusof, 2012). However, a key challenge remains: updating the human resources base with young agripreneurs who will determine the prospects for its development according to a smart model (Ahmad, Ngah, 2020). Associated with this, in particular, are the tasks of adapting to changing market conditions, mastering technological advances, and developing entrepreneurial skills, including dynamic capabilities. The Ministry of Agriculture has developed a Program to support young agripreneurs (under 40 years of age) (Young Agropreneur Program)[3], including various training initiatives. However, its full potential is hampered by a lack of understanding of the determinants of entrepreneurial orientation (EO) and its impact upon the performance of young professionals. Addressing this gap will enable the development of more effective and targeted initiatives to foster a thriving agripreneurship ecosystem in Malaysia. Therefore, the objective of this study is to examine the relationship between the entrepreneurial mindset and agripreneurship performance, assess the impact of innovativeness, proactive attitude and risk-taking on performance, and inform the development of policy initiatives and support mechanisms for young agripreneurs.

Research Concepts

A key concept in entrepreneurship research is entrepreneurial orientation (EO), which includes strategies, processes, and decision-making styles of organizations in identifying and exploiting business opportunities. The relationship between EO and business performance is complex and non-linear, and is influenced by a variety of mediating factors (Miller, 1983). We focus on three key aspects: proactivity, innovativeness, and risk-taking, the impact of which on business success is especially significant in turbulent conditions (Lumpkin, Dess, 1996). They are also relevant in the context of agribusiness, which is characterized by instability and fluctuations (weather conditions, etc.). In such conditions, the ability to make the right decisions, despite incomplete data, becomes an indispensable condition for the transition to sustainable, adaptive development.

Research has highlighted the importance of EO in agriculture, particularly as agripreneurs operate in an unpredictable environment. Agripreneurs who are willing to take creative risks are more likely to engage in innovative activities that require a certain amount of courage. Those who actively anticipate market trends will be able to find the best solution to meet demand earlier than others. Players with high EO levels tend to achieve greater success due to their ability to adapt to rapidly changing conditions, create innovations, and overcome resource constraints (Kraus et al., 2022). Access to diverse resources and government support play a decisive role in increasing the effectiveness of software (Al Mamun et al., 2020). Thus, the last of the mentioned factors, which involves stimulating innovation and the resource provision of agricultural enterprises, plays the role of an "intermediary" that ensures the conversion of software into improved business performance (Liguori et al., 2020). Access to technology and training also serve a similar function (Hansen et al., 2011).

This study assesses how agribusiness SME owners perceive the role of public policy in providing support for high-tech development.

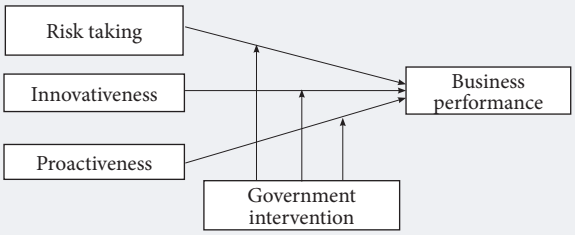
Research Structure

This study integrates various theoretical perspectives and empirical data to analyze the relationship between key aspects (risk-taking, innovativeness, proactivity) and the mediating role of government support. Our framework involves developing six hypotheses regarding both the direct impact of the aforementioned aspects of software on company performance and the mediating role of government incentives. Each dimension is operationalized using specific indicators, ensuring that the methodological approach meets the objectives of the study (Figure 3). As a result, a set of hypotheses was formulated that boils down to the fact that there are positive relationships between risk-taking, innovativeness, and a proactive stance, on the one hand, and business performance, on the other (H1, H3, H5), and that government measures play a mediating role in these relationships (H2, H4, H6).

[2] https://www.dosm.gov.my/, accessed 18.12.2024.

[3] https://www.lkim.gov.my/en/young-agropreneur/, accessed 18.12.2024.

Figure 3. **Research Structure**



Source: authors.

Research Methodology

Our study is based on a deductive approach, which involves validating the theories used through hypothesis testing. The approach is complemented with a survey of respondents to collect quantitative data using structured questionnaires designed to explore the factors influencing the activities of Malaysian agribusiness entrepreneurs. Risk-taking is defined as the willingness to commit significant resources and take bold steps despite the turbulent conditions inherent in agricultural activities.

The innovation dimension requires ingenuity in developing original solutions to maintain and expand competitive advantage (Lumpkin, Dess, 2001) and the ability to develop new products or modify existing ones. In turn, proactivity consists of the ability to anticipate trends and introduce offers to the market before other players in order to take a leading position (Lumpkin, Dess, 1996, 2001). The use of a cross-sectional design allowed us to collect data at a specific point in time to gain insight into current trends and the behavior of young entrepreneurs. The target group included emerging potential leaders in the agricultural sector. Data were collected using both self-administered questionnaires and online surveys, which ensured a wide coverage. SPSS and Smart-PLS were used as the main analytical tools, which allowed us to comprehensively study the interrelationships of the data.

Data Analysis and Results

The majority of respondents were men (56.9%) aged 29–40 years (76.6%) (Table 3). Many had an STPM certificate (37.9%) or a bachelor's/master's degree (33.2%). Overall, the level of education of the sample participants could be considered satisfactory. High levels of participation in the Young Agropreneur Program were found in 2022–2023 (58.7%), primarily individual players (80.3%). Most of them (83.9%) have fewer than five employees and annual sales of less than RM100,000 (approximately $23,000) (84.2%). For more details, see Table 4.

Table 3. **Respondent Background**

Indicator	Frequency	Percentage (%)
Gender		
Male	219	56.9
Female	166	43.1
Age		
18-28 years old	90	23.4
29-40 years old	295	76.6
Higher Education		
Standard 6/UPSR	8	2.1
PMR / SPM	97	25.2
STPM / Certificate / Diploma	146	37.9
Bachelor's Degree/ Master	128	33.2
PhD	6	1.6

Source: authors.

Table 4. **Company Background**

Indicator	Frequency	Percentage (%)
Year of Participation in Program		
2014–2015	18	4.7
2016–2017	28	7.3
2018–2019	44	11.4
2020–2021	69	17.9
2022–2023	226	58.7
Legal Status of Firm		
Sole Proprietorship	309	80.3
Partnership	28	7.3
Limited Liability Partnership	5	1.3
Private Limited Company	43	11.2
Sub-sector Currently Operating		
Crop-Farming	150	39.0
Fishery	9	2.3
Livestock Farming	25	6.5
Agro-based	201	52.2
Location of Business		
Northern region	102	26.5
Southern region	150	39.0
East coast region	32	8.3
Central region	74	19.2
East Malaysia	27	7.0
Number of Employees		
Less than 5 employees	323	83.9
5 – 75 employees	59	15.3
75 – 200 employees	3	0.8
Annual Sales Turnover (2018)		
0-RM 100,000	324	84.2
RM 100,000 – RM 200,000	33	8.6
RM 200,000 – RM 300,000	17	4.4
RM 300,000 – RM 1M	5	1.3
RM 1M - RM 7.5M	4	1.0
RM 15M – RM 30M	1	0.3
RM 50M – RM 75M	1	0.3

Source: authors.

Table 5. **Internal Consistency and Convergent Validity Results**

Construct	Loading	AVE	CR
Risk-Taking	0.737	0.783	0.915
Innovativeness	0.501	0.612	0.922
Proactivity	0.595	0.759	0.759

Note: none deleted items.

Source: authors.

Table 6. **Discriminant Validity**

	Business Performance	Innovativeness	Proactivity	Risk-Taking
Business Performance	0.815			
Innovativeness	–0.171	0.782		
Proactivity	0.338	0.054	0.769	
Risk-Taking	0.396	–0.061	0.811	0.885

Source: authors.

Measuring Internal Consistency. This indicator is assessed using composite reliability (*composite reliability,* CR) and convergent validity – through the loading of the items and the average extracted variance (*average variance extracted,* AVE). If the load value exceeds the recommended threshold, we can talk about the reliability and validity of the design, otherwise it is excluded from the analysis. From Table 5 it follows that almost all load indicators exceeded the recommended threshold of 0.708 (Hair et al., 2014). Thus, all relevant constructs were retained.

Assessing Discriminant Validity. Its presence is confirmed by the fact that the specific construct under consideration is under a higher loading from the elements compared to others. The test was performed using the Fornell – Larcker test (Fornell, Larcker, 1981). The average variance extracted (AVE) values presented in Table 6 indicate satisfactory discriminant validity for all constructs.

Path Coefficient Analysis. Risk is a decisive factor in business performance, especially for SMEs. The results provide insight into how different dimensions of risk affect business performance. A significant positive effect of risk willingness was found ($\beta = 0.261$, $p = 0$). This means that the performance of companies open to reasonable risks usually increases. Such players are more likely to implement innovative solutions, explore new opportunities in the face of uncertainty, and increase competitive advantages. In this case, evidence of the relationship between risk willingness and business performance is a fairly high p-value ($p < 0.05$). However, the role of government measures as a factor mediating the relationship between risk strategies and business success turned out to be insignificant ($\beta = –0.049$, $p = 0.401$) (Table 7).

Since the p-value is greater than 0.05, it can be concluded that government initiatives do not have a significant impact on the relationship between risk strategies and business performance. This means that risk-taking players, depending on their own potential, will either develop successfully or lose in the competitive struggle.

Innovativeness is another critical parameter of software, which also significantly influences positive dynamics. The values $\beta = –0.298$ and $p = 0$ indicate a strong negative relationship. However, despite the negative sign, the p-value indicates a stable pattern: the value of efficiency is directly related to the degree of innovativeness. Innovative companies often develop unique products, services, and processes, which distinguishes them from competitors and ensures long-term sustainability.

With respect to innovativeness, the mediating role of government support is more significant ($\beta = 0.168$, $p = 0$). For example, if the government offers support (grants, incentives for research, or favorable legal regulations), innovative firms will be able to take advantage of such opportunities better than others. In contrast, no significant relationship was found between the proactive stance of firms and their performance ($\beta = 0.019$, $p = 0.758$). Although proactivity (the ability to anticipate future trends and act ahead of the curve) is often considered a desirable business characteristic, this study has shown that in this context this quality does not necessarily translate into higher SME performance. Moreover, government support does not significantly affect the relationship between proactivity and performance ($\beta = –0.049$, $p = 0.396$). This may be due to the very nature of proactivity, which involves anticipating and seizing opportunities regardless of external circumstances, in particular government incentives.

Discussion of Results

The results of the study reveal important aspects of the dynamics of agribusiness, including the influence of demographic factors (gender, age, and education) and business structure on entrepreneurial behavior and performance. A gender imbalance was revealed: 56.9% of respondents were men, which indicates systemic barriers or cultural biases that limit women's participation in the business. This finding is consistent with the work (OECD, 2018), which notes the need for special programs to support female entrepreneurs in order to create a more balanced entrepreneurial ecosystem. In terms of age structure, 76.6% of respondents are between 29 and 40 years old. This age group can be considered relatively mature and highly willing to take risks and

Table 7. **Path Coefficient Analysis**

Hypothesis	Relationship	T-Value	P-value	Result
H1a	Risk Taking → Business Performance	3.827	0.000	Significant
H1b	Risk Taking*Government Intervention → Business Performance	0.841	0.401	not significant
H2a	Innovativeness → Business Performance	5.782	0.000	Significant
H2b	Innovativeness *Government Intervention → Business Performance	3.65	0.000	Significant
H3a	Proactiveness → Business Performance	0.308	0.758	not significant
H3b	Proactiveness*Government Intervention → Business Performance	0.849	0.396	not significant

Source: authors.

implement innovations. Their representatives often have the necessary experience for effective strategic decision-making, which ensures more competent risk management.

Agri-entrepreneurship performance is significantly determined by the level of education. Among our respondents, 33.2% have a bachelor's or master's degree, and 37.9% have an STPM certificate or diploma. Higher education builds critical competencies that enhance one's ability to innovate and manage risks (Nabi et al., 2017). The growing interest in agribusiness is evidenced by the fact that 58.7% of respondents were participants in the Young Agropreneur Program in 2022–2023. This surge is likely due to the introduction of new government incentives and increased awareness of the sector's potential. In terms of the business structure, 80.3% of respondents are sole proprietors, which provides them with flexibility and reduces overhead costs. The downside of this status, however, may be limited growth opportunities and difficulties in accessing markets (Andersson, 2023).

In terms of intra-industry diversity, two segments dominate – agricultural (52.2%) and crop production (39.0%), indicating the potential for further diversification and innovation. Agripreneurs should consider alternative business models that could increase scalability and market reach (Evans, 2023).

There is also a regional disparity, with 39.0% of companies operating in the Southern region, and a small number on the East Coast and in East Malaysia. Addressing this will be key to achieving balanced growth and ensuring equal access to resources and opportunities for all participants in the sector. Most of the companies we surveyed (83.9%) have fewer than five employees and their annual sales (84.2% of companies) do not exceed RM100,000, meaning they are at an early stage of development. It is too early to talk about their efficiency and scalability.

Strong internal consistency was found for key aspects of behavior in the field of agribusiness: innovativeness (CR = 0.833), willingness to take risks (CR = 0.933), and proactivity (CR = 0.879). The calculations presented support the theses previously put forward in the literature (Garcia, Martinez, 2023). In particular, the role of reasonable risk in stimulating business growth is substantiated, while a proactive position, despite its importance, does not always directly affect business performance.

Discriminant validity analysis confirmed that each construct used in the study correctly measures the relevant aspects of agribusiness behavior and business performance. This allows for a deeper understanding of specific success dimensions. High average variance extracted (AVE) values for innovativeness, proactivity, and willingness to take risks indicate that all these factors play a significant role in improving process efficiency. Thus, our calculations become empirical confirmation of the theses previously presented in the publication (Garcia, Martinez, 2023).

The identified relationship between various software dimensions and performance allows us to draw important conclusions. The positive role of risk openness ($\beta = 0.261$, $p < 0.05$) indicates that companies willing to take reasonable risks are able to profitably exploit new opportunities and gain competitive advantages. At the same time, the weak mediating effect of government measures ($\beta = -0.049$, $p > 0.05$) suggests that in this context, the internal potential of enterprises is more important than external support.

Notably, there is a negative relationship between innovativeness and business performance ($\beta = -0.298$, $p < 0.05$), indicating that initial costs and problems associated with implementing innovations may hinder rapid improvements in performance.

However, its significance highlights the need for innovative practices ($\beta = 0.168$, $p < 0.05$), and government support significantly enhances the positive effects in this direction (Garcia, Martinez, 2023). On the other hand, proactivity does not significantly affect its effectiveness ($\beta = 0.019$, $p > 0.05$), that is, the preventive strategy may not produce immediate results. Possible explanations include the market situation and resource constraints. The insignificant mediating effect of government measures ($\beta = -0.049$, $p > 0.05$) suggests that, in this context, proactive firms may not receive significant benefits from the government.

Conclusion

This study reveals complex interactions between different dimensions of entrepreneurial orientation and government support in influencing agribusiness performance. Innovativeness and risk-taking are significant predictors of success. The willingness to take calculated risks becomes the key to exploiting new opportunities and achieving competitive advantages. In contrast, proactivity has no direct or indirect effect on performance, suggesting that, particularly in a volatile agribusiness landscape, a proactive strategy alone does not guarantee immediate success. Although government measures do not always play a significant role, this is not the case when it comes to enhancing the benefits of creating and implementing innovations, especially for SMEs. Providing grants, incentives, or resources for research and development can amplify the positive effects of innovation and ultimately improve business performance.

Another important mechanism is the development of individual support programs aimed primarily at improving risk management and the practical implementation of innovative ideas. This approach can significantly increase the effectiveness of initiatives aimed at helping young agribusinesses and promoting business sustainability.

Further research could examine other variables that may influence agribusiness success, including access to resources, market conditions, and socioeconomic factors. An expanded demographic analysis could provide a more complete picture of the challenges and problems faced by agribusinesses in different regions. Such insights could help develop more effective policies and support systems to promote sustainable growth in the agribusiness sector.

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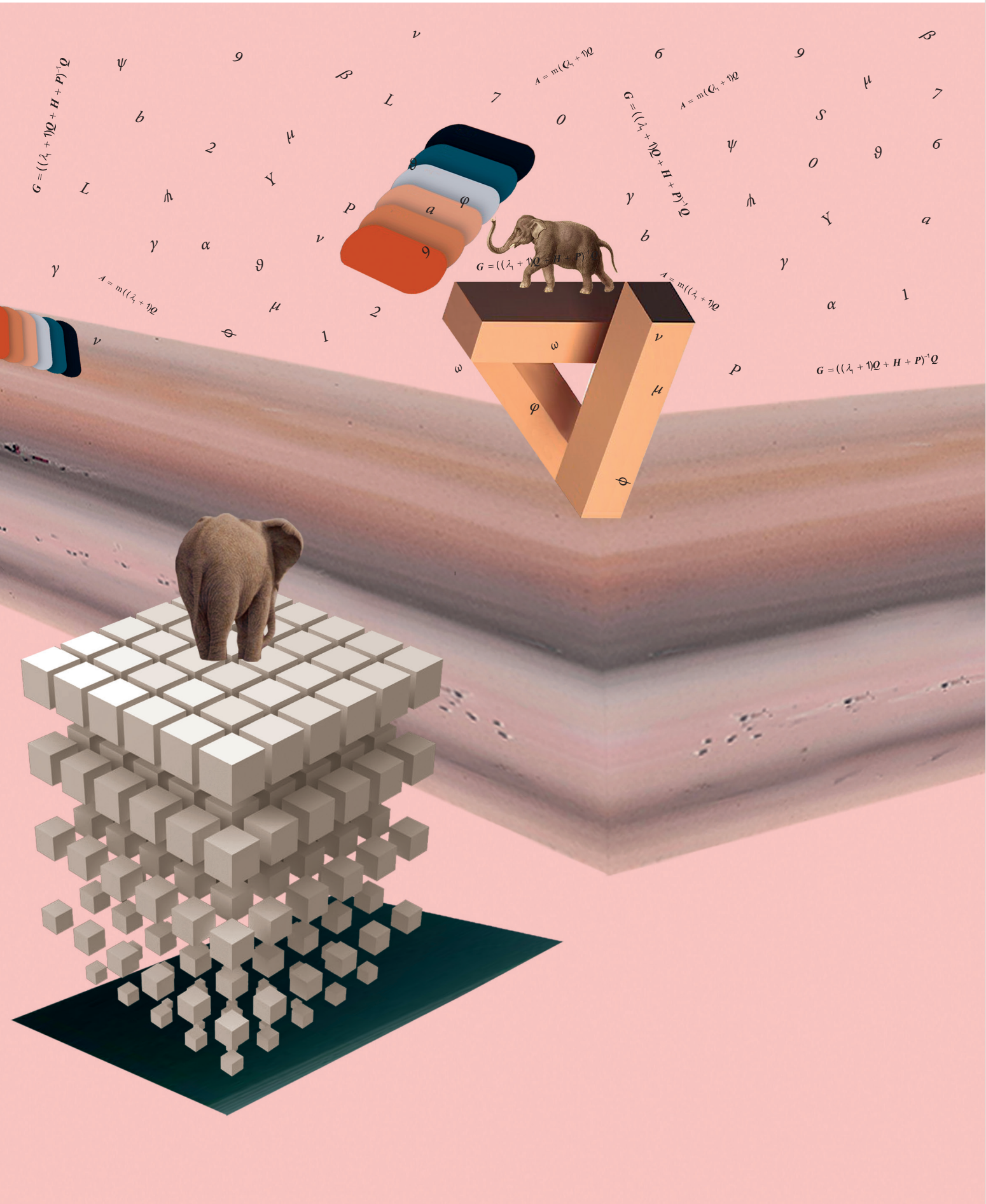
$G = ((\lambda_1 + \eta)Q + H + P)^{-1}Q$
$A = m((\lambda_1 + \eta)Q$

Technology Adoption: Evidence from an E-Government Cloud Service

Kriti Priya Gupta
Professor, kriti.gupta@scmsnoida.ac.in

Symbiosis Centre for Management Studies, Noida Campus, Symbiosis International (Deemed University), Pune, India

Abstract

This study investigates the effects of formal and informal external factors on citizens' intention to use DigiLocker, which is a government-backed cloud storage service (CSS). It also examines how trust in government moderates these effects. This research framework is grounded in institutional theory. The proposed model was validated by quantitative analysis of primary data collected through a survey in Delhi, the national capital region (NCR) of India.

The findings indicate that pressures can be divided into two categories — 1) formal (coercive pressure), and 2) informal (mimetic, and normative). Both significantly influence citizens' attitudes, which in turn influence their intention to use DigiLocker. Moreover, coercive pressure has been found to be the strongest influencer of citizens' attitudes. The moderating function of trust in the government has an ambiguous impact on different dimensions. That is, it is positive regarding the relationship between coercive pressures and citizens' attitudes. At the same time it negatively moderates the relationships between mimetic and normative pressures and citizens' attitudes. This study suggests that in order to effectively encourage the adoption of public CSSs, policymakers and service providers should consider the interplay of coercive, normative, and mimetic pressures along with trust.

Keywords: DigiLocker; cloud storage service; e-government; trust; institutional theory

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Introduction

Government-led technological advancements greatly enhance citizens' lives by making essential services more accessible, simplifying administrative processes, and increasing governmental transparency. The introduction of new technologies helps nations to stay internationally competitive. Among these tools are cloud storage services (CSSs) such as Google Drive, OneDrive, or Dropbox. One notable example here is "DigiLocker" - a digital document storage and sharing service provided by the Indian government. Unlike other CSSs, DigiLocker specializes in securely storing and providing access to the digital copies of the official government-issued documents and certificates (such as Aadhaar cards, driver's licenses, educational certificates, and property documents), thereby simplifying interactions between citizens and government agencies. DigiLocker enables citizens to conveniently access their official documents through a secure cloud platform, leading to enhanced transparency and accountability in governmental processes. By centralizing and digitizing official records, DigiLocker empowers citizens to monitor government activities and hold public officials accountable. It signifies a transformative shift in governance, promoting deeper citizen engagement, transparency, and inclusivity.

Currently, DigiLocker has around 387.16 million registered users, 1,640 issuers, and around 2,002 requesters.[1] However, it has not been widely adopted beyond tech-savvy individuals (including students and professionals). Recent research has extensively examined the challenges related to the adoption, continued use, and post-adoption use of various CSSs developed by private firms like Dropbox, OneDrive, Google Drive, and iCloud.[2] However, limited information is available regarding users' acceptance of DigiLocker, which is an e-government service (Sivathanu, 2018; Rathore, Panwar, 2020). Though previous studies have adequately discussed the design features of DigiLocker (Bakshi, Nandi, 2020; Babrekar et al., 2021), and utilities of DigiLocker (Meenakshi et al., 2023), there is a lack of comprehensive quantitative studies that aim to understand the factors influencing its adoption (Sivathanu, 2018).

The literature suggests that individuals' behaviors and attitudes toward accepting new technologies and services are often shaped by their social environment (Al-Saleh, Thakur, 2019). Nonetheless, few studies have analyzed the impact of social forces or institutional aspects on user acceptance of CSSs. While some have examined the role of informal memetic pressures like peer influence (Alsmadi, Prybutok, 2018), and normative pressures such as social influence (Yue, 2013; Yang, Lin, 2015), the role of formal institutional influences such as coercive pressures, has been overlooked. Prior studies have called for empirical examination of the roles of both formal and informal institutional factors on users' behavior toward CCSs (Ghaffari, Lagzian, 2018).

Considering the aforementioned gaps in the literature, the present study attempts to investigate the institutional factors that influence users' intention to use the DigiLocker service. Being an e-government service, DigiLocker is subject to specific regulatory frameworks, policies, and institutional structures, making its case unique compared to other CSSs that operate in the private sector. Therefore, trust in the government can plays a crucial role in shaping how citizens perceive and respond to institutional pressures. Hence, drawing upon the institutional theory, the study attempts to answer the following research questions:

RQ1: How do institutional pressures (i.e., coercive, memetic and normative pressures) influence citizens' behavior toward using DigiLocker?

RQ2: Does trust in the government moderate the effects of institutional pressures on citizens' attitudes toward DigiLocker? If yes, how?

This study provides an understanding of the institutional influences the driving adoption of DigiLocker. The findings of the study will enable policymakers and stakeholders to develop targeted strategies that foster the widespread acceptance and utilization of CSSs such as DigiLocker.

Literature Review

Global Comparison of e-Governance Systems

The main emphasis of India's digital interactions between citizens and the government is on scale and availability, which is mainly driven by initiatives such as DigiLocker and Aadhaar. Compared to other countries, India's approach is remarkable because of its ability to cater to a vast and diverse population. However, there are certain areas, where other countries have excelled. For example, the X-Road platform and e-Residency program in Estonia provide seamless and secure citizen services by using an integrated system of digital identity (Hardy, 2023). This enables the efficient exchange of information and a very user-friendly environment, thereby making Estonia a model in e-governance. Similarly, Singapore has one of the most advanced e-governance models globally. Through its

[1] https://www.digilocker.gov.in/statistics (accessed 08.11.2024). Registered users are individuals (citizens) who sign up for DigiLocker to store and access their digital documents securely. Issuers are organizations or institutions that generate and provide digital documents to users through DigiLocker (such as government departments, universities issuing digital certificates or transcripts). Requesters include entities that access or verify users' documents through DigiLocker (such as banks verifying identity or income documents for opening accounts or processing loans.

[2] Most of the previous studies have examined the adoption of CSSs from technological perspectives such as users' expectations of usefulness and ease of use of CSSs (Cao et al., 2013; Oredo, 2020), service and system quality (Burda, Teuteberg, 2015; Burda, Teuteberg, 2016; Chen et al., 2024), concerns related to risk, security, privacy (Alsmadi, Prybutok, 2018), and synchronization and backup issues (Hui et al., 2023).

Smart Nation initiative and SingPass digital identity system, it provides over 400 government services, with a strong emphasis on improving the daily lives of its citizens (Hoe, 2018). South Korea has also developed a strong e-Government system and runs an efficient Hometax service that grants transparent access to public services (Sung, Lee, 2024). China has a different approach where it utilizes its Social Credit System in conjunction with digital services provided by platforms such as AliPay and WeChat (Li, 2021). However, this model raises significant privacy concerns due to its surveillance aspects, making it distinct from the more democratic and privacy-focused approaches seen in India, Estonia, and Singapore. While India has made substantial progress in making digital services accessible to a broad population, the levels of integration, security, and user-friendliness are much higher in countries such as Estonia and Singapore. Therefore, some lessons could be learned regarding how India's framework of digital governance needs to be strengthened further.

The DigiLocker Service

DigiLocker was officially launched by the Indian Department of Communications and Information Technology (DietY) in July 2015. Since its launch as part of the Digital India initiative, DigiLocker has changed a lot in what it does and in its coverage. It has come a long way since its inception, particularly in terms of security, accessibility, and service integration. In the first place, DigiLocker was thought up as a very secure cloud-based system to store and share documents. However, today it has become one of the fundamental tools used for India's digital governance. Over time, various government services and organizations have integrated DigiLocker into their systems. Some of the key organizations linked with DigiLocker include the Ministry of Road Transport and Highways for driving licenses and vehicle registration certificates, the Ministry of Human Resource Development for educational certificates, the Income Tax Department for income tax returns, and various state departments for land records and other documents. This integration ensures the authenticity and legality of the documents stored in DigiLocker, enhancing trust and reliability in the digital ecosystem. This also allows citizens to access their documents directly from issuing authorities.

In the course of its growth process, DigiLocker has undergone significant changes and improvements. In order to protect user information, enhanced security mechanisms such as two-factor authentication, have been implemented. Further, there has been a steady increase in the acceptance of DigiLocker-issued documents across different organizations such as schools, banks, and government departments. The mobile application of DigiLocker has also been updated by adding features like offline access to documents, thereby improving user accessibility and experience. Additionally, DigiLocker's seamless integration with Aadhaar identity cards has streamlined the process of accessing and auto-fetching documents, making it more convenient for citizens. Currently, it provides a dedicated 10MB free personal storage space, which is linked to the citizen's Aadhaar number (Rathore, Panwar, 2020). Citizens can utilize this space for storing, accessing, and sharing various official documents and certificates (such as Aadhaar cards, driving licenses, vehicle registration certificates, and educational certificates).

DigiLocker has a bright future, with numerous opportunities for technological advancements. The emerging technologies such as blockchain and artificial intelligence (AI) can be incorporated into DigiLocker to further enhance the security and authenticity of the documents stored on the platform (Chavan, Rajeswari, 2019). The integration of AI can improve document management, retrieval, and validation, thereby making the service even more efficient. The services offered by DigiLocker can also be expanded by integrating with private sector entities, such as banks, insurance companies, and healthcare providers. Moreover, there is also potential for international recognition of DigiLocker documents, which can benefit the Indian expatriates.

Despite the advancements and future prospects mentioned above, there are certain areas within DigiLocker, that need to be addressed. For example, increased user awareness regarding the full potential of this service is required since many citizens are still unaware of its capabilities and do not fully understand what it can do. Other than this, some users experience connectivity and interoperability issues while trying to access DigiLocker services through non-governmental entities. This calls for improvement in these areas for the successful diffusion of this service. Moreover, the digital divide among Indian citizens, particularly in rural areas where internet access is limited, poses a significant challenge to the widespread adoption of DigiLocker.

Prior Studies on the Adoption of DigiLocker

Very few studies have explored the users' attitudes toward accepting DigiLocker. For example, Sivathanu (2018) investigated the citizen's perspectives on adopting DigiLocker by integrating the Unified Theory of Acceptance and Use of Technology (UTAUT) with the e-Government adoption model (eGAM). The author found that the behavioral intention to use DigiLocker is determined by various factors such as performance expectancy, effort expectancy, social influence, facilitating conditions, computer self-efficacy, as well as perceptions of trust, awareness, and information quality. Rathore and Panwar (2020) found that users' intention to use DigiLocker is determined by users' personal innovativeness, as well as the ease of use and usefulness of the service. In an attempt to explore the barriers to the adoption of e-governance initiatives by the Indian youth, Narang et al. (2021) concluded that lack

of computer knowledge, fear of fraud, and resistance to change are the major factors that restrict the implementation of e-services such as DigiLocker.

Prior studies have examined the adoption of DigiLocker by considering technological factors and users' personal characteristics and concerns. However, the roles of formal and informal external factors in influencing citizens to use DigiLocker have not been adequately addressed in the literature.

Emerging Trends in Technology Adoption

Contemporary research on technology acceptance is shaped by various frameworks that address distinct aspects of the technology adoption process. Some of the notable frameworks that have been recently emerged are the Human-Organization-Technology Fit (HOT Fit) Model (Xu, Lu, 2022), which examines the alignment of human, organizational, and technological dimensions to understand adoption heterogeneity; the Ethical Governance Framework (Xue, Pang, 2022), which highlights the role of ethical considerations such as fairness, transparency, and trust in driving technology acceptance; the Cognitive Model for Technology Adoption (Sobhanmanesh et al., 2023), which emphasizes the importance of cognitive processes and user-centric design to reduce barriers to adoption; and the Socio-Technical Systems Approach (Lombardo et al., 2021), which integrates social and technical factors to ensure the joint optimization of social systems and technical systems.

While these models provide valuable insights into specific drivers of technology adoption, they are often limited in their applicability to broader systemic influences. For instance, the HOT Fit Model focuses on the interaction of individual, organizational, and technological factors but does not account for external institutional pressures (Xu, Lu, 2022). Similarly, the Ethical Governance Framework is instrumental in ensuring trust and ethical compliance but does not explore how societal norms or regulatory mandates influence adoption (Xue, Pang, 2022). The Cognitive Model and the Socio-Technical Systems Approach address usability and socio-technical integration but lack a systemic view of institutional dynamics (Sobhanmanesh et al., 2023; Lombardo et al., 2021). Hence, while these frameworks offer insights into specific adoption drivers, they are either limited to micro-level dynamics or require a localized focus, making them less effective in addressing systemic, institution-driven influences like those present in the adoption of DigiLocker.

Institutional Theory

Institutional theory is a prominent framework for analyzing the processes by which social behavior is regulated within institutional environments (DiMaggio, Powell, 1983). It provides insights into how institutions influence individuals' attitudes, beliefs, and behavior, such as information system adoption (Teo et al., 2003). According to Scott (2004), institutions are defined as "social structures that have attained a high degree of resilience". Institutional theory posits that the attitudes and behaviors of individuals are guided by institutions that comprise systems of established and prevalent rules, norms, and structures (DiMaggio, Powell, 1983). Institutions can be formal, such as laws and regulations, or informal, such as customs and traditions. The theory holds that individuals experience institutional pressures to adhere to commonly accepted forms and behaviors because they think that deviating from those behaviors might undermine their legitimacy, which in turn could impact their ability to obtain resources and social support (DiMaggio, Powell, 1983). The theory identifies three types of isomorphic pressures: formal/informal coercive pressures that arise from regulations and laws imposed by authoritative bodies; informal mimetic pressures that stem from the tendency to imitate successful people; and informal normative pressures that come from societal norms (DiMaggio, Powell,1983). Although institutional theory has been widely applied within the organizational contexts (Zheng et al., 2013), it is applicable at individual levels as well (Scott, 2004). Prior studies have employed institutional theory to examine individuals' technology adoption behavior in the contexts of internet banking (Shi et al., 2008), health (Bozan et al., 2015), and education (Gao, Yang, 2015).

Since the institutional theory accounts for both formal and informal pressures that influence individual behavior, we find it suitable for our study. It can help explain how government mandates (coercive pressures), adoption by influential peers and organizations (mimetic pressures), and societal expectations (normative pressures) collectively shape citizens' attitudes and intentions toward using new technologies, in our case, DigiLocker.

Development of Hypotheses

Attitude and Intention to Use

Attitude represents an individual's feelings toward using a specific technology or service (Aizen, 2011). Intention to use refers to an individual's plan to engage in a particular behavior (Davis, 1989). In the present study, attitude indicates citizens' overall assessment of using DigiLocker as a digital platform for storing and accessing their documents; and intention to use represents their willingness to engage with DigiLocker in the near future. Attitude has been observed as a significant determinant of intention in various theoretical models, such as the Theory of Planned Behaviour (TPB; Aizen, 2011), the Theory of Reasoned Action (TRA; Fishbein, Ajzen, 1975), and the Technology Acceptance Model (TAM) (Davis, 1989). It is a common observation in the literature that individuals' behaviors are motivated by their attitudes (Shi et al., 2008). Prior studies suggests that the relationship between these two variables is crucial for understanding and predicting citizens' adoption of e-government services

(Azamela et al., 2022). Prior studies also demonstrate that attitude significantly influences individuals' intention to use cloud-based services for storing personal documents (Garrison et al., 2018; Arpaci, 2019).

In the context of the present study, a positive attitude toward DigiLocker is likely to lead to a higher intention to use it for document storage and retrieval. Hence, we propose that:

H1: Citizens' attitudes have a significant positive influence on their intention to use DigiLocker

Coercive Pressures

Coercive pressures refer to the influence exerted on individuals to adopt certain practices or behaviors due to formal or informal regulations imposed by powerful external entities (Shi et al., 2008). The literature suggests that coercive pressures may stem from various sources such as governments, regulatory bodies, or other authoritative institutions (Anderson, Jakobsen 2018). This pressure arises from the need to comply with the standards set by governing bodies, rather than from the voluntary choice of individuals (Vos, Voets, 2022). Ramirez-Madrid et al. (2022) demonstrated that coercive pressure from the government is an important predictor of citizens' adoption of e-government services. Governments use coercive pressure in the form of appropriate legal frameworks, laws, and regulations to encourage citizens to embrace e-government services (Al-Mamari et al., 2013).

The Indian government is enforcing the use of DigiLocker for accessing certain public services such as passport services[3] and road transport services[4], as well as issuing educational certificates[5]. Such mandates create a coercive pressure on citizens to use DigiLocker. Hence, we hypothesize that:

H2: Coercive pressures have a significant positive influence on citizens' attitudes toward DigiLocker

Normative Pressures

Normative pressures arise from the norms and expectations of one's professional associations, social groups, and society at large (Maity et al., 2019). These pressures occur when individuals voluntarily, but unconsciously, follow the behaviors and practices of other people. Institutional theory suggests that individuals are more likely to adopt a certain behavior if it has been adopted by a large number of others (DiMaggio, Powell, 1983). Normative pressures compel individuals to conform to accepted standards and practices to gain legitimacy within their social and professional circles (Shi et al., 2008). Prior research has demonstrated that individuals' attitudes toward adopting e-government services are determined by various normative pressures such as subjective norms (Hujran et al., 2020; Azamela et al., 2022) and the social influence of family members and peers (Camilleri, 2019).

India's push toward digital literacy and modernization through initiatives like Digital India creates a societal expectation for citizens to adopt digital technologies and services. Such normative pressures can foster positive attitudes in citizens toward DigiLocker. Hence, we posit that:

H3: Normative pressures have a significant positive influence on citizens' attitude toward DigiLocker

Mimetic Pressures

Mimetic pressures refer to the influence exerted on individuals keen to imitate the behaviors and practices of other successful and high-status individuals (DiMaggio, Powell, 1983). These pressures force individuals to voluntarily and consciously copy successful people because of the belief that the practices followed by those successful people are more likely to be correct and less risky (Teo et al., 2003). Individuals tend to mimic the practices of those who are perceived as successful, popular or respected, in order to achieve similar success and improve their self-image (Zheng et al., 2013). Prior studies have demonstrated the significant influence of mimetic pressures on individuals' adoption of technologies in the context of mobile banking (Abayomi et al. 2020), mobile technologies (Chen, Wong, 2003), and educational technologies (Gupta, Maurya, 2022).

When citizens observe the successful adoption of DigiLocker by influential people in society, they will perceive it as a safe and effective service. Therefore, citizens driven by mimetic pressures will develop positive attitude towards DigiLocker. Hence, we propose that:

H4: Mimetic pressures have a significant positive influence on citizens' attitude toward DigiLocker

Moderating Effects of Trust in the Government

CSSs are subject to various risks such as data breaches, unauthorized access, and data loss (Cheng et al., 2019). Users of CSSs are often concerned with the privacy and security of their data (Yue, 2013). Therefore, trust is a vital key for generating a positive attitude in users toward CSSs (Burda, Teuteberg, 2016). In the context of DigiLocker, the role of trust is even more important, as DigiLocker is integrated with various government departments, and citizens do not have other alternatives serving the same purpose. Therefore, building citizen trust is a key factor for the successful implementation of DigiLocker (Narang et al., 2021).

Prior studies suggest that trust moderates the effects of social pressures on individuals' behavioural outcomes (Ng et al., 2020). Higher trust levels reduce ambigu-

[3] https://www.thehindu.com/news/cities/Madurai/passport-applicants-must-upload-documents-on-digilocker/article67147197.ece, accessed 19.10.2024.

[4] https://parivahan.gov.in/parivahan/sites/default/files/NOTIFICATION%26ADVISORY/08-08-2018.pdf, accessed 19.10.2024.

[5] https://www.cbse.gov.in/cbsenew/documents/Circular_for_access_code_Digilocker_Final_04052024.pdf, accessed 19.10.2024.

ity about others' actions and hence result in positive attitudes. Previous studies have identified trust to be one of the crucial enablers of citizens' positive behavior toward e-government services (Alzahrani et al., 2017), and have called for examining the moderating effect of trust in government in assessing e-government initiatives (Teo et al., 2008). Citizens' trust in the government can significantly influence how they perceive and respond to institutional pressures regarding the adoption of DigiLocker. It can act as a buffer against institutional pressures. Citizens with a high trust in the government are more likely to view institutional influences as beneficial endorsements rather than forced pressures. Such perception can lead to a more positive attitude toward using DigiLocker. Hence, we propose the following hypotheses:

Trust in the government significantly moderates the effect of coercive (H5), normative (H6), and mimetic (H7) pressures on citizens' attitudes toward DigiLocker.

Methodology

Measures

There are six latent constructs in our proposed model, namely, coercive pressure (CP), normative pressure (NP), mimetic pressure (MP), trust in government (TG), attitude (AT), and intention to use (IN). All the constructs were measured using validated scales available in previous studies. Specifically, the items for CP were adapted from Klöcker et al. (2014); the items for NP, MP, and AT were adapted from Shi et al. (2008); items for TG were adapted from Belanger and Carter (2008); and the items for IN were adapted from Alharbi et al. (2017). Small modifications were implemented for some of the items to fit the present research context. All items were measured using five-point Likert scale, which ranged from 1 = "strongly disagree" to 5 = "strongly agree".

Table 1. **Sample Profile**

Categories	Response (%)
Gender	
Female	38.5
Male	61.5
Age	
18-29 years	25.7
30-39 years	26.0
40-49 years	27.0
50-59 years	14.9
60 years and above	6.4
Education	
Primary or secondary level	29.7
Under-graduate	36.1
Post-graduate or above	26.7
Other	7.4

Source: author.

Sample and Data Collection

We conducted a survey in to collect the primary data using a structured questionnaire. Individuals who have used DigiLocker during the previous year were considered the target respondents for the survey. The convenience sampling technique was used to select the respondents. Both online as well as offline methods were used to collect the data. For online method, the questionnaires were sent to 300 respondents via email or social media, out of which 214 questionnaires were returned. For offline method, paper questionnaires were distributed to 150 respondents, out of which 102 questionnaires were returned. After removing the incomplete or unviable responses, 296 questionnaires were considered to be valid. Table 1 displays the demographic information of the respondents.

Results

The primary data were analyzed using the Partial Least Squares-Structural Equation Modeling (PLS-SEM) technique. First, the measurement model was evaluated to assess the reliability and validity of model constructs. Thereafter, the structural model was assessed to test the proposed hypotheses.

Measurement Model

Table 2 indicates the results of the reliability and convergent validity of the constructs. As can be noted from the table, all the items loaded significantly ($p<0.001$) to their respective constructs, and the item loadings were greater than 0.5, which indicated adequate convergent validity (Hair et al., 2012). Moreover, the values of average variance extracted (AVE) for all the constructs were greater than 0.5 which further ensured the convergent validity (Fornell, Larcker, 1981).

The constructs exhibited sufficient reliability as the values of Cronbach's alpha as well as composite reliability (see Table 2) were greater than the recommended threshold of 0.7 (Hair et al., 2012).

To assess the discriminant validity, we used two approaches: 1) the Fornell and Larcker (1981) criterion which states that the square root of the AVE of each construct should be greater than other inter-construct correlations; and 2) heterotrait–monotrait (HTMT) criterion (Henseler et al., 2015), which states that the HTMT ratios should be less than 0.85. Table 3a shows the inter-construct correlations with square roots of AVE at the diagonal, and Table 3b shows the HTMT ratios. As can be observed from Tables 3a and 3b, discriminant validity was satisfied according to both criteria.

Structural Model

The hypotheses were tested by analyzing the structural model. In line with the prior studies (Shi et al., 2008),

Table 2. **Reliability and Convergent Validity**

a) Item loadings

Construct	Item	Loadings
Coercive pressure	CP1	0.911***
	CP2	0.911***
	CP3	0.907***
Normative pressure	NP1	0.928***
	NP2	0.920***
	NP3	0.936***
Memetic pressure	MP1	0.944***
	MP2	0.908***
	MP3	0.871***
Trust in government	TG1	0.849***
	TG2	0.931***
	TG3	0.896***
	TG4	0.859***
Attitude	AT1	0.945***
	AT2	0.908***
	AT3	0.885***
	AT4	0.930***
Intention	IN1	0.897***
	IN2	0.909***
	IN3	0.877***

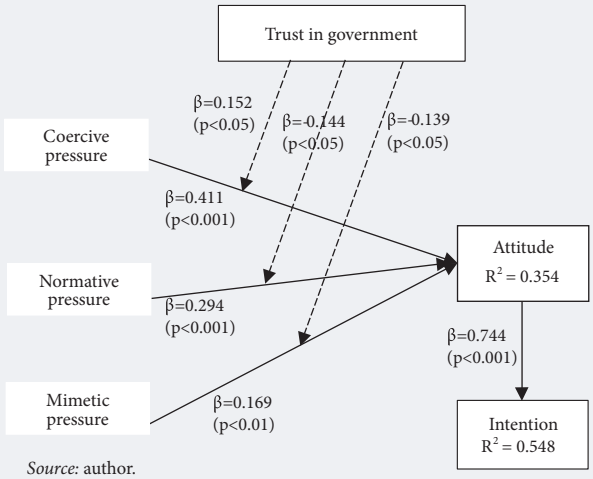
Note: *** p<0.001.

b) Cronbach's alpha, Composite reliability and Average variance extracted values

Construct	Cronbach's alpha	Composite reliability	Average variance extracted
Coercive pressure	0.896	0.901	0.827
Normative pressure	0.919	0.925	0.861
Memetic pressure	0.893	0.901	0.825
Trust in government	0.909	0.979	0.782
Attitude	0.937	0.938	0.841
Intention	0.875	0.877	0.8

Source: author.

Figure 1. **Structural Model**



Source: author.

we included gender and age as the control variables in our model. Figure 1 shows the results of hypothesis testing. The results indicate that AT has a significant positive influence on IN (b=0.744, p<0.001); and CP (b=0.411, p<0.001), NP (b=0.294, p<0.001) and MP (b=0.169, p<0.01) have significant positive influences on AT. Thus, the hypotheses H1, H2, H3, and H4 were supported. With regard to the hypotheses concerning the moderating effects of TG, the results indicate that TG has a significant positive moderating effect in the relationship between CP and AT (b=0.152, p<0.05); but negative moderating effects in the relationships between NP and AT (b=-0.144, p<0.05), and MP and AT (b=-0.139, p<0.05). Hence the hypotheses H5, H6, and H7 were supported. Regarding the control variables, the effects of both gender and age were found to be insignificant (b=0.036 and 0.031 respectively). Overall, the model explained 35.4% variation in AT and 54.8% variation in IN.

Discussion and Conclusion

This study examined the role of institutional pressures in shaping citizens' attitude and intention toward using DigiLocker. The findings suggest that all three institutional pressures, coercive, normative, and mimetic, significantly influence citizens' attitudes, which, in turn, has a significant influence on their intention to use DigiLocker. Our finding regarding the positive influence of attitude on intention to use, is in line with the prior studies on CSSs (Garrison et al., 2018; Arpaci, 2019). It indicates that when citizens perceive DigiLocker positively, considering it beneficial for them, they are more likely to use it.

The positive influence of all three types of institutional pressures on attitudes toward DigiLocker highlight the importance of both formal as well as informal social forces in shaping citizens' attitudes. While coercive pressures build a positive attitude through formal regulations, normative and mimetic pressures foster positive attitudes through social norms and the imitation of successful practices. Our findings regarding the significant influence of informal normative and mimetic pressures are in line with prior studies, which indicate that social influence is an important determinant in e-government contexts (Azamela et al., 2022), as well as in the context of cloud computing (Alsmadi, Prybutok, 2018) and other CSSs such as Dropbox (Yamin, Ishak, 2015). Further, our findings suggest that coercive pressure has the strongest influence (b=0.411) on citizens' attitudes toward using DigiLocker as compared to normative and mimetic pressures. This finding highlights the importance of coercive pressure, which stems from formal mandates and regulations imposed by the government. Such regulations leave little room for non-compliance (Ali, Osmanaj, 2020). When the government mandates the use of DigiLocker for accessing and managing educational certificates and official documents, citizens are compelled to use it. Coercive pressure ties the use of DigiLocker to essential

Table 3. **Discriminant Validity**

a) Fornell and Larcker criterion

	AT	IN	CP	MP	NP	TG
AT	**0.917**					
IN	0.739	**0.894**				
CP	0.437	0.442	**0.91**			
MP	0.279	0.271	0.194	**0.908**		
NP	0.288	0.239	0.102	-0.084	**0.928**	
TG	0.167	0.167	0.126	0.246	0.048	**0.884**

b) HTMT criterion

	AT	IN	CP	MP	NP	TG
AT						
IN	0.816					
CP	0.474	0.496				
MP	0.303	0.308	0.218			
NP	0.310	0.264	0.114	0.095		
TG	0.170	0.181	0.129	0.285	0.072	

Source: author.

services that citizens need to access regularly, such as healthcare records, educational certificates, and identity verification (Rathore, Panwar, 2020). Such practical necessities ensure that citizens develop a positive attitude toward DigiLocker by considering it a valuable tool for digitally managing their documents and certificates. Our finding is line with prior studies, which underscore the importance of regulatory measures in driving the adoption of digital services (Shi et al., 2008; Alhajjaj, Ahmad, 2022).

Our findings further indicate that trust in the government strengthens the effect of coercive pressure on attitude. This implies that trust acts as a catalyst that enhances the effectiveness of coercive measures. When citizens trust the government, they believe that the government's mandates are legitimate and in their best interest, which fosters a favorable attitude toward government-backed services (Carter, Bélanger, 2005), such as DigiLocker. Trust in the government also reduces citizens' resistance toward government-imposed mandates. Citizens who trust the government are less likely to question the necessity of these mandates, leading to positive attitudes and higher acceptance of government initiatives (Teo et al., 2008). On the other hand, our results indicate that trust in the government negatively moderates the relationships between normative pressure and attitudes as well as mimetic pressures and attitudes. This implies that citizens' trust in the government can override the influence of informal social pressures on their attitude. High trust in the government reduces citizens' reliance on societal norms and others' behaviors to form their attitudes. When citizens trust the government, they do not need to look to others for using government's digital initiatives, such as DigiLocker. They form their attitudes on the basis of the government's guidance rather than social imitation or norms.

Implications

This study extends institutional theory by incorporating the moderating role of trust in the government, to explore the adoption of a government-initiated cloud storage service, i.e., DigiLocker. It contributes to the literature on the adoption of cloud storage services by identifying how institutional pressures shape users' attitudes. This study also demonstrates the relevance of institutional theory in the context of e-government adoption by highlighting how formal and informal external influences shape citizen attitudes and behaviors. By demonstrating the dominant role of coercive pressure, the study contributes to the understanding of how formal and authoritative directives can significantly influence citizens' behavior toward using e-government services. Finally, the study contributes to the literature by considering trust in the government as a moderator. The study demonstrates that trust is a critical factor that can either enhance or weaken the influence of institutional pressures, thereby providing deeper insights into the dynamics of trust and its role in the adoption of technologies, in this case, cloud storage systems as well as e-government services.

The findings of this study offer practical insights for the government and policymakers to design targeted interventions for accelerating the use of DigiLocker. Considering the important role of coercive pressure, government should clearly communicate the regulations regarding the use of DigiLocker. Regular updates and reminders about the benefits of using DigiLocker can be disseminated through official channels and public campaigns. For citizens with high trust in the government, these coercive pressures will more effectively translate into positive attitudes and higher adoption rates. The government should focus on increasing transparency in the implementation of DigiLocker by providing clear information about data security, privacy measures, and government intentions. For example, the government can engage citizens in dialogues to address their concerns and build trust. Considering the significant role of normative pressure, the government can partner with educational institutions, professional organizations, community leaders, and social influencers to endorse DigiLocker amongst citizens. For citizens with lower trust in the government, emphasizing the use of DigiLocker through normative influences, can mitigate the negative moderating effect of trust. Finally, considering the significant influence of mimetic pressure, government can run marketing campaigns that feature testimonials of successful people using DigiLocker. The government can also organize workshops, seminars, and community events to demonstrate DigiLocker's benefits and usage.

Though the present study has been conducted within the context of an Indian cloud storage service, i.e., Di-

giLocker, our findings present practical implications for global service providers of cloud storage services. The service providers should ensure that their services comply with the relevant regulations and standards, such as data protection laws and security protocols (coercive influence). They should regularly update their users about compliance with legal standards and any regulatory changes. They should position cloud storage as a socially responsible and modern solution for data management (normative influence). They can design marketing campaigns that highlight the environmental benefits of cloud storage such as saving paper and reducing physical storage needs. Finally, they can feature the testimonials of prominent individuals and organizations (who have successfully used their cloud storage services) in their promotional materials and advertisements (mimetic influence). They can create a supportive environment for their users through user forums and online communities, where users can share experiences, tips, and best practices for utilizing their cloud storage services.

Limitations and the Future Scope of the Study

The present study has a few limitations. First, the sample used in this study has been selected from only one region in India i.e., Delhi. It may not fully represent the diverse population of India, restricting the generalizability of the findings. Second, the study has employed a cross-sectional design, which limits the ability to infer causality between institutional pressures, attitudes, and use intentions. Longitudinal studies should be conducted in future to establish causal relationships and observe changes over time. Third, the present study has examined the citizens' use intentions from an institutional theory perspective. Future studies could include technological (such as perceived usefulness, ease of use, complexity, compatibility) and personal factors (such as innovativeness, self-efficacy, resistance to change) to provide a holistic understanding of the citizens' behavior toward using DigiLocker. Lastly, this study has examined the adoption of DigiLocker, which is a specific e-government service. This service may have unique characteristics that are not applicable to other types of cloud storage systems or e-government services. Therefore, future studies should test the proposed model in the contexts of other cloud storage services in order to validate the findings. The presented cases could be useful for other nations, which can potentially adopt such services to enhance their own governance systems.

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Unveiling a Governance Analysis Framework for Basic Research in Iran

Zohreh Karimmian

Assistant Professor, Department of Technology Management, Zohreh.Karimmian@iau.ac.ir

Islamic Azad University, South Tehran Branch), Valiasr University Complex, Imam Hossein Square, 4492, Tehran, Iran

Mostafa Zamanian

Assistant Professor, Department of Governance, Zamanyan@ut.ac.ir

University of Tehran, Enghelab St., 16, Tehran, Iran

Abstract

Basic science, as a cornerstone of the national innovation system, has long been at the center of debates on which management approaches are most effective for this activity due to its specific nature that distinguishes it from other types of research. For example, given the long time lag between investment in basic research and the manifestation of economic and social effects from its results, many organizations, especially in the private sector, are reluctant to invest in it. However, insufficient support for basic science becomes a brake on further innovative development and creates the risk of stagnation. This article contributes to the development of these discussions. It considers key concepts of research governance with an emphasis on their application and achieved results in the Iranian context. A comprehensive theoretical framework for analyzing the processes of basic research management in Iran is developed, which can be adapted to similar contexts worldwide. Strategies for improving the alignment of needs and priorities at different funding levels, both operationally and strategically, are proposed. It is concluded that improving the governance of basic science can not only increase the economic returns from research activities, but also bring them into line with societal needs.

Keywords: research governance; fundamental/basic research; innovation system; research funding; economic and social effects; fuzzy cognitive mapping; meta-synthesis

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Introduction

Basic research plays a special role in the evolution of the human knowledge base as a basis for further development. Basic research aims for deep understanding in a subject through experimental or theoretical efforts, focusing on fundamental phenomena without immediate practical applications. It provides the foundation for long-term technological innovations and economic benefits (Nelson, 1959), though it involves challenges like ambiguity and high risk, with outcomes that are often unpredictable and knowledge that may become "caged" after discovery (Salter, Martin, 2003). Despite the lack of immediate financial returns, basic research is crucial for leadership in innovation and managing the risks of new technologies (Rosenberg, 1990). Within the comprehensive scope of research and development, which includes basic and applied research, and development activities, emphasizing basic sciences is essential. This entails fostering an ecosystem conducive to understanding and addressing challenges in knowledge-based industries and reverse engineering advanced technologies (OECD, 2015). The imposition of sanctions on Iran, limiting access to certain industrial knowledge-based necessities, has spurred domestic production of knowledge-based products, thereby enhancing economic efficiency. Such occurrences underscore the indispensable role of basic research in bolstering national capacity. Despite economic downturns and budgetary constraints, channeling resources towards effective interventions in basic research remains paramount. Additionally, with a growing recognition of the importance of foundational research in today's landscape, there is an increased emphasis on examining governance structures within this realm. Research governance requires a systemic management and oversight approach to ensure coordinated and effective research activities, characterized by shared responsibilities among all stakeholders rather than centralized control (Shaw et al., 2005).

Relyilng on literature review, the article further considers key definitions and concepts of basic research and research governance, with an emphasis on their application and achieved results in the Iranian context. Finally, conclusions are drawn regarding its findings, and recommendations for future research are provided.

The Role of Basic Research in Contemporary Innovation Systems

Corporate fundamental research

Most previous studies examining the impact of basic research on innovation have focused on increasing corporate R&D activity. The paper (Ceccagnoli et al. 2024) provides new data describing the links between fundamental research and the degree of radicality of innovations created by both in-house and external ideas in American companies. Over 5,100 manufacturing companies in the United States were studied. The results of fundamental research are usually difficult to adapt at the company level. However, it has been established that the more diversified the company itself, the easier it is to find application for these results, perhaps even in directions that are not obvious at first glance (Rosenberg, 1989; Akcigit et al., 2021).

Many researchers have noted a trend that has emerged in recent decades that large corporations may abandon fundamental research and rely on external research from universities and start-ups (Arora et al., 2019). These observations provide important theoretical implications as an information basis for guiding basic research to create innovation. The authors conclude that firms that conduct fundamental research are more likely to launch more radical innovations. In turn, companies that abandon fundamental research, even though they exploit the capabilities of established technologies, lose the potential for creative destruction, become bogged down at best in incremental innovations, and become path dependent. Thus, fundamental research proves to be an important complement to applied research, maintaining a company's overall high potential for renewal and adaptation (Akcigit et al., 2021; Pavitt, 1991; Rosenberg, 1990). However, this benefit may vary depending on the extent to which a company is able to exploit the results of basic research. Diversified companies are more likely to generate radical innovations when conducting such research, as they master the diversity of product areas and develop the ability to see unexpected solutions. This is determined by the very nature of basic research, since it also generates knowledge that is less tied to established company practices.

In the last few decades, companies have shifted their focus to external knowledge acquisition (Arora et al., 2019; Chesbrough, 2003; Lariviere et al., 2018), curtailing their own activities in basic research. At the same time, a number of researchers express concerns that such an imbalance will also lead to a decrease in the company's potential for creating radical innovations (Arora, Gambardella, 1994; Cohen, Levinthal, 1989), which may negatively affect the company's development in the long term. It is also noted that radical innovations are not always better than incremental innovations, as the literature shows that significant social (and private) benefits for well-being are often created on the basis of incremental innovations (Pisano, 2015; Rosenberg, 1982). The final conclusion of the authors is that companies need to maintain a balance between the use of internal and external resources to create innovations, between fundamental and applied research, between radical and incremental innovations. At the same time, the more diversified the company, the easier it is for it to assimilate knowledge from different sources and find a "profitable" application for them, maintain the potential for renewal and adaptation.

Public Fundamental Research

The results of basic research in China are presented in the paper (Hu et al., 2023) also confirm the thesis that the results of fundamental research play an important

role in promoting strategic and radical innovations. China's investment in basic research has continued to increase in recent years, with state investment totaling 181.7 billion yuan in 2021, up 23.9% year-on-year. However, China's impressive basic research results have not been effectively translated into practical technologies to drive technological revolution and industrial change. The authors come to the valuable conclusion that fundamental research, which is predominantly privately funded, has a higher potential to develop into breakthrough innovations that will contribute to the long-term competitiveness of both the company and the economy as a whole.

This difference between the public and private sectors is explained by the fact that companies have a smaller resource base than the state, and they are forced to manage it more efficiently, which leads to a higher level of conversion of the results of fundamental research into innovative products in demand by the market. Effective integration of basic and applied research has been shown to result from a combination of private investment, responsible management, and a comprehensive assessment of the implementation of university research results into corporate practice (Wiesbaden, 2015).

Data from 23 OECD countries show that significant effects of investments in basic research on economic development only appear in the long term and have a positive effect on the economic complexity index of countries (Laverde-Rojas, Correa, 2019) .

Another important topic discussed in the literature is the role of intellectual property rights protection in generating breakthrough innovations. Authors (Nelson, 1959; Arrow, 1962) point to positive effects of this mechanism for which it was conceived. However, more recent studies have noted the negative consequences of the abuse of this mechanism, showing that the purchase of intellectual property rights is used by individual companies as a restraining mechanism that hinders the innovative activity of competitors, and thereby slows down the overall pace of innovative development and reduces the prospects for economic renewal.

Basic fundamental research has its own specific features that serve as the basis for arguments in favor of more active state participation in its support. Among these features are a long development cycle, the need for specialized laboratories and precise research equipment, which requires significant capital investment. The topic of the balance of support for fundamental research from public and private sources is developed by the authors of the study (Marchiori, Minelli, 2023). It is shown that if the task of supporting fundamental research is assigned primarily to the state (which has more resources for this activity than companies), then the risks of inefficient distribution of funds between performers and the creation of a distorted system of incentives for them increase. As a result, such researchers lose motivation to generate useful and breakthrough results, in particular for reasons of the "safety and reliability" of the topic. Such attitudes negatively affect the overall potential for converting fundamental science into practice.

The authors (Gersbach et al., 2023) reveal the influence fundamental research on the general economy, and public investments are also analyzed with a view to achieving a balance in the provision of resources for fundamental research between the private and public sectors. The main motive for national investment in basic research is to support private innovation in the domestic economy. The costs and benefits of these investments depend critically on the country's integration into the world economy. On the one hand, innovative domestic firms benefit from supplying their products to the world market. On the other hand, domestic consumers benefit from importing foreign innovations, which allows countries to free ride on investment in basic research. On the other hand, innovation combines the ideas and insights of basic research with industry-specific know-how. The more complex and diverse the domestic economy, the greater its potential for innovation and, consequently, the greater the domestic benefits from investment in basic research. The authors conclude that the costs and benefits associated with public basic research in a given country are critically dependent on the global economy: first, in a globalized world, national benefits from basic research ideas are determined by the cost of their commercialization in global markets. The authors show that positive effects dominate when basic research is at least as skill-intensive as manufacturing, implying that more advanced countries invest a higher share of their GDP in basic research. Moreover, due to their broad industrial base, these countries benefit more from knowledge spillovers from the rest of the world and are thus highly innovative. Their high levels of innovation allow these countries to capture a disproportionate share of global profits.

It has been found that a coordinated policy of fundamental research will lead to an improvement in welfare in three dimensions. The first is a more even distribution of investments in fundamental research among performers. In reality, developing countries are insufficiently effective in fundamental research because, due to the general inefficiency of the economic system, they become "victims" of the process of knowledge spillover. This is expressed in the fact that, on the one hand, they do not receive enough external knowledge, and on the other, they suffer from the leakage of internal knowledge. In developing the thesis about the unequal distribution of resources between the performers of fundamental research, the authors (Gersbach et al., 2023) provide data on the distribution of investments in basic research by country. In developing countries, the underdevelopment of basic science may be due to the temptation to use a simpler management model and focus on exploiting and trading the existing resource

base in order to extract immediate benefits, without bothering with costly investments in the long term, for which the results of basic research are designed. This leads to a lock-in in such patterns as "raw material orientation", the "middle income trap", etc.

The thesis is put forward that the main volumes of investment, due to imperfect evaluation systems and for other reasons, may be allocated to ineffective performers. At the same time, other recipients of such investments, which have a much higher potential for breakthrough R&D , may remain underfunded. Because of this, the overall effectiveness of fundamental science falls. Improvement of evaluation systems and improvement of mechanisms for coordinating the distribution of funds "from above" are proposed as general measures to correct this imbalance.

As for the state's support for fundamental research, it is stated that the state can "compulsorily" offer individual enterprises and industries to use the results generated by fundamental science. However, such a measure is not effective. It is more correct to increase the ability of the companies themselves to assimilate new knowledge and diversify, so that it is the companies that select for themselves the fundamental knowledge that has the greatest potential for commercial implementation.

The findings presented in this paper contribute to a better understanding of effective approaches to coordinating basic research policies at the international level.

Research Background

Numerous researchers have explored governance in basic research. Salo and Liesio (2006) emphasized prioritization and its implementation, linking these to achieving economic and social goals through both top-down and bottom-up strategies. Similarly, Hellström et al. (2017) studied institutional support mechanisms, advocating for an integration of governance levels, emphasizing the critical role of organizational capabilities. Gassler et al. (2007) identified policy and operational levels as key for supporting basic research, stressing the effectiveness of bottom-up feedback processes. Building on these ideas, Hicks (2012) suggested a model linking financial support with performance assessment to enhance government aid for research. He highlighted the importance of aligning research interests with cost evaluations and accountability. Guida (2018) also stressed the need for aligning financial support with research quality and national priorities. Shokatian and Ghazinoory (2020) argued for an effective prioritization process to optimize resource allocation and impact, proposing a hybrid prioritization approach that considers inputs from various levels. Shokatian and Ghazinoory (2019) also described a policy framework for basic research that includes prioritization, funding allocation, and research evaluation, advocating for a governance structure that combines top-down and bottom-up processes.

In summary, the literature underscores a governance division between policy and operational levels, with prioritization, funding, and evaluation as core functions. This study aims to clarify these functions, their interactions, and their implications for governance enhancement in Iran.

A brief overview of the Iranian context

The management of basic research in Iran faces significant challenges, primarily due to reliance on government funding, weak priority-setting, and misalignment between policies and national needs. One major challenge is assessing the benefits and effectiveness of basic research, given its long-term nature and lack of immediate practical applications. This makes it difficult for policymakers to measure return on investment (Shokatian, Ghazinoory, 2019). In Iran, basic research is predominantly funded by the government. However, the prioritization process is fragmented and lacks coordination among key bodies, such as the Ministry of Science and the Ministry of Health. This fragmentation leads to inefficient resource allocation, as projects are funded without sufficient alignment with the country's strategic needs (Ghazinoory, Shokatian, 2021). The absence of intermediary institutions to regulate and coordinate research priorities exacerbates this inefficiency. In contrast to developed countries, where independent scientific foundations guide research agendas and funding distribution, institutions like the National Elites Foundation and the Iran Science Fund have limited influence in shaping scientific directions (Ghazinoory, Safari, 2022). Additionally, weak governance and the lack of robust monitoring and evaluation systems contribute to these inefficiencies. Vague evaluation criteria and ineffective oversight mechanisms hinder the effective management of basic research. Global experiences suggest that multi-layered assessment frameworks, addressing economic, technological, and social impacts, can significantly improve research governance (Karimmian et al., 2021). While these governance challenges are common globally, their impact in Iran's state-driven research ecosystem presents unique dynamics. The Iranian government plays a central role in funding and prioritizing basic research, given the resource-dependent economy and the structure of the national innovation system (Karimmian et al., 2019). National funding schemes are controlled by bodies such as the National Science Foundation of Iran, which prioritizes state-driven development goals over scientific curiosity. This contrasts with more decentralized research systems in some Western countries, where research priorities are less influenced by government intervention (Shokatian, Ghazinoory, 2019). A key challenge in Iran is balancing applied and fundamental research. Policymakers often prioritize research that yields immediate economic benefits, despite acknowledging the long-term importance of fundamental science. Bureaucratic hurdles, fragmented funding structures, and an overemphasis on short-term outcomes

have hindered the development of a coherent strategy for basic research (Shokatian, Ghazinoory, 2020). Despite increasing research output, there are inadequate mechanisms for technology transfer and industrial collaboration, leading to the underutilization of scientific advancements (Ghazinoory, Aghaei, 2021). Unlike countries with stable research ecosystems, Iran's funding patterns are volatile, heavily dependent on fluctuating state budgets. A shift toward a more diversified funding model, including private sector involvement and international collaboration, could mitigate current constraints and strengthen the research system (Ghazinoory, Safari, 2022).

While the governance challenges of basic research in Iran are shared globally, their manifestation within the country's unique policy environment requires tailored solutions. Integrating insights from Iranian policy literature and empirical studies, this analysis provides a contextually grounded discussion of the governance of basic research in Iran, offering a comprehensive view of the situation. The study is based on publicly available national statistics on fundamental research funding, but detailed data on specific research fields or publication activity is not accessible in Iran due to the generalized nature of the available statistics.

Figure 1 presents the number of research projects, categorized by type of research. The rapid increase in the total number of publications is evident particularly after 2010, when it reached over 180,000 publications by 2021. This reflects a significant surge in research activity across all fields. While fundamental research also shows growth, it remains much lower compared to the overall total. The number of fundamental research publications starts at 3,420 in 1996 and increases steadily to around 40,000 in 2021, though the growth rate is more gradual compared to total research. The gap between total research and fundamental research widens notably after 2010, suggesting that while total research activity has exploded, fundamental research has not experienced the same level of exponential growth. This could be due to various factors, such as a shift towards applied research or more targeted government funding in certain areas. A notable jump in both categories can be seen from 2019 to 2021, likely reflecting a combination of increased government investment, research policy changes, and possibly the growing international focus on scientific advancements in Iran. This graph illustrates the overall growth in scientific output, but the slow growth of fundamental research in relation to overall research activity points to a key challenge: despite significant investment, much of the funding has not been directed toward fundamental research. This discrepancy may reflect weaknesses in governance and structural factors that have hindered the allocation of resources to the fundamental research domain.

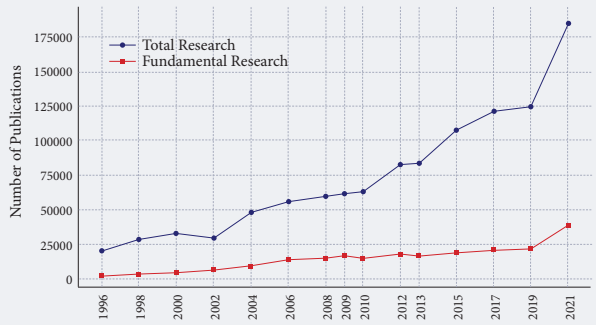
According to the Iranian legislation, all executive bodies are required to allocate at least 1% of their operational budget (excluding non-operational expenses) to research and technological development[1] . This funding is in addition to the annual research budget assigned to these organizations in the national budget laws. The High Council for Science, Research, and Technology (ATF) and the Statistical Center of Iran are responsible for monitoring and reporting the performance of research expenditures.

As shown in tables 1 & 2, Investment in basic research remains minimal, as only 6% of total research projects and the overall research budget are allocated to this area, indicating weak support for foundational scientific studies. Additionally, there is a significant gap between budget allocation and actual spending. While 81,158 million IRR was allocated for basic research, only 76% of this amount was ultimately spent. In contrast, developmental research not only received its full budget but exceeded the estimated allocation, receiving 140% of the planned amount. Meanwhile, developmental research, despite making up only 6% of research projects, secured 21% of the total research budget. This imbalance further reinforces the preference for practical research over fundamental scientific exploration.

Figures 2 and 3 show the trends in proposals received, approved projects, and allocated budgets by scientific field in basic research from 2014 to 2024 according to Iran National Science Foundation[2]. A key takeaway is that basic sciences consistently received the highest number of proposals and the largest share of the allocated budget, highlighting that foundational research continues to dominate in both attention and funding. However, this dominance of basic sciences also reveals a significant gap: basic research in applied fields like engineering sciences and agriculture has not been adequately recognized or funded, despite the growing interest in these areas. The National Science Foundation in Iran appears to have struggled in effectively bridging the gap between basic research and its applications in these practical fields. The foundation has been more focused on well-established research in basic sciences, leading to an imbalance in support for applied research. This is reflected in the data where, despite increasing proposals in engineering sciences and agriculture, the approval rates and allocated budgets in these fields were lower for many years. This suggests that the foundation has not fully identified and supported the necessary basic research needed to drive innovation in applied areas. However, there is a positive shift in recent years, particularly from 2023 onwards, where we see an increase in the allocated budgets for engineering sciences and agriculture, signaling a recognition of the need for basic research in these ap-

[1] Article 65 of the «Law on Adding Certain Articles to the Law on Regulating Part of Government Financial Regulations», as well as «Article 56 of the Sixth Development Plan». (https://www.fao.org/faolex/results/details/en/c/LEX-FAOC182369/, accessed 16.01.2025).

Figure 1. **Number of Research Projects by Type of Research**



Source: Iran Statistical Center. https://amar.org.ir/statistical-information/statid/21820, accessed 19.02.2025.

plied sectors. This gradual decrease in the proportion of funding allocated to basic sciences and the increase in funding for engineering sciences and agriculture reflect a growing understanding that the development of applied fields depends on solid foundational research. The relatively low funding for environment and health throughout the years indicates that despite the societal importance of these sectors, the funding and proposal approval have not kept pace with the growing challenges in these fields. This area, like engineering sciences and agriculture, requires more attention in terms of basic research funding to address environmental and health crises.

Thus, while the basic sciences field continues to be prioritized, the shift towards recognizing and funding basic research in applied fields is a positive development. However, the slow pace of this shift and the ongoing underfunding of critical areas like Environment and Health underscore the need for Iran NSF to strengthen its role in linking basic research with real-world applications. By doing so, it can better address national priorities and global challenges.

Research Methodology and Data Description

In our present study, employing a systematic literature review method, specifically meta-synthesis, and drawing upon documents and credible sources accessible via the Web of Science database, we identified a total of 422 pertinent documents. These documents were sourced from a diverse collection of primary articles, covering the period from 1940 to 2022. Subsequently, we scrutinized the selected documents, using the *Bibliometrix* package within the R software primarily focusing on fundamental research, and derived a classification of significant and noteworthy dimensions

Notably, "innovation" emerged as the most frequently occurring keyword followed by "research and development", "science policy", and "economic development". The combined assessment of development degree and relationship degree suggests that science policy and applied research are key areas of interest within this domain. Moreover, within scholarly documents focused on exploring fundamental research and its associated definitions and concepts, "applied research" ranks as the second most common keyword. This underscores the intrinsic connection between fundamental and applied research, where the latter often builds upon the findings of the former.

The studies also identified three distinct literature streams within the field of fundamental research: one concentrating on conceptualizations and definitions, another focusing on theoretical frameworks, and a third emphasizing the social and economic dividends of fundamental research. By analyzing time intervals, two primary periods were delineated. The first, spanning from 1934 to 1994, spotlighted concepts such as benefits, research, investment, system, development, fundamental, science, and indicators. In contrast, the second interval, from 1995 to 2021, saw an emergence of research on fundamental concepts, policy implications, economic considerations, applied research, and various influencing factors within the field. Finally, qualitative analysis using the meta-analysis method involved a thorough examination and discussion of the texts extracted from the identified articles, along with the concepts comprising the knowledge base encompassing 422 cases. Among these, 40 articles were found fitting for final coding. Through meta-synthesis studies, we identified three primary themes: inputs, processes, and outputs (table 3). These were catego-

Table 1. **Approved Research Projects by Type**

Type of Research	Number of Projects	Percentage of Total Projects
Basic Research	182	6
Applied Research	1418	88
Developmental Research	62	6
Total	**1655**	**100**

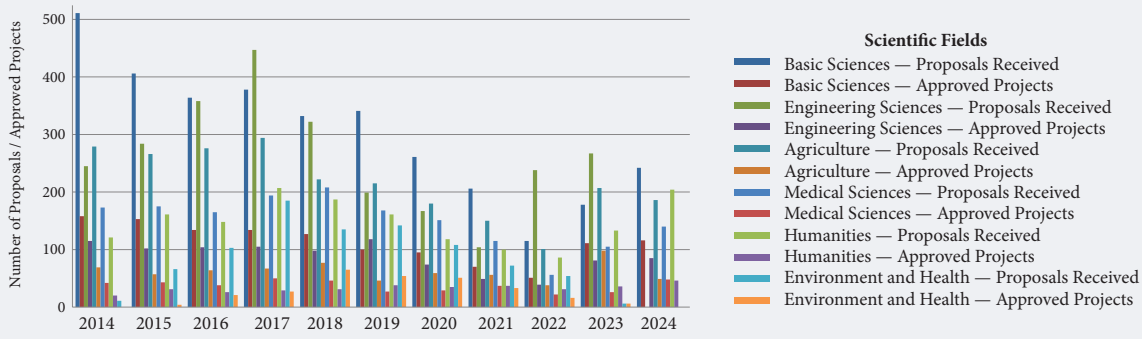
Source: Iran Statistical Center. https://amar.org.ir/statistical-information/statid/21820, accessed 19.02.2025.

Table 2. **Comparison of Estimated vs. Allocated Budget for Research Projects (Million IRR)**

Type of Research	Estimated Budget	Allocated Budget	Ratio of Allocated to Estimated
Basic Research	81 158	61 888	76%
Applied Research	1 652 651	868 618	53%
Developmental Research	611 566	858 556	140%
Total	**2 515 126**	**1 215 626**	**58%**

Source: Iran Statistical Center. https://amar.org.ir/statistical-information/statid/21820, accessed 19.02.2025.

Figure 2. **Proposals Received and Approved Projects by Year for Each Scientific Field (2014-2024)**



Source: Iran Statistical Center. https://amar.org.ir/statistical-information/statid/21820, accessed 19.02.2025.

rized under the title of dimensions and components of governance in fundamental research.

Based on the articles' focus on combining functions at both operational and strategic levels, along with the findings by (Shokatian, Ghazinoory, 2019; Ghazinoory, Shokatian, 2021) and these two levels were used to analyze Iran's fundamental research system. To ensure the validity, experts were interviewed that were selected using a snowball sampling method.[3] Based on the findings, a conceptual framework (Figure 4) was developed, outlining the various institutions involved in science and research governance in Iran. Their distribution by levels with a description of their composition is shown in Table 4.

Through literature review and the application of document analysis method, and finally interviewing experts in the field of fundamental research, 14 fundamental influential factors, including functions and role players of the fundamental research domain, were identified and presented in a conceptual framework. This set of factors and the conceptual framework formed the basis for designing questionnaires with a fuzzy cognitive mapping approach and generating primary research data. A cognitive map consists of two main elements: concepts and relationships. Concepts represent the variables of the model, variables that cause a change, known as cause variables, and those affected by the change are called effect variables. Nodes or concepts typically represent features, characteristics, qualities, variables, and states of a system, and each concept represents one of the key factors of the modeled system. In fact, cognitive mapping simplifies the information of a complex system and reduces it to a knowledge map, which is presented as a visual overview. Therefore, cognitive mapping can model any system with any level of complexity and with an infinite number of concepts, links, and feedback. The concepts represented in a map are connected to each other through causal and effect relationships, known as cause-effect or means-end relationships. Concepts that represent causes are located at the beginning of the arrow, and those representing effects are located at the arrowhead (Timulak, 2009). One of the topics discussed in cognitive mapping is related to the decomposition and analysis of concepts and calculating the impact of each concept in the mapping structure. One of the most important measures is centrality, which is based on the "research purpose and hypothesis" using one or a combination of these measures and concepts. Centrality has a broad concept that is used to identify and determine the most important actors or connections in a network. The most important and practical centralities are degree and betweenness. The simplest type of centrality is degree, which indicates the number of neighbors of each point; the higher the degree of a point, the more access it has to resources and the more central it is considered (Faust, Wasserman, 1994).

After the conceptual framework was determined in the form of a co-occurrence matrix and preliminary analyses were conducted, fuzzy cognitive maps were drawn and related indices were calculated using social network analysis software. The present study uses UCINET software for social network analysis. Therefore, the definition of the most important analysis criteria in this method is as follows:

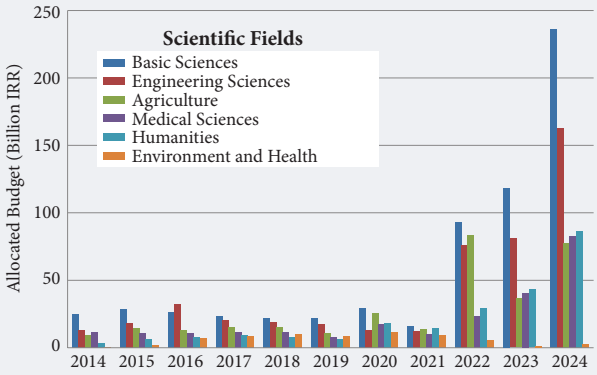
a) Degree centrality: Measures the number of direct links to a node and indicates the most connected node in the group.

b) Closeness centrality: Measures the degree of proximity of a node to the rest of the network, reflecting the

[2] https://insf.org/en, accessed 10.02.2025.

[3] Including faculty members from the Institute for Research in Fundamental Sciences and researchers from the International Center for Theoretical Physics, Abdusalam, the head of the Center for Development and Coordination of Research, Deputy of Research and Technology of the Ministry of Health, former and current presidents of the National Science Foundation, the deputy head of the National Science Foundation, a specialist in science and research funding, a faculty member from the National Center for Research on Science Policy (NRISP), an expert in research funding, and a policy expert on fundamental research.

Figure 3. **Allocated Budget by Year for Each Scientific Field (2014-2024)**



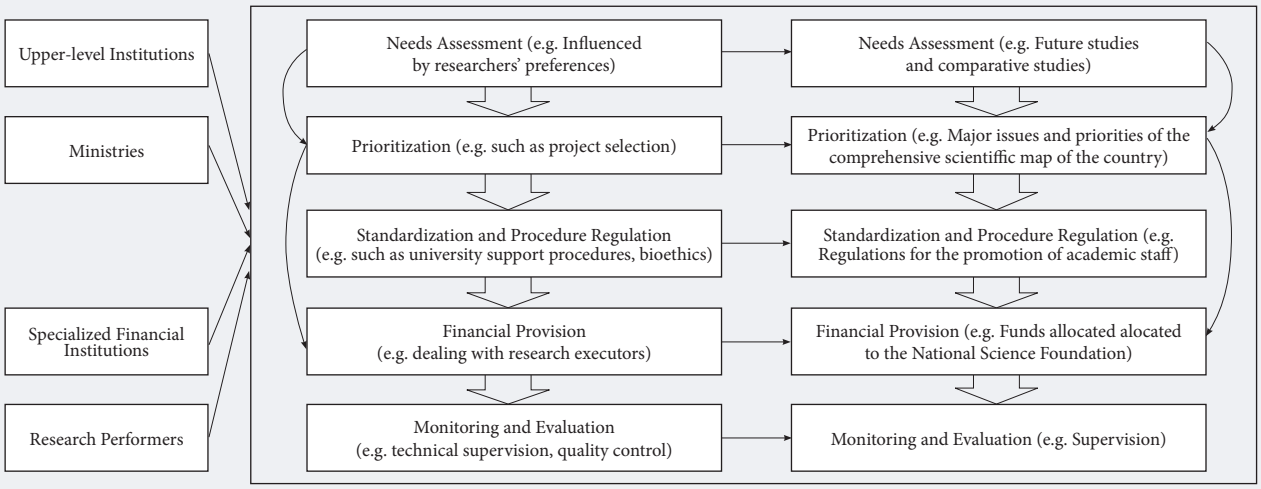
Source: Iran Statistical Center. https://amar.org.ir/statistical-information/statid/21820, accessed 19.02.2025.

Table 3. **Output of the Meta-synthesis Method**

Relevant Issue/Topic	Themes
Inputs	Capital, human resources, universities, laboratories, and government institutions
Processes	Financial provision, research needs identification (needs assessment), prioritization, monitoring and evaluation, and standardization and procedure regulation
Outputs	Economic growth in the form of productivity growth, efficiency, and profitability, technology development in the form of product innovation, knowledge dissemination through knowledge transfer in the form of publications, knowledge overflow, patents, social welfare, commercialization

Source: authors.

Figure 4. **Conceptual Framework of Research***



* Derived from Empirical Background and International Studies and Validated by Experts.

Source: authors.

Table 4. **Institutions Involved into Governance of Fundamental Research in Iran**

Category	Items
Upper-level institutions	Supreme Council of Cultural Revolution, the Parliament, the Cabinet, and the Organization of Budget and Planning.
Ministries	Ministries of Health, Defense, Deputy for Science, Technology, and Knowledge-based Economy and its Councils.
Specialized financial institutions	National Science Fund and the Supreme Council of Science, Research and Technology (ATF) Fun, etc.
Research performers	Research institutes, universities, government laboratories, individual researchers, and the private sector (Royan Institute, Institute for Research in Fundamental Sciences, Academic Center for Education, Culture and Research (ACECR), universities, etc.

Source: authors.

node's ability to access other nodes in the network. It is calculated as the inverse of the sum of the distances between a node and other nodes in the network.

c) Betweenness centrality: A measure indicating the frequency of a node's presence in the shortest path connecting two other nodes. Betweenness centrality is calculated based on the position of actors in the network and their placement in the shortest path between pairs of other actors. Therefore, a point with the highest betweenness centrality is located between many other pairs of points, and pathways from other points pass through it. Betweenness centrality measures the number of times a point needs to pass through intermediary points to connect with other points along the shortest path. Essentially, betweenness centrality measures the likelihood of an actor being positioned along the path of communication between other actors.

Finally, consensus centrality aggregates these three centralities based on the simple unweighted average and enables the causal analysis of the governance framework (Karimmian et al., 2021). In this study also, consensus centrality has been calculated and serves as the basis for the analyses.

The identified factors and conceptual framework laid the groundwork for crafting the questionnaire and gathering primary research data. We constructed a two-way matrix, where rows and columns represented the various functions, organizations, and institutions within the fundamental research domain. Following the conceptual framework, this matrix evaluated how upper-level institutions, ministries, specialized funding bodies, and research entities influenced both operational and strategic functions. It delved into the interplay between operational and strategic functions, assessing how operational needs assessment impacted operational prioritization, how prioritization affected operational funding, how strategic needs assessment influenced strategic prioritization, and how prioritization shaped strategic funding. Ultimately, we examined the collective impact of these factors on the structure of governance in basic research.

A resulting matrix was generated, honing in solely on these aspects, where the cell values depicted the degree of influence of the row factor on the column factor. A value of zero signified no influence. To distill causal maps from expert insights, causal relationships between structural and performance criteria were gleaned through interviews. These relationships and their implications were then integrated into fuzzy adjacency matrices and scrutinized using specialized software to sketch out cognitive maps of the experts. In this study, a consensus centrality index was employed to dissect the cognitive maps. The outcomes were fed into UCINET software for quantitative analysis, and the findings derived from the software outputs were subsequently presented. Finally, the qualitative analyses stemming from theoretical literature reviews, comparative studies, and amalgamated quantitative analyses unfolded.

Results

Summarizing calculations are represented at Table 5. As evident from the table, the factor that has the greatest impact on the governance of basic research in Iran is predominantly the specialized funding agencies and ministries. According to the experts' opinions, in the first category, the National Foundation for the Support of Researchers and Technologists has a major share of this impact, while in the second category, the Ministries of Health, Defense, and the Vice Presidency for Science and Technology bear the brunt of this influence. This aligns with the structural conformity observed in leading countries supporting basic research, such as the United States and China, where leading ministries and specialized funding agencies have the most significant influence. This trend can be preserved and strengthened in Iran as well. This assertion is also in line with the experts' views regarding the necessity of strengthening the National Foundation for the Support of Researchers and Technologists. On the other hand, the least consensus centrality (and hence causal weight) is attributed to operational needs assessment. The reason for this, according to experts, could be the general neglect of needs assessment for research at the operational level. As evident from the experts' opinions, due to the distant nature of basic research from the economy and the strong preferences of researchers in selecting research topics, this needs assessment has been overlooked more than in other areas. In other words, these national needs or specific financial resource needs for research do not necessarily drive researchers towards a particular field of activity, but rather their backgrounds, interests, and skills determine the direction of needs assessment.

Furthermore, it can be observed that all operational-level functions are weaker causally compared to strategic-level functions, indicating a top-down and non-collaborative approach in the governance of basic research. Although this approach is somewhat predominant in Iran, it is particularly noticeable in the field of basic research, where private sector actors are absent, and researchers are often more immersed in their activities and distant from decision-making processes than other researchers. According to experts, the failure to materialize what is referred to in the literature as the "scientific community" exacerbates this issue. Although relying on international experiences (especially in China and the United States), this trend can be partially justified in some functions such as standardization, funding, and evaluation, the lack of influence of research performers in the functions of needs assessment and prioritization is unacceptable.

In the broader scope of strategic functions, prioritization emerges as the key driver influencing the governance of basic research in Iran. Experts highlight that while aligning with global trends and channeling limited resources towards genuine priorities and societal needs is justifiable, Iran has deviated from this path. The experiences drawn from the Nano Council un-

Table 5. **Consensus Centrality in the Network of Actors and Functions of the Basic Research Area, by Factor type**

Factor	The degree of consensus centrality index	Causal weight
Actors		
Specialized Financial Institutions	12.51	1
Ministeries	12.51	1
Resrarch Performers	10.57	0.355482
Upper-Level Institutions	9.98	0.159468
Strategic-level		
Prioritization	10.14	0.212625
Needs Assessment	9.89	0.129568
Financial Provision	9.70	0.066445
Standardization and Procedure Regulation	9.64	0.046512
Monitoring and Evaluation	9.64	0.046512
Operational-level		
Prioritization	9.62	0.039867
Financial Provision	9.62	0.039867
Standardization and Procedure Regulation	9.61	0.036545
Monitoring and Evaluation	9.61	0.036545
Needs Assessment	9.50	0

Source: authors.

derscore this point, where financial allocations have been directed towards numerous high-quality research projects with minimal relevance—a glaring example of misalignment with strategic priorities.

Based on our findings, we can pinpoint the primary pathways that significantly influence the governance of fundamental research in Iran, and propose policy interventions accordingly. Here are some examples.

Pathway 1 (Most impactful): This pathway originates from ministries and specialized financial institutions. It plays a pivotal role in enhancing the governance of fundamental research by shaping operational prioritization, which subsequently influences strategic prioritization. Given its considerable causal impact, as supported by theoretical literature, comparative studies, and expert opinions, bolstering this pathway could yield positive outcomes for governance in this realm. Strengthening institutions like the National Fund for Researchers and Technologists, particularly in guiding strategic and operational priorities, and fostering closer alignment between these priorities can enhance governance performance in this domain.

Pathway 2: This pathway originates from research performers and holds substantial potential to shape the overall governance performance of fundamental research. It does so by influencing operational prioritization, thereby indirectly impacting strategic prioritization. Experts corroborate this pathway, emphasizing the dynamic interplay between strategic and operational prioritization. Notably, operational prioritization tends to be more influenced by researchers' awareness of the relevance of their field of activity rather than their personal interests, highlighting the intricate nature of this relationship.

Pathway 3 (Least Impactful): This pathway initiates from upper-level institutions and operates through strategic oversight and the evaluation of overall governance performance. Presently, these upper-level institutions, particularly in their role of monitoring and evaluating Iran's fundamental research status, are not optimally positioned. According to experts, this lack of comprehensive oversight results in excessive dispersion of resources, wastage, and ultimately diminishes Iran's standing compared to leading nations in a manner that may soon become irreparable. Hence, intervention is imperative. Drawing from international best practices and expert insights, enhancing the capacity and awareness of these institutions concerning the scientific and authoritative priorities of fundamental research in Iran, alongside designing evaluation and oversight mechanisms akin to successful models in other countries, can revitalize this pathway. Consequently, incorporating strategic evaluation criteria such as assessing the impact of basic research on advancements in various economic sectors and addressing societal challenges like aging can be instrumental. These criteria can be formulated and implemented by upper-level institutions, akin to the role played by the National Science Foundation in the United States.

Discussion

The proposed governance framework for basic research in Iran offers several advantages, particularly in enhancing the coordination between strategic and operational levels, strengthening the role of intermediary institutions like the National Science Foundation, and aligning fundamental research with broader societal and economic priorities. However, despite these strengths, several challenges and potential limitations must be acknowledged to provide a more balanced perspective. One of the key benefits of this framework is the enhanced coordination it promotes across governance levels. By reinforcing the role of intermediary institutions, the framework fosters better alignment between strategic priorities set by upper-level institutions and operational needs assessed by research performers. This can lead to more efficient resource allocation and improved responsiveness to national challenges. Furthermore, the integration of research networks as a tool can further enhance the exchange of data and collaboration between research institutions (Caminati, 2009; Al-Mawali et al., 2020). These networks help overcome some of the isolation that often characterizes basic research activities (Broekel, Graf, 2010). By introducing collaborative networks at national and international levels, the innovation cycle is accelerated, creating a more dynamic and interconnected research environment (Plucknett, Smith, 2005). The framework also stands out for its deliberate effort

to integrate economic growth imperatives with fundamental societal concerns, such as air pollution and aging. This integration ensures that basic research remains relevant and impactful beyond academic circles (Dooly, O'Driscoll, 2022). A key element of this approach is the impact-driven prioritization, which assesses the societal and economic benefits of research. It helps align funding with national needs, addressing critical issues like climate change, healthcare, and sustainability (Chubb, Reed, 2018). Such an approach not only makes research more impactful but also ensures it is more responsive to society's evolving needs. Another notable strength is the increased strategic direction and prioritization introduced by the framework. By implementing a structured prioritization mechanism, both at strategic and operational levels, the framework helps steer research investments toward areas of high impact. This approach mitigates the risks associated with fragmented and uncoordinated funding distribution. Moreover, prioritizing based on social and economic outcomes, rather than solely academic achievements, enhances the relevance of research in addressing pressing national issues (Mulligan, Conteh, 2016; Shokatian et al., 2024; Bozeman, Youtie, 2017).

This helps ensure that resources are not wasted, maximizing the potential for research to deliver tangible societal benefits. Inspired by successful models in research-intensive countries such as the United States and China, the framework emphasizes the role of national science funding bodies in guiding and overseeing research priorities. The lessons drawn from these systems underscore the importance of integrating open innovation models, where public and private sectors collaborate to leverage external knowledge and push the boundaries of basic research (Ito, Nagano, 2011; Meissner, 2019). By adapting these best practices, Iran can establish a more sustainable and globally competitive research system. However, the framework also faces several challenges that must be addressed to fully realize its potential. One major challenge is the complexity of implementing the proposed governance framework within Iran's existing bureaucratic and institutional structures. Resistance from established research institutions and government agencies may slow the adoption of new governance mechanisms. The integration of open data policies could alleviate some of these challenges by enhancing transparency and accountability (Mayernik, 2017), allowing for easier tracking of progress and greater buy-in from stakeholders (Budin-Ljøsne et al., 2023). Nevertheless, overcoming institutional inertia will require significant policy shifts and investments in capacity building. While strengthening intermediary institutions can enhance coordination, it may also add layers of bureaucracy that could delay decision-making processes (Heitmann et al., 2019). Striking a balance between oversight and administrative efficiency is crucial to avoid excessive red tape. In this regard, involving multiple stakeholders in the decision-making process can help reduce bureaucratic inefficiencies, ensuring that decisions are made more inclusively and swiftly (Vignola et al., 2013).

Another challenge is the potential constraint on researcher autonomy. The push to align basic research with economic and societal needs, although beneficial for national development, may limit researchers' freedom to pursue curiosity-driven inquiries (Brown, 1985). A rigid prioritization system could restrict the exploration of unconventional, yet potentially groundbreaking scientific ideas. Social impact assessment models (Bornmann, 2013) offer a solution here by evaluating both the short-term societal benefits and the long-term potential of fundamental research. These models ensure that even unconventional or niche research areas are not overlooked due to their lack of immediate societal returns.

The financial sustainability of the proposed framework also presents a challenge. It relies heavily on increased financial commitment from specialized funding institutions. Given Iran's economic challenges, securing sustained funding for fundamental research remains a concern. The feasibility of long-term investments in basic research must be carefully considered, especially in the context of potential economic downturns. Here, private sector engagement is critical (Robson, 1993; Rosenberg, 2010), thus, introducing policy measures that incentivize private sector participation in funding basic research could help mitigate this limitation, attracting alternative funding sources and increasing the commercialization potential of research outcomes. In Iran, unlike applied research, which often attracts industry collaboration, basic research remains primarily government-funded. This lack of private sector involvement limits alternative funding sources and reduces opportunities for knowledge transfer and commercialization (Rosenberg, 2010). Adopting open innovation models could incentivize industry partners to invest in fundamental research, thereby bridging the gap between academic and commercial research (Beck et al., 2022; Akcigit et al., 2021).

Finally, the challenge of evaluating the performance of governance reforms in basic research is an ongoing issue. Given the long gestation periods between research investments and tangible outcomes, measuring effectiveness is inherently difficult. Developing robust evaluation metrics that can accurately capture the impact of research governance reforms is essential for assessing success (Hao et al., 2023). The use of social impact assessment models could provide a framework to evaluate the broader societal and economic effects of basic research, going beyond traditional academic metrics (Soler-Gallart, Flecha, 2022; Shi et al., 2022; Jiang et al., 2024).

Summary and Conclusion

Fundamental research, as a cornerstone of national innovation systems, has long been a subject of debate regarding government intervention in its policy and governance structures. However, it is recognized that

government engagement with fundamental research differs significantly from other types of research due to inherent uncertainties, challenges in assessing its economic and social benefits, substantial time lags between research and application, and other unique factors. In recent decades, theories advocating unconditional support for fundamental research or relying solely on the internal logic of science and researchers' interests have been deemed flawed, just as complete government funding allocation. Similarly, the push to increase private sector involvement with arguments akin to those for technology development and applied research has its shortcomings.

This article aims to identify functions tailored to these differences in the governance system and analyze the entire governance structure of fundamental research in Iran while offering recommendations. At higher levels of the governance system, policies determine funding mechanisms and budget allocations for fundamental research. Prioritization, occurring at both strategic and operational levels, is influenced by these policies and needs assessments. Macro-level policies set perspectives within defined timeframes, guiding strategic prioritization, which is then implemented by ministries, research institutions, scientific foundations, and universities. National needs assessments draw on international and domestic studies, foresight analyses, and strategic objectives. Additionally, local assessments at research centers and universities inform operational prioritization through a bottom-up approach. Prioritization aligns with strategic goals and drives resource allocation to priority areas, enhancing research relevance to long-term socio-economic objectives. It should ideally engage stakeholders in defining and implementing priorities, employing a bidirectional approach.

Evaluation is another critical aspect, complicated by the time lag between supporting fundamental research and its impacts. Questions arise regarding the timeframe for assessing success, the relevance of academic outputs versus tangible societal impacts, and the role of capacity-building evaluations. Key institutions responsible for these functions include upper-level specialized bodies like the Supreme Council of the Cultural Revolution, ministries such as the Ministry of Health, specialized financial institutions like the Research Support Fund, and research performers such as individual researchers.

Drawing from the preceding analysis, the following recommendations are suggested:

1. Empower institutions like the Research and Technology Fund, particularly in strategic and operational prioritization, and foster closer alignment between these levels of prioritization.

2. Heighten awareness among researchers to align their research interests with overarching priorities, recognizing the significance of researchers' contributions in fundamental research.

3. Enhance the capacity of higher-level institutions to comprehend and incorporate the scientific and authoritative priorities of fundamental research in Iran.

4. Develop strategic evaluation and monitoring mechanisms akin to those employed by leading nations, encompassing assessments of basic research impact across various economic sectors, as well as its contribution to improving quality of life and addressing societal challenges such as aging.

These recommendations are geared towards amplifying the effectiveness and impact of fundamental research within the broader spectrum of innovation governance.

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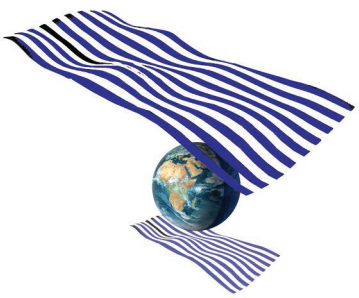

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