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4.1 Acceptance
4.2 Revisions Required
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Editorial Note

The Social Science Innovation and Applied Management (SIAM) is an academic journal prepared by Institute of Research and Development, Rajamangala University of Technology Thanyaburi (RMUTT). The SIAM aims to disseminate and share knowledge and ideas in the form of high-quality articles related Business, Economics, Education, Humanities, Human and Community Resource Development, Psychology, Sociology, Anthropology, Linguistics, Political Science and Arts Program in History to researchers, academics, faculty members and students both national and international.

This journal published two research articles and two review articles. Each of the research articles presented interesting concepts such as Comparative Study of Fertility between Migrant and Nonmigrant Populations, The Influence of Digital Investment on Enterprise Resilience: A Case Study of Heavily Polluting Industries in A-Shares, Monitoring Postpartum Risk Using Information System Decision-Making Support System: A Literature Review and Assessment of Sustainability in Supply Chain Management: Literature Study. Therefore, this journal is a channel disseminating the knowledge areas of social sciences which related persons could apply it for further benefits.

Lastly, the editorial team would like to considerably thank you for supporting and pushing forward this journal to occur and well accomplish. We are hopeful of your good cooperation and continuing support in the future.

Editorial Team

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SOCIAL SCIENCE INNOVATION AND APPLIED MANAGEMENT

Contents

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Assessment of Sustainability in Supply Chain Management: Literature Study

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Abstract

This research extensively delves into sustainability measurement in supply chains, examining its importance, approaches, challenges, and prospects. The research commences by analyzing the multifaceted nature of sustainability, including environmental, social, and economic dimensions, and their incorporation into supply chain management methodologies. It highlights several frameworks and tools employed for measurement, such as life cycle assessments, social audits, and economic impact studies, emphasizing the intricate and varied nature of these methodologies. The study examines primary obstacles in measuring sustainability, including the complexity of global supply networks, diverse industries, and the lack of internationally recognized standards. These barriers serve to complicate the process of collecting, analyzing, and comparing data across various businesses and industries. Furthermore, the paper investigates emerging trends, namely the impact of cutting-edge technologies such as blockchain, the Internet of Things (IoT), and artificial intelligence on improving the precision and comprehensiveness of measurements. Moreover, the research examines the incorporation of sustainability measurement into other management systems, such as risk management and financial reporting, which demonstrates the increasing acknowledgment of sustainability as a fundamental business goal. The study underscores the significance of involving stakeholders and the necessity for more flexible and responsive quantification methods to tackle changing sustainability issues. In conclusion, the study consolidates important results and suggests areas for further investigation, such as the creation of uniform measurement frameworks, enhanced techniques for evaluating multi-tier supply chains, and approaches for successful implementation in small and medium-sized businesses. This paper enhances the evolving discipline of sustainable supply chain management by offering a comprehensive analysis of existing methods, obstacles, and potential future directions in sustainability assessment.

Keywords: Supply chain sustainability, Performance measurement, Sustainable development

Introduction

Sustainability Measurement in Supply Chains

In today's business landscape, supply chains have become critical components driving organizational success, particularly in an era of intensified competition (Silvestre et al., 2020). Simultaneously, there has been a significant increase in the emphasis on sustainability across all sectors, compelling organizations to adapt and consider the environmental, social, and economic impacts of their operations (Karmaker et al., 2021). Supply chain management is intricately linked to sustainability, as various activities within the supply chain directly affect resource utilization, pollution emissions, and community well-being (Zhu et al., 2022). For example, selecting environmentally friendly raw materials can reduce negative impacts on ecosystems, while improving working conditions in manufacturing plants can enhance laborers' quality of life.

Consequently, measuring sustainability in supply chains has become paramount, enabling organizations to assess operational efficiency, identify areas for improvement, and make strategic decisions effectively (Bag et al., 2020). However, measuring sustainability in supply chains remains challenging due to the complexity of systems and

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the diversity of relevant indicators. Currently, a variety of methods and tools are utilized to measure supply chain sustainability, such as Life Cycle Assessment (LCA), carbon footprint analysis, and social impact assessments (Nimsai et al., 2023). Nevertheless, gaps persist in the research and development of standardized measurement approaches that can be practically applied across diverse industries.

This literature review aims to explore and analyze concepts, methodologies, and tools used in measuring supply chain sustainability, encompassing environmental, social, and economic dimensions. Furthermore, it seeks to identify gaps in current knowledge and suggest future research directions. The article will begin by defining relevant concepts, followed by a discussion of frameworks and indicators used in measuring supply chain sustainability. It will then address methods and approaches for data collection and analysis, including challenges and limitations inherent to measurement. Finally, it will present trends and future developments in measuring sustainability in supply chains.

This literature review holds significance both academically and industrially, helping researchers and practitioners understand the current status of sustainability measurement in supply chains while identifying opportunities for improvement and innovation (Gold & Schleper, 2017). Moreover, it will contribute to the ongoing dialogue on integrating sustainability into business practices and decision-making processes. As organizations strive to balance economic growth with environmental stewardship and social responsibility, the need for robust and comprehensive sustainability measurement in supply chains becomes increasingly crucial.

This review aims to provide a foundation for further research and practical implementation of sustainability measurement strategies in supply chain management (Gong et al., 2018). By synthesizing current knowledge and highlighting emerging trends, this literature review aspires to contribute to the advancement of sustainable supply chain practices and foster a more resilient and responsible global business environment.

Literature Review

1. Sustainability in the Context of Supply Chains

1.1 Definition of Sustainability Sustainability, in its broadest sense, encompasses the ability to meet present needs without compromising the ability of future generations to meet their own needs (WCED, 1987). In the business context, sustainability is often conceptualized through the Triple Bottom Line (TBL) framework, which integrates environmental, social, and economic dimensions (Elkington, 1998). Recent research by Schaltegger et al. (2020) emphasizes that the definition of sustainability in business has evolved to include not only risk mitigation but also the creation of positive impacts and value for stakeholders.

1.2 Supply Chain Management (SCM) Supply Chain Management (SCM) refers to the coordination and management of all activities involved in sourcing, procurement, conversion, and logistics management (CSCMP, 2021). It encompasses the planning and management of all activities involved in sourcing and procurement, conversion, and all logistics management activities (Carter et al., 2015). Key components of SCM include supplier relationship management, demand planning, inventory management, and distribution (Lambert & Enz, 2017).

1.3 Sustainable Supply Chain Management (SSCM)

Sustainable Supply Chain Management (SSCM) integrates sustainability principles into traditional supply chain management practices. Seuring and Müller (2008) define SSCM as "the management of material, information, and capital flows as well as cooperation among companies along the supply chain while taking goals from all three dimensions of sustainable development, i.e., economic, environmental, and social, into account that are derived from customer and stakeholder requirements." Key drivers for adopting SSCM include regulatory pressures, stakeholder demands, competitive advantage, and risk management (Geng et al., 2017). However, implementing SSCM faces challenges such as complexity inherent to global supply chains, lack of transparency, and conflicting objectives among stakeholders (Mani et al., 2018).

1.4 Dimensions of Sustainability in Supply Chains

1.4.1 Environmental Sustainability

Environmental sustainability in supply chains focuses on minimizing negative impacts on the natural environment. This includes resource conservation, pollution prevention, waste reduction, and biodiversity preservation (Ahi & Searcy, 2015). Recent studies by Govindan et al. (2020) highlight the importance of circular

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economy principles for enhancing environmental sustainability within supply chains.

1.4.2 Social Sustainability

Social sustainability in supply chains addresses the human and societal aspects of business operations. Key areas include labor practices and human rights, community engagement, health and safety, and diversity and inclusion (Yawar & Seuring, 2017). Mani et al. (2016) emphasize the growing importance of social sustainability in supplier selection and evaluation processes.

1.4.3 Economic Sustainability

Economic sustainability in supply chains ensures long-term profitability while considering ethical and sustainable practices. This dimension encompasses fair trade practices, local economic development, innovation, and competitiveness (Carter & Rogers, 2008). Recent research by Geissdoerfer et al. (2018) suggests that integrating sustainability can lead to increased economic performance through innovation and improved stakeholder relationships.

The interplay between these three dimensions – environmental, social, and economic – forms the foundation of sustainable supply chain management, presenting both challenges and opportunities for organizations striving to balance profitability with responsibility (Dubey et al., 2017).

2. Definitions and Concepts in Sustainable Supply Chain Measurement

2.1 Measuring Sustainable Supply Chains

2.1.1 Importance of Measurement in SSCM

Measurement plays a crucial role in Sustainable Supply Chain Management (SSCM) by providing quantifiable data for decision-making and performance evaluation. Beske-Janssen et al. (2015) argue that effective measurement enables organizations to assess their progress toward sustainability goals, identify areas for improvement, and communicate performance to stakeholders. Furthermore, measurement facilitates benchmarking and continuous improvement in sustainable practices (Searcy, 2016).

2.1.2 Key Principles of Sustainability Measurement

Effective sustainability measurement in supply chains adheres to several key principles. These include relevance and materiality, ensuring that measured aspects are significant to the organization and its stakeholders; completeness and accuracy, providing a comprehensive and precise representation of performance; consistency and comparability, allowing for meaningful analysis over time and across organizations; and transparency and verifiability, enabling stakeholders to understand and validate the measurement process (GRI, 2021; Kühnen & Hahn, 2019).

2.1.3 Frameworks for Measuring Sustainability in Supply Chains

Several frameworks guide the measurement of sustainability in supply chains. The Global Reporting Initiative (GRI) provides widely adopted standards for sustainability reporting (GRI, 2021). The UN Sustainable Development Goals (SDGs) offer a global framework for addressing sustainability challenges, with increasing adoption in corporate sustainability strategies (Sachs et al., 2019). The ISO 14000 series provides standards for environmental management systems; while emerging Circular Economy indicators focus on resource efficiency and waste reduction (Kristensen & Mosgaard, 2020).

2.1.4 Types of Sustainability Measures

2.1.4.1 Quantitative Measures

Quantitative measures in SSCM include Key Performance Indicators (KPIs) that provide numerical data on specific aspects of sustainability performance. Life Cycle Assessment (LCA) offers a comprehensive approach to evaluating environmental impacts throughout a product's life cycle (Hellweg & Milà i Canals, 2014). Carbon footprint and water footprint measurements focus on specific environmental impacts and are increasingly used in supply chain management (Montoya-Torres et al., 2015).

2.1.4.2 Qualitative Measures

Qualitative measures in SSCM include supplier assessments, which evaluate suppliers' sustainability practices through questionnaires and audits (Gimenez & Sierra, 2013). Stakeholder feedback provides valuable insights into the perceived sustainability performance of an organization. Case studies and best practice benchmarking offer in-depth analysis of successful sustainability initiatives in supply chains (Beske et al., 2014).

2.1.5 Challenges in Measuring Sustainability in Supply Chains

Measuring sustainability in supply chains faces several challenges. Data collection and

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quality issues arise due to the complexity and global nature of modern supply chains (Bai & Sarkis, 2014). The lack of standardization in measurement approaches hinders comparability across organizations and industries (Ahi & Searcy, 2015). Balancing competing priorities, such as economic performance and environmental protection, presents ongoing challenges in sustainability measurement (Wu & Pagell, 2011).

2.1.6 Emerging Trends in Sustainability Measurement

Emerging trends in sustainability measurement leverage technological advancements. Big data and analytics enable more comprehensive and real-time sustainability performance monitoring (Hazen et al., 2016). Blockchain technology enhances traceability and transparency in supply chains (Saberi et al., 2019). Artificial Intelligence and Machine Learning facilitate predictive analytics and optimization of sustainable practices (Nishant et al., 2020). The Internet of Things (IoT) enables real-time monitoring of sustainability parameters throughout the supply chain (Ben-Daya et al., 2019). These definitions and concepts provide a comprehensive foundation for understanding and measuring sustainability in supply chains, reflecting the evolving nature of the field and the increasing importance of sustainable practices in global business operations.

2.2 The Importance of Sustainability Measurement in Supply Chains

Sustainability measurement in supply chains has become increasingly crucial in today's business environment. This section explores the necessity of effective measurement tools and explains how measurement aids in decision-making and process improvement.

2.2.1 The Need for Effective Measurement Tools

The complexity and global nature of modern supply chains necessitate robust and efficient measurement tools for sustainability. Several factors underscore this need.

2.2.2 Complexity Management Supply chains often span multiple countries and involve numerous stakeholders. Effective measurement tools help organizations navigate this complexity by providing clear, comparable data (Carter & Rogers, 2008).

2.2.3 Regulatory Compliance With increasing environmental and social regulations, companies need reliable tools to measure and report their compliance. Effective measurement ensures adherence to legal requirements and industry standards (Gualandris et al., 2015).

2.2.4 Stakeholder Expectations Investors, customers, and NGOs increasingly demand transparency in sustainability performance. Measurement tools enable organizations to meet these expectations by providing verifiable data (Meixell & Luoma, 2015).

2.2.5 Risk Management Sustainability risks in supply chains can have significant financial and reputational impacts. Effective measurement helps for early risk identification and mitigation (Giannakis & Papadopoulos, 2016).

2.2.6 Continuous Improvement Without measurement, it's challenging to identify areas for improvement. Effective tools provide the basis for setting targets and tracking progress over time (Beske-Janssen et al., 2015).

2.2.7 How Measurement Aids Decision-Making and Process Improvement

Sustainability measurement plays a pivotal role in enhancing decision-making and driving process improvements in supply chains.

1. Data-Driven Decision Making measurement provides quantifiable data that supports informed decision-making. For instance, lifecycle assessment data can guide product design choices for improved environmental performance (Hellweg & Milà i Canals, 2014).

2. Performance Benchmarking Measurement allows organizations to benchmark their performance against industry standards and competitors, identifying areas for improvement (Searcy, 2016).

3. Resource Allocation By quantifying sustainability performance, organizations can prioritize resources towards areas with the greatest potential for improvement or impact (Wu & Pagell, 2011).

4. Supplier Management Measurement enables effective supplier evaluation and selection based on sustainability criteria, fostering a more sustainable supply base (Gimenez & Sierra, 2013).

5. Process Optimization Regular measurement and analysis can reveal inefficiencies in processes, leading to optimizations that improve both sustainability and operational performance (Brandenburg et al., 2014).

6. Innovation Driver Sustainability measurement can highlight areas where innovation is needed, driving research and

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development efforts towards more sustainable solutions (Nidumolu et al., 2009).

7. Stakeholder Communication Measurement provides concrete data for reporting to stakeholders, enhancing transparency and trust (Gualandris et al., 2015).

8. Long-term Strategy Development Consistent measurement over time allows organizations to track long-term trends, informing strategic planning and goal-setting (Schaltegger & Wagner, 2017).

In conclusion, effective sustainability measurement in supply chains is not just a reporting tool but a strategic asset. It provides the necessary insights for organizations to make informed decisions, continuously improve their processes, and create long-term value while minimizing negative environmental and social impacts. As supply chains continue to evolve in complexity and global reach, the importance of robust and efficient sustainability measurement tools will only increase, driving the need for ongoing innovation in this field.

2.3 Current State of Sustainability Measurement in Supply Chains

Diversity of Methods and Tools

The field of sustainability measurement in supply chains has evolved rapidly, resulting in a wide array of methods and tools available to organizations. This diversity reflects the complexity of sustainability issues and the varied needs of different industries and organizations.

1. Standardized Frameworks Global Reporting Initiative (GRI) Widely adopted for sustainability reporting, providing standardized metrics across environmental, social, and economic dimensions (GRI, 2021). UN Sustainable Development Goals (SDGs) Increasingly used as a framework for aligning corporate sustainability efforts with global priorities (Sachs et al., 2019).

2. Life Cycle Assessment (LCA) Comprehensive method for assessing environmental impacts throughout a product's lifecycle (Hellweg & Milà i Canals, 2014). Various software tools are available, such as SimaPro and GaBi, offering different levels of complexity and industry-specific databases.

3. Carbon and Water Footprinting Focused tools for measuring specific environmental impacts, gaining popularity due to increasing concerns about climate change and water scarcity (Montoya-Torres et al., 2015). Examples include the GHG Protocol for carbon accounting and the Water Footprint Network's assessment methodology.

4. Supplier Assessment Tools Questionnaires and audit protocols designed to evaluate supplier sustainability performance (Gimenez & Sierra, 2013). Industry-specific initiatives like the Sustainable Apparel Coalition's Higg Index for the textile industry.

5. Circular Economy Indicators An emerging set of metrics focused on resource efficiency, waste reduction, and closed-loop systems (Kristensen & Mosgaard, 2020). Examples include material circularity indicator and recycling rates.

6. Social Impact Assessment Tools for measuring social sustainability aspects, including labor practices, community impact, and human rights (Yawar & Seuring, 2017). The Social Life Cycle Assessment (S-LCA) methodology gaining traction.

7. Integrated Scorecards Balanced Scorecard approach adapted for sustainability, integrating sustainability metrics with traditional financial and operational measures (Hansen & Schaltegger, 2016).

8. AI and Big Data Analytics Emerging tools leveraging artificial intelligence and big data for real-time sustainability performance monitoring and predictive analytics (Hazen et al., 2016).

2.4 Challenges in Selection and Implementation

While the diversity of methods and tools offers flexibility, it also presents significant challenges in selection and implementation.

1. Lack of Standardization The multitude of approaches makes it difficult to compare performance across organizations or even within complex supply chains (Ahi & Searcy, 2015). Challenge in selecting the most appropriate tools for specific organizational needs.

2. Data Collection and Quality Gathering accurate and comprehensive data, especially from suppliers in different geographical locations, can be resource-intensive (Bai & Sarkis, 2014). Ensuring data quality and reliability across diverse sources remains a significant challenge.

3. Complexity and Resource Requirements Many tools, particularly comprehensive ones like LCA, require significant expertise and resources to implement effectively (Hellweg &

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Milà i Canals, 2014). Small and medium-sized enterprises may find it challenging to allocate necessary resources.

4. Balancing Breadth and Depth Striking a balance between comprehensive measurement and focused, actionable metrics is often difficult (Searcy, 2016). There is a risk of information overload or oversimplification.

5. Supply Chain Visibility Limited visibility beyond tier-one suppliers hinders comprehensive sustainability measurement (Busse et al., 2017). There are challenges in cascading measurement practices throughout the supply chain.

6. Alignment with Business Strategy Integrating sustainability measurement with overall business strategy and operations can be challenging (Schaltegger & Wagner, 2017). It is difficult to demonstrate the direct link between sustainability performance and financial outcomes.

7. Regulatory Compliance Keeping up with evolving regulations and ensuring measurement tools meet compliance requirements across different jurisdictions (Gualandris et al., 2015).

8. Stakeholder Expectations Addressing diverse and sometimes conflicting stakeholder expectations in sustainability measurement and reporting (Meixell & Luoma, 2015).

9. Technology Integration Integrating new measurement tools with existing IT systems and processes can be technically challenging and resource-intensive (Hazen et al., 2016).

In conclusion, while the current state of sustainability measurement in supply chains offers a rich array of methods and tools, organizations face significant challenges in selecting and implementing the most appropriate approaches. The key lies in understanding organizational needs, industry context, and stakeholder expectations to develop a tailored approach to sustainability measurement that is both effective and feasible.

2.5 Framework for Measuring Sustainability in Supply Chains

The measurement of sustainability in supply chains typically follows a triple bottom line approach, encompassing environmental, social, and economic dimensions. This framework provides a comprehensive view of an organization's impact and performance across these three interconnected areas.

Environmental indicators, highlighting the growing concern for ecological impact. Key measures include greenhouse gas emissions, energy efficiency, water usage, waste management, and biodiversity impact. These indicators provide a holistic view of a supply chain's environmental footprint.

Greenhouse gas emissions, measured in CO2 equivalent, directly address climate change concerns. Energy efficiency metrics help companies optimize resource use and reduce costs. Water usage indicators are crucial in addressing scarcity issues, while waste management metrics promote circular economy principles. The inclusion of biodiversity impact demonstrates a growing awareness of supply chains' effects on ecosystems.

The social dimension of sustainability is equally important, focusing on the human aspect of supply chains. The framework includes indicators for labor practices, human rights compliance, community impact, diversity and inclusion, and product responsibility.

These indicators ensure that companies maintain ethical standards throughout their supply chains. By measuring factors such as workplace safety, adherence to human rights principles, and community development initiatives, organizations can foster positive relationships with workers and local communities. The inclusion of diversity and product responsibility metrics further emphasizes the broader social impact of supply chain operations.

The economic dimension completes the sustainability triad, focusing on long-term financial health and ethical business practices. Key indicators include financial performance, innovation and R&D, local economic impact, fair trade practices, and risk management.

These metrics go beyond traditional financial measures to include sustainability-focused investments and their returns. By assessing local economic contributions and fair-trade practices, companies can ensure their operations benefit all stakeholders. The inclusion of risk management emphasizes the importance of anticipating and mitigating sustainability-related challenges.

This comprehensive framework of sustainability indicators provides a robust tool for organizations to assess and improve their supply chain practices. By addressing environmental, social, and economic factors,

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companies can create more resilient, ethical, and sustainable supply chains. As global awareness of sustainability issues grows, such frameworks will become increasingly vital in guiding business practices and fostering responsible corporate citizenship.

Methodology

The measurement of sustainability in supply chains is a complex process that requires a systematic approach to data collection, analysis, and reporting. This overview provides a comprehensive look at the methods and approaches used in each of these crucial stages.

Data Collection

The measurement of sustainability in supply chains is inherently complex and requires a systematic approach to data collection, analysis, and reporting. This section provides a comprehensive overview of the methods used in each of these critical stages.

Effective sustainability measurement begins with robust data collection practices, utilizing both primary and secondary sources to provide a complete picture of supply chain performance.

Primary Data Collection

Organizations often start with direct engagement with supply chain stakeholders. This involves standardized surveys and questionnaires distributed to suppliers and other key partners, as noted by Mani et al. (2018), enabling consistent data collection across diverse supply chain actors. To validate responses, site visits and audits are conducted. Gimenez & Sierra (2013) emphasize that on-site assessments are critical for verifying sustainability practices and identifying improvement areas.

In addition to surveys and audits, in-depth interviews with key personnel provide valuable qualitative insights that may not be captured through quantitative data alone (Seuring & Müller, 2008). The use of Internet of Things (IoT) technology has also revolutionized data collection, as IoT sensors now offer real-time data on various sustainability metrics, such as energy use and emissions (Ben-Daya et al., 2019).

Secondary Data Collection

Secondary data collection complements primary methods by analyzing existing documents. This includes reviewing sustainability reports from suppliers (Tachizawa & Wong, 2014), accessing industry databases for benchmarking (Ahi & Searcy, 2015), and evaluating reports from government agencies and NGOs (Gold et al., 2010).

Ensuring Data Quality

Ensuring data quality is paramount throughout the collection process. Bai & Sarkis (2014) emphasize the need for robust verification processes to ensure accuracy. Standardizing data formats and units across the supply chain is crucial for meaningful analysis (Beske-Janssen et al., 2015). Clear data governance protocols, including guidelines for data ownership, access, and security, are essential for managing large volumes of information (Hazen et al., 2016).

Data Analysis

After data collection, the next critical step is analysis, which combines quantitative and qualitative methods to derive meaningful insights.

Quantitative Analysis

Statistical methods are commonly used to identify trends and correlations within the data, revealing patterns in sustainability performance (Brandenburg et al., 2014). Life Cycle Assessment (LCA) provides a comprehensive view of environmental impacts throughout a product's lifecycle (Hellweg & Milà i Canals, 2014).

For more complex decision-making, multi-criteria decision analysis methods, such as the Analytic Hierarchy Process (AHP) or Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), are applied. Govindan et al. (2015) demonstrate how these techniques help balance multiple sustainability criteria in supplier evaluation.

Qualitative Analysis

Qualitative methods complement quantitative approaches by offering context-rich insights. Content analysis of reports and interviews can reveal qualitative patterns not captured by numerical data (Seuring & Gold, 2012). Case study analysis provides an in-depth look at specific sustainability initiatives (Pagell & Wu, 2009), while stakeholder mapping helps assess the influence and interests of various stakeholders, guiding engagement strategies (Meixell & Luoma, 2015).

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Advanced Analytical Techniques

As technology advances, more sophisticated techniques are being adopted. Big data analytics allows organizations to process large datasets, uncovering patterns that traditional methods might miss (Hazen et al., 2016). Predictive modeling is used to forecast future sustainability performance, enabling proactive issue resolution (Sarkis & Zhu, 2018). Machine learning and artificial intelligence methods are increasingly applied to recognize patterns and optimize performance across complex supply chains (Nishant et al., 2020).

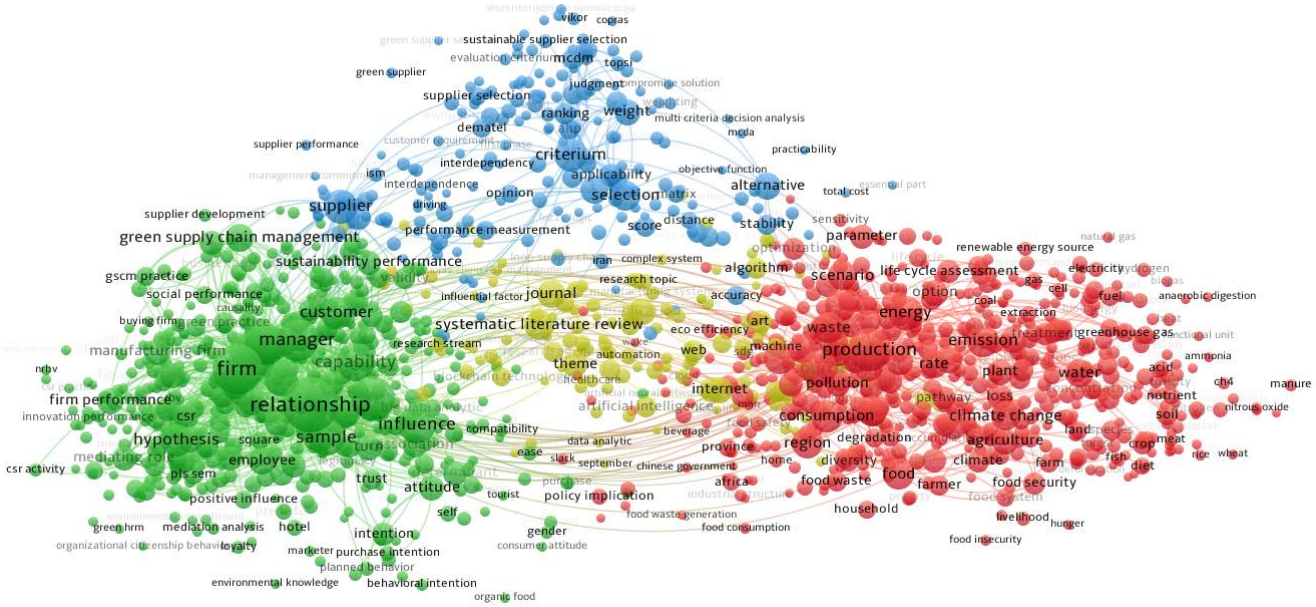

Figure 1 Mapping relation form Paper 5,000 scopus.

Results

Figure 1 presents a complex network visualization of interconnected concepts related to sustainability, supply chain management, and environmental impact. This visualization appears to be the result of a systematic literature review, as evidenced by the central position of terms like "systematic literature review" and "journal" (Tranfield et al., 2003). The network can be broadly divided into three main clusters, each representing a distinct but interrelated aspect of sustainable supply chain management.

The blue cluster, occupying the upper portion of the image, focuses on supplier-related concepts and decision-making processes. Key terms in this cluster include "supplier selection," " criterion," "weight," and "multi criteria decision analysis." This cluster highlights the importance of sustainable supplier selection and evaluation methods in supply chain management. The prominence of these terms suggests a significant research focus on developing and implementing frameworks for assessing suppliers based on sustainability criteria (Govindan et al., 2015). The inclusion of terms like "fuzzy AHP" and "TOPSIS" the use of advanced decision-making techniques in this context, reflecting the complexity of balancing multiple sustainability criteria in supplier selection processes (Kannan et al., 2014).

The green cluster, positioned on the left side of the image, emphasizes organizational and relational aspects of sustainable supply chain management. Prominent terms in this cluster include "firm", "relationship", "customer", "manager", and "green supply chain management". This cluster underscores the importance of stakeholder relationships and the integration of sustainability practices into core business operations. The presence of terms like "social performance" and "innovation performance" suggests a focus on the broader impacts of sustainable practices on organizational outcomes (Seuring & Müller, 2008). This cluster also includes concepts related to employee attitudes and behaviors, indicating research interest in the successful implementation of sustainable supply chain practices (Daily et al., 2012).

The red cluster, dominating the right side of the image, primarily deals with environmental

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and production-related concepts. Key terms in this cluster include "emission", "energy", "waste", "water", "climate change", and "agriculture". This cluster represents a strong emphasis on the environmental impacts of supply chain operations and resource management in production processes. The inclusion of terms like "life cycle assessment" and "greenhouse gas" indicates a focus on comprehensive environmental impact analysis methodologies (Hellweg & Milà i Canals, 2014). The presence of agriculture-related terms suggests significant attention to sustainability issues in food supply chains, a critical area given the sector's substantial environmental footprint (Garnett, 2011).

Central to the image are terms related to research methodologies and dissemination, such as "systematic literature review", "journal", and "research topic". This centrality emphasizes the academic nature of the visualization and suggests that it represents the current state of research in the field of sustainable supply chain management. The interconnectedness of the clusters illustrates the complex and multifaceted nature of sustainability in supply chains, encompassing supplier relations, organizational management, and environmental considerations.

The visualization also includes terms related to emerging technologies and methodologies, such as "artificial intelligence", "blockchain technology", and "internet of things". This indicates that the field is evolving to incorporate cutting-edge technologies in addressing sustainability challenges in supply chain management (Saberi et al., 2019).

In conclusion, this network visualization effectively demonstrates the holistic approach required in addressing sustainability challenges in modern supply chain management. It highlights the need for integrated strategies that consider multiple stakeholders, environmental impacts, and technological innovations across the entire supply chain ecosystem. The complexity of the network underscores the interdisciplinary nature of sustainable supply chain management research and practice, reflecting the field's evolution towards more comprehensive and nuanced approaches to sustainability (Carter & Rogers, 2008).

The final stage in the measurement process is reporting and communicating results. This stage is crucial for driving action based on the insights gained from data collection and analysis.

Internal reporting often takes the form of dashboards that provide real-time monitoring of key sustainability performance indicators. Searcy (2016) emphasizes the importance of these visual tools in making complex sustainability data accessible to decision-makers. Many organizations are also integrating sustainability metrics into their balanced scorecards, a practice (Hansen & Schaltegger, 2016) note as effective for aligning sustainability with overall business strategy. Regular management reports synthesizing key findings and recommendations are also crucial for informing strategic decision-making (Schaltegger & Wagner, 2017).

External reporting is equally important for transparency and stakeholder engagement. Many organizations publish comprehensive sustainability reports following established standards such as the Global Reporting Initiative (GRI, 2021). There's also a growing trend towards integrated reporting, which combines financial and non-financial performance information into a single report, as discussed by Churet & Eccles (2014). For consumer-facing companies, product labeling has become an important way to communicate sustainability performance directly to customers (Hardt et al., 2017).

Effective stakeholder communication goes beyond formal reports. Many organizations hold regular stakeholder engagement sessions to discuss sustainability performance and gather feedback (Meixell & Luoma, 2015). Online platforms and social media are increasingly used for more frequent and interactive communication about sustainability efforts (Tachizawa & Wong, 2014; Etter, 2014).

Finally, the reporting process should feed into a cycle of continuous improvement. This involves establishing feedback loops to incorporate stakeholder input, as suggested by Beske-Janssen et al. (2015). Regular benchmarking against industry best practices helps organizations identify areas for improvement (Searcy, 2016). Setting clear sustainability targets and regularly reviewing progress against these targets is crucial for driving ongoing performance improvements (Schaltegger & Wagner, 2017).

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In conclusion, measuring sustainability in supply chains is a complex but crucial process. By employing a comprehensive approach to data collection, analysis, and reporting, organizations can gain valuable insights, drive improvements, and demonstrate their commitment to sustainability to both internal and external stakeholders. As the field continues to evolve, new technologies and methodologies will likely emerge, offering even more sophisticated ways to measure and manage supply chain sustainability.

Challenges and Limitations

The measurement of sustainability in supply chains, while crucial for modern business practices, faces numerous challenges and limitations. These obstacles stem from the inherent complexity of global supply chains, the diversity of industries involved, and the lack of universally accepted standards. This article explores these challenges in depth, providing insights into the difficulties organizations face when attempting to quantify and assess their sustainability efforts.

The complexity of supply chains presents a formidable challenge in sustainability measurement. Modern supply chains often span multiple countries and involve numerous tiers of suppliers, each with its own operational practices and local contexts. As noted by Mena et al. (2013), this complexity makes it difficult to obtain a comprehensive view of sustainability performance across the entire supply chain. Organizations often have limited visibility beyond their first-tier suppliers, leading to potential blind spots in their sustainability assessments. Sarkis (2012) points out that this lack of transparency can result in overlooking significant environmental or social impacts occurring in the deeper tiers of the supply chain.

Furthermore, the interconnectedness of supply chain actors means that sustainability initiatives in one part of the chain can have unforeseen consequences elsewhere. For instance, a decision to source more sustainable materials might inadvertently lead to increased transportation emissions if the new suppliers are located farther away. Capturing these complex interactions and trade-offs in sustainability measurements is a significant challenge, as highlighted by Brandenburg et al. (2014).

The diversity of industries involved in global supply chains adds another layer of complexity to sustainability measurement. Different sectors have varying sustainability priorities and impacts. For example, the environmental concerns of a technology company might center around electronic waste and energy consumption, while a food and beverage company might focus more on water usage and agricultural practices. This diversity makes it challenging to develop standardized measurement approaches that can be applied across different industries.

Moreover, as Ahi and Searcy (2015) discuss, the sustainability impacts of different industries can vary significantly in their nature and scale. Some impacts, such as carbon emissions, are relatively straightforward to quantify across industries. Others, like biodiversity loss or community impact, are more qualitative and context-dependent, making cross-industry comparisons difficult. This variability poses challenges in developing comprehensive sustainability metrics that are relevant and applicable across diverse supply chains.

The lack of universally accepted standards for sustainability measurement in supply chains further complicates the issue. While numerous frameworks and guidelines exist, such as the Global Reporting Initiative (GRI) or the UN Global Compact, there is no single, universally adopted standard for measuring supply chain sustainability. This lack of standardization, as pointed out by Beske-Janssen et al. (2015), leads to inconsistencies in how organizations define, measure, and report on their sustainability performance.

The absence of standardized metrics makes it challenging to compare sustainability performance across different organizations or even within the same organization over time. It also creates difficulties for stakeholders, including investors and consumers, who seek to assess and compare the sustainability performance of different companies. Searcy (2016) argues that this lack of comparability can hinder the effectiveness of sustainability initiatives and reporting.

Furthermore, existing standards and frameworks often struggle to keep pace with evolving sustainability challenges and stakeholder expectations. New issues, such as microplastics pollution or the social impacts of artificial

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intelligence, may not be adequately covered by current measurement frameworks. This gap between emerging sustainability concerns and established measurement practices can lead to incomplete or outdated assessments of supply chain sustainability.

The challenges of data collection and verification add another dimension to the difficulties of sustainability measurement in supply chains. Obtaining accurate, timely, and comprehensive data from multiple tiers of suppliers is often a resource-intensive process. Boström et al. (2015) highlight the challenges of ensuring data quality and reliability, particularly when dealing with suppliers in regions with different regulatory environments or reporting practices.

Additionally, the cost and effort required to implement comprehensive sustainability measurement systems can be prohibitive, especially for smaller organizations or those operating in resource-constrained environments. This can lead to inequalities in sustainability reporting capabilities across the supply chain, potentially skewing overall assessments of sustainability performance.

In conclusion, while measuring sustainability in supply chains is essential for promoting responsible business practices, it is fraught with challenges. The complexity of global supply networks, the diversity of industries involved, and the lack of universally accepted standards all contribute to making sustainability measurement a complex and often imperfect process. Addressing these challenges requires ongoing collaboration between academia, industry, and policymakers to develop more robust, flexible, and universally applicable measurement approaches. As supply chains continue to evolve and new sustainability challenges emerge, the methods and frameworks for measuring sustainability must also adapt to ensure they remain relevant and effective.

Future Trends and Developments in Sustainability Measurement for Supply Chains

As the field of sustainability in supply chain management continues to evolve, new trends and developments are emerging that promise to revolutionize how organizations measure and manage their sustainability performance. This article explores two key areas of future development new technologies in measurement and the integration of sustainability measurement with other management systems. The rapid advancement of technology is significantly impacting the landscape of sustainability measurement in supply chains. One of the most promising developments is the application of blockchain technology. Saberi et al. (2019) highlight how blockchain can enhance transparency and traceability in supply chains, providing a tamper-proof record of sustainability-related data. This technology allows for real-time tracking of products from source to consumer, verifying sustainability claims and reducing the risk of greenwashing. For instance, blockchain can be used to track the origin of raw materials, ensuring they come from sustainable sources and have been processed under fair labor conditions.

Another technological trend is the increasing use of Internet of Things (IoT) devices for data collection. As discussed by Ben-Daya et al. (2019), IoT sensors can provide real-time data on various sustainability metrics, such as energy consumption, water usage, and emissions. This continuous stream of data allows for more accurate and timely measurement of sustainability performance. For example, smart meters can monitor energy use in real-time, enabling immediate identification and response to inefficiencies. Artificial Intelligence (AI) and Machine Learning (ML) are also set to play a crucial role in the future of sustainability measurement. Nishant et al. (2020) explore how these technologies can analyze vast amounts of sustainability data, identifying patterns and insights that might be missed by human analysts. AI can help in predicting future sustainability trends, optimizing resource allocation, and even suggesting innovative solutions to sustainability challenges. For instance, ML algorithms could analyze historical data to predict potential sustainability risks in the supply chain, allowing for proactive mitigation strategies.

The development of advanced analytics capabilities is another significant trend. Big Data analytics, as highlighted by Hazen et al. (2016), allows organizations to process and analyze enormous volumes of sustainability data from diverse sources. This capability enables more comprehensive and nuanced understanding of sustainability performance across complex global supply chains. Advanced analytics can

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help in identifying correlations between different sustainability metrics, understanding the impact of specific initiatives, and benchmarking performance against industry standards. In terms of integration with other management systems, there is a growing trend towards holistic approaches that embed sustainability measurement into core business processes. The concept of integrated reporting, as discussed by Churet and Eccles (2014), is gaining traction. This approach combines financial and non-financial (including sustainability) performance into a single, coherent report, reflecting the interconnected nature of these aspects in modern business.

There is also an increasing focus on aligning sustainability measurement with broader risk management systems. Giannakis and Papadopoulos (2016) emphasize the importance of integrating sustainability risks into enterprise risk management frameworks. This integration allows organizations to better understand and manage the complex interplay between sustainability performance and overall business risks. The integration of sustainability measurement with supply chain management systems is another key trend. As Tachizawa and Wong (2014) note, this integration allows for more effective decision-making by providing sustainability data alongside traditional supply chain metrics like cost and delivery time. For example, supplier selection processes are increasingly incorporating sustainability criteria alongside traditional factors, necessitating integrated measurement systems.

Furthermore, there is a growing trend towards the integration of sustainability measurement with product lifecycle management systems. This approach, as explored by Gmelin and Seuring (2014), allows organizations to consider sustainability impacts from the design phase through to end-of-life management. Such integration enables more comprehensive sustainability assessments and facilitates the development of more sustainable products from the outset. The future also holds potential for more standardized and interoperable sustainability measurement systems. While the current lack of standardization is a challenge, efforts are underway to develop more universally accepted frameworks. The work of organizations like the Sustainability Accounting Standards Board (SASB) and the Global Reporting Initiative (GRI) is moving towards more standardized metrics and reporting formats. This standardization will facilitate better comparison and benchmarking across industries and supply chains.

In conclusion, the future of sustainability measurement in supply chains is characterized by technological innovation and increasing integration with other business systems. These developments promise to make sustainability measurement more accurate, comprehensive, and actionable. As organizations navigate these changes, they will need to stay abreast of technological advancements and be prepared to adapt their measurement systems accordingly. The integration of sustainability measurement with other management systems will require a holistic approach to business management, breaking down silos between sustainability and other business functions. While these developments present challenges, they also offer exciting opportunities for organizations to enhance their sustainability performance and create more resilient, responsible supply chains.

Results and discussion

The measurement of sustainability in supply chains has become a vital component of modern business management, reflecting the increasing importance of environmental, social, and economic considerations in global commerce. This review has examined various aspects of sustainability measurement, covering conceptual frameworks, practical challenges, and future trends. Below, key findings are synthesized, and directions for future research are identified.

Multidimensional Nature of Sustainability

A primary insight from this review is the complex, "Multidimensional Nature of Sustainability" and "Diversity of Measurement Tools and Methodologies" in supply chains. The Triple Bottom Line (TBL) framework, encompassing environmental, social, and economic dimensions, serves as a comprehensive foundation for sustainability measurement. However, these dimensions are deeply interconnected, presenting challenges for measurement and management. As Ahi and Searcy (2015) suggest, a holistic approach is necessary to effectively capture the nuanced interactions between different sustainability aspects.

Diversity of Measurement Tools and Methodologies

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The evolving nature of the field is reflected in the wide array of available tools and methodologies, ranging from life cycle assessments to social audits and economic impact analyses. This diversity offers organizations flexibility but also highlights a significant gap in standardization, making comparability and benchmarking across industries challenging. Beske-Janssen et al. (2015) stress the need for standardized approaches that facilitate meaningful comparisons while allowing for industry-specific adaptations.

Role of Technology in Sustainability Measurement

Emerging technologies such as blockchain, Internet of Things (IoT), and artificial intelligence (AI) are transforming data collection, analysis, and reporting processes. As Ben-Daya et al. (2019) note, these technologies offer the potential for real-time, accurate, and comprehensive sustainability measurements. However, their implementation introduces challenges related to data management, privacy, and potential disparities between large corporations and smaller suppliers.

Integration with Other Management Systems

The integration of sustainability measurement with other management systems is a critical trend. The shift towards integrated reporting and the incorporation of sustainability metrics into enterprise risk management and supply chain management systems reflect a growing recognition of sustainability as a core business objective. Churet and Eccles (2014) highlight that this integration supports more holistic decision-making by aligning sustainability with traditional business metrics.

Persistent Challenges

Despite advancements, several challenges persist Complexity of Global Supply Chains: Obtaining comprehensive sustainability data across multi-tier supply chains remains difficult, particularly beyond the first-tier suppliers (Mena et al., 2013). Stakeholder, Diversity Different priorities and capabilities among stakeholders complicate the consistent implementation of measurement practices.

Evolving Nature of Sustainability Concerns: As new sustainability issues emerge, existing measurement frameworks may struggle to keep pace, requiring ongoing adaptation (Sarkis, 2012).

Future Research and Development Priorities

The following key areas emerge as priorities for future research and development, Standardization and Comparability. Research should focus on developing more standardized frameworks for sustainability measurement, enabling meaningful comparisons across industries while allowing for context-specific adaptations. Technology Integration, Future research should explore the practical implementation of emerging technologies in sustainability measurement, such as AI for predictive analytics and blockchain for enhanced transparency and traceability. Multi-Tier Supply Chain Measurement, more effective methods are needed to measure sustainability performance across all supply chain tiers, particularly in complex global networks.

Impact Measurement

Research should aim to better quantify the actual impact of sustainability initiatives, transitioning from output metrics to outcome-based measurements that demonstrate tangible effects. Stakeholder Engagement, Effective stakeholder engagement in the sustainability measurement process is crucial. Future studies should focus on approaches that ensure diverse stakeholder priorities are reflected in measurement practices. Dynamic Measurement Systems, As sustainability challenges evolve, more adaptive measurement systems are needed to incorporate new concerns and metrics quickly. Integration with Business Strategy, Further exploration is needed on how to effectively integrate sustainability measurement with overall business strategy and decision-making processes. Focus on SMEs, developing feasible and effective sustainability measurement approaches for small and medium-sized enterprises (SMEs) is essential, given their limited resources compared to larger corporations.

Conclusions and Recommendations

Conclusions

Multidimensional Nature of Sustainability: Sustainability in supply chains is inherently complex, encompassing environmental, social, and economic dimensions. The interconnectedness

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of these dimensions requires a holistic approach to measurement, recognizing that improvements in one area may impact others.

Diverse Tools and Methodologies, A wide array of tools and methodologies exists for sustainability measurement, ranging from life cycle assessments to social audits and economic impact analyses. However, the lack of standardization remains a significant challenge, hindering comparability and benchmarking across industries and supply chains.

Technological Advancements, Emerging technologies like blockchain, IoT, and AI are revolutionizing sustainability measurement by providing real-time, accurate, and comprehensive data. These technologies offer new opportunities for enhancing transparency and traceability, though they also introduce challenges related to data management and privacy.

Integration with Business Processes, there is a growing trend toward integrating sustainability measurement with other management systems, such as enterprise risk management and supply chain management. This integration enables more holistic decision-making and ensures that sustainability is considered alongside traditional business metrics.

Challenges in Measurement, despite advancements, significant challenges persist, particularly in obtaining comprehensive data from multi-tier supply chains and addressing the varying priorities of different stakeholders. The complexity of global supply chains and the evolving nature of sustainability concerns continue to complicate effective measurement.

Recommendations

- Key Conclusions

Multidimensional Nature of Sustainability, Sustainability in supply chains is inherently complex, requiring a holistic approach to measurement that accounts for the interconnected environmental, social, and economic dimensions.

Diverse Tools and Methodologies, while a wide range of tools and methodologies exist for sustainability measurement, the lack of standardization remains a significant challenge, hindering comparability across industries.

Technological Advancements, Technologies like blockchain, IoT, and AI are revolutionizing sustainability measurement by enhancing transparency and real-time data accuracy. However, they also present new challenges related to data management and privacy.

- Integration with Business Processes

There is a growing trend toward integrating sustainability measurement with other management systems, enabling more comprehensive decision-making that aligns sustainability with core business strategies.

Challenges in Measurement, Significant challenges persist, particularly in obtaining comprehensive data from multi-tier supply chains and addressing varying stakeholder priorities. The complexity of global supply chains and the evolving nature of sustainability concerns continue to complicate effective measurement.

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The Influence of Digital Investment on Enterprise Resilience: A Case Study of Heavily Polluting Industries in A-Shares

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Abstract

In the face of increasing economic uncertainty caused by public health emergencies, geopolitical conflicts and supply chain disruptions, building enterprise resilience has become a key issue for enterprises around the world. Previous studies have mainly focused on the direct impact of digital investment on enterprise resilience. Still, the conclusions are inconsistent, and the characteristics of green development are not fully considered when exploring the relationship between the two. To address this research gap, this study explores how digital investment affects enterprise resilience via green technology innovation. Based on the natural resource-based view and knowledge-based view, we proposed four hypotheses. To test these research hypotheses, we developed four regression models and empirically tested them using a sample of 624 heavily polluting industries in China from 2016 to 2020. Our findings indicate that digital investment positively affects enterprise resilience, with green technology innovation as a partial mediator in this relationship. This study not only confirms the beneficial impact of digital investment on resilience but also contributes to the literature by demonstrating how enterprises can effectively utilize their digital assets for greater resilience. The findings provide two key recommendations for managers: first, companies should continuously adopt and implement digital technologies, as well as increase their digital investment, to better cope with economic downturns and other unexpected events, especially in the context of Industry 4.0 and with a long-term mission of green development; second, attention should be given to the channels through which digital investments influence enterprise resilience, particularly through green technology innovation.

Keywords: Digital investment, Enterprise resilience, Green technology innovation, Heavy pollution industry

Introduction

Public health emergencies, geopolitical conflicts, and shifts in industrial and supply chains have significantly heightened economic uncertainty and downward pressure on both national and global levels, making economic sustainability a critical concern for current development (Luo et al., 2024). As core economic entities, enterprises now face increasingly complex and dynamic external environments, resulting in heightened uncertainties surrounding their survival and growth trajectories. In response, enhancing enterprise resilience against external shocks and risks, while simultaneously striving for sustainable development has become an urgent priority.

Enterprise resilience is generally understood as an organization's ability to maintain stability, recover rapidly, and sustain growth amidst various disruptions (Markman and Venzin, 2014; Zhang et al., 2021; Luo et al., 2024). As resilience is crucial for companies aiming to navigate both immediate crises and long-term sustainability goals, it has drawn increasing attention from both researchers and practitioners alike.

Existing literature has examined how digital transformation-the broad adoption and integration of digital technologies within organizations-can enhance resilience (Luo et al., 2024). However, digital transformation encompasses a wide range of organizational

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changes that extend beyond individual technology investments; it often involves shifts in corporate culture, structural reorganization, and changes in strategic management practices (Bellantuono et al., 2021). In contrast, digital investment specifically refers to the strategic allocation of resources toward targeted digital technologies, such as big data analytics, artificial intelligence, and cloud computing, to enhance operational efficiency and gain competitive advantages. Despite increasing scholarly attention, there remains a limited understanding of how digital investments, as distinct from comprehensive digital transformation efforts, contributes directly to resilience.

While some scholars argue that digital investment can strengthen resilience by increasing operational flexibility and adaptability (Dubey et al., 2021; Li et al., 2022), others highlight the so-called "digital paradox." This paradox posits that, despite substantial investment in digitalization, many companies struggle to achieve expected gains in short-term revenue growth, often due to high costs and low efficiencies (Kohtamäki et al., 2019). As Industry 4.0 progresses, enterprises are likely to increase their digital investment further (Ye et al., 2023). In this context, the following question warrants further discussion: can enterprises leverage their digital investment to develop the ability to adapt to a downturn market environment and achieve stable, sustainable development? In other words, can enterprises derive resilience from their digital investment?

The Natural Resource-Based View (NRBV) and the Knowledge-Based View (KBV) offer frameworks for understanding how digital investment impacts enterprise resilience and the underlying mechanisms. Both the KBV and NRBV suggest that firms must seek the knowledge, resources, and capabilities necessary to enhance their resilience (Ji et al., 2020).

The NRBV emphasizes that a company's sustainability relies on its ability to balance economic efficiency with its environmental impact. This can be achieved through improving clean technologies, designing green products with low life-cycle costs, and implementing sustainable practices to enhance productivity (Hart, 1995; Sehnem et al., 2022; Alkaraan et al., 2024). Digitalization theoretically allows companies to optimize resource allocation for implementing sustainable practices (Hwang and Kim, 2022) and to dismantle barriers to both internal and external knowledge exchange, thereby facilitating green technological innovation (Marion and Fixson, 2021). Green technology innovation significantly boosts firms' sustained growth and resilience by mitigating risks associated with environmental regulations and disasters, enhancing brand image and customer loyalty, and optimizing internal processes. Consequently, digital investment may enhance enterprise resilience through green technology innovation.

The KBV asserts that knowledge is a firm's primary strategic resource (Grant, 1996). Firms must integrate knowledge and information to generate innovative ideas for addressing surprises and uncertainties encountered during business operations (Ji et al., 2020). Additionally, integrating both internal and external knowledge is an effective means of achieving green technology innovation (Strambach, 2017). However, despite theoretical support, existing discussions about the impacts and mechanisms of digital investment on enterprise resilience are largely conceptual and lack empirical evidence. A theoretical framework is needed to clarify the channels through which digital investment impacts enterprise resilience.

Overall, the role of digital investment in enhancing enterprise resilience needs further exploration. Thus, this study aims to address the following research questions:

1. Does digital investment enhance firm resilience?

2. If so, does digital investment enhance enterprise resilience through its impact on green technology innovation?

To address these questions, this study examines publicly listed companies in China's heavily polluting industries. Building on NRBV and KBV, this research explores the relationships among digital investment, green technology innovation, and enterprise resilience within a "digital investment - green innovation behavior - enterprise resilience" framework. The originality and significance of this study are evident in several aspects: (1) it clarifies the direct impact of digital investment on resilience, distinguishing it from broader digital transformation; (2) it introduces green technology innovation as a mediator, underscoring its role in adapting to environmental changes; (3) it addresses the "digital paradox" by demonstrating that digital

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investment, when aligned with green innovation, can yield long-term resilience benefits; and (4) it provides empirical insights specific to high-pollution industries, offering guidance for balancing economic and environmental objectives in high-pressure sectors.

The structure of this paper is as follows: We begin with a systematic review of the literature on digital investment and enterprise resilience, identifying gaps in current research and proposing relevant research hypotheses. This is followed by a detailed description of our research methodology. Subsequently, we empirically test the proposed theoretical relationships and provide an in-depth discussion of the research findings. Finally, we conclude with key insights and policy recommendations based on our study.

Literature Review

Digital Investment

In the context of Industry 4.0, companies are increasingly prioritizing the use of digital technologies to significantly transform their business models, production methods, and value creation strategies (Verhoef et al., 2021). Digital investment encompasses a company's investments in various areas, including information technology, software, hardware, cloud computing, big data analysis, and artificial intelligence. These investments aim to enhance operational efficiency, improve the customer experience, and drive business innovation.

Existing research has extensively discussed the impact of digital investments. On one hand, scholars primarily concentrate on the economic effects of digital investment. For instance, Yunis et al. (2018) analyzed the significant positive relationship between information and communication technologies and overall organizational performance based on questionnaire survey data. Jin et al. (2023) utilized China's A-share listed industrial enterprises as research samples and found a significant U-shaped relationship between digital investment and corporate environmental performance. Based on NRBV, Ye et al. (2023) analyzed 273 pollution-intensive enterprises in China from 2016 to 2020 and discovered a positive impact of digital investment on the environmental performance of these enterprises. On the other hand, some scholars have further investigated the additional benefits of digital investment. The empirical findings of Nwankpa and Merhout (2020) indicated a significant positive relationship between digital investment and IT innovation. Wang et al. (2024) argued that digital investment can foster radical innovation by effectively integrating external and internal resources. The empirical results of Bai et al. (2024) demonstrated that digital investment can enhance enterprise value through the utilization of intellectual capital.

Enterprise Resilience

Amid heightened global economic volatility, compounded by the effects of COVID-19 and other emergencies, enterprise resilience has emerged as a significant focus of research. When confronted with external shocks, enterprise resilience refers to an organization's ability to maintain stability, achieve rapid recovery, and ensure sustainable development. The core of enterprise resilience is risk resistance and sustainable development (Ortiz-de-Mandojana and Bansal, 2016). Risk resistance refers to the ability of enterprises to effectively identify, assess and respond to various risks in the face of uncertainties and emergencies. Sustainable development hinges on an organization's ability to balance economic benefits with environmental impacts (Ye et al., 2023). To effectively respond to changing market conditions, organizations must continually enhance their adaptability and flexibility, ensuring they can not only survive risks during crises but also achieve sustainable development. Rapid technological advancements, proactive policy support, and heightened awareness of social responsibility are broadening the concept and scope of corporate resilience. Consequently, understanding and enhancing enterprise resilience will be a critical issue that cannot be overlooked in future management practices.

Current research primarily examines the antecedents of enterprise resilience at the individual, organizational, and network levels. At the individual level, employees' positive behavior and mental health can enhance organizational innovation and coping abilities, thereby improving the enterprise's flexibility and adaptability in responding to changes and challenges (Coutu, 2002). Competent leaders can guide employees and the organization to recover quickly and return to normalcy (Hillmann & Guenther, 2002).

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At the organizational level, effective corporate governance (Carmeli and Markman, 2011), technological innovation (Zhao et al., 2023), and digital technology deployment (Li et al., 2022) contribute to improved responsiveness and recovery during challenges and crises. At the network level, enterprises can leverage established social network relationships to expedite their recovery to the original state when facing difficulties (Xie et al., 2022).

Digital Investment and Enterprise Resilience

As the global digital wave rises and economic volatility intensifies, scholars increasingly focus on the relationship between digital investment and enterprise resilience. Some studies indicate that digital investment serves as an effective strategy for enhancing enterprise resilience. For instance, Dubey et al. (2021) state that investing in data analytics capabilities enables managers to identify potential threats or outages, facilitating the development of business continuity plans that expedite recovery following an outage. Li et al. (2022) argue that high-intensity deployment of digital technologies can significantly enhance Supply chain resilience.

Conversely, some scholars have introduced the concept of the digital paradox, suggesting that enterprises frequently fail to attain the anticipated revenue growth from digital investment (Kohtamäki et al., 2019). Research by Kohtamäki et al. (2019) indicated that when the cumulative level of digital investment is relatively low, enterprises can typically meet their revenue growth expectations. However, as investment continues to increase, an increasing number of companies are encountering the digital paradox and failing to achieve their anticipated revenue growth. As digital investment rises, the likelihood of encountering this paradox also increases, with only a few companies ultimately achieving significant revenue growth that matches their high investment. This implies that digital investment does not consistently result in sustained growth or enhanced resilience. Li et al. (2022) argued that while digital investment allows enterprises to acquire diverse data, excessive data volume may disrupt decision-making, particularly in emergencies, resulting in negative consequences for risk management.

Overall, there is a lack of consensus regarding the impact of digital investment on enterprise resilience. As a result, some enterprises have become skeptical of digital investments, hindering their ability to effectively deploy and utilize digital assets in the digital age and maximize both direct and indirect benefits. Furthermore, the existing research does not consider the characteristics of The Times of green development. In the context of green development, green technology innovation is crucial for promoting the sustainable growth of enterprises and addressing environmental challenges (Shu et al., 2022; Zhang et al., 2023). Additionally, digital investment can foster enterprises' green technology innovation (Marion and Fixson, 2021). Consequently, green technology innovation may serve as a mediating factor in the relationship between digital investment and corporate resilience. To address this research gap, this study aims to explore how digital investment influences firm resilience through green technology innovation and the underlying mechanisms involved.

Impact of Digital Investment and Enterprise Resilience

The core of enterprise resilience is risk resistance and sustainable development (Ortiz-de-Mandojana and Bansal, 2016). Enterprise resilience should not be viewed as a capability that can be independently acquired; it relies on digital technologies for support and advancement (Li et al., 2022). This study posits that digital investment positively influences both the sustainability and risk resilience aspects of firm resilience. First, the NRBV theory highlights the unique capabilities of firms in utilizing and managing natural resources, which are integral to sustainable growth. Digital investments, utilizing big data analytics and Internet of Things technologies, allow firms to monitor and optimize natural resource management in real time. This capability reduces production costs, minimizes environmental impacts, and enhances corporate sustainability.

Second, firms need knowledge and information to generate creative and innovative ideas to cope with external shocks and crisis scenarios (Ji et al., 2020). Based on KBV, firms' capabilities often depend on their knowledge acquisition and sharing (Grant, 1996; Ji et al., 2020). The application of digital technology enables firms to access market and industry information more efficiently and accurately,

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and to formulate response strategies quickly, so that they can quickly adjust their business strategies and maintain the standardization and agility of their risk management activities in the face of unforeseen events or market volatility (Zhang et al., 2021).

Accordingly, this paper proposes the following hypotheses.

H1: Digital investment enhances firm resilience.

Impact of Digital Investment on Green Technological Innovation

While the importance of green technological innovation is widely acknowledged, it is characterized by long cycles, high risks, and negative externalities. Enterprises, as the primary contributors to green technological innovation activities, often lack the motivation to engage in these efforts (Ye et al., 2023). From a knowledge management perspective, introducing and applying digital technology enables enterprises to dismantle communication barriers internally and externally, providing avenues for creating and disseminating green technology innovation knowledge (Marion and Fixson, 2021). Adopting digital tools can help enterprises acquire real-time information on market dynamics, technological advancements, and environmental policies. This enhances information flow and transparency, allowing for better identification of green technology innovation opportunities and increasing enterprises' willingness to innovate.

According to NRBV, technology is a key resource for enterprises to carry out green technological innovation and build sustainable competitive advantages (Yang and Chai, 2015). Green technological innovation usually involves the intersection and application of multidisciplinary knowledge, and it is difficult to achieve success in carrying out green technological innovation only by relying on the enterprise's previous technological experience and knowledge in a single technological field. The introduction and application of digital technology help to absorb and utilize technological knowledge in a wider field and on a larger scale, which is conducive to solving the complexity of breakthrough innovation problems, reducing the risk of enterprise innovation, optimizing the allocation of resources, and enhancing the efficiency of innovation (Shu et al.,.2022). Based on this, hypothesis 2 is proposed.

H2: Digital investment has a positive impact on green technology innovation.

Impact of Green Technological Innovation on Enterprise Resilience

Green technological innovation involves the adoption of new technologies, materials, and processes in production and operations to reduce resource consumption and environmental pollution, achieving a harmonious balance between economic and environmental benefits. Green technological innovation focuses on the long-term sustainable development of enterprises. Through green technological innovation, enterprises can create more environmentally friendly products that meet market demand while minimizing resource consumption and preventing further environmental damage. This long-term perspective is crucial for the sustainable development of enterprises committed to green development.

By implementing green technological innovation, enterprises can effectively mitigate dysfunction within their original production systems during green development scenarios. Additionally, they can enhance their ability to anticipate and respond to environmental crises, thereby strengthening their risk defense capabilities and resilience (Zhang et al., 2023). Enterprises that adopt green technological innovations often enjoy a better reputation among the public and consumers. This positive social image fosters consumer support and trust during crises, enhancing firms' market resilience.

Based on these observations, this paper proposes the following hypothesis.

H3: Green technological innovation positively impacts enterprise resilience.

The Mediating Role of Green Technological Innovation

As discussed above, digital investment is beneficial for enhancing green technological innovation. Firms with a high level of green technological innovation can not only respond to environmental crises but also improve their sustainability in green development scenarios, thereby enhancing organizational resilience. In other words, green technological innovation may mediate the relationship between digital

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investment and enterprise resilience. Therefore, we propose the following hypothesis:

H4: Digital investment can enhance enterprise resilience by improving the level of green technological innovation.

Based on the above theoretical analysis, this study constructs a conceptual model, as shown in Figure 1.

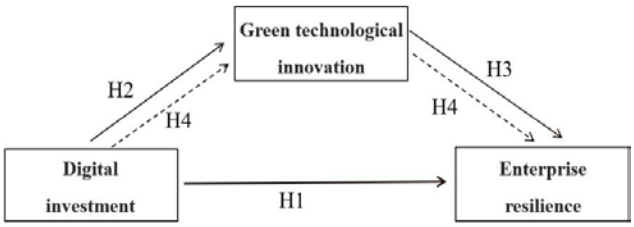

Figure 1 Conceptual model.

Methodology

Sample Selection and Population

This study focuses on publicly listed companies within China's heavily polluting industries, specifically those listed on the Shanghai and Shenzhen Stock Exchanges, covering the period from 2016 to 2020. Pollution-intensive industries, such as chemicals, steel, and mining, were chosen because of their high environmental impact, energy consumption, and emissions, which make them ideal candidates for studying the intersection of digital investment, green technological innovation, and enterprise resilience in the sustainability context (Chirumalla, 2021). With the rise of Industry 4.0, pollution-intensive enterprises are facing an increasing demand for green development and are actively seeking to enhance their environmental performance through digital investment and digital technologies, thereby achieving sustainable development goals (Chirumalla, 2021). Studying the strategies these enterprises employ to address environmental challenges is crucial not only for their own survival and growth but also for the broader sustainable development of society.

The population of this study consists of all pollution-intensive enterprises listed on both exchanges during the specified period. To ensure data integrity and reliability, we implemented specific inclusion and exclusion criteria: (1) companies with outliers in key indicators and those with a listing period of fewer than three years were excluded to avoid volatility; (2) companies with "Special Treatment" (ST, SST, and PT) status due to financial distress were removed, as their resilience metrics could skew results. The application of these filtering criteria resulted in a final sample of 624 companies suitable for further examination.

Measurement of Variables

Dependent variable: enterprise resilience. Based on the methodology described by Markman and Venzin (2014), ROE data for the enterprises were collected, and enterprise resilience was calculated using their outlined steps.

Independent variable: digital investment. Based on the work of Zhao et al. (2021), the enterprise digital transformation index was developed through text analysis techniques applied to the annual reports published by the enterprises. This index was used to evaluate the extent of digital investment in this study. Measuring digital investment is a multidimensional process that involves not only investment in technology and capital but also investment in cultural change within the enterprise, as well as the limited attention of management (Bellantuono et al., 2021; Sun and Sun, 2021). We believe the digital transformation index more comprehensively captures the depth and breadth of an enterprise's digital investment.

Mediating variables: green technological innovation. Referring to Xu et al. (2023), the quantity of green patent applications was quantified by taking the natural logarithm of the number of applications plus one to measure green technological innovation.

Control variables. In addition to being influenced by the levels of digital investment and green technological innovation, enterprise resilience is also affected by other variables. The control variables selected for this study include: firm size (SIZE), ownership type (SOE), listing age (AGE), and growth capability (GROW).

Data Collection and Processing

The digital transformation index reflecting digital investment was obtained through the collection and organization of annual report data from 2016 to 2020, utilizing text analysis methods. The ROE data used to calculate organizational resilience was sourced from the CSMAR database, while data on green technological innovation was obtained from the National Intellectual Property Patent

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Database. To ensure the integrity of the data and mitigate the impact of outliers, a 1% winsorization was applied to all continuous variables. The processing and analysis of the data were conducted utilizing tools such as Excel, Python, and Stata, thereby facilitating robust statistical evaluation of the relationships under study.

Statistical Techniques and Model Specification

The study employed a series of regression models to evaluate the hypothesized relationships, following Baron and Kenny's (1986) method for testing the direct and mediated effects:

$$ER_{it} = \alpha_0 + \alpha_1 DI_{it} + \alpha_2 Controls_{it} + \varepsilon_{it} \quad (1)$$

$$GTI_{it} = \beta_0 + \beta_1 DI_{it} + \beta_2 Controls_{it} + \varepsilon_{it} \quad (2)$$

$$ER_{it} = \gamma_0 + \gamma_1 GTI_{it} + \gamma_2 Controls_{it} + \varepsilon_{it} \quad (3)$$

$$ER_{it} = \theta_0 + \theta_1 DI_{it} + \theta_2 GTI_{it} + \theta_3 Controls_{it} + \varepsilon_{it} \quad (4)$$

Here, ER_{it} denotes the resilience level of enterprise i at time t, DI_{it} represents the digital investment level of enterprise i at time t, GTI_{it} indicates the level of green technological innovation of enterprise i at time t, and $Controls_{it}$ refers to a set of control variables, while ε_{it} representing the residual term.

Initially, Models (1) to (3) will be run to establish the direct relationships. If α_1 in Model (1) is significantly greater than 0, then H1 is accepted; if β_1 in Model (2) is significantly greater than 0, then H2 is accepted; and if γ_1 in Model (3) is significantly greater than 0, then H3 is accepted.

Following this, the study constructs Model (4) based on Models (1) and (3) to examine the mediating effect of green technology innovation. Once H1 to H3 are confirmed, it can be inferred that digital investment influences both enterprise resilience and green technology innovation, with the latter significantly correlated to enterprise resilience. In this context, digital investment can indirectly strengthen enterprise resilience by fostering green technology innovation, thus providing support for H4. Moreover, the significance of the parameter θ_1 in Model (4) determines the type of mediating effect. If θ_1 is not significant, it indicates that green technology innovation plays a full mediating role. If θ_1 is significant, it implies that green technology innovation serves as a partial mediator.

However, before proceeding with the regression analysis, we performed correlation and multicollinearity analyses. This preliminary step is essential as it identifies potential relationships between variables and checks for multicollinearity, ensuring the reliability of the regression models. By establishing these foundational insights, we enhance the robustness of our subsequent analysis, thereby providing greater confidence in the validity of our findings.

Results and Discussion

Results

Table 1 presents the correlation analysis and variance inflation factor analysis among variables. Digital investment positively correlates with green technological innovation and enterprise resilience, providing initial support for our hypothesis. Importantly, the correlation coefficients are below 0.5, and VIF values remain under 10, suggesting no significant multicollinearity and permitting valid regression analysis.

Table 1 Correlation analysis and Variance inflation factor analysis.

Variables	1	2	3	4	5	6	7
1.ER	1						
2.GTI	0.0131**	1					
3.DI	0.0020**	0.0312*	1				
4.SIZE	0.1341***	0.3332***	0.1301***	1			
5.SOE	-0.0130	0.0671***	0.0291	0.1272***	1		
6.AGE	0.0191	0.0150	0.0362**	0.3512***	0.1321***	1	
7.GROW	0.0880***	0.0080	0.0240	0.0781***	0.0240	0.0632***	1
VIF Value	——	3.1071	2.3532	1.8017	1.7549	2.0518	1.9543

Note: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

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Table 2 Regression Analysis Results for Testing Direct and Mediating Effects.

Variables	Model (1)	Model (2)	Model (3)	Model (4)
Control variable				
SIZE	0.0380***	0.1928***	0.0413***	0.0432***
SOE	-0.0969	0.2319**	-0.0941	-0.0922
AGE	-0.0011	-0.0115***	-0.0013	-0.0014
GROW	0.0709***	-0.0524*	0.0698***	0.0707***
Independent variable				
DI	0.0070*	0.0098*		0.0066**
Mediating variable				
GTI			0.0187*	0.0192*
$\overline{R}^2$	0.0244	0.1232	0.0240	0.0251

Note: * p<0.05, ** p<0.01, *** p<0.001

In the regression analysis (Table 2), Model (1) confirms that digital investment is significantly related to enterprise resilience ($\alpha_1 = 0.0070$, p<0.05), supporting H1. Model (2) reveals a positive relationship between digital investment and green technology innovation ($\beta_1 = 0.0098$, $p < 0.05$), supporting H2.

In Model (3), green technology innovation significantly impacts enterprise resilience ($\gamma_1 = 0.0187$, $p < 0.05$)), confirming Hypothesis H3. Model (4) introduces green technological innovation based on Model (1). The results show that the regression coefficient of digital investment on enterprise resilience is $\theta_1 = 0.0066$ ($p < 0.01$), which is lower than the regression coefficient of $\alpha_1 = 0.0070$ ($p < 0.05$) in Model (1). This indicates that green technological innovation plays a partial mediating role in the relationship between digital investment and enterprise resilience, supporting H4.

Discussion

Digital investment has a significant impact on enterprise resilience, consistent with the findings of Li et al. (2022). Li et al. (2022) examined how digital technology deployment affects supply chain resilience, arguing that it enhances transparency, visibility, and speed within the supply chain, thereby positively influencing supply chain disruptions and improving overall resilience. In the current context of uncertainty and increasing downward pressure on both the Chinese and global economies, enterprises are confused about how to increase their resilience to external shocks and achieve sustainable development goals. The findings offer a feasible solution: increasing digital investment and actively implementing digital technologies within enterprises. Specifically, digital investment enhances resilience by introducing and implementing digital technologies that allow companies to monitor and optimize natural resource management in real-time, reduce costs, and minimize environmental impact, while also improving the efficiency of market information acquisition and strategy development, thus bolstering both resilience and sustainable development. This interpretation is further supported by Soni et al. (2014), who identified information sharing and collaboration as key resilience drivers.

Digital investment also significantly impacts green technology innovation, aligning with Sia et al. (2021), who argued that digital transformation improves resource integration, information acquisition, and data analysis capabilities, thereby becoming a key driver of technological innovation in enterprises. This finding is further supported by the empirical study conducted by Ye et al. (2023), which found that digital investment significantly promotes green innovation in enterprises.

The positive relationship between green technological innovation and resilience mirrors Ardito et al. (2021), who identified innovation as a key factor for resilience during downturns. Expanding this understanding, our study finds that green technology innovation enhances resilience by improving companies' public image and satisfying environmentally conscious consumers, thus supporting sustainable development goals.

The findings indicate that digital investment enhances enterprise resilience by fostering green technology innovation, which drives efficient resource allocation, improvements

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in clean production technologies, and the development of green products, thereby bolstering the company's environmental image. This process aligns with the Natural Resource-Based View (NRBV), suggesting that while pursuing economic gains, companies can also achieve environmental benefits through digital-enabled green innovation. Acting as a mediating mechanism, green technology innovation enhances customer satisfaction and loyalty, further reinforcing the resilience of enterprises, and equipping them to adapt robustly to evolving environmental policies, changing consumer demands, and market fluctuations.

The broader implications of green technology innovation as a mediating mechanism lies in its redefinition of the relationship between enterprises and the natural environment, integrating sustainability as a core strategic component of resilience. Through digital investment, firms can establish long-term competitive advantages within a broader ecological system, characterized by operational efficiency and optimized resource management, brand reputation, and corporate social responsibility. The synergy of digitalization and green technology innovation enables companies to secure a sustainable market position amid increasingly stringent global environmental standards and societal expectations, driving them toward sustainable business models. Thus, the mediating role of green technology innovation further underscores the strategic importance of digital investment, establishing it as a crucial pathway to achieving resilience and sustainable development.

Conclusions and Recommendations

Conclusions

Amid global economic volatility, pandemics, and other emergencies, corporate resilience has emerged as a central focus in management research. While previous studies have examined the direct impact of digital investment on resilience, findings have been inconsistent, and few studies have explored this relationship within the context of green development. This study addresses this gap by analyzing how digital investment influences firm resilience and investigating the mediating role of green technology innovation in this relationship. We constructed four regression models to test our hypotheses based on data from companies in heavily polluting industries listed on the Shanghai and Shenzhen stock exchanges from 2016 to 2020.

Our findings reveal that digital investment not only enhances enterprise resilience directly but also promotes resilience indirectly by fostering green technology innovation. This dual pathway suggests that digital investments, when aligned with sustainability goals, can offer enterprises a strategic advantage in navigating disruptions while contributing to long-term sustainable development. These insights underscore the importance of incorporating green innovation into digital investment strategies, particularly for firms in high-pollution industries facing increasing regulatory and environmental pressures.

Recommendations

This study provides valuable insights with practical recommendations for managers and policymakers.

The findings indicate that companies should prioritize increasing digital investment and integrating digital technologies to confront environmental challenges and navigate economic pressures. In the context of Industry 4.0 and with a focus on long-term green development, digital investment can facilitate cleaner production practices and optimize resource allocation, strengthening resilience to external shocks and the capacity for sustainable development. Managers are encouraged to view digital technologies as operational tools and strategic levers that support green innovation and resilience simultaneously.

A critical aspect of leveraging digital investment lies in understanding how this investment impacts resilience, particularly through green technology innovation. Many companies struggle to fully realize the benefits of digital transformation because managers often allocate resources and establish strategies without a comprehensive grasp of these underlying pathways. The findings indicate that, particularly within Industry 4.0, focusing on digital investment that drive green technology innovation is essential for building resilience. Recognizing the synergy between digital and green transformations is paramount in markets where environmental standards are increasingly prioritized. For instance, companies can implement

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production management systems that monitor resource consumption and emissions, using real-time feedback to optimize production and resource use continuously. Additionally, engaging with stakeholders through digital platforms can help develop environmentally sustainable products and practices, fostering a culture of shared innovation and sustainability.

The study also highlights the importance of supportive policy frameworks that encourage digital investment aimed at advancing green technology innovation. Such policies incentivize businesses to adopt digital solutions and align this investment with broader resilience and sustainability goals. Policymakers can support this alignment by providing incentives for companies investing in green technologies, thereby fostering a stronger connection between economic objectives and environmental responsibilities. For industry leaders, digital investment should be recognized as strategic assets that reinforce resilience and green development, making sustainability a key component of digital transformation agendas.

Sector-specific strategies are crucial to maximize the effectiveness of digital investment. Different industries can leverage digital investment based on unique operational requirements and environmental impacts. For example, heavy manufacturing sectors can benefit from real-time monitoring systems to track environmental metrics like emissions and waste, improving efficiency and regulatory compliance. Conversely, sectors such as pharmaceuticals and high-tech industries might focus on innovations in clean production and efficient resource utilization. By tailoring digital strategies to each sector's specific challenges and goals, companies can more effectively harness digital investment, enhancing resilience in ways that resonate with the distinct demands of their industry.

Finally, for companies operating across various international contexts, adapting these recommendations to fit local regulatory and environmental landscapes is essential. International applications of digital investment strategies should account for regional variations in regulatory standards and market expectations. Comparative studies across countries with differing environmental regulations can validate these strategies on a global scale, offering insights into how digital investment in green innovation enhance resilience in diverse settings. Such adaptations can ensure that digital transformation and green innovation strategies remain effective and sustainable across different geopolitical and regulatory environments, ultimately fostering resilience on a global scale.

Limitations and future research

While this study provides valuable insights, several limitations highlight opportunities for further research. For instance, although the research centers on heavily polluting industries, it does not differentiate between sub-sectors within this broad category. Different types of heavy polluting industries-such as the capital- and technology-intensive pharmaceutical manufacturing industry versus the labor-intensive textile industry-are likely to exhibit distinctive operational and environmental characteristics. Therefore, future studies that explore these distinctions in greater detail may reveal industry-specific insights. Segmenting these industries to analyze how distinct sub-sectors interact with digital investment and green technology innovation might provide tailored strategies for resilience-building.

Additionally, given that this study's data primarily reflects Chinese enterprises, the findings may have limited generalizability across global contexts. To extend the applicability of these results, cross-national studies that test and refine the model across diverse geopolitical and regulatory settings would be beneficial. Comparative studies across countries and regions would affirm the model's relevance and provide insights into how differences in environmental regulations and market conditions affect the dynamics between digital investments, green innovation, and resilience. Such research could offer valuable perspectives for adapting resilience-building strategies in line with international environmental standards and policies.

Finally, this paper examines enterprise resilience as a holistic construct. Considering that enterprise resilience can be divided into situation awareness, management of keystone vulnerabilities and adaptive capacity (He et al.,

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2023), investigating these sub-dimensions may provide new insights.

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Monitoring Postpartum Risk Using Information System Decision-Making Support System: A Literature Review

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Abstract

The postpartum period begins after the expulsion of the placenta and fetal membranes and ends when the mother's reproductive organs return to their pre-pregnancy state. This recovery period is the most critical for a woman. Increased maternal morbidity and mortality rates mark maternal mortality during this period. Each year, there are 295,000 maternal deaths and 6 million prenatal deaths during childbirth and the postpartum period. This study aims to find out the health disorders that can be experienced by mothers in the postpartum period as well as information systems to monitor these problems. The study is a literature review of original articles published between 2018 and 2023. Sources were searched using the Science Direct, Scopus, and Proquest databases with the keywords "postpartum" and "monitoring system." Inclusion and exclusion criteria were used to determine article eligibility. The inclusion criteria were articles discussing the high-risk postpartum period and monitoring efforts, published between 2018-2023, and original articles. The exclusion criteria included inaccessible articles, abstracts or reviews, and articles not aligned with the study's objectives. Based on the article search results, 16 out of 6,152 identified articles met the criteria for review in this literature review. Health issues that can arise during the postpartum period include both physical and psychological problems. Physical issues include postpartum hemorrhage, postpartum hypertension, and venous thromboembolism. The most common psychological issue is postpartum depression. Developed and developing countries have increasingly implemented information systems during high-risk postpartum periods. These information systems are developed based on the specific issues mothers face during the postpartum period in each country.

Keywords: Information system, Monitoring system, Postpartum period

Introduction

The postpartum period is the period experienced by the postpartum mother, which generally lasts 6-8 weeks after delivery but is uncertain in the span of the week (Yasmini et al., 2022). The postpartum period begins after the removal of the placenta and fetal membranes and ends when the mother's reproductive organs return to their pre-pregnancy state (Sugita & Widiastuti, 2016). The postpartum period is one of the most critical periods for a woman. During this period, her organs recover to the same condition as before pregnancy (Anggorowati et al., 2022).

The period of childbirth and postpartum is a high-risk period for both mothers and babies, where 295,000 maternal deaths and 6 million prenatal deaths occur every year (Boatin et al., 2021). Postpartum bleeding is the leading cause of maternal mortality and severe morbidity globally, affecting 26% of women who give birth in Africa and 13% of women who give birth in Europe and North America (Pertile et al., 2022). South Korea, as one of the developed countries in Asia, is also still facing the problem of postpartum hemorrhage. Hemorrhage is one of the main causes of maternal death in the country (Misugi et al., 2022).

Hypertension is one of the diseases that aggravate the problem in the postpartum period. Postpartum hypertension is associated with various types of maternal morbidity and accounts for a quarter of all hospital readmissions in the United States (Lopes Perdigao et al., 2020). Postpartum depression is also one of the most common complications of postpartum. This depression affects 15% and 13% of postpartum

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mothers, respectively, in the U.S. and around the world (Shin et al., 2020).

Other problems associated with the postpartum period are obesity and venous thromboembolism. The postpartum period triggers significant disruptions in circadian rhythms, including rhythms related to eating, physical activity, sleep, and exposure to dark and light, which are related to obesity and cardiometabolic disease, respectively (Conlon et al., 2023). Meanwhile, venous thromboembolism is a health disorder that often occurs in the postpartum period. There are about 120 cases per 100,000 pregnancies and is 9% of the cause of death due to pregnancy (Walker et al., 2023).

Research that discusses health disorders in postpartum mothers has been carried out to date, but there is still little discussion about the use of information systems in monitoring problems in the postpartum period. This study aims to find out the health disorders that can be experienced by mothers in the postpartum period as well as information systems to monitor these problems.

Methodology

This research is a literature review that traced the article's source through the Science Direct, Scopus, and Proquest databases. The keywords used in the article search are *postpartum* and "*monitoring system*". The article eligibility criteria used include inclusion criteria and exclusion criteria as shown in Table 1.

From the search results with the determined keywords, 24 articles met the inclusion criteria, exclusion criteria, and research objectives. Figure 1 shows a flowchart for article search.

Table 1 Article inclusion and exclusion criteria.

Inclusion Criteria	Research articles on the postpartum period at risk and monitoring efforts carried out during that period
	Published in 2018-2023
	Original article
Exclusion Criteria	Inaccessible
	Only abstract
	Articles are only a literature review
	Not following with the purpose of the research

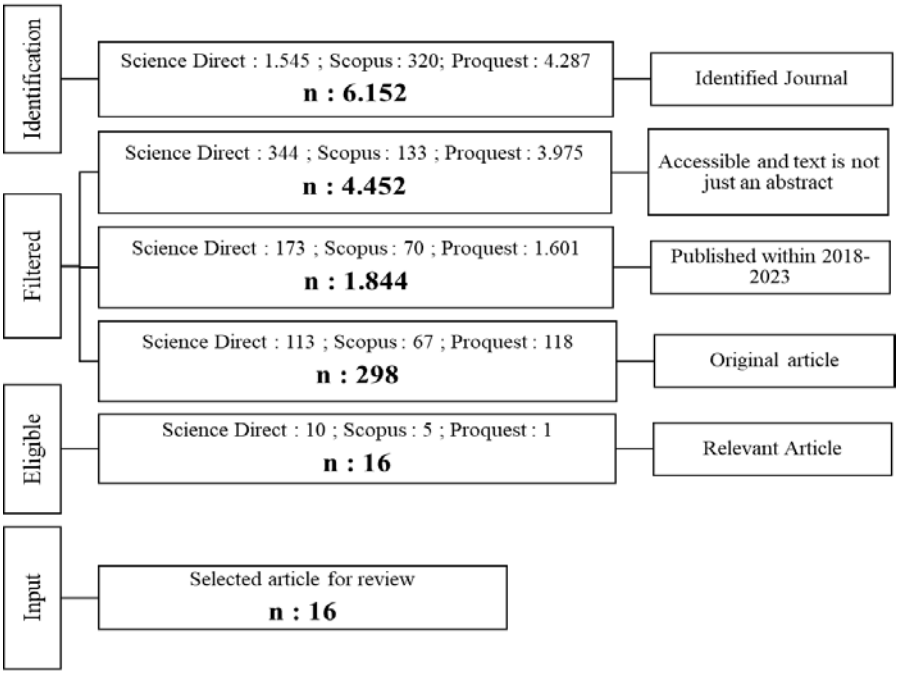

Figure 1 Article selection flowchart.

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Results and Discussion

Table 2 The results of the research article used.

No.	Author, Year, Country	Research Methods	Sample	Key findings
1.	Riccardo Pertile, Fabrizia Tenaglia, Silvano Piffer, 2022, Italy	Retrospective analysis observational studies	Women who had a postpartum hemorrhage in the Province of Trento during the period 2011-2016	The risk of postpartum bleeding is five times higher in mothers with third-degree vaginal tears due to spontaneous delivery. Furthermore, the risk of postpartum bleeding is three times greater in mothers with a cesarean delivery of more than one baby.
2.	Kenesha Smith Barber et al. 2019, Missouri	Analysis of U.S. Prams secondary data in 2012-2014	89,366 new mothers aged >12 years	Premature birth is significantly associated with despair for mothers who experience premature birth. However, the opposite result occurs in losing the mother's interest in her routine.
3.	Gabriela A. Barber, Julia R. Steinberg, 2022, United States	Cross-sectional *study* from Pregnancy Risk Assessment Monitoring System Data in 2012–2019	243,677 women	Postpartum depression symptoms are more at risk in women who have an unwanted pregnancy. Similar results also occurred in women who became pregnant after taking fertility enhancing drugs compared to women who became pregnant with the help of drug insemination procedures/ART.
4.	Adeline A Boatin et al., 2021, Uganda	Pilot pragmatic implementation with quasi-experimental	An average of 10 women per day who are ≥ 18 years old and undergo emergency cesarean delivery at Mbarara Regional Referral Hospital (MRRH)	The effectiveness of the system is assessed based on the number of near-miss accidents according to WHO, the maternal mortality rate, and the case fatality rate for postpartum hemorrhage, hypertension, and sepsis. Furthermore, the effectiveness of the implementation of system interventions will be assessed using the Reach, Efficacy, Adoption, Implementation, and Maintenance framework after four months of experimentation.
5.	Joana Lopes Perdigao, 2020, United States	Random Controlling Trial Method	84 women with gestational hypertension disorder who gave birth between August 2016 and January 2017 in the United States	Postpartum blood pressure is affected by race and BMI. Black women have a higher average blood pressure compared to non-black women. In addition, the decrease in postpartum blood pressure in women with a BMI of < 35 was more stable than that of those with a BMI of ≥ 35.
6.	Mengrui Lin et al., 2022, China	A cohort study	1,496 mother-infant pairs who had complete medical record questionnaire data from June 2015 and May 2018	Exposure to nine mixtures of perfluoroalkyl substances was positively correlated with the risk of postpartum hemorrhage. The riskiest exposure chemical for postpartum bleeding is perfluorohexane sulfonate.

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No.	Author, Year, Country	Research Methods	Sample	Key findings
7.	Edward J. Booth et al., 2021, Amerika	Cross-sectional retrospective study of Massachusetts PRAMS data from 2012-2017	8,453 women which 710 of whom have a disability	The risk of developing postpartum depressive symptoms in women with disabilities is higher than in non-disabled women. Moreover, a similar condition also occurs in stress-triggering events. Stress-triggering events were reported to be more common in women with disabilities (86.6%), compared to women without disabilities (66.6%).
8.	Amanda H.X. Lee et al., 2019, Kanada	Multicenter research with a retrospective approach	102 women who gave birth after a spinal cord injury	The prevalence of postpartum depression (25–37%) and postpartum anxiety (18–33%) is higher in women with spinal injuries than in the general maternal population.
9.	Rob F. Walker et al., 2023, United States	Retrospective cohort study using the MarketScan Commercial and Medicare Supplemental administrative databases	757,303 women of childbearing age whose date of delivery is valid for at least 12 weeks of follow-up	Women with autoimmune diseases such as systemic lupus, erythematosus, and Crohn's disease are at a higher risk of developing venous thromboembolism at 12 weeks after giving birth than those who do not.
10.	Chen Chi Duan et al., 2022, Chinese	A cohort study	10,209 women who received ANC services and gave birth from October 11, 2019 and February 14, 2021 at five hospitals participating in the study	Exposure to airborne chemicals such as PM10, CO, and NO_2 can increase the production of stress hormones during pregnancy. Among these hormones, namely cortisone, cortisone, epinephrine, and norepinephrine, will affect the neuropathology of postpartum depression.
11.	Alzina Koric et al., 2021, United States	A cohort study	3,906 postpartum women (2-6 months)	Women with PCOS had a 76% higher prevalence of postpartum depression/ anhedonia than women who did not have PCOS.
12.	Rachel P. Kolko Conlon, et al., 2023, United States	Experimental research with theory-based intervention methods	Seven postpartum mothers with BMI before pregnancy ≥ 25	Respondents perceive that ClockWork intervention and digital monitoring can help manage weight-related health behaviors during the postpartum period.
13.	Lisette T. Jacobson et al., United States, 2020	Controlled randomization test	72 healthy pregnant women who had a check-up at Ascension Via Christi Hospitals Wichita or Kearny County Hospital	eMOMS™ (Electronic Monitoring of Mom's Schedule) is an information system focusing on diet, exercise, and education about breastfeeding. The development of this system is based on the discovery that maternal overweight and obesity conditions contribute to postpartum overweight gain.

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No.	Author, Year, Country	Research Methods	Sample	Key findings
14.	Meishan Cui et al., Japan, 2020	The cohort study was based on data from the Japan Environment Children's Study (JECS)	80,872 pregnant women	Women who quit smoking early in pregnancy or five years before giving birth and who smoke after pregnancy have a higher risk of developing *postpartum* depression compared to women who have never smoked.
15.	Takuya Misugi et al., South Korea, 2022	Prospective observational studies	21 patients	The Clear Sight system is more accurate and precise than invasive monitoring systems in monitoring the blood pressure of the mammalian artery that is sensitized with spinal anesthesia. The system measures the presence of hemodynamic changes during a cesarean section.
16.	Dayeon Shin et al., United States, 2020	Retrospective cohort study of pregnancy risk assessment monitoring system data on 2012-2013	28,755 records	Mothers who had a history of depression before pregnancy were 3.15 times more likely to experience postpartum depression than mothers who did not have a history of postpartum depression.

Health Problems in the Postpartum Period

The postpartum period is one of the most critical periods for a woman. During this period, various health problems often arise as complications caused by the pregnancy and childbirth process. From Table 2, health problems in the postpartum period can be classified into physical and psychological problems.

a. Physical Problems

Some of the physical health disorders that occur in the postpartum period include postpartum bleeding, postpartum hypertension, and venous thromboembolism.

1. Postpartum hemorrhage

Postpartum hemorrhage is a blood loss of more than 500 cc experienced by mothers after giving birth vaginally or more than 1000 cc in mothers with cesarean delivery within 24 hours to before six weeks after delivery (Satriyandari & Hariyati, 2017) (Simanjuntak, 2020). Postpartum hemorrhage is the leading cause of maternal mortality and morbidity globally and is estimated to be responsible for a quarter of deaths that occur during pregnancy, childbirth, and postpartum (Pertile et al., 2022).

2. Postpartum Hypertension

Postpartum hypertension has a meaningful relationship with various occurrences of maternal diseases such as stroke, seizures, congestive heart failure, pulmonary edema, kidney failure, and even death. Postpartum hypertension accounts for at least a quarter of all hospital return hospitalizations in the United States (Lopes Perdigao et al., 2020).

3. Venous Thromboembolism

Venous thromboembolism is a disorder consisting of pulmonary embolism and deep vein thrombosis that occurs in about 120 out of every 100,000 pregnancies. Venous thromboembolism is characterized by the formation of blood clots in the deep veins in the legs, groin, or arms. If it moves in the blood circulation to the lungs and settles in the lungs it is known as a pulmonary embolism. In the postpartum period, the highest risk of venous thromboembolism occurs during the first week after delivery (90 per 100,000) and then decreases as the weeks go by (Walker et al., 2023).

b. Psychic Problems

Psychic problems are a common complication in pregnancy and are the underlying cause of about 9% of pregnancy-

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related deaths (Bauman et al., 2018). The main and most frequent psychological problem during the postpartum period is postpartum depression. Postpartum depression is a form of abnormal physiological adaptation experienced by postpartum mothers. Postpartum depression is a serious mental health disorder that can trigger a variety of impacts on maternal and infant health, affecting about 10% of women worldwide (Booth et al., 2021).

Risk Factors Related to Postpartum Disorders

a. Postpartum Hemorrhage

Some of the risk factors that cause postpartum bleeding are vaginal tears, multiple births, and exposure to chemicals (*perfluoroalkyl*).

1. Vaginal Tears

Vaginal tears occur due to sudden and excessive stretching of the birth canal when the fetus is born. Vaginal tears can be a separate wound or a continuation of a perineal tear (Booth et al., 2021). A vaginal tear can cause a rupture of a vein (Eriza et al., 2015).

2. Multiple Births

Multiple births or multiple (twin) pregnancies are pregnancies with two or more fetuses at once (Julizar et al., 2019). Multiple pregnancies are related to excessive uterine stretching (Aisyah, 2022). This condition can cause the uterus to be unable to contract immediately after the placenta is born, which often triggers uterine atony. Uterine atony increases the risk of postpartum bleeding (Julizar et al., 2019).

3. Exposure to Chemicals (Substances *perfluoroalkyl*)

Perfluoroalkyl substance is an artificial chemical usually used in various models, such as food packaging, kitchen utensils, foam fire extinguishers, paper, textile coatings, and medical equipment. Exposure to substances *perfluoroalkyl* in the mother can cause negative impacts, such as placental dysfunction, gestational hypertension, gestational diabetes, and preeclampsia. Research shows that if the placenta malfunctions, the placenta will attach to the myometrium, which causes no separation between the surface of the placenta and the uterus, so a separation process is needed. This separation process can increase the risk of postpartum hemorrhage. Exposure to substances such as perfluoroalkyl can also impair liver function, decreasing liver coagulation function. This condition triggers an increased risk of postpartum bleeding (Lin et al., 2022).

b. Postpartum Hypertension

Risk factors for postpartum hypertension are black women, BMI (Body Mass Index), age, and maternal readiness to undergo the postpartum period, which affect the mother's calm so that blood pressure in the mother tends to be high.

1. Skin Color (Race)

Skin color is related to trends and postpartum blood pressure recovery periods *(Lopes Perdigao et al., 2020)*. Black women experienced a slower decline in postpartum blood pressure compared to white women and had higher blood pressure than white women at the end of the 6th week of the postpartum period. Black women have twice as long cardiovascular recovery as white women (Hauspurg et al., 2020).

2. Body Mass Index (BMI)

A high pre-pregnancy BMI can increase the risk of postpartum hypertension and increase blood pressure trends in all trimesters of pregnancy *(Lopes Perdigao et al., 2020)*. The body mass index (BMI) correlates directly with blood pressure. The greater the body mass, the more blood is needed to supply oxygen and food to the body's tissues. Thus, the volume of blood circulating through the blood vessels increases, putting greater pressure on the artery walls (Simamora et al., 2019).

c. Venous Thromboembolism

One of the risk factors for venous thromboembolism is the presence of autoimmune diseases suffered by the mother. Systemic autoimmune diseases such as systemic lupus erythematosus are associated with increased inflammation. Systemic lupus erythematosus can potentially increase molecular procoagulant factors, ultimately triggering venous thromboembolism. Another autoimmune disease that can be a risk factor is Crohn's disease, which generally affects the digestive system. Disease-induced inflammation Crohn's can lead to complications outside the intestinal system that increase the risk of venous thromboembolism. Other factors such as smoking, obesity, and certain obstetric procedures and complications (e.g., cesarean delivery, obstetric bleeding, or preeclampsia) are also known to increase the risk of venous thromboembolism (Walker et al., 2023).

d. Postpartum Depression

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Risk factors that can increase the incidence of postpartum depression are premature birth, unwanted pregnancy, pregnant women who use fertility enhancing drugs, women with disabilities, women with spinal cord injuries, exposure to chemicals (PM10, CO, and NO_2), *Polycystic Ovary Syndrome* (PCOS), smoking history, maternal age, education, marital status, first pregnancy age, and history of depression that has been experienced.

1. Premature Birth

Increased levels of prematurity will increase the likelihood that mothers will feel hopeless. Parents of babies born prematurely are more likely to have feelings of fear and anxiety as a result of their new role as parents coming sooner than expected. As the rate of premature birth increases, the likelihood of mothers feeling hopeless also increases (Barber et al., 2021).

2. Unwanted Pregnancy

Unwanted or unplanned pregnancies will have a psychological impact on the mother due to the burden that the mother must bear (Solama et al., 2023). Unplanned pregnancies are related to the physical, mental, and economic readiness of the mother. If the mother has strong physical and mental readiness, she will be more able to adapt to her new role. This condition is different for mothers who are not ready for pregnancy; for example, if the mother experiences an unplanned pregnancy, the risk of postpartum depression will be higher (Qiftiyah, 2018).

3. Use of Fertility Enhancing Drugs

Some fertility enhancement drugs, such as Clomiphene Citrate, work directly in the hypothalamus, which plays a role in the regulation of emotions and moods. This drug is known to disrupt mood so mothers who use it have a higher risk of experiencing postpartum depression (Barber & Steinberg, 2022).

4. Disability Circumstances

Women with physical disabilities are likely to experience a variety of reactions to their new status as mothers, such as distrust, intrusive questions, or even feelings of inferiority (Lee et al., 2021). Women with physical limitations are more prone to experiencing various types of stress such as financial stress, traumatic experiences, relationships, and emotions (Booth et al., 2021).

5. Spinal Injuries

Spinal cord injuries can trigger muscle stiffness, neuropathic pain, bladder and bowel dysfunction, and autonomic dysreflexia. This can restrict/interfere with a mother from activities such as breastfeeding her baby due to limited mobility and lactation dysfunction. Breastfeeding is known to reduce the risk of postpartum depression (Lee et al., 2021). Mobility limitations also make it difficult for women with spinal cord injuries to access health services to monitor their physical and mental condition. Thus, it will trigger stress, depression, and anxiety as well as other mental health problems in mothers who have suffered spinal cord injuries.

6. Chemical Exposure $(PM)_{10}$, CO, and NO_2)

PM_{10} exposure, CO, and NO_2 during pregnancy increases the risk of postpartum depression. Air pollution can trigger oxidative stress and neuroinflammation that can increase the production of stress hormones such as cortisol, cortisone, epinephrine, and norepinephrine, which affect the neuropathology of postpartum depression (Duan et al., 2022).

7. *Polycystic Ovary Syndrome* (PCOS)

Women with PCOS have an increased vulnerability to postpartum depression and anxiety due to hormonal imbalances and metabolic disorders such as increased androgens, hypothalamic-pituitary-adrenal axis hypersensitivity, plasma adrenocorticotropic hormone, and serum cortisol levels. So they are more susceptible to stress triggered by the pregnancy process (Koric et al., 2021).

8. Mother's Smoking History

Women are prone to depression and are prone to mood swings during periods of hormonal changes such as pregnancy, postpartum period, and menopause due to changes in sex steroid hormones (estrogen and progesterone). Smoking has an anti-estrogenic effect by decreasing endogenous estrogen biosynthesis as well as bioavailability resulting in an increased risk of postpartum depression (Cui et al., 2020).

9. History of Depression

Women who have depressive symptoms will continue until the postpartum period (Arami et al., 2020). A history of depression is related to the interaction of cortisol levels with cytokinins. Cortisol is a hormone in the body that plays a role in responding to stress (Ambarwati et al., 2018). The existence of this interaction causes

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mothers who have a history of depression to be more at risk of postpartum depression.

Information System Related to Postpartum Disorders

Health risks during the postpartum period should not be ignored. Let's take one example of gestational diabetes mellitus in the United States, where 6%-20% of pregnant women experience it. This problem can trigger various pregnancy and childbirth complications that can increase maternal and neonatal morbidity and mortality. The main risk factors for gestational diabetes mellitus are overweight and obesity. In the United States, the prevalence of overweight and obesity in women is relatively high, at around 27% and 41% respectively. In addition, the rate of mothers who breastfeed exclusively for six months is also relatively low, at 25%. Exclusively breastfeeding is one of the protective factors of gestational diabetes mellitus. This condition is the reason for the development of the Electronic Monitoring of Mom's Schedule (eMOMS™), which adopted the Diabetes Prevention Program (DPP). eMOMS™ has been tested nationally to reduce the risk of diabetes and combined with breastfeeding support. Table 2 also shows us some information systems have been developed to help handle health problems in the postpartum period in several countries.

1. Birth Assistance Certificate (CedAP) of Italy

The Clinical Epidemiology and Evaluation Service of the Provincial Health Authority of Trento, Italy, has a birth event monitoring system, namely the Birth Assistance Certificate (CedAP). The annual CedAP provincial database is recorded by midwives in each maternity unit's electronic media as a basic tool for recording the incidence of postpartum hemorrhage. Information regarding the occurrence and entities of blood loss is recorded in the "*placenta removal*" section in CedAP. The advantages of CedAP include allowing the identification of risk factors for postpartum hemorrhage, especially those related to maternal factors and childbirth factors. CedAP can also be used to monitor the quality of health services and improve efficiency and effectiveness in both data collection, analysis, and access. The disadvantages of CedAP are the lack of in-depth analysis of the data produced and the limited data and information because the scope of the system only covers the Province of Trento, Italy (Pertile et al., 2022).

2. eMOMS™ in the United States

The Electronic Maternal and Obstetric Monitoring System (eMOMS™) is a lifestyle change program through Facebook that focuses on diet, exercise, education, and breastfeeding support through regular face-to-face counseling sessions during and after pregnancy. The program also provides weekly 15-minute videos on nutrition and exercise during and after pregnancy, as well as online breastfeeding education and ongoing support. Electronic Maternal and Obstetric Monitoring System (eMOMS™) as a system for monitoring the health of pregnant women and fetuses during pregnancy, during childbirth, and postpartum. Data is taken from patients through fetal monitoring devices, blood pressure, and blood glucose. eMOMS™ will provide reports and analysis of maternal and fetal health risk factors so doctors can provide more appropriate and effective treatment. The advantages of eMOMS™ include content that is easy to access anywhere and anytime, affordable program costs, and support pregnant women and postpartum mothers to adopt a healthy lifestyle. The eMOMS™ system is still in the trial stage, so further research is needed to determine its long-term effectiveness. The delivery of program content through social media requires participants to have access to the internet and technological capabilities (Jacobson et al., 2020).

3. ClockWork in the United States

In the postpartum period, mothers can experience healthy behavioral irregularities such as disturbances in circadian rhythms related to obesity and weight management and a dark and light 24-hour cycle related to the regularity of biopsychosocial rhythms. Biological clocks regulate these behavioral deviations with the dark-light cycle of the environment. The advantages of ClockWork include 12 personal coaching sessions that deal with behavioral indicators and factors related to weight management and the postpartum period. The app is also easy for digital self-monitoring to provide real-time feedback and interventions. The calendar view on this app allows users to see which behavioral indicators they have monitored over a while. Further research is still needed to find out the effectiveness and shortcomings of ClockWork (Conlon et al., 2023).

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4. Heart Rate Variability *monitoring system* via *smartwatch* in Finland

A study in Finland implemented an information system to monitor Heart Rate Variability (HRV) during pregnancy and postpartum. Heart rate variability can indicate the presence of hypertension or preeclampsia and reflect the mental health status of pregnant and postpartum women. The parameters of Heart Rate Variability (HRV) are typically measured using an electrocardiogram (ECG) or photoplethysmogram (PPG). The system collected data by capturing photoplethysmogram (PPG) sensors using a Samsung Gear Sport smartwatch and a cross-platform mobile application. The collected data was stored in the smartwatch's internal memory and manually transmitted via a Wi-Fi connection to a cloud server. The advantages of using a smartwatch for HRV monitoring include providing early remote warnings non-invasively, being more affordable, and being more straightforward to use daily. However, the limitations of HRV monitoring systems include reduced accuracy due to sensitivity to environmental temperature, skin movement, and skin condition, as well as the limited number of measurable parameters (Sarhaddi et al., 2022).

Conclusions and Recommendation

The postpartum period is a critical period for mothers as they are vulnerable to health issues. Health problems that may arise during the postpartum period include physical issues such as postpartum hemorrhage, postpartum hypertension, and venous thromboembolism, as well as mental health issues such as postpartum depression.

The use of information systems during the postpartum period at risk has begun to be widely applied in various countries. For example, CedAP in Italy is used to monitor bleeding during the delivery which is then used to identify risk factors for postpartum hemorrhage, especially those related to maternal factors and childbirth factors. Furthermore, in the United States there is an eMOMS designed to monitor the health of pregnant women and fetus during pregnancy, childbirth, and postpartum and support mothers to breastfeed exclusively as an effort to prevent gestational diabetes mellitus. In the United States, there is also ClockWork that helps mothers maintain a healthy lifestyle after childbirth as an effort to manage the mother's postpartum weight. In addition, in Finland there is a monitoring system for heart rate variability through smartwatches during pregnancy and postpartum to detect hypertension or preeclampsia, and describe the mental health status of pregnant women and postpartum.

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Comparative Study of Fertility between Migrant and Nonmigrant Populations

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Abstract

Fertility refers to the actual reproductive outcomes of a woman or a group of women. This demographic characteristic is influenced by various factors, including migration, income, education, age at first marriage, and the use of contraceptives. This study aims to explore the differences in fertility patterns between migrant and non-migrant populations across different regions and to identify the factors influencing these patterns. Utilizing a literature review approach, the study adheres to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) methodology. Relevant literature was gathered from electronic databases such as Google Scholar, ScienceDirect, and Scopus using keywords like "fertility, migration, migrant population, and non-migrant population". The selection process, based on inclusion and exclusion criteria, yielded 17 articles for detailed review. The review of these articles revealed that fertility patterns among migrant and non-migrant populations do not follow a specific or consistent trend. In some regions, migrants exhibit higher fertility rates than non-migrants, while in other areas, the reverse is true. This variability suggests that fertility is a complex phenomenon influenced by multiple interacting factors. Key determinants identified include cultural practices, economic conditions, educational levels, political environments, and demographic characteristics. For instance, migrants from regions with high fertility norms may continue to exhibit high fertility in their new locations, while economic opportunities and educational advancements in the host country might lead to lower fertility rates among some migrant groups. Understanding these nuanced patterns is crucial for policymakers and public health officials as they design interventions and programs aimed at managing population growth and supporting reproductive health. By recognizing the diverse factors that influence fertility, more effective and culturally sensitive strategies can be developed to address the unique needs of both migrant and non-migrant populations.

Keywords: Fertility, Migration, Migrant population, Non-migrant population

Introduction

Population is a group of people who are administratively registered as occupying an area. As time goes by, the population continues to increase, it is even feared that the increase will exceed the required food supply. This is in accordance with Malthus's theory, which states that "The rate of population growth is like a geometric series, while the rate of food growth is like an arithmetic series", meaning that the rate of population growth is faster than the rate of food growth. If the rate of population growth is not suppressed, then in the long term, humans will experience a crisis of natural resources and will compete with each other to get them (Suartha, 2016).

Rapid population growth, without being accompanied by good quality, will be a burden on national development (Ramadani, 2022). The high rate of population growth in a country will have a complex impact because it can influence various aspects, starting from economic, social, cultural, political, educational and health aspects. In fact, the impact can cross national borders because in this era of globalization, people can easily migrate from one country to another (Suartha, 2016).

The rate of population growth in a region is influenced by three components, namely fertility, mortality and migration. Fertility increases

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the rate of population growth, while mortality decreases the rate of population growth. Meanwhile, migration has two effects, namely that it can increase the rate of population growth if in-migration is greater than out-migration, and it can reduce the rate of population growth if out-migration is more than in-migration. This shows that the components of fertility and migration both play an important role in increasing the rate of population growth (Sudibia et al., 2013).

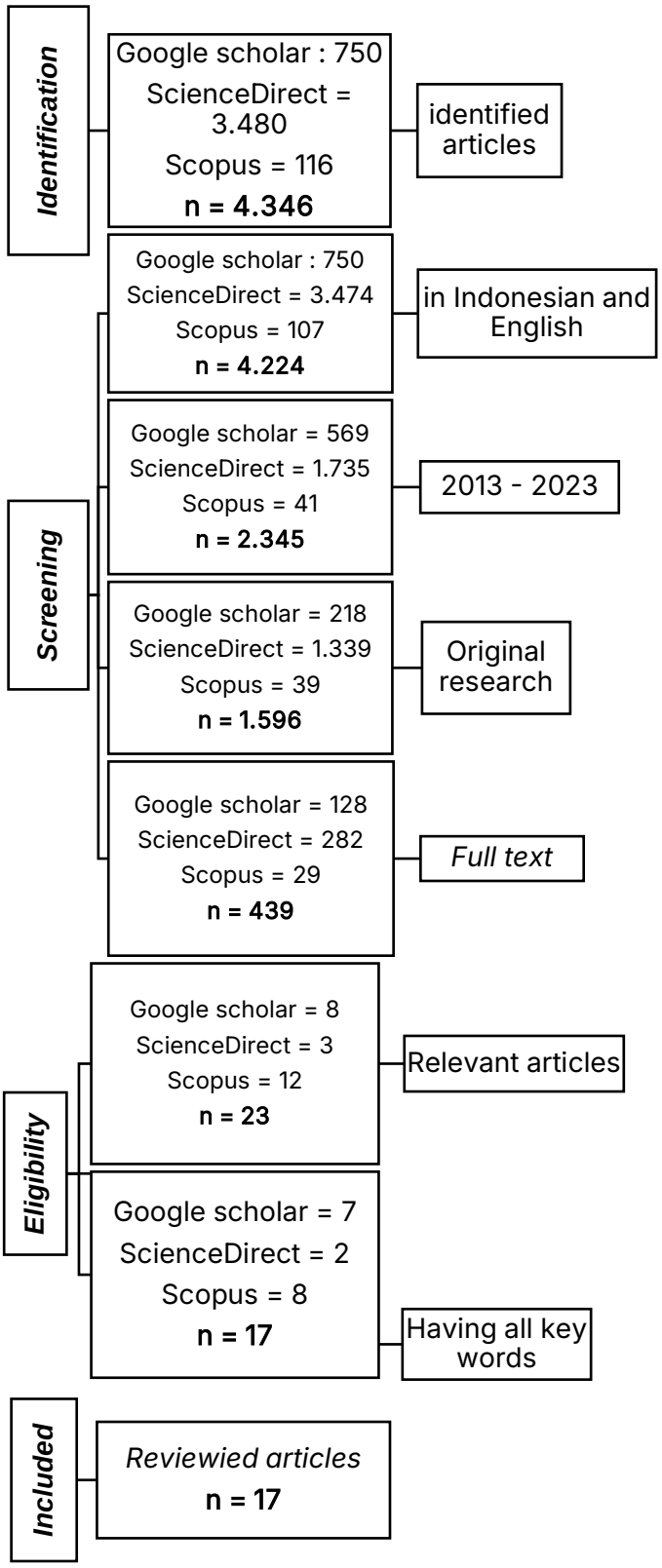

Figure 1 Literature Collection Stage using the PRISMA Method

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Fertility is the actual reproductive result of a person or group of women. Fertility levels can be measured by the Total Fertility Rate (TFR). Total Fertility Rate (TFR) is the average number of children a woman gives birth to during her reproductive period. One of the factors that influences fertility is migration, in addition to other factors, such as income, education, age at first marriage, and use of contraception. (Mahendra, 2017).

Migration is the movement of people from one place to another across political/state boundaries or administrative boundaries within a country, with the aim of settling (Dewi et al., 2019). The factors that influence migration are pull factors from the destination and push factors from the place of origin. Pull factors, such as the rapid development of industry and education as well as the desire to foster sustainable extended family relationships at the destination. Meanwhile, push factors, such as the desire to escape from restrictive social and cultural rules, disasters, and economic constraints from the place of origin (Suartha, 2016).

Migration status can affect fertility. The relationship between migration and fertility can be explained by several hypotheses, namely the socialization hypothesis, adaptation hypothesis, selection hypothesis, and disruption hypothesis. The socialization hypothesis shows that migrant fertility is reflected in the dominant fertility during childhood, so that migrant fertility will match fertility in the region of origin and will begin to adjust to fertility in the destination region in the next generation. The adaptation hypothesis suggests that migrant fertility will resemble destination fertility over time. Selection hypothesis suggests that a certain group's fertility preferences are more similar to fertility at the destination than at the origin. Meanwhile, the disruption hypothesis shows that after migration, migrant fertility will decrease or be low due to disturbing factors (Ekawati et al., 2017).

Based on the description of the problem above, it is necessary to carry out a literature review, in the form of a fertility comparison study between migrant and non-migrant populations to determine the differences in fertility patterns between migrant and non-migrant populations from various regions and the factors that influence them.

Methodology

This research uses a literature review method that refers to the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analysis) method. Literature collection was sourced from the electronic databases Google Scholar, ScienceDirect, and Scopus by including the keywords "Fertility, Migration, Migrants and Non-Migrants". The literature searched was in the form of scientific articles which were analyzed and adjusted to the inclusion criteria and exclusion criteria. Article inclusion criteria are scientific articles published in 2013–2023, using Indonesian-English, in the form of original articles, open access, and available in full text. Meanwhile, article exclusion criteria are articles that are not related to the theme of fertility in migrant and non-migrant populations and do not include all keywords. Based on the inclusion and exclusion criteria, 17 articles were obtained for analysis.

Results and discussion

Table 1 Literature Review.

No	Title, year	Research method	Result
1.	Comparative Study of Population Fertility between Migrants and Non-migrants in Bali Province, 2013	Research was conducted qualitatively and quantitatively through structured interviews and observations.	It was found that the average plenary parity (age group for women 45-49 years) for migrants was 2.50 and for non-migrants it was 2.32. The average height of migrants' plenary parity is compared Non-migrants are determined by a lower age at first marriage, shorter duration of breastfeeding, lower participation in family planning programs, lower education level, and a lower proportion of those working. The use

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No	Title, year	Research method	Result
			of stable contraceptives among migrants is lower than non-migrants. The ideal number of children among migrants is between 1-6 children, while for non-migrants it is between 1-5 children (Sudibia et al., 2013).
2.	Fertility and Migration: Population Policy for Migrants in Sleman Regency, 2015	Survey research with a quantitative approach.	The fertility rate of migrants in Sleman Regency is greater than the fertility rate of non-migrants. This also means that the increase in TFR in Sleman Regency was contributed more by the migrant PUS group than the non-migrant PUS group because the value was higher. (Arif et al., 2015).
3.	The Influence of Urbanization, Education and Income on Fertility Levels in five Cities of Aceh Province, 2016	The model used is a panel model with an OLS (Ordinary Least Square) approach with the Fixed Effect Model analysis method.	Based on the results of research that has been conducted, it can be concluded that urbanization (URB) has a positive and significant effect on fertility levels in five cities in Aceh, because residents living in urban areas in Aceh have a mindset that is not much different from village residents and villagers who have moved. to the city are rural residents who are poor and have low education so that behavior in the city still has village characteristics, this results in fertility in urban areas continuing to increase along with increasing urbanization (Arialdi & Muhammad, 2016).
4.	Fertilitas Migran dan Faktor yang Memengaruhi Fertilitas di Jawa Barat, 2017	This study uses a quantitative approach, namely secondary data analysis, while the data source used is the 2015 Susenas.	The research results show that there is a tendency for migrants to have higher fertility compared to non-migrants. Meanwhile, socio-economic factors that influence fertility are education, age at first marriage, use of contraception, and main activity (work).(Ekawati et al., 2017).
5.	The Effect of Culture on the Fertility Decisions of Immigrant Women in the United States, 2018	Cultural identification uses data on immigrant women by exploiting variations in the average number of children born by country of origin, age, education level, and employment status.	The results show that the average number of children born in the country of origin is positively related to the number of children born to immigrants living in the US, indicating that culture matters (Marcén et al., 2018).

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No	Title, year	Research method	Result
6.	The Fertility of Internal Migrants to Kinshasa, 2017	Identify migrant characteristics that may explain fertility differences between migrants and non-migrants in terms of fertility and other fertility-related characteristics. In addition, to find information about fertility based on duration of residence, number of lifetime moves, and age at first migration	Migrants have significantly higher fertility rates than permanent residents of Kinshasa (non-migrants), but the differences are relatively small. This higher fertility is partly due to patterns of contraceptive use among migrants (Anglewicz et al., 2017).
7.	A Comparative Study of Fertility Preferences of Nigerian Female Migrants and Non-migrants in Benin City, Nigeria. 2018	Data were collected from 760 migrants and non-migrants through stratified sampling techniques and analyzed using descriptive statistics, Chi-square, correlation, and ordinal regression.	The fertility preferences of non-migrants are lower (average 3.89 children) compared to migrants (4.14). Migrants who stay abroad longer are 1.06 times more likely to choose a larger family size compared to those who stay for a shorter period of time (Peter & David, 2018).
8.	Comparing the Fertility of Ghanaian Migrants in Europe with Nonmigrants in Ghana, 2018	Researchers used 2 stages to identify the problem, the first was to identify discrete time hazard model estimates of first births to evaluate whether the timing of first births was influenced by migration, the second was to apply Poisson regression techniques to test differences in complete fertility.	It was found that Ghanaian migrants delayed first birth compared with nonmigrants. The largest differences occur at ages 20 to 24 years for women and 20 to 29 years for men. Findings regarding complete fertility show that migrants have fewer children compared to non-migrants and this difference reduces significantly if we take into account their educational level (Wolf & Mulder, 2019).
9.	Impact of internal migration on fertility in Cotonou, Benin Republic, 2018	This study used data from the 2012 Benin Republic Demographic and Health Survey and focused on married women aged 15-49 years and living in	The results show that migrants adapt gradually to the fertility patterns of non-migrants. This gradual adaptation is compounded by the relative selectivity of migrants who have similar fertility preferences to non-migrants. Finally, migrants who recently moved for work or school reasons had the

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No	Title, year	Research method	Result
		Cotonou (n=722). Tobit regression was used for multivariate level analysis.	lowest number of births over the past five years, supporting the disruption hypothesis (Banougnin et al., 2018).
10.	Comparative Study of Migrant and Non-migrant Fertility in Singaraja City, 2017	This research was conducted qualitatively and quantitatively. The sample for this study was 10% migrant PUS (62 people) and 10% non-migrant PUS (61 people) taken using proportional random sampling. Differences between migrant and non-migrant fertility were analyzed using independent sample t-tests.	There is a significant difference between the fertility of migrants and non-migrants in Singaraja City (t-test=4.236, at a significance level of 0.05%). The differences in these characteristics lie in the number of children and the birth distance between children. The number of children owned by migrant PUS is higher than that of non-migrant PUS. The majority of children in PUS are migrant, namely 3-4 children, while in PUS non-migrant, namely 1-2 children. The birth interval between children in migrant PUS is irregular, while the birth interval between children in non-migrant PUS is regular, namely 4-6 years. These two things are because knowledge and awareness of family planning among non-migrant PUS is still low, and vice versa (Haribaik et al., 2017).
11.	The Influence of Socio-Economics and Demography on Fertility Levels in West Denpasar, 2021	This research was carried out quantitatively with path analysis.	The number of children of migrant residents is less than the number of children of non-migrant residents because migrant residents tend to use long-term contraceptives due to low socio-economic factors (difficulty getting work and the high cost of living in urban areas) (Pranata & Sudibia, 2021).
12.	The Influence of Migration Status, Employment, Education, and Economic Background on UKP and Fertility of Women of Childbearing Age, 2022	This research was carried out quantitatively with data analysis, in the form of descriptive statistics and inferential statistics, consisting of path analysis and Sobel test. The sample size was 123 WUS with purposive sampling and accidental sampling techniques.	Migrant WUS have higher fertility, amounting to 0.310 people compared to non-migrant WUS. Migrant WUS have a lower age at first marriage, amounting to 1.092 times compared to non-migrant WUS. Low marriage age is influenced by low education level, informal employment status, and high economic background (Jayakusuma & Sudibia, 2022).
13.	Increased Number of Live Births by Migrant Mothers Shows Areal	This research was conducted qualitatively by	Over the last 3 decades (1990-2020), the number of live births to migrant residents increased from 16,154 (1.31%) in 1990 to

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No	Title, year	Research method	Result
	Inequality in Japan: A Descriptive Study, 2023	describing live birth data for Japanese mothers and migrant mothers. This research uses vital statistics data from the Ministry of Health, Labor and Welfare (MHLW) data from Japan, and foreign population statistics data from the Immigration Services Agency (ISA) of Japan.	26,517 (3.08%) in 2020, while the number of live births to native Japanese residents decreased drastically from 1,212 ,890 in 1990 to 83,115 in 2020. The increase in the number of live births was contributed by an increase in the number of live births to migrant mothers whose husbands were not Japanese, which increased from 46.2% in 1990 to 70.9% in 2020. Births living by migrant mothers, concentrated in four prefectures, namely Tokyo, Aichi, Kanagawa and Osaka. The increase in the number of live births is due to high income levels and local communities that can help with the language and cultural barriers of migrant mothers in the process of pregnancy and delivery (Nishino et al., 2023).
14.	Ethnic Fertility Behavior and Internal Migration in Nigeria: Revisiting the Migrant Fertility Hypotheses, 2020	This research was carried out quantitatively with data analysis using the chi-square test and Poisson regression.	The majority of migrants have a lower Children Ever Born (CEB) than non-migrants in the migration destination area. This is because migrants bring aspects of cultural and social values from their area of origin. Low CEB is influenced by high levels of education and wealth status (Odimegwu & Adewoyin, 2020).
15.	Migrants' Fertility in Italy: A Comparison Between Origin and Destination, 2020	This research was conducted quantitatively with data analysis using the Kaplan–Meier method	The socialization hypothesis applies to migrant WUS from Morocco because the fertility rate remains the same as the country of origin over time. The fertility of migrants is higher than the fertility of non-migrants in Italy. This is because they adhere to a patriarchal culture. Meanwhile, the adaptation hypothesis applies to migrant WUS from Albania, because over time, their fertility rate decreases, until it resembles the fertility of the Italian non-migrant population. This is because they uphold gender equality. Meanwhile, WUS migrants from Ukraine experienced disruption because since migrating to Italy, their fertility has continued to decline. This is because the majority of migrants are more than 30 years old (Impicciatore et al., 2020).
16.	Fertility Differences between Migrants and Stayers in a Polygamous	This research was carried out quantitatively with data analysis	External migrant women and men to Europe have fewer children than non-migrants in Senegal, Africa during their reproductive years. This is because prolonged separation

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No	Title, year	Research method	Result
	Context: Evidence from Senegal, 2020	using Poisson regression.	of a couple makes fertility recovery difficult or even impossible. Polygamous migrant men have more children than monogamous migrant men. However, polygamous migrant men have fewer children than polygamous non-migrant men because of difficulties in restoring their fertility (Kraus & González-Ferrer, 2023).
17.	Does Emancipation Matter? Fertility of Chinese International Migrants to the United States and Nonmigrants during China's One-child Policy Period, 2021	This research was conducted quantitatively with data analysis using logistic regression.	Chinese WUS who migrate to the USA have higher fertility than non-migrant WUS in China. This is because China implements the one child policy for population control. The chance of migrant WUS experiencing a second birth is 3.4 times higher than migrant WUS. Apart from that, fertility rates also increase with increasing time of residence in the USA, where migrant WUS are 14 times more likely to give birth again after 3 years of residence than non-migrant WUS (Nie & Baizan, 2021).

Model of the Relationship between Migration and Fertility

Fertility among migrant and non-migrant populations does not form a particular pattern. In some areas, the fertility of migrants is higher than that of non-migrants, and vice versa. Higher fertility among migrants occurs in migrants in Bali (migrant parity 2.5; non-migrants 2.32), Sleman, West Java, Aceh, Japan, the United States, Italian immigrants from Morocco, and immigrants from Kinshasa, Congo. Meanwhile, lower fertility among migrants occurred among migrants in Benin City, Nigeria (migrant parity 3.89; non-migrants 4.14), Ghana, West Denpasar, Bali, Italian immigrants from Ukraine, and immigrants from Cotonou, Benin Republic. In fact, there are migrants' fertility that reflects the fertility of their destination, such as United States immigrants from China, Italian immigrants from Albania, and immigrants from Cotonou, Benin Republic.

The high and low levels of fertility among migrants and non-migrants in a region refer to three models of the relationship between migration and fertility, namely the socialization model, adaptation model and disruption model.

1. Socialization Model

This model shows that migrants' fertility preferences correspond to fertility in their place of origin (Ekawati et al., 2017). This is influenced by the culture brought from the place of origin and influenced by the characteristics of the educational level and economic conditions of migrants.

This model is experienced by many migrants, both national and international migrants. National migrants who experience this model are migrants who urbanize in five cities in Aceh Province. Fertility among migrants is higher than non-migrants because they still carry the culture from the village in their mindset to have children. Apart from that, the high fertility of migrants is also influenced by their low level of education and economy (Arialdi & Muhammad, 2016).

International migrants who experience this model include United States immigrants, Italian immigrants from Morocco, Japanese immigrants, Nigerian immigrants, and immigrants from Kinshasa, Congo. Preferences for fertility levels among migrants in these countries are influenced by culture. Moreover, Italian immigrants from Morocco still adhere to the patriarchal culture of their region of origin, so that fertility levels remain similar to their region of origin, and

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are higher than their destination region, namely Italy (Impicciatore et al., 2020). Similar to Italian immigrants from Morocco, Japanese immigrants also have the same preferences as their region of origin, where fertility preferences are higher than in Japan. This is because cultural factors from the area of origin are still strongly attached, as evidenced by the formation of a community of fellow migrants who help each other with cultural and language barriers during pregnancy and childbirth in Japan. (Nishino et al., 2023). Apart from being caused by cultural factors, as well as the socialization model of national migrants, the fertility rate of Nigerian immigrants is lower than non-migrants, due to high education and economics (Odimegwu & Adewoyin, 2020).

2. Adaptation Model

This model shows that migrants' fertility preferences will tend to adjust to the fertility of their destination over time (Ekawati et al., 2017). Migrants who experience this adaptation model are United States immigrants from China, Italian immigrants from Albania, and immigrants from Cotonou, Benin Republic. Migrants in this country experience a model of adaptation because they do not bring the culture of their region of origin. Moreover, for US immigrants from China, they do not bring their culture of origin, so their fertility level preferences adjust to their destination, namely the United States. They tend to have more children than non-migrants (Chinese residents), because they have escaped the one child policy of their home country (Nie & Baizan, 2021).

3. Disruption Model

This model shows that post-migration migrants' fertility rate preferences will decrease or be low due to disturbing factors (Ekawati et al., 2017). This is influenced by age structure, education and employment. This model is experienced by immigrants from Cotonou, Benin Republic. Meanwhile for immigrants from Cotonou, Benin Republic, the fertility rate decreased in the first 5 years after migration because the migrants had the aim of focusing on education and work first (Banougnin et al., 2018).

Factors Influencing Higher Fertility Rates in Migrants

1. Cultural Model

Higher fertility in Italian immigrants from Morocco, urbanization migrants in Aceh, and immigrants in Japan, is caused by cultural factors. They brought culture from their place of origin. The culture possessed by Italian immigrants from Morocco is a patriarchal culture. Patriarchal culture is a social structure in society that prioritizes men over women in various aspects, including education, so that it is more difficult for women to gain access to self-development, and can even end in early marriage. This early marriage has the potential to increase fertility because couples of childbearing age have a longer reproductive period to utilize (Fushshilat & Nurwati, 2021).

In addition, this patriarchal culture will inhibit participation in family planning programs by couples of childbearing age because of the view of the importance of having a son. This will increase fertility and tend to lead to the formation of large families, because they will continuously increase their birth rate, until they have sons. (Herawati & Purnomo, 2015).

The culture brought by urbanization migrants in Aceh is the culture of their home villages, such as the culture of early marriage which is influenced by low educational and economic levels. This culture of early marriage is caused by family and community thoughts, such as parents' fear of their child if they become old maids and there is pride from parents if their child is immediately proposed to and immediately reduces the burden and responsibility of parents (Yuniarti & Setiowati, 2015).

Meanwhile, the culture inherent in immigrants in Japan is a culture of helping each other. In Japan, a community of immigrants has been formed to help each other during pregnancy and childbirth despite language and cultural barriers. This can increase their self-efficacy in the process of pregnancy and childbirth, without any fear. This high self-efficacy has a positive effect on migrant fertilityMeanwhile, the culture inherent in immigrants in Japan is a culture of helping each other. In Japan, a community of immigrants has been formed to help each other during pregnancy and childbirth despite language and cultural barriers. This can increase their self-efficacy in the process of pregnancy and childbirth, without any fear. This high self-efficacy has a positive effect on migrant fertility (Nishino et al., 2023).

2. Sosio Economic Factors

Higher fertility among urbanization migrants in Aceh is due to low income. This is because income has an indirect negative effect

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on fertility. The lower the income of a couple of childbearing age, the higher the fertility. This is influenced by education, cultural age at marriage, and low participation in family planning programs (Arialdi & Muhammad, 2016).

3. Education Factors

The higher fertility of migrants in Bali, West Java and Aceh is caused by lower education than non-migrants. Other research shows that there is a negative relationship directly or indirectly through age at first marriage on fertility. The higher the education of women of childbearing age, the longer it will take to complete that education. These risks delaying the age of first marriage, especially if after education they choose to focus on work. The higher the age at first marriage, the lower the fecundity of a woman's ability to give birth. Vice versa, so that low education risks increasing a woman's fertility (Sinaga et al., 2017).

4. Political Factors

The higher fertility of Chinese emigrants to the United States than non-migrants in China is because they have escaped the policy in their place of origin, namely the one child policy. In their destination, namely the United States, there is no policy to limit the number of children, either for the native population or the migrant population, so over time they adapt to the fertility preferences of the United States (Nie & Baizan, 2021).

The one child policy aims to reduce China's huge population. The implementation of this policy has succeeded in reducing the TFR of the Chinese population, from 2.63 births per woman in 1980 to 1.61 births per woman in 2009. However, this decrease in TFR was not only influenced by policy, but there were other factors that influences it, such as economic growth and high levels of education. The economic growth that occurred in China contributed to the decline in TFR. This economic growth is due to the population's culture of hard work which tends to pursue the family's economic prosperity in order to invest in the future of their children's education (Sinaga et al., 2017).

5. Demography Factors

Demographic factors that influence higher fertility rates among migrants, namely lower age at first marriage and low knowledge and participation in the Family Planning (KB) program. The age at first marriage is lower among migrant residents compared to non-migrants in Bali and West Java, causing higher fertility among migrant residents. This is in accordance with research conducted by Sinaga et al. (2017), which shows that age at first marriage has a direct influence on fertility. The age at first marriage has a negative influence on fertility. If the age at first marriage is lower, then fertility will be higher. This is because couples of childbearing age who marry at a younger age will have a longer time to carry out the reproductive process, so they are at risk of having a higher birth rate (Sinaga et al., 2017).

Apart from the age at first marriage, the higher fertility among migrants in Bali, West Java, and Kinshasa, Congo, is due to low knowledge and participation in family planning so that they tend to reproduce without planning and control, including not using contraception during sexual intercourse. The results of other studies show a relationship between the use of contraceptives and fertility. Women who use contraception will limit the number of children born, resulting in low fertility. Vice versa, women who do not use contraception cannot limit the number of children born, so their fertility is high (Adiputra & Septiani, 2017).

Factors Influencing Lower Fertility Rates in Migrants

1. Economic Factors

The lower fertility rate of migrants in Denpasar, Bali is caused by indirect factors, in the form of low economic conditions. This low economy is because it is difficult for them to find work. The difficulty of getting a job is accompanied by the high cost of living in their destination, so they choose to control their fertility in order to survive and minimize the problems that will occur. (Wijayanti, 2022).

In contrast to migrants in Denpasar Bali, immigrants in Nigeria have lower fertility than non-migrants due to high economic conditions. This is influenced by other factors, such as a high level of education and decent work, so that the use of their reproductive period tends to decrease due to the process of completing their studies and focusing on their career. (Odimegwu & Adewoyin, 2020).

2. Education Factors

Lower fertility rates among immigrants in Nigeria, due to higher education. This causes the opportunity to utilize their reproductive period to be reduced, resulting in low fecundity of WUS

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(Odimegwu & Adewoyin, 2020). A similar thing was experienced by immigrants in Cotonou, Benin Republic. These immigrants have lower fertility than non-migrants due to disruption factors in the first five years of migration, namely the process of completing education (Banougnin et al., 2018). This focus on completing higher education aims to have a decent job with a high income. Like the population in developed countries, the higher the level of education and income, the lower the fertility, because they tend to choose the quality of children compared to the quantity of children (Arialdi & Muhammad, 2016).

3. Demography Factors

Demographic factors that influenced lower fertility for migrants in Denpasar, Bali, are the high use of Long-Term Contraceptive Methods (LTMs). The reason is because of low economic conditions caused by difficulities of finding a job, so LTMs were chosen as a solution to minimize additional expenses if they have another children (Wijayanti, 2022).

Conclusions and Recommendation

Fertility among migrant and non-migrant populations does not have a specific pattern. The high and low levels of fertility among migrant populations in a region refer to the socialization model, adaptation model, and disruption model. Factors that influence higher fertility in migrant populations are culture, economics, education, politics, and demographics. Meanwhile, the factors that influence lower fertility in migrant populations are economics, education and demographics. Factors that have a direct influence on the high and low levels of fertility among migrants are demographic factors, especially age at first marriage and participation in family planning programs.

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