University of Tehran Press

Industrial Management Journal

Online ISSN: 3115 - 7386

Homepage: https://imj.ut.ac.ir

Doing More with Less: A Meta-Analysis of How Frugal Innovation Drives Circular Economy

Hossein Bakhtiari [1], **Hossein Shirazi** [2]✉, **Abolfazl Edalatipour** [3], **and Mooud Dabaghiroodsari**[4]

1. MSc, Department of Management, University of Qom, Qom, Iran. E-mail: h.bakhtiari.ac@gmail.com
2. Corresponding author, Assistant Prof., Department of Technology Management, Islamic Azad University, Qom Branch, Qom, Iran. E-mail: hossein.shirazi63@gmail.com
3. Ph.D., Department of Computer Science, University of Maryland, Baltimore, USA. E-mail: KC14696@umbc.edu
4. Ph.D., Department of Computer Science, University of Maryland, Baltimore, USA. E-mail: VP47458@umbc.edu

Article Info

Article type:
Research Article

Article history:
Received June 07, 2026
Received in revised form July 11, 2026
Accepted September 19, 2026
Available online October 01, 2026

Keywords:
Frugal Innovation, Circular Economy, Meta-Analysis, Systematic Review.

ABSTRACT

Objective: Among the different types of innovation that firms can pursue, frugal innovation has attracted practitioners in the sustainability domain. Frugal innovation can improve the Circular Economy by driving resource efficiency, cutting waste, and promoting the reuse and recycling of materials. However, the existing research has not drawn consistent conclusions about the relationship between FI and CE. Hence, in this study, an effort has been made to aggregate the quantitative results obtained through a systematic review and meta-analysis method to determine the overall impact of FI on the CE.

Methodology: The paradigm of this research is positivist, its reasoning method is deductive, and its approach is quantitative. The study population consisted of English-language articles published between 1979 and 2025 in the Scopus and WoS databases. Using the PRISMA method, out of 876 studies on the impact of FI on the CE, a final number of 6 studies were selected based on the inclusion and exclusion criteria defined by the researchers, and their data were included in the final analysis.

Results: The meta-analysis conducted using the Comprehensive Meta-Analysis software (CMA3) showed that, overall, FI has a significant positive impact on CE. Also, the studies were heterogeneous, and the effect size's value fell within the medium range (Based on Cohen's criterion). Additionally, Egger's linear regression method rejected the hypothesis of publication bias, and the results of the fail-safe N method indicated the robustness of the study's findings.

Conclusion: This meta-analysis demonstrates that frugal innovation is a powerful engine for transition to a circular economy and provides a pragmatic pathway where sustainability intersects with economic viability and strategic innovation. By embracing the "more with less" paradigm, businesses can unlock circularity as a source of resilience, efficiency, and long-term value creation.

Cite this article: Bakhtiari, H., Shirazi, H., Edalatipour, A., & Dabaghiroodsari, M., (2026). Doing more with less: a meta-analysis of how frugal innovation drives circular economy, ***Industrial Management Journal***, 18(4), 78-103. https://doi.org/10.22059/imj.2026.413756.1008315

Publisher: University of Tehran Press.

DOI: https://doi.org/10.22059/imj.2026.413756.1008315

Introduction

The tension between economic development and environmental sustainability is intensifying, posing a significant threat to future progress. This progression is increasingly hindered by critical challenges such as resource scarcity and ecosystem vulnerability (Shirazi & Bakhtiari, 2025). Furthermore, escalating concerns about resource overconsumption, climate change, and social inequality are driving urgent calls for a shift toward sustainable societies and business models (Secomandi, 2025). In response to mounting stakeholder apprehensions, particularly from consumers, manufacturers worldwide are under pressure to enhance their circular economy performance and are consequently re-evaluating their strategic approaches (Fang et al., 2024).

Historically, industrial systems have predominantly followed a linear "take-make-dispose" model. This one-way process results in significant waste and environmental degradation. In contrast, the circular economy (CE) is a closed-loop paradigm that maximizes resource utilization through strategies such as recycling, reuse, and recovery. By minimizing waste and pollution, CE aids managers in improving efficiency and safeguarding the environment. The CE framework emphasizes three core domains: sustainability, resilience, and human-centricity (Shirazi et al., 2025). In recent years, CE has gained considerable attention as a vital industrial model for addressing climate change (García-Quevedo et al., 2020). It fundamentally reorients the traditional linear flow into a regenerative "make-use-recycle" system and is recognized as a critical pathway for achieving the United Nations Sustainable Development Goals by 2030 (Perera & Badir, 2025). The potential economic benefits of CE are substantial, with annual gains estimated at approximately €1.8 trillion by 2030 (Shirazi et al., 2025). Consequently, CE principles are increasingly viewed as enabling organizations to advance their economic, environmental, and social sustainability outcomes—a focus garnering significant attention from governments, academia, and industry (Sahoo et al., 2025).

Within this transition, innovation is a key enabler, providing new methods, tools, and processes that align with corporate environmental objectives and support CE adoption (Al-Khatib, 2022). The growing imperative for sustainable development has accelerated the global uptake of innovative practices aimed at waste reduction and resource efficiency (Zhang, 2025). Among various innovation typologies, frugal innovation (FI) has recently emerged as a focal point for both scholars and practitioners in sustainability. As firms recognize its strategic importance, interest in cultivating frugal innovation capabilities has surged. FI is characterized by developing products, services, or solutions of acceptable quality while utilizing minimal resources (Al-Khatib et al., 2025). It achieves cost-effectiveness through design simplification, incorporating only essential features and optimizing the use of available resources without compromising core functionality (Hossain, 2021). By enhancing resource efficiency, reducing waste, and promoting material reuse and recycling, FI presents a compelling mechanism to bolster circular economy performance. This potential has sparked growing scholarly and practical interest in empirically investigating the FI-CE relationship. Precisely quantifying the magnitude of this impact is crucial for advancing both theory and practice (Rahmani et al., 2024). As illustrated in Fig. 1, publication trends over 46 years (1979–2025), particularly the marked increase since 2015, reflect this rising engagement and signal a robust movement toward embracing circular economy principles.

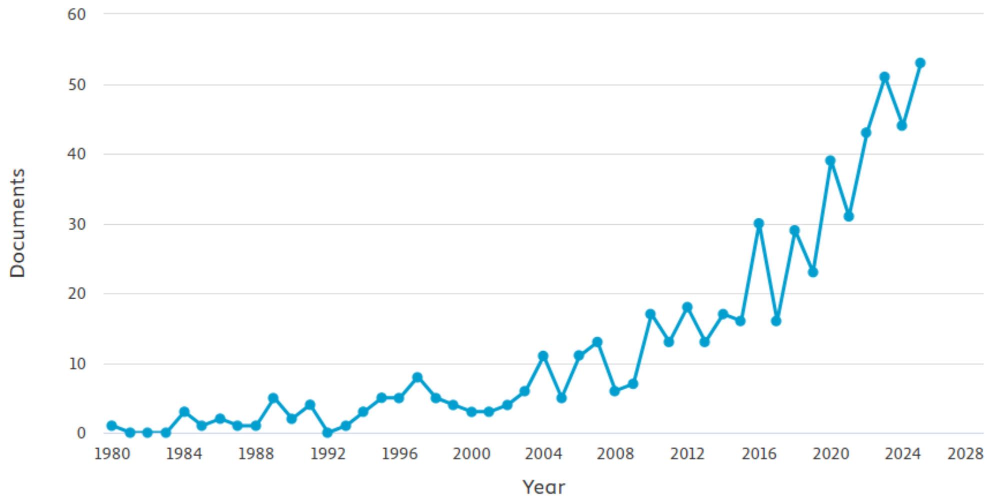

Fig. 1. Annual publication trend on the intersection of Frugal Innovation and Circular Economy. Source: Scopus database. The figure was produced by the authors based on records retrieved from Scopus on November 1, 2025, using a title–abstract–keyword search strategy (see Appendix A).

Due to the diverse quantitative findings of prior studies assessing the effect of FI on CE, there is a need for a study that aggregates the existing quantitative outcomes. Therefore, this study employs a meta-analytic methodology to derive generalizable practical results and provide a reliable basis for global-level decision-making. This study makes several significant contributions to the literature by examining the impact of FI on CE. In this regard, it conducts a systematic review and meta-analysis, an approach not previously applied to this relationship. This method allows for the mathematical synthesis of correlations between the two variables. At its core, this research addresses a pressing question in industrial operations strategy: how can firms reconfigure their innovation processes and operational routines to effectively transition from linear to circular models? By investigating the FI-CE link, it speaks directly to the concerns of operations managers seeking to reduce waste at the source, supply chain specialists designing reverse logistics networks, and R&D managers tasked with developing products for multiple lifecycles.

This article is organized as follows: the literature reviewed and theoretical background are presented in Sec. 2; the methodology and materials are described in Sec. 3; the results are presented in Sec. 4; the issue is discussed in Sec. 5, and the conclusion and the policy recommendations are given in Sec. 6.

Literature Background

Frugal Innovation

The conceptualization of Frugal Innovation (FI) has evolved from a principle of frugality into a distinct strategic paradigm that redefines constraints as catalysts for sustainable value creation. Initially framed simply as "doing more with less" or making short-term sacrifices for long-term gains (Bhatti & Ventresca, 2013), FI is now understood as a process where individuals actively turn resource-constrained environments into opportunities (Dost et al., 2025). It represents a distinct manifestation of innovation under constraints, wherein scarcity is not a barrier but a defining condition of the process itself (Ukbaeva et al., 2026). Besides, the effectiveness of companies depends on transforming innovative inputs into tangible results that enhance competitive advantage (Moradi et al., 2026). FI has been the concentration of innovators in recent years, particularly in the emerging markets, because of reasons such as resource constraints and low incomes. FI is known as products that do not compromise on necessary quality, reliability, or safety standards but can enable significant cost reductions (Niroumand et al., 2021). FIs tend to emphasize sustainability more than mainstream innovations. Hossain et al. (2016; p. 133) define "frugal innovation as a resource scarce solution (i.e., product, service, process, or business model) that is designed and implemented despite financial, technological, material or other resource constraints, whereby the outcome is significantly cheaper than competitive offerings (if available) and is good enough to meet the basic needs of customers who would otherwise remain un(der)served." (Hossain et al., 2016). According to Hossain et al. (2022), frugal innovators mobilize what limited abilities and resources they have at hand to overcome obstacles and arrive at alternative solutions to fill a gap where the existing products and services are either unavailable or inadequate (Hossain et al., 2022). Frugal innovation is the process of making cost-effective solutions (Hindocha et al., 2021). These solutions are designed to meet market needs while maintaining quality and sustainability (Zhang, 2025). FI aligns with environmental goals by emphasizing resource parsimony, waste reduction, and the delivery of essential value with lower material and energy intensity—characteristics that resonate with circular economy principles (Sant'Ana et al., 2026). Thus, frugal innovation not only enhances operational efficiency but also aligns with the principles of sustainability (Zhang, 2025). From a sustainability perspective, frugal innovation contributes to economic efficiency, social inclusion, and environmental responsibility by reducing material intensity, limiting unnecessary consumption, and improving access to affordable solutions for broader segments of society (Alsharaideh et al., 2026). Companies that adopt frugal innovation tactics can enable development along the three pillars of sustainability—

environment, society, and economy—though in what ways and to what extent can differ (More & Shrivastava, 2026). In synthesis, contemporary research reframes frugal innovation as a strategic mechanism. It is increasingly recognized as a means by which firms, especially resource-constrained ones, can transform limited assets into sustained competitive advantages (Al Omoush et al., 2025), positioning it as a critical framework for inclusive and sustainable development.

Circular Economy

The circular economy (CE) represents a transformative socio-economic paradigm that encourages firms to enhance material and resource efficiency through business models aligned with CE principles (Blackburn et al., 2026). The concept was initially defined in research by Pearce & Turner (1989) as an economy where waste from one process serves as raw material for another. The Ellen MacArthur Foundation (2013) offers a widely accepted definition, describing CE as an industrial system designed to be restorative and regenerative (MacArthur, 2013). The European Action Plan defines CE as an economy "where the value of products, materials and resources is maintained in the economy for as long as possible, and the generation of waste is minimized" (European Commission, 2015). While CE terminology is broad, the core of these definitions can be distilled for this study as preserving value within the economy by closing material loops. This is achieved through a series of maximization and minimization efforts. CE aims to minimize resource wastage, pollution, and greenhouse gas emissions while maximizing resource efficiency (Konietzko et al., 2020). Alternatively, preserving value through loop-closing can be accomplished by following principles such as reuse, repair, refurbishment, remanufacturing, redistribution, and recycling. Nevertheless, the widely acknowledged core principles of CE are summarized as reduce, reuse, and recycle (Sahoo et al., 2025). The circular economy is a system that replaces the "end-of-life" concept with the principles of reduction, reuse, recycling, and resource recovery across production and supply chains (Perera & Badir, 2025). The CE concept is not a theory but a method for producing and consuming goods that generates significant interest and enthusiasm, as it can help establish a new framework to address numerous challenges (Narula et al., 2023). A widely accepted definition among scholars frames CE as sustainable industrial production. It is believed that the concept embodies a set of holistic perspectives aimed at achieving a sustainable, waste-free society (Shirazi et al., 2025). The Ellen MacArthur Foundation suggested that new designs and advanced practices should prioritize reusing discarded products instead of continuously introducing new resources at the start of each cycle (MacArthur, 2013). CE represents a paradigm shift in producer operations, aiming to prevent resource depletion and enhance resource and energy efficiency. Its primary focus is on minimizing costs and creating pathways to greater value (Shirazi et al., 2025). Thus, circular economy and circularity are best understood not as ends in themselves, but as instrumental pathways that contribute to sustainability outcomes when aligned with broader social and environmental goals (Sewenet et al., 2026).

Analytical Framework

This research is grounded in the Schumpeterian view of innovation strategy, whose role is to invest resources (human and material) in innovative activities and direct firm efforts toward innovation goals and market targets. This perspective is deeply rooted in the competence-based view (Barney, 1991; Wernerfelt, 1984). Innovation activities tend to enhance firms' capabilities to acquire new knowledge (Cohen & Levinthal, 1990). Introducing innovation enables firms to improve their competitive positions by developing new routines and renewing their capabilities (Dosi et al., 2000). Consequently, firms that have built a competence base in the past through various innovations are well-positioned to adopt changes in the transition to CE by implementing new routines as practices. The empirical relationships between innovation strategies and the adoption of CE practices are persistent rather than short-term (Jiménez-Jiménez & Sanz-Valle, 2011). Recent literature has proposed sustainable innovation strategies, among which is frugal innovation—a concept gaining significant traction (Pisoni et al., 2018). Being a frugal innovator supports the adoption of three types of CE practices: waste minimization through recycling or resale; review of uses to mitigate energy consumption; and review of uses to minimize water consumption or maximize water reuse. These outcomes are generalizable across different industrial sectors, as frugal innovation inherently involves conserving energy and natural resources (Bas, 2023). The fact that a frugal innovation strategy stimulates the implementation of CE practices supports the argument that FI has attracted considerable interest over the last decade. It lends particular credence to the perspective that a circular economy requires a frugal production system (Arfaoui et al., 2023). The results of the study by Feitosa et al. (2026) showed that combining CE and FI strategies can generate 27 social impacts, including job creation, improved living conditions, and equitable access to affordable products, particularly benefiting low-income populations (Feitosa et al., 2026).

On the other hand, public sector institutions have a social and fiduciary responsibility to conserve natural resources and promote social welfare and equity. It has far greater responsibilities for advancing the notion of sustainable development than corporations (Ball et al., 2014). Lieder and Rashid (2016) proposed top-down and bottom-up approaches to support CE implementation. The top-down approach contains legislation and policy and supports infrastructure and social awareness. Hence, public institutions advocate a collective consciousness about environmental issues as well as the societal benefit of industrial activities through strict control of industrial businesses. Termeer and Metze (2019) analyzed the extent to which and the ways in which governments can contribute to transitions or transformative change, especially since the circular economy inherently conflicts with norms underlying existing policies and regulations (Kirchherr et al., 2017; Korhonen et al., 2018). Therefore, legal support can also be considered as an effective factor in establishing and implementing a circular economy.

Materials and Methods

Research Philosophy and Approach

This research is grounded in a positivist paradigm and employs a deductive approach. In terms of purpose, it is applied research. Methodologically, it is quantitative, as it involves a meta-analysis of prior quantitative studies. Meta-analysis is a systematic and structured statistical technique for aggregating and synthesizing findings from multiple studies that address a common research question, thereby enabling a more accurate single estimate than that provided by any individual primary study (Hernanda et al., 2023).

Systematic Search Strategy

Determining the scope of relevant studies is one of the most important and challenging steps in a systematic literature review, as it requires defining appropriate search criteria and selecting suitable databases (Mohseni Kiasari et al., 2024). In this regard, A systematic search strategy was designed to achieve three primary objectives: 1) maximally identifying relevant, high-quality quantitative empirical studies, 2) minimizing citation and selection biases, and 3) ensuring the comprehensiveness and reliability of the final dataset. The strategy centered on two leading databases in the social sciences, Scopus and Web of Science, chosen for their extensive coverage, controlled quality, and precise indexing. A comprehensive search string based on the core research constructs was developed. Its validity and suitability were reviewed and confirmed by a panel of subject matter experts (see Appendix A). The study period was limited from 1979 to 2025. A comprehensive literature search across both databases on November 1, 2025, yielded an initial 1048 records, including journal articles and conference proceedings.

Screening and Study Selection Process (PRISMA)

To ensure the highest quality of findings, this study focused exclusively on original articles published in English in reputable journals. The article selection adhered to the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) protocol (Liberati et al., 2009), a widely recognized method for enhancing review accuracy and mitigating researcher bias (Haque et al., 2021). Following the PRISMA guidelines, records were imported into Rayyan.ai for screening. After removing 172 non-journal items (e.g., conference papers) and 208 duplicates, 668 studies remained for title and abstract screening. At this stage, 602 studies were excluded due to irrelevance. The full texts of the remaining 66 studies were assessed for eligibility against predefined criteria. In the end, 6 studies satisfied all criteria for inclusion in the final meta-analysis. The complete screening process is depicted in the PRISMA flow diagram (Figure 2).

Methodological Quality Assessment (CASP) and Inter-Rater Reliability

To uphold the robustness of the meta-analytic findings, a rigorous assessment of the methodological quality of the six included studies was performed. Given that all studies were cross-sectional correlational surveys, an adapted version of the Critical Appraisal Skills Programme (CASP) checklist for cohort studies was employed. From the original 12 questions, the seven most pertinent to correlational survey research were selected, covering study focus, design appropriateness, participant representativeness, clarity of data collection, control for confounders, analytic appropriateness, and result interpretation. An eighth custom question was added to specifically address the reporting of reliability and validity for the FI and CE constructs. The eight CASP-aligned criteria for correlational survey research are as follows: (C1) clear research focus, (C2) appropriateness of design, (C3) participant/setting representativeness, (C4) clarity of data collection, (C5) control for confounding variables, (C6) appropriateness of analytical approach, (C7) clarity and precision of results, and (C8) reporting of reliability and validity for the FI and CE constructs. Two authors independently appraised each study using a binary scale (1 = criterion met, 0 = not met or insufficient information). The average quality score across the six studies was 7.16 (SD = 0.75), indicating a generally high level of methodological rigor, with all studies exceeding the pre-defined threshold score of 5.

Table I. Item-by-Item CASP Quality Appraisal Scores for the Six Included Studies

Study (Author, Year)	C1	C2	C3	C4	C5	C6	C7	C8	Total (/8)
Al-Khatib (2025)	1	1	1	1	0	1	1	1	7
Zhang (2025)	1	1	1	1	0	1	1	1	7
Arfaoui et al. (2023)	1	1	1	1	1	1	1	0	7
Perera & Badir (2024)	1	1	1	1	0	1	1	1	7
Sahoo et al. (2025)	1	1	1	1	1	1	1	1	8
Dost et al. (2024)	1	1	1	1	0	1	1	1	7

As shown in Table I, the most common methodological limitation across the six studies was inadequate reporting of control for confounding variables (C5; four studies scored 0), followed by incomplete reporting of construct reliability and validity (C8; one study scored 0). Despite these limitations, the overall quality of the evidence base was generally satisfactory, with all studies scoring 6 or higher out of 8. The identified weaknesses inform our recommendations for future research design.

To ensure objectivity, inter-rater reliability during the full-text eligibility screening stage was evaluated using Cohen's Kappa (κ). The resulting κ statistic was 0.78, categorized as a "substantial agreement" according to the benchmarks established by Landis and Koch (1977). Any discrepancies were resolved through discussion between the authors.

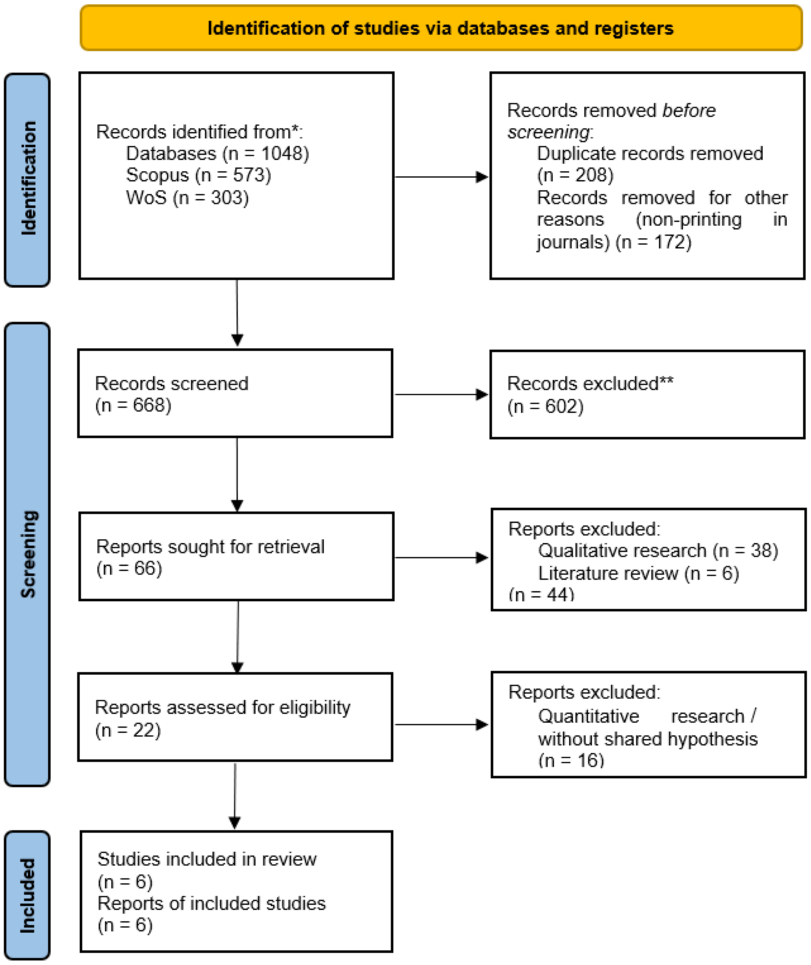

Fig. 2. PRISMA flowchart

Eligibility and Inclusion Criteria

The inclusion of studies was governed by the following criteria: (A) Publication indexed in either the Web of Science (WoS) or Scopus database; (B) Publication type limited to articles; (C) Language restricted to English; (D) Publication window spanning 1979 to 2025 (with a cut-off date of November 1, 2025); (E) Quantitative research employing a correlational method (including the quantitative segment of mixed-methods research with a correlational approach); (F) Full-text accessibility; (G) Reporting of necessary statistical information (such as correlation coefficients (r) or beta coefficients, and sample size). These criteria are summarized in Table 1.

Effect Size Extraction and Conversion

This meta-analysis aimed to aggregate the Pearson correlation coefficient (r) between FI and CE. Since the primary studies (k=6) did not report this correlation directly, the effect size was derived from the reported standardized coefficients. For the five studies utilizing Structural Equation Modeling (SEM), the analysis adopted a method supported by Peterson and Brown (2005), where the standardized path coefficient (β) can serve as a direct and reasonable estimate of the bivariate correlation (r), particularly when control variables are present with limited multicollinearity. For the single study employing Probit regression, the standardized coefficient was first converted to Cohen's d and subsequently to r using a standard conversion formula. All final correlation estimates (r) were then transformed into Fisher's Z scores for subsequent analysis. The final effect sizes for the included studies are presented in Table 2.

Table 1. Eligibility and Inclusion Criteria

Index	Eligibility and Inclusion Criteria
A	Published in the WoS or Scopus database
B	Publications as articles
C	Articles in the English language
D	Published within 1979–2025 (cut-off date: November 1, 2025)
E	Quantitative research with correlational method - quantitative part of mixed research (with correlational approach)
F	Access to full-text articles
G	Articles with statistical information on correlation coefficient/r/beta coefficient, and sample size

Table 2. Summary of information from the studies reviewed

N. O	Author(s) & Year	Publications	Country / Region	Sample / Unit of Analysis	Sample Size (N)	Reported Effect Size
1	Al-kahtib, 2025	Elsevier	Jordan	Textile industry Firms	210	0.394
2	Zhang, 2025	Elsevier	China	SMEs	207	0.397
3	Arfaoui, et al, 2023	De Boeck Supérieur	France	Chemical industry Firms	1000	0.495
4	Lalani Perera & Badir, 2024	Wiley	India & Pakistan	SMEs	306	0.490
5	Sahoo et al, 2025	Wiley	India	manufacturers	889	0.341
6	Dost et al, 2024	Wiley	Malaysia	SMEs	338	0.401

Meta-Analytic Procedure

The meta-analytic synthesis was performed using a random-effects model, which accounts for variance both within and between studies. The inverse-variance-weighted pooling of the Fisher's Z scores, their conversion back to the correlation metric, and all related statistical tests were carried out using Comprehensive Meta-Analysis (CMA3) software.

Reflection on Sample Size and Study Limitations

A key consideration pertains to the final number of included studies (k = 6). This figure reflects the current state of the empirical literature rather than a limitation of the search strategy. While numerous publications discuss Frugal Innovation and the Circular Economy conceptually, very few provide the direct quantitative correlational data required by the inclusion criteria. Consequently, the present sample represents the current population of such studies. Conducting a meta-analysis at this nascent stage can be valuable for establishing a baseline effect size and identifying heterogeneity.

Results

In the data analysis process, to compare the studies, the results of each study were converted into a standardized effect size. Effect size is a quantitative index that summarizes and standardizes statistical results and findings. The purpose of using effect size is to unify diverse statistical findings from studies into a standard metric, thereby enabling the comparison and aggregation of statistical results across studies (Bazrafshan et al., 2015). The results obtained from the reviewed articles are presented in Table 3.

Table 3. Effect size of variables with 95% confidence interval and relative weight of each study

Study Name	Fisher's Z	Lower limit	Upper limit	Z-Value	P-Value
Arfaoui et al 2023	0.543	0.481	0.605	17.135	0.000
Zhang 2025	0.420	0.283	0.557	6.000	0.000
Al-khatib et al 2025	0.417	0.280	0.553	5.993	0.000
Dost et al 2024	0.425	0.318	0.532	7.776	0.000
Sahoo et al 2025	0.355	0.289	0.421	10.573	0.000
Perera & Badir 2024	0.536	0.423	0.649	9.331	0.000
Fixed	0.454	0.418	0.491	24.607	0.000
Random	0.451	0.374	0.527	11.513	0.000

Table 3 shows that in studies conducted in the field of frugal innovation and circular economy, the relationships between these two variables are significant with 99% confidence. The largest effect size value is related to the study by Arfaoui et al. (2023) by the amount of 0.543, and the smallest effect size value is associated with the survey by Sahoo et al. (2025) by the amount of 0.355. Among the final 6 articles, all articles have a medium effect size (between 0.3 and 0.5). Overall, given that all the studies are assessed in the medium group, it can be said that based on the results of the meta-analysis of effect sizes, Frugal innovation has an average relationship with the circular economy.

To complement the tabular results and provide an intuitive graphical summary of the meta-analysis, a forest plot is presented in Figure 3. The forest plot allows for an immediate assessment of the direction, magnitude, and consistency of effects across the diverse set of studies analyzed in this review. This plot displays the effect size (ES) and its Upper and lower limits for each study included in the aggregate.

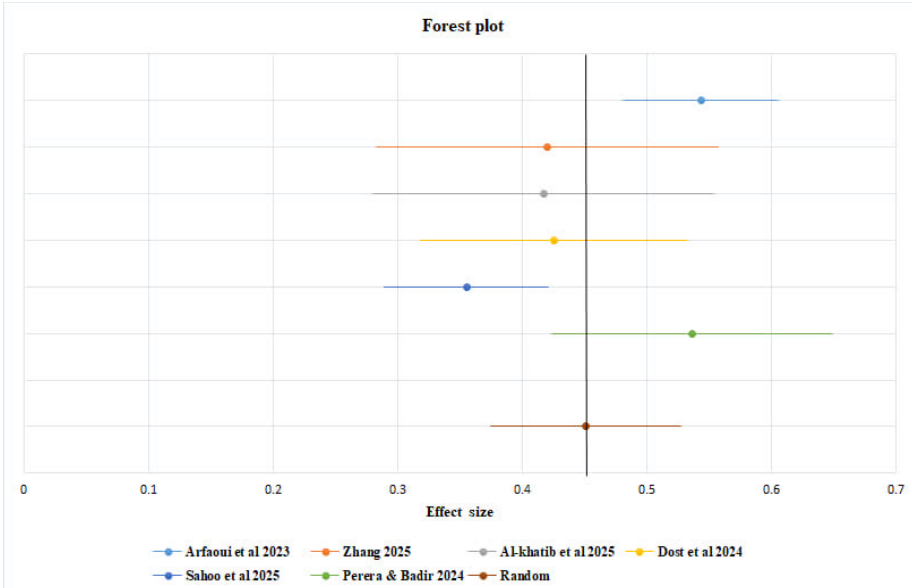

Fig. 3. Forest plot

Checking the assumption of homogeneity of studies

To aggregate effect sizes in the meta-analysis, either a fixed-effects model or a random-effects model may be employed. If the heterogeneity test is significant, the random-effects model is used. For this reason, one of the fundamental assumptions of meta-analysis is the assessment of study homogeneity, for which Q-Value and I-square tests are applied to examine this assumption. The results of this test are presented in Table 4.

Table 4. Q-Value and I-square Test results

Model	Heterogeneity			
Index	Q-Value	df	P-Value	I-Squared
Result	19.332	5	0.002	74.136

According to the test results (Q-Value = 19.332, $p < .01$), with 99% confidence, the hypothesis of homogeneity is rejected, and heterogeneity among the studies is confirmed. The results of the I^2 statistic further substantiate this, indicating that approximately 74.1% of the total variance observed across the included studies is attributable to study heterogeneity. This falls into the 'substantial' range of heterogeneity according to Higgins et al. (2003), meaning true effect sizes likely differ meaningfully across studies due to contextual or methodological factors. Consequently, the random-effects model (DerSimonian & Laird method) was deemed the appropriate choice, as it incorporates this between-study variance into the weighting of studies and yields an estimate of the average effect across the distribution of true effects present in the literature.

After examining the assumption of homogeneity of meta-analysis and determining the random effect model to combine the results and report the effect size, Table 5 presents the reports of studies conducted in the random model.

Table 5. Results from effect size studies of the relationship between FI and CE

Hypothesis	N.O of articles	Correlation	Lower limit	Upper limit	Z-Value	P-Value
Effect FI on CE	6	0.451	0.374	0.527	11.513	0.000

According to the results, the random-effects model is the appropriate and primary model for synthesizing the effect sizes. The main result of this meta-analysis, therefore, is the random-effects pooled estimate of $r = 0.451$ (95% CI [0.374, 0.527]). The relationship is statistically significant ($P<.001$). Based on Cohen's (1988) conventional benchmarks (where $r = 0.1$ is small, 0.3 is medium, and 0.5 is large), this indicates a moderate positive correlation between Frugal Innovation and Circular Economy performance. For comparative purposes only, the fixed-effects estimate is also reported in Table 3. Subsequently, due to the heterogeneity of the studies, moderator variables were used to determine this heterogeneity and account for the variance across studies.

Publication Bias Assessment

The assessment of publication bias is another essential component of meta-analysis, arising from the non-publication of studies and various types of errors. In other words, one of the issues that can compromise the validity of meta-analysis results is the researcher's inability to access all studies conducted on a specific topic within a given time frame. Researcher bias in the article selection and analysis of articles can undermine the quality of a review article. Selection bias can be avoided by following a systematic review protocol and an objective article selection procedure. Furthermore, the potential for analysis bias was avoided and addressed through a preliminary protocol design that predetermined the analysis methods (Rupasinghe et al., 2024). In the current study, to reduce the potential for bias, first, inclusion criteria were clearly described in detail to avoid inconsistent application in study selection, and the inclusion criteria are documented in Table 1. Second, the resulting flow of studies was tracked through the PRISMA diagram. Meanwhile, a funnel plot is one of the most common methods for assessing publication bias. Therefore, to evaluate publication bias, a funnel plot was used, and the results are presented in the following section.

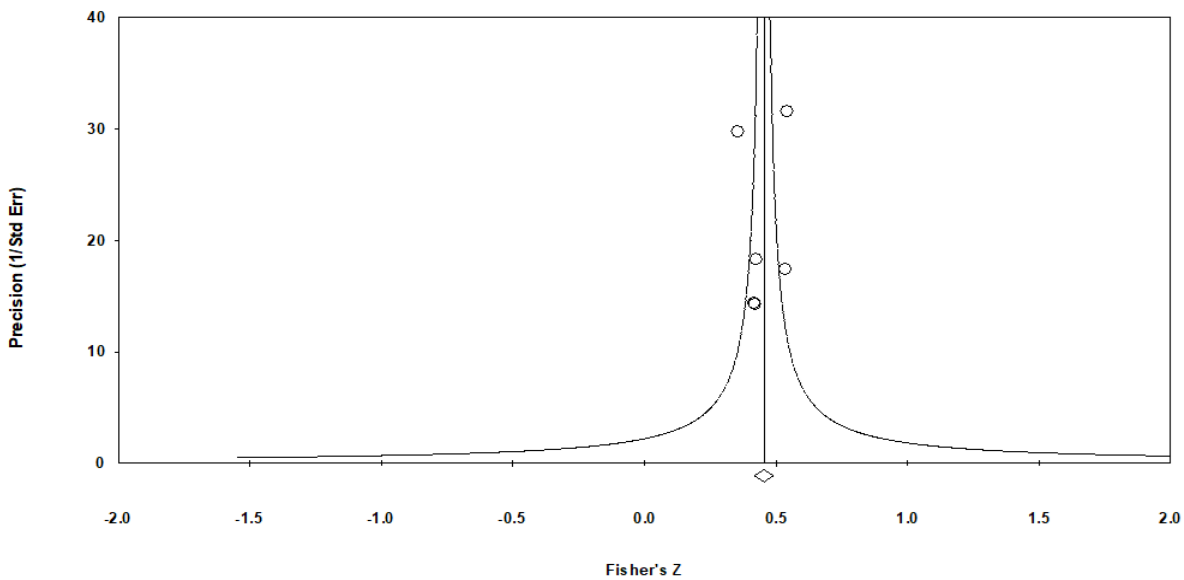

Fig. 4. Funnel plot by Fisher's Z for assessing publication bias

The results of the inverted funnel plot (Fig. 4) suggest a relative symmetry in the included studies; however, a definitive judgment cannot be made based on this alone. Therefore, the following methods were employed: the trim-and-fill method, Egger's Linear Regression Method, and the fail-safe N. According to the data in Table 6, and based on the random-effects model, no missing studies were found.

Table 6. Duval and Tweedie's trim and fill

Index	Studies Trimmed	Point Estimate	Lower Limit	Upper Limit	Q value
Observed values		0.42251	0.35750	0.48345	19.331
Adjusted values	0	0.42251	0.35750	0.48345	19.331

In Egger's Linear Regression Method, the null hypothesis (H0) indicates a symmetrical funnel plot and the absence of bias. In contrast, the alternative hypothesis (H1) indicates an asymmetrical funnel plot and the presence of publication bias. According to the data in Table 7, the intercept is -0.53 with a 95% confidence interval of 0.190. The significance level of this test is greater than 0.05 ($p > 0.05$); therefore, the null hypothesis regarding the symmetry of the funnel plot and the absence of publication bias is confirmed.

Table 7. Egger's Linear Regression result

Egger's Linear Regression	B	t-Value	P-value
Values	-0.53	0.190	0.858

According to Table 8, an additional 835 studies would need to be added and reviewed to ensure that the two-tailed P-value does not exceed 0.05. This means that even if 835 additional studies were conducted, it would not lead to an error in the final calculation and analysis results, indicating the appropriate accuracy and validity of the information and findings obtained in this research. A fail-safe N of 835 represents a substantial and meaningful margin of error tolerance, which demonstrates the precision of the analysis in this study.

Table 8. Classic Fail-Safe N calculation

Index	Values
Z-value for observed studies	23.19175
P-value for observed studies	0.000
Alpha	0.05
Tails	2
Z for alpha	1.9599
Number of observed studies	6
Number of missing studies that would bring P-value to > alpha	835

Moderator Variable Analysis

After a meticulous review of the sample articles, the unit of analysis "Legal Support" in the studies was considered as a moderator variable, the results of which are presented in Table 9.

Table 9. Results of legal support moderation

Moderator Variable	Number of Studies (k)	Point Estimate	Std error	Z value	P value	Q value	df	PValue
Not Supported	3	0.464	0.034	13.456	0.000	2.481	2	0.289
Supported	3	0.451	0.022	20.605	0.000	16.750	2	0.000
Total within						19.230	4	0.001
Total between						0.101	1	0.750
Overall	6	0.454	0.018	24.607	0.000	19.332	5	0.002

To examine whether legal support acts as a moderator in the relationship under study, the included studies were analyzed separately based on the presence or absence of such support. The results indicate that the difference between the mean effect sizes of the two groups was not statistically significant. This finding clearly demonstrates that the mere existence of a supportive legal framework does not have a decisive influence on the magnitude of the effect reported across studies.

Discussion

This study makes three pivotal contributions to the intersection of innovation management and sustainable operations. First, it provides the first meta-analytic evidence establishing a statistically significant, positive relationship of moderate strength between FI and CE ($r = 0.451$). This moves the discourse beyond theoretical propositions and anecdotal case studies, offering a quantitative benchmark for the field. Second, the confirmed substantial heterogeneity ($I^2 = 74.14\%$) is a critical finding in itself. It signals that the FI-CE link is not uniform but is contingent on contextual factors, thereby challenging overly simplistic models and redirecting future research toward investigating boundary conditions and moderators. Third, by synthesizing empirical data from diverse geographical and industrial contexts (e.g., France, China, India, Malaysia; textiles, chemicals, manufacturing), this analysis offers a more generalizable understanding than any single primary study could, setting a foundation for globally relevant theory and practice.

The combined evidence indicates that FI functions as a capability enabling firms to restructure their innovation and operational routines in ways that better advance circularity outcomes. Within operations management, FI's focus on designing within constraints translates into tangible improvements in production and processes that reduce resource intensity and facilitate circular pathways. Regarding supply chain design, the observed variability suggests that the advantages of FI are contingent upon the practical feasibility of coordinating material flows, such as reverse logistics, recovery efforts, and supplier collaboration. Lastly, concerning sustainable production strategies, our results offer empirical backing for positioning FI as a strategic precursor to circular initiatives: when FI is fully integrated into innovation governance and product or process design, circularity shifts from being a mere conceptual or compliance-driven idea to an operationally achievable reality.

To better understand the combined effect, we compared the effect sizes reported in the six primary studies. These estimated effects vary across the studies (see Table 3), reflecting the considerable heterogeneity observed in the meta-analysis. This variation suggests that the relationship between FI and CE is likely influenced by the specific contexts and implementation settings of each study. Importantly, the direction of the effects remains consistently positive across all included studies, reinforcing the strength and reliability of our overall conclusion. Situating our findings within the broader academic discourse highlights their importance. Unlike prior systematic reviews that primarily catalogued conceptual models and qualitative evidence on the FI-CE link (e.g., Feitosa et al., 2026; Arshad et al., 2025; Alo et al., 2025; Machkour & Abriane, 2026), this meta-analysis offers the necessary quantitative synthesis to confirm the empirical validity of the relationship. Our pooled effect size ($r = 0.451$) is consistent with and builds upon meta-analytic results from related domains such as eco-innovation and environmental performance (Zheng & Iatridis, 2022), while specifically emphasizing the strength of the frugality paradigm in contexts constrained by limited resources.

The objective of this study was to measure the impact of frugal innovation on the circular economy using a meta-analytic approach. In this study, a search strategy that was approved by an expert panel was used for the systematic literature review. The PRISMA method was employed for screening studies, and at the end of the screening process, a total of 6 articles were selected as the basis for analysis. The main hypothesis test result indicated that the effect of frugal innovation on the circular economy is significant with 99% confidence. Furthermore, based on other findings of the study, the assumption of heterogeneity among studies was also confirmed with 99% confidence. Additionally, the results showed that approximately 74.1% of the total variance in the reviewed studies is related to heterogeneity. According to the random-effects model results, it can be inferred that frugal innovation has a moderate effect on the circular economy (based on Cohen's criterion), so it is a substantive and meaningful driver, comparable to other key strategic initiatives. It indicates that fostering FI is not a marginal activity but a potent lever with considerable potential to advance circularity. Subsequently, to assess the quality of the research, the random-effects model was used as the basis for further analyses.

A significant problem that can compromise the validity of meta-analysis results is the researcher's inability to access all studies conducted on the topic. To assess publication bias, a funnel plot and related methods were employed. The results from the Duval and Tweedie's trim and fill method table indicated that all possible studies have been examined. Moreover, the results of Egger's linear regression test confirmed the null hypothesis of no publication bias. Finally, the findings from the robustness assessment using fail-safe N calculations revealed that more than 835 additional studies would need to be conducted to alter the final results and analyses. This finding demonstrates the high accuracy and reliability of the information and results obtained in this study.

Finally, given the heterogeneity among the studies, the variable legal support was considered as a moderating variable, because the included studies provide sufficient information for this variable, while other candidate moderators (e.g., industry type, firm size, or regional context) are not consistently reported in the primary studies in a way that allows reliable harmonization and comparison. The findings showed that the difference between the mean effect sizes of the two groups is not statistically significant. However, an interesting pattern emerged from the within-group heterogeneity tests. While the small number of studies in each subgroup (k=3) limits the robustness of this observation, the Q-statistic was non-significant for the 'Not Supported' group but highly significant for the 'Supported' group. This suggests the possibility that the relationship between FI and CE may be more uniformly expressed in contexts lacking formal legal frameworks, whereas within legally supportive environments, other contextual factors may introduce greater variability. This hypothesis warrants investigation in future research with larger samples. In summary, it can be concluded that while legal support alone is not a determining moderator, legal environments may set the stage for the influence of more complex contextual factors that drive heterogeneity in results. While our investigation of legal support as a moderator provides initial evidence that context matters, the small number of primary studies (k = 6) constrained our ability to test a more comprehensive set of moderators. We therefore do not claim that the pooled estimate is a universal constant. Rather, our contribution to generalizability is twofold: (i) we establish that a positive FI–CE relationship exists on average across the eligible contexts, and (ii) we quantify substantial between-study heterogeneity, indicating that the effect is likely conditional on contextual and implementation factors. In emerging research streams, early-stage meta-analyses can still play an important field-shaping role by offering a quantitative baseline, identifying inconsistency, and clarifying what future primary studies should report to enable more powerful moderator testing. As the evidence base grows—particularly from underrepresented contexts and industries—the precision of pooled estimates and the scope of generalizable conditional inferences will improve. We explicitly encourage future primary researchers to design studies that capture contextual variables (e.g., industry resource intensity, national innovation culture, firm age) with validated measures. As the corpus of quantitative studies grows, future meta-analyses will be well-positioned to employ meta-regression techniques and provide a much richer, contingent understanding of the FI-CE relationship.

To further enhance the generalizability and depth of future syntheses, we propose a two-pronged approach. First, we call on researchers to conduct and publish quantitative studies in under-represented contexts (e.g., Southeast Asia and African economies, service sectors) and to consistently report zero-order correlations. Second, we advocate for and plan to undertake periodic updates to this meta-analysis. As the body of primary research grows, future iterations will not only refine the pooled estimate but also enable more powerful moderator and meta-regression analyses, moving the field from establishing if a relationship exists to understanding the conditions under which it thrives.

Conclusion

The investigation, conducted through a rigorous systematic review and meta-analysis of six high-quality empirical studies, yields several significant findings with broad theoretical, practical, and policy implications. The primary and most definitive finding of this study is that Frugal Innovation exerts a statistically significant positive effect on the Circular Economy. The combined effect size ($r = 0.451$), derived from a random-effects model due to confirmed heterogeneity among studies, indicates a medium-strength relationship according to established benchmarks. This outcome robustly supports the core theoretical proposition underpinning this research: the inherent philosophies of FI—“doing more with less,” minimizing waste, simplifying design, and maximizing resource utility—are fundamentally aligned with and actively promote the principles of a CE, which aims to close material loops and retain value within the economy.

Implications for Theory and Research

This study makes a pivotal theoretical contribution by moving from conceptual framing to quantitative validation. Meanwhile, the finding that legal support did not serve as a statistically significant moderator is, in itself, a critical theoretical insight. Just as by carrying out a comparison between eco-cycle and circular economy policies in Sweden, Johansson and Henriksson (2020) also showed that the state is represented rather as an inherent obstacle than as a facilitator to other actors. Therefore, results suggest that the FI-CE relationship is driven more by intrinsic firm-level strategies, managerial philosophy, and market/competitive pressures than by the mere presence of a supportive regulatory framework. The high heterogeneity observed within studies conducted with legal support further implies that other contextual factors—such as national culture, industry sector dynamics, technological infrastructure, or supply chain maturity—likely interact with legal frameworks to produce varied outcomes. This opens a rich avenue for future research to identify and test these complex, higher-order moderators and mediators.

Implications for Practitioners and Managers

The meta-analytic evidence presented herein offers actionable insights that bridge the gap between empirical findings and industrial practice. We delineate these implications across three interconnected managerial domains:

- a) Operations and Production Management: Our findings substantiate that process-level frugality—manifested in material input minimization, energy intensity reduction, and design simplification—serves as a foundational enabler of circularity at the operational level. Operations managers should therefore reconceptualize frugality not as a peripheral cost-reduction tactic, but as a strategic capability that directly influences downstream circular outcomes such as remanufacturability, recyclability, and material recovery rates. Specifically, embedding design-for-disassembly principles during the product development phase can reduce end-of-life processing costs, thereby improving the economic feasibility of closed-loop systems. We recommend that firms establish formal frugality metrics within their operational dashboards to systematically track progress.
- b) Supply Chain Design and Procurement: From a supply chain perspective, our results suggest that sourcing and procurement strategies should incorporate “frugal innovation capability” as a weighted criterion in supplier selection and evaluation frameworks. Suppliers that demonstrate resource efficiency and bricolage behavior are more likely to engage constructively in reverse logistics arrangements and circular supply chain partnerships. The moderate pooled effect size ($r = 0.45$) indicates that investments in developing such supplier capabilities, while not transformative in isolation, yield consistent and statistically meaningful

improvements in circular supply chain performance. Supply chain managers should therefore prioritize supplier development programs that emphasize resource parsimony and collaborative innovation for circularity.

- c) Strategic Management and Corporate Decision-Making: At the strategic level, our findings imply that corporate leaders should elevate frugal innovation from a niche R&D activity to a core strategic priority within the firm's sustainability roadmap. The moderate but significant effect size suggests that FI functions as a complementary rather than substitute mechanism for achieving CE goals. A balanced innovation portfolio—combining incremental frugal innovations with more radical circular innovations—is likely to produce optimal outcomes. We recommend that firms allocate a dedicated proportion of their innovation budgets to projects specifically designed to enhance resource parsimony and circularity, as these investments build organizational resilience against resource price volatility and escalating regulatory pressures.

Taken together, these implications bridge the gap between the often-separate domains of lean operations, innovation management, and sustainable business strategy.

Policy Recommendations

While legal support was not a direct moderator, policymakers play an indispensable role in creating an ecosystem where the FI-CE synergy can flourish at scale. The findings suggest that policy should move beyond blunt regulatory instruments to more nuanced enablers:

Create a Level Playing Field: Develop standards and certifications that recognize and validate the environmental and economic value created through frugal-circular business models, helping them gain market credibility.

Invest in Enabling Infrastructure: Support the development of reverse logistics, shared recycling facilities, and digital platforms for material marketplaces that reduce the transaction costs for firms pursuing circular strategies, making frugal circular innovation more feasible.

Concluding Reflection

In an era defined by resource scarcity, climate urgency, and the imperative for inclusive sustainable development, the transition to a circular economy is non-negotiable. This meta-analysis demonstrates that frugal innovation is a powerful, empirically validated engine for this transition. It provides a pragmatic pathway where sustainability intersects with economic viability and strategic innovation. By embracing the "more with less" paradigm, businesses can unlock circularity not as a cost center but as a source of resilience, efficiency, and long-term value creation.

Future research, building on this foundational evidence, should delve deeper into the contextual recipes for success and the longitudinal impact of FI on specific CE performance indicators. For now, the conclusion is clear: fostering frugal innovation is a critical and practical step toward closing the loop and building a more sustainable economic future.

Limitations and Future Research Direction

While meta-analysis can generally yield more robust and accurate conclusions, this study is not without limitations that may introduce bias. One limitation concerns the inclusion of articles published solely in English, a choice driven by the reliance on records retrieved from the Scopus and Web of Science databases. To mitigate this issue, future meta-analytic work could incorporate high-quality publications in other languages. A further limitation is that this study considered only peer-reviewed journal articles, a decision intended to maximize methodological rigor and ensure the overall quality of the included evidence. As with all meta-analytic approaches, however, the credibility of the synthesized findings ultimately depends on the characteristics and quality of the underlying data in the selected sample. Notably, authors and journals have shown increasing interest in quantitative research on frugal innovation and the circular economy, partly because these phenomena are relatively emergent and their interrelationships are still not fully understood. Nevertheless, the final meta-analysis comprised a relatively small number of studies. Accordingly, we recommend that, once a larger body of quantitative evidence accumulates, a new meta-analysis be conducted with an expanded sample size. In addition, scoping reviews may help further map and refine the relevant research variables and conceptual boundaries. Moreover, the current evidence base is concentrated in a limited number of regions and industries. Future studies should therefore examine FI–CE linkages in underrepresented contexts—for example, service sectors and less studied geographic regions—and assess circular economy performance using harmonized, comparable dimensions. Finally, because only one moderator (legal support) could be harmonized across the existing studies, subsequent meta-analyses should adopt multi-moderator designs once sufficient evidence becomes available. Consistent with this recommendation, future research should explicitly measure and report potential moderators such as industry characteristics, firm size, resource intensity, and regulatory stringency, using operationalizations that are comparable across studies.

Author Contributions

All authors contributed equally to the conceptualization of the article and writing of the original and subsequent drafts.

Acknowledgements

The authors would like to thank anonymous referees for their constructive comments.

Ethical considerations

The authors avoided data fabrication, falsification, and plagiarism, and any form of misconduct.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Conflict of interest

The authors declare no conflict of interest.

References

Al Omoush, K., Lassala, C., & Ribeiro-Navarrete, S. (2025). The role of digital business transformation in frugal innovation and SMEs' resilience in emerging markets. *International Journal of Emerging Markets,* 20(1), 366–386. https://doi.org/10.1108/IJOEM-12-2022-1937

Al-kahtib, A., Alghababsheh, M., & Khattab, M. (2025). The role of organizational ambidexterity and frugal innovation in enhancing circular supply chains: The effect of artificial intelligence capabilities. *Technological Forecasting and Social Change*, 210, 123905. https://doi.org/10.1016/j.techfore.2024.123905

Al-Khatib, A. W. (2022). Can big data analytics capabilities promote a competitive advantage? Green radical innovation, green incremental innovation and data-driven culture in a moderated mediation model. *Business Process Management Journal,* 28(4), 1025–1046. https://doi.org/10.1108/BPMJ-05-2022-0212

Alo, O., Arslan, A., Choudrie, J., & Elo, M. (2025). Revalorization, frugal innovation, and circularity: A qualitative exploration of African used automotive parts business. *Technovation*, 144, 103231. https://doi.org/10.1016/j.technovation.2025.103231

Alsharaideh, A. M. A., Alzubi, M. M. S., Alqudah, A. M. A., Alqudah, O. M. A., & Darabah, K. (2026). AI-enabled frugal innovation: extending the dynamic capabilities framework for sustainable development. *Economics*, 14(2). https://doi.org/10.2478/eoik-2026-0044

Arfaoui, N., Le Bas, C., Vernier, M.-F., & Vo, L.-C. (2023). Innovation strategies and implementation of various circular economy practices: Findings from an empirical study in France. *Journal of Innovation Economics & Management,* 42(3), 149–183. https://doi.org/10.3917/jie.pr1.0141

Arshad, H., Khakwani, M. I., & Olan, F. (2025). Frugal Meets Circular: A Transformative Approach towards Sustainability. *IEEE Engineering Management Review*. https://doi.org/10.1109/EMR.2025.3645686

Barney, J. (1991). Firm resources and sustained competitive advantage. *Journal of management*, 17(1), 99–120. https://doi.org/10.1177/014920639101700108

Bas, C. L. (2023). The Economics of Frugal Innovation (1035302322).

Bazrafshan, A.; Hejazi, R.; Rahmani, A., & Bastani, S. (2015). Metaanalysis of Audit Committee Independence and Financial Reporting Quality. *Management Accounting*, 8(25), 101-117. (In Persian) https://sid.ir/paper/198943/en

Bhatti, Y. A., & Ventresca, M. (2013). How can 'frugal innovation'be conceptualized? Available at SSRN 2203552. https://dx.doi.org/10.2139/ssrn.2203552

Blackburn, O., Ritala, P., Keränen, J., & Bocken, N. (2026). Circular economy platforms: A systematic review. *Business Strategy and the Environment*, 35(2), 2810-2841. https://doi.org/10.1002/bse.70307

Cohen, W. M., & Levinthal, D. A. (1990). Absorptive capacity: A new perspective on learning and innovation. *Administrative science quarterly*, 35(1), 128–152.

Dagilienė, L., Varaniūtė, V., & Bruneckienė, J. (2021). Local governments' perspective on implementing the circular economy: A framework for future solutions. *Journal of Cleaner Production*, 310, 127340. https://doi.org/10.1016/j.jclepro.2021.127340

Dosi, G., Nelson, R. R., & Winter, S. G. (2000). The nature and dynamics of organizational capabilities. Oxford university press.

Dost, M., Lee, M., & Umrani, W. A. (2025). Implementing circular economy through bricolage, frugal innovation and technological turbulence. *Sustainable Development*, 33(2), 1610–1622. https://doi.org/10.1002/sd.3200

European Commission. 2015. Communication From the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions: Closing the Loop—An EU Action Plan for the Circular Economy (COM/2015/0614 final). Accessed November 25, 2021.

Fang, M., Yu, Y., Park, K., Liu, F., Xiao, S. S., & Shi, Y. (2024). Supply chain relationship dependencies and circular economy performance: the contingency role of digitalization capability. *Journal of Purchasing and Supply Management,* 30(4), 100902. https://doi.org/10.1016/j.pursup.2024.100902

Feitosa, P., Oliveira, M. C. C., Torres Ximenes, E. F., & Souza Piao, R. (2026). Integrating circular economy and frugal innovation for social inclusion: a multi-case study. *Social Responsibility Journal*, 1-19. https://doi.org/10.1108/SRJ-10-2024-0749

Ferasso, M., Beliaeva, T., Kraus, S., Clauss, T., & Ribeiro-Soriano, D. (2020). Circular economy business models: The state of research and avenues ahead. *Business strategy and the environment*, 29(8), 3006–3024. https://doi.org/10.1002/bse.2554

García-Quevedo, J., Jové-Llopis, E., & Martínez-Ros, E. (2020). Barriers to the circular economy in European small and medium-sized firms. *Business strategy and the environment*, 29(6), 2450–2464. https://doi.org/10.1002/bse.2513

Haque, A., Fernando, M., & Caputi, P. (2021). Responsible leadership and employee outcomes: a systematic literature review, integration and propositions. *Asia-Pacific Journal of Business Administration,* 13(3), 383–408. https://doi.org/10.1108/APJBA-11-2019-0243

Hernanda, T., Wardiono, K., Azhari, A. F., Arlinwibowo, J., Azizah, N., & Budiono, A. (2023). The Impact of Environmental Regulation Implementation: A Meta-Analysis. *International Journal of Sustainable Development & Planning,* 18(10). https://doi.org/10.18280/ijsdp.181023

Higgins, J., & Thompson, S. G. (2002). Quantifying heterogeneity in ameta-analysis. Statistics in medicine, 21, 1539-1558. [https://www.ncbi.nlm.nih.gov/pubmed/12111919] https://doi.org/10.1002/sim.1186

Hindocha, C. N., Antonacci, G., Barlow, J., & Harris, M. (2021). Defining frugal innovation: a critical review. *BMJ Innovations*, 7(4). https://doi.org/10.1136/bmjinnov-2021-000830

Hossain, M. (2021). Frugal innovation and sustainable business models. *Technology in society*, 64, 101508. https://doi.org/10.1016/j.techsoc.2020.101508

Hossain, M., Agarwal, N., Bhatti, Y., & Levänen, J. (2022). Frugal innovation: Antecedents, mediators, and consequences. *Creativity and Innovation Management*, 31(3), 521–540. https://doi.org/10.1111/caim.12511

Hossain, M., Simula, H., & Halme, M. (2016). Can frugal go global? Diffusion patterns of frugal innovations. *Technology in society*, 46, 132–139. https://doi.org/10.1016/j.techsoc.2016.04.005

Jiménez-Jiménez, D., & Sanz-Valle, R. (2011). Innovation, organizational learning, and performance. *Journal of business research*, 64(4), 408–417. https://doi.org/10.1016/j.jbusres.2010.09.010

Johansson, N., & Henriksson, M. (2020). Circular economy running in circles? A discourse analysis of shifts in ideas of circularity in Swedish environmental policy. *Sustainable Production and Consumption*, 23, 148–156. https://doi.org/10.1016/j.spc.2020.05.005

Kantola, J., Liu, Y., Peura, P., de Leeuw, T., Zhang, Y., Naaranoja, M., Segev, A., & Huisingh, D. (2017). Innovative products and services for sustainable societal development: Current reality, future potential and challenges. *Journal of Cleaner Production*, 162, S1–S10. https://doi.org/10.1016/j.jclepro.2017.07.091

Kemmerling, B., Schetter, C., & Wirkus, L. (2022). The logics of war and food (in) security. *Global Food Security,* 33, 100634. https://doi.org/10.1016/j.gfs.2022.100634

Konietzko, J., Bocken, N., & Hultink, E. J. (2020). Circular ecosystem innovation: An initial set of principles. *Journal of Cleaner Production*, 253, 119942. https://doi.org/10.1016/j.jclepro.2019.119942

Landis, J. R., & Koch, G. G. (1977). The measurement of observer agreement for categorical data. *Biometrics*, 33(1), 159-174. https://doi.org/10.2307/2529310

Liberati, A., Altman, D. G., Tetzlaff, J., Mulrow, C., Gøtzsche, P. C., Ioannidis, J. P., Clarke, M., Devereaux, P. J., Kleijnen, J., & Moher, D. (2009). The PRISMA statement for reporting systematic reviews and meta-analyses of studies that evaluate healthcare interventions: explanation and elaboration. Bmj, 339. https://doi.org/10.1136/bmj.b2700

Lieder, M., & Rashid, A. (2016). Towards circular economy implementation: a comprehensive review in context of manufacturing industry. *Journal of Cleaner Production*, 115, 36–51. https://doi.org/10.1016/j.jclepro.2015.12.042

MacArthur, E. (2013). Towards the circular economy. Journal of industrial ecology, 2(1), 23–44.

Machkour, B., & Abriane, A. (2026). Frugal Innovation and Artificial Intelligence as Drivers of Circular Economy in Waste Management Systems: A Prospective Review. *International Network on Green Digital Innovation and Business,* 42-49. https://doi.org/10.1007/978-3-032-19760-3_5

Mohseni Kiasari, M., Azizi Hasanabadi, A., & Talebi, H. (2024). Unveiling Hidden Aspects of Intermediary Organizations in Innovation: A Systematic Review through the Lens of Industry Taxonomy. *Industrial Management Journal.* https://doi.org/10.22059/imj.2024.365894.1008091

Moradi, M., Zarea, H., Jalalat, S., Akbari, M., & Kooche Moshki, M. (2026). Ambidextrous Market Orientation and Innovation Performance: The Mediating Role of Entrepreneurial Capabilities. *Industrial Management Journal*, 18(2), 265-297. https://doi.org/10.22059/imj.2026.412919.1008308

More, A. B., & Shrivastava, A. (2026). Scaling Frugal Innovation-Based Startups to Accelerate Sustainable Development. In Business and Management in Asia: Opportunities and Entrepreneurship (pp. 71-93). Singapore: *Springer Nature Singapore*. https://doi.org/10.1007/978-981-95-4909-2_5

Narula, S., Tamvada, J. P., Kumar, A., Puppala, H., & Gupta, N. (2023). Putting digital technologies at the forefront of Industry 5.0 for the implementation of a circular economy in manufacturing industries. *IEEE Transactions on Engineering Management*, 71, 3363–3374.

Niroumand, M., Shahin, A., Naghsh, A., & Peikari, H. R. (2021). Frugal innovation enablers, critical success factors and barriers: A systematic review. *Creativity and Innovation Management*, 30(2), 348–367. https://doi.org/10.1111/caim.12436

Pearce, D. W., & Turner, R. K. (1989). Economics of natural resources and the environment. Johns Hopkins University Press.

Perera, R. L., & Badir, Y. F. (2025). Bridging the Gap between the Source of Innovation and the Implementation of Circular Economy Principles in SMEs Within Emerging Economies: The Mediating Role of Frugal Innovation. *Business strategy and the environment*, 34(2), 1847–1863. https://doi.org/10.1002/bse.4074

Peterson, R. A., & Brown, S. P. (2005). On the use of beta coefficients in meta-analysis. *Journal of Applied Psychology,* 90(1), 175–181. https://psycnet.apa.org/doi/10.1037/0021-9010.90.1.175

Peterson, R. A., & Brown, S. P. (2005). On the use of beta coefficients in meta-analysis. *Journal of Applied Psychology,* 90(1), 175–181. https://psycnet.apa.org/doi/10.1037/0021-9010.90.1.175

Pisoni, A., Michelini, L., & Martignoni, G. (2018). Frugal approach to innovation: State of the art and future perspectives. *Journal of Cleaner Production*, 171, 107–126. https://doi.org/10.1016/j.jclepro.2017.09.248

Rahmani, A., Naeini, A. B., Mashayekh, J., Aboojafari, R., Daim, T., & Yalcin, H. (2024). Green innovation for a greener future: A meta-analysis of the impact on environmental performance. *Journal of Cleaner Production,* 460, 142547. https://doi.org/10.1016/j.jclepro.2024.142547

Rupasinghe, L., Pushpakumari, M., & Perera, G. (2024). Mapping the knowledge of green innovation: a systematic literature review, *Journal of Humanities and Applied Social Sciences*, 6(4). 357-376. https://doi.org/10.1108/JHASS-10-2023-0148

Sahoo, S., Mukhuty, S., Upadhyay, A., & Kaliyan, M. (2025). Digital platform capabilities and circular economy: impact of customer green pressure on frugal innovative strategies. *Business strategy and the environment.* https://doi.org/10.1002/bse.70281

Sant'Ana, J. Q., Gomes, G., Alegre, J., & Munhoz, P. G. (2026). Frugal Innovation as a Strategic Mechanism Linking Learning, International Growth Orientation, and Performance. *Business Strategy and the Environment.* https://doi.org/10.1002/bse.70827

Sarasvathy, S. D. (2001). Causation and effectuation: Toward a theoretical shift from economic inevitability to entrepreneurial contingency. *Academy of management Review*, 26(2), 243–263. https://doi.org/10.5465/amr.2001.4378020

Secomandi, N. (2025). OM Forum—Asset-level perspectives on the clean energy transition. *Manufacturing & Service Operations Management,* 27(1), 8–20. https://ssrn.com/abstract=4902770

Sewenet, A. D., Boulaksil, Y., & Pisano, P. (2026). Circular economy, circularity, and sustainability: A systematic review and conceptual framework. *Cleaner Environmental Systems*, 20, 100405. https://doi.org/10.1016/j.cesys.2026.100405

Shirazi, H., & Bakhtiari, H. (2025). Navigating the Green Road: Predicting New Green Product Development Behavior from a Dynamic Capability Perspective. *Iranica Journal of Energy & Environment*, 16(4), 680–691. https://doi.org/10.5829/ijee.2025.16.04.11

Shirazi, H., Alba, K. & Bakhtiari, H. (2025). Towards Sustainability in Industry 5.0: Analysis of Drivers and Barriers to Implementing Circular Economy in the Petrochemical Industry Supply Chain, *Journal of Supply Chain Management*, 27(3), 35-59. 20.1001.1.20089198.1404.27.88.1.7

Stanley, T. D., & Doucouliagos, H. (2012). Meta-regression analysis in economics and business. Routledge.

Termeer, C., & Metze, T. (2019). More than peanuts: Transformation towards a circular economy through a small-wins governance framework. *Journal of Cleaner Production*, 240, 118272. https://doi.org/10.1016/j.jclepro.2019.118272

Ukbaeva, Z., Wöllner, T., & Bican, P. M. (2026). Constraints and Frugal Innovation: Enabling Sustainable Production Through the New Product Development Process. *Sustainable Development*, 34, 1392-1413. https://doi.org/10.1002/sd.70399

Wernerfelt, B. (1984). A resource-based view of the firm. *Strategic management journal*, 5(2), 171–180. https://doi.org/10.1002/smj.4250050207

Zhang, P. (2025). Implementing circular supply chain in Chinese SMEs: The role of bricolage capability, frugal innovation, and entrepreneurial leadership. *International Review of Economics & Finance*, 104526. https://doi.org/10.1016/j.iref.2025.104526

Zheng, L., & Iatridis, K. (2022). Friends or foes? A systematic literature review and meta-analysis of the relationship between eco-innovation and firm performance. *Business strategy and the environment*, 31(4), 1838-1855. https://doi.org/10.1002/bse.2986

Appendix A

Search string in Scopus and Web of Science databases

Scopus:

TITLE-ABS-KEY (("Circular Economy" OR "Sustainable Economy" OR "Green Economy" OR "Waste Management" OR "Recycling Economy" OR "Sustainable Development" OR "Regenerative Economy") AND ("Frugal Innovation" OR "Cost Innovation" OR "Grassroots Innovation" OR "Jugaad Innovation" OR "Reverse Innovation" OR "Low-Cost Innovation" OR "Resource-constrained Innovation" OR "Constraint-based Innovation" OR "Appropriate Technology" OR "Affordable Innovation"))

WoS:

TS= (("Circular Economy" OR "Sustainable Economy" OR "Green Economy" OR "Waste Management" OR "Recycling Economy" OR "Sustainable Development" OR "Regenerative Economy")) AND TS= (("Frugal Innovation" OR "Cost Innovation" OR "Grassroots Innovation" OR "Jugaad Innovation" OR "Reverse Innovation" OR "Low-Cost Innovation" OR "Resource-constrained Innovation" OR "Constraint-based Innovation" OR "Appropriate Technology" OR "Affordable Innovation")).