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Green Innovation: A Meta-Analytic Exploration of Green Supply Chain and Knowledge Sharing Dynamics

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ABSTRACT

This study investigates the relationship between Green Supply Chain Management (GSCM) and Green Innovation (GI) through a meta-analysis of 24 peer-reviewed studies, addressing gaps in the literature by exploring their interconnectedness across various sectors. The findings reveal a significant positive correlation between GSCM and GI, emphasizing their role in enhancing operational efficiency, environmental sustainability, and competitiveness. A key contribution of this study is the novel integration of learning contexts into the analysis, an area previously underexplored. Furthermore, the research aligns its findings with global sustainability frameworks, such as the Global Reporting Initiative (GRI) and Dow Jones Sustainability Index (DJSI), highlighting the practical implications for environmental reporting, cost management, and risk mitigation. This study advances academic understanding and provides actionable insights for practitioners and policymakers, underscoring the transformative potential of GSCM and GI in driving sustainable innovation and achieving financial and environmental goals.

Keywords: Collaborative eco-friendly practices in MSMEs; environmental sustainability in supply chains; government policies in sustainable business; green supply chain management and innovation.

INTRODUCTION

Environmental issues have garnered significant attention from industry and academia in recent years [106], coinciding with increased scrutiny of environmental problems [10], [114]. Organizations increasingly recognize that to maintain superior reputations [16], enhance market positions [28], attract customers, and gain competitive advantages [19], [43], they must transform their business operations to align with environmentally friendly growth [55]. One strategy an organization can employ is Green Innovation (GI), which is essential for attaining the dual objectives of preservation of the environment and economic development [43]. Furthermore, rising consumer awareness of environmental issues [16], [100] and stringent environmental regulations such as those implemented by the European Union have driven organizations to adopt corporate environmental management practices [8], [98], [99]. Collectively, these factors reflect a strong impetus toward more environmentally friendly production [49], [120].

Escalating environmental challenges and regulatory demands are compelling organizations to reassess their supply chain practices from a financial and reporting perspective [41]. Organizations that fail to integrate Green Supply Chain Management (GSCM) and GI risk incurring significant costs due to environmental penalties, operational inefficiencies, and reputational damage [67]. The global shift toward Environmental, Social, and Governance (ESG) reporting and compliance with frameworks like the Global Reporting Initiative (GRI) and benchmarks like the Dow Jones Sustainability Index (DJSI) [72] further intensifies the urgency. These standards emphasize transparency in environmental performance and sustainability integration within supply chains [8], [98]. Organizations unable to align with these metrics may face difficulties in accessing sustainable financing, maintaining stakeholder trust, and achieving long-term financial stability [55].

GI is a concept driven by internal motivations and responsive to external factors [54]. It encompasses the creation of novel products, processes, or technologies aimed at safeguarding the environment through pollution control, waste recycling, energy conservation, and emissions reduction [9], [13]. Organizations can achieve GI by taking into account environmental impacts like unpredictable climate changes and scarce natural resources. Consequently, organizations must innovatively modify their business activities whilst accounting for environmental impacts [15],

[45]. Implementing GI can improve organization performance [59] because enhanced performance can create competitive advantages [67].

GI ability is demonstrated through adopting cutting-edge technologies, introducing novel products, and implementing innovative management strategies to enhance market reach and propel organizational growth [24]. As Wang et al. [101] highlighted, organizations that excel in GI often secure more advantageous positions within the supply chain. A notable example is a small to medium-sized U.S. enterprise that developed groundbreaking green packaging materials, drawing the attention of industry giants like Unilever and Dell. Despite these advancements, current theoretical research requires a deeper exploration of the impact of GI capability on an enterprise's standing within the supply chain. While prior studies have predominantly examined the internal benefits of GI capability—such as boosting green product development [27], enhancing environmental performance, and achieving sustainability goals [108]—there is a gap in understanding its broader influence on supply chain partners.

Organizations not only contribute to a country's economic growth but also to pollution and environmental degradation if they fail to manage these effects properly [67], [94]. GSCM is an environmental management approach recognized and adopted by many firms [15], [65], [83]. GSCM addresses relevant issues such as (1) stakeholder implementation of environmentally friendly practices, (2) stakeholder motivation in applying GSCM, (3) barriers faced by stakeholders in GSCM implementation, and (4) implications for overall organization performance [104]. Supply Chain Management encompasses relationships from suppliers through distribution to consumers, where organizations strive to maintain environmental sustainability within the supply chain. Implementing GSCM can enhance organization performance in terms of profitability and GI by developing eco-friendly products [83]. Consequently, the number of organizations adopting GSCM to improve performance is increasing [18]. GSCM can bolster GI to address external pressures [83] and enhance organization performance [18].

GSCM emphasizes integrating environmentally sustainable practices into firms' supply chain management activities [69], [79]. The primary focus of GSCM research involves evaluating the effectiveness of different practices in improving supply chain sustainability [66], [77], [97]. Despite the growing interest in how GSCM can foster GI within firms [22], [39], the link between GSCM and GI remains unclear and inconsistent.

For instance, while some studies suggest that the green capabilities and qualifications of suppliers, such as environmental management systems and ISO 14001 certification, significantly impact a firm's GI [39], [107], other research finds no significant effect [53]. Similarly, while customers' environmental demands can motivate firms to adopt GI practices [40], [51], they do not always lead to increased investment in GI initiatives [44], [64]. In some cases, customer pressure for environmental performance has negatively affected green process innovation [56], [118].

Moreover, collaboration with suppliers and customers on GI has a mixed impact. Some studies indicate that such collaboration significantly enhances GI [23], [73], whereas others suggest that it has no notable effect [32], [47]. These varied findings highlight the need for a deeper understanding of the contextual factors and mechanisms that mediate the GSCM-GI relationship.

Due to the diverse findings regarding the relationship between Green Supply Chain Management (GSCM) and Green Innovation (GI)—spanning positive, negative, and non-significant outcomes—this study seeks to investigate the specific impacts of GSCM on GI, as well as the contextual factors that might affect these impacts. For several key reasons, the author adopts an inter-organizational learning (IOL) framework to construct the research model to achieve this goal.

Firstly, as supply chains progress toward greater sustainability, they undergo a complex, dynamic, and evolving learning process [65]. Analyzing GSCM from a learning perspective allows a clearer understanding of its driving role. Secondly, GI is inherently more intricate than traditional forms of innovation [61], [91], necessitating a range of technical resources and capabilities often distributed across multiple organizations [36]. The organizational learning theory provides an exciting viewpoint on how collaborative learning and interconnections among multiple organizations might enhance knowledge creation. [50]. Lastly, organizational learning theory highlights the significance of contextual factors in the process of knowledge creation [6], [14]. This theory underpins the development of a comprehensive framework to determine the boundary conditions that could influence the interaction between GSCM and GI.

By adopting this perspective, we can better understand the direct influence of GSCM on GI and how various contextual factors, such as organizational capabilities and inter-firm dynamics, modulate this relationship. This approach enables a nuanced exploration of how GSCM strategies can be leveraged to enhance GI outcomes across diverse supply chain contexts [117].

This study offers actionable insights into how GSCM can drive GI, enhancing both financial performance and compliance with evolving sustainability reporting frameworks. This study serves as a meta-analysis that specifically examines the effect of GSCM on GI. While several previous meta-analyses have examined the performance outcomes associated with GSCM or Sustainable Supply Chain Management (SSCM), specifically focusing on aspects such as operational, economic, and sustainability performance [24], [29], [30], and [31], there is still a significant gap in research that explicitly addresses the direct relationship between GSCM and GI. Review articles covering this particular interaction are scarce, making this study an important addition that aims to fill this research void and provide deeper insights into how GSCM influences innovative environmental practices.

Literature Review

Inter-Organizational Learning

The repository of information within an organization underpins the establishment and maintenance of a competitive advantage [70]. Engaging in learning activities is not only essential but also serves as a pathway for firms to enhance their knowledge and make the most of their existing knowledge base. Moreover, when a firm acquires new insights through learning activities, its existing knowledge significantly influences its ability to comprehend and integrate this new information [38], [71]. Inter-organizational learning (IOL) occurs beyond the boundaries of individual firms, functioning at the inter-organizational level [110]. It plays a vital role in the creation and application of knowledge, enabling firms to gain access to novel and diverse knowledge from external sources, thereby facilitating innovation and fostering a competitive edge.

In supply chains, IOL typically occurs between buyers and suppliers [76]. Firms can learn from these partners, who provide unique and valuable knowledge. The depth of the source's knowledge and expertise affects the transfer of information across enterprises [17]. When a firm perceives a source as credible and reputable, it is more likely to trust and value its knowledge. This trust is the bedrock that enables firms to evaluate and utilize knowledge effectively, enhancing their performance and innovation capabilities [95].

A firm's learning intent influences and shapes its willingness to learn and exploit external knowledge [38]. Yang et al. [110] suggested that the intent to learn is a critical factor in determining the success of IOL. Firms with a strong learning intent are not just better positioned, but they are in control of absorbing knowledge from their supply chain partners, fostering innovation [3].

Learning processes are inherently contextual [68]. The environmental context, which includes factors beyond the firm's boundaries—such as institutional frameworks and cultural norms—plays a significant role in shaping learning outcomes [68]. Multiple studies have emphasised the impact of macroeconomic variables, including corporate governance and governmental regulations, on organisational learning. [41], [63]. Given the substantial impact of the institutional environment on strategic formulation and execution and organizational learning dynamics, it is clear that these contextual factors have a profound effect on how firms learn and adapt [6], [48], [111].

This review emphasizes the critical role of both internal and external learning mechanisms in enhancing firm capabilities. By actively engaging in inter-organizational learning and considering the contextual environment, firms can effectively leverage external knowledge to drive innovation and maintain a competitive advantage.

Green Supply Chain Management

Green Supply Chain Management (GSCM) integrates environmental considerations into all stages of Supply Chain Management (SCM), aiming to minimize the environmental impacts of products and processes throughout the supply chain [34], [112]. This approach not only involves adhering to environmental regulations but also proactively implementing sustainable practices that go beyond compliance. From the Inter-Organizational Learning (IOL) perspective, which refers to the process of learning and knowledge sharing among different organizations, GSCM practices can be categorized into several key components, such as green supplier management, green customer management, proactive behaviour of GSCM, and reactive behaviour of GSCM.

Green Supplier Chain Management involves engaging with suppliers to ensure their practices align with the focal firm's environmental objectives [75]. Green Supplier Management can include requiring suppliers to have ISO 14001 certification, adopting environmentally friendly raw materials, and collaborating on eco-innovation projects, which could be initiatives to develop more sustainable packaging or reduce energy consumption in production processes [58]. Effective green supplier management enables firms to leverage their suppliers' capabilities to enhance overall supply chain sustainability and to co-create innovative solutions that reduce environmental footprints [76].

Green Customer Management focuses on understanding and responding to customer expectations for sustainable products and services [109]. It involves providing eco-friendly products, transparently communicating about environmental practices, and incorporating customer feedback into product development processes [1], [4]. Organizations that excel in managing green customer relations can strengthen their connections with environmentally aware consumers, setting themselves apart in the competitive market [40].

Proactive GSCM, in contrast, is a realm of exciting possibilities. It refers to initiatives that organizations undertake voluntarily to go beyond regulatory requirements and actively contribute to environmental sustainability [103]. GSCM initiatives, such as investing in renewable energy, designing products for recycling, and implementing closed-loop supply chains, are not just about compliance [81]. They are about innovation and the potential for long-term competitive advantages through sustainability leadership [32].

Conversely, reactive GSCM involves implementing environmental practices primarily in response to external pressures such as regulations, customer demands, or stakeholder activism [96]. While reactive GSCM helps firms comply with environmental standards and avoid penalties, it often lacks the strategic depth and innovation potential associated with proactive GSCM [47], [84].

By breaking down GSCM practices into these categories, the IOL perspective highlights how different types of learning and collaboration among supply chain partners can drive GI and improve environmental performance. Organizations that effectively manage their green supplier and customer relationships and adopt both proactive behaviour and reactive behaviour GSCM strategies are better positioned to achieve sustainable competitive advantage and contribute to broader environmental goals. This strategic alignment enhances organizational resilience and enables firms to respond more effectively to regulatory and market demands for sustainability. Consequently, organizations can build a stronger reputation while fostering long-term business growth through environmentally responsible practices.

Green Innovation

GI is a powerful strategy that organizations employ to address the environmental impacts of their manufacturing and production processes [25]. It offers many benefits, from reducing resource consumption to minimizing pollution and waste, all while safeguarding the environment [116]. This approach, whether through new products, advanced technologies, or more sustainable management practices, is a key to sustainable business growth [109].

Organizations often favor GI due to cost savings, which serve as a significant motivator for adopting environmentally friendly processes and organizational changes [40], [57], and [62]. Hojnik & Ruzzier [40] emphasize that cutting costs and investing in research and development focused on sustainability can drive product and process innovation. This financial aspect of GI is particularly appealing, as it can lead to significant reductions in energy use and material costs, thereby driving product and process innovation [57].

Embracing green technology is a boon for the planet and a game-changer for businesses [74]. It opens up commercial opportunities in the growing market for eco-friendly products and enhances organization's competitive edge [16], [67]. By improving efficiency and reducing expenses, GI can significantly boost organization's bottom line, making it more competitive in the long run [5], [67]. Seytaningrum & Muafi [85] even suggest that GI can become a crucial driver for organizations looking to stand out with sustainable products, ultimately balancing business growth with environmental responsibility.

Organizations increasingly see that adopting eco-friendly practices is not just about being beneficial for the planet but also makes smart business sense [1]. By incorporating sustainable methods into their daily operations, they are minimizing their environmental impact and positioning themselves more competitively in the market [62], [78]. This approach does not just pay off now; it sets them up for future success. When businesses commit to GI, they are embracing a strategy that's both sustainable and promising for long-term growth [57], [58]. It is a reassuring move that balances doing what is suitable for the environment with what is right for their bottom line [43]. Adopting these practices can lead to increased consumer loyalty and brand differentiation, making organizations stand out in a market that increasingly values sustainability. As a result, organizations not only benefit the environment but also create a solid foundation for future business opportunities.

Hypothesis Development

Relationship of GSCM and GI

GSCM integrates environmental considerations into supply chain activities, such as procurement, production, and logistics, to reduce environmental impact and improve sustainability [43], [55], [58]. GI refers to developing new products, processes, or

practices that minimize adverse environmental effects and promote sustainability [40], [57], [62]. Understanding the relationship between GSCM and GI is crucial for organizations aiming to enhance their environmental and economic per–formance.

This hypothesis proposes that implementing GSCM practices contributes positively to the development of GI. Firms adopting GSCM engage in green procurement, sustainable product design, and eco-friendly logistics, creating a conducive environment for GI. For instance, adopting sustainable materials and processes can create new environ–mentally friendly products and new technologies [90], [109]. This positive association suggests that firms committed to GSCM are more likely to innovate in ways that support environmental sustain-ability.

H_1: Green supply chain management is positively associated with green innovation.

This hypothesis focuses on the manufacturing sector, where the impact of GSCM on GI is expected to be particularly significant. Manufacturing processes are often resource-intensive and have a substantial environmental footprint [93]. Implementing GSCM in this context can lead to innovations that reduce waste, improve energy efficiency, and minimize emissions. For example, incorporating closed-loop systems or cleaner production technologies can significantly enhance GI outcomes in manufacturing [5], [108]. Thus, GSCM is likely a key driver of GI in this sector.

H_2: Green supply chain management is positively associated with green innovation in the manufacturing industry.

This hypothesis suggests that GSCM practices also positively impact GI in non-manufacturing industries, such as services, retail, and logistics. While these sectors may not directly engage in production, they can still drive GI through sustainable supply chain practices. For instance, optimizing logistics to reduce carbon emissions or developing sustainable packaging solutions are examples of how non-manufacturing firms can innovate in response to GSCM initiatives [32], [40]. This hypothesis posits that GSCM practices in non-manufacturing sectors contribute to GI and enhance service delivery and operational efficiency.

H_3: Green supply chain management is positively associated with green innovation in the non-manufacturing industry.

These hypotheses highlight the significance of GSCM as a strategic instrument for boosting GI across a variety of industries. Researchers will be able to gain a better understanding of the mechanisms via which GSCM affects GI and how these relationships differ between the manufacturing sector and the non-manufacturing sector if they apply these hypotheses to the test. Organizations that are looking to develop efficient GSCM strategies in order to improve their environmental performance and innovation capabilities will find this knowledge to be extremely beneficial.

RESEARCH METHOD

This research utilizes a meta-analysis method to systematically analyze the relationship between GSCM and GI, focusing on studies that used questionnaires as their primary data collection method. We chose meta-analysis because it can synthesize findings from multiple studies, thereby providing a comprehensive understanding of the research topic and identifying overall trends, patterns, and potential gaps [33].

Sample

The data for this study were sourced from 24 peer-reviewed journal articles published between 2013 and 2023. We selected these articles from two primary databases: Scopus and Google Scholar. We established the inclusion criteria to ensure both relevance and quality, concentrating on studies that used questionnaires to investigate the relationship between Green Supply Chain Management and Green Innovation.

This study employed the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) method to ensure a systematic and transparent selection process for the articles included in the meta-analysis [33]. The PRISMA framework guided the identification, screening, eligibility, and inclusion of studies, ensuring consistency and minimizing potential bias [87]. A comprehensive literature search was conducted using Scopus and Google Scholar to identify relevant articles. We conducted a comprehensive literature search using Scopus and Google Scholar to identify relevant articles. We utilized the query 'TITLE-ABS-KEY (supply AND chain AND management AND green AND innovation) AND ABS (questionnaire)' in Scopus to find studies that featured'supply chain management,' 'green inno–vation,' and 'questionnaire' in their titles, abstracts, or keywords. This search focused on articles published in English between 2013 and 2023. We employed the keywords "green supply chain management" + "green innovation" + "questionnaire" in Google Scholar, using Boolean operators and quotation marks to refine the results and include only studies explicitly addressing the intersection of

these concepts. These searches yielded two initial datasets: 121 articles from Google Scholar and 57 articles from Scopus. Following the removal of duplicates through the merging process, the final consolidated sample consisted of 73 unique articles, ensuring a robust foundation for the subsequent analysis. To ensure the quality criterion, we further excluded articles published in proceedings, books, or meetings. Thus, we get a sample of 53 peer-reviewed journal articles.

The articles underwent further evaluation based on four eligibility criteria: (1) The study needed to focus on environmental issues, with studies addressing only social sustainability excluded. (2) The study had to employ a quantitative approach, provide clear construct definitions and measurements, and simultaneously investigate GSCM and GI. Consequently, case studies, mathematical modeling papers, and studies with ambiguous construct definitions were excluded. (3) The study was required to report Pearson's correlation between GSCM and GI, as reliance solely on β coefficients was deemed inadequate due to the higher accuracy of meta-analytic results based on Pearson's correlations [11], [80]. (4) For datasets utilized in multiple studies, only the version providing detailed information and published in a high-impact journal was retained. After this screening process, we excluded 45 studies that did not meet all the criteria.

We identified four outliers during data processing and subsequently excluded them from the remaining sample, which consisted of 28 inde–pendent studies. This resulted in a final sample of 24 valid studies. The earliest study included in the sample was published in 2013, with 18 articles published between 2020 and 2023, highlighting the GSCM–GI relationship as a growing and significant area of research.

The analysis reveals the frequent use of several theoretical frameworks to explain the relationship between GSCM and GI. Among these, Resource-Based View (RBV), Organizational Capability Theory, Stakeholder Theory, and Institutional Theory emerge as the most commonly utilized. These theories provide robust explanations for the mechanisms linking GSCM to GI by emphasizing resource allocation, organizational competencies, stakeholder influence, and regulatory environments. While some studies incorporate Organizational Learning Theory, it is notable that none have explicitly integrated the learning context into their research models. This omission highlights an important gap in the literature, as the learning context could offer valuable insights into the dynamic processes that drive innovation within green supply chains. Addressing this gap presents an opportunity for future research to enrich the understanding of how inter-organizational learning and contextual factors contribute to the effectiveness of GSCM practices in fostering GI.

Data extraction focused on gathering detailed information from each selected article, including essential details such as authors, year of publication, journal name, and country of study. We documented the research methodology for each article, empha–sizing the type of questionnaire used, sample size, and employed data analysis methods. We also carefully noted key findings related to the relation–ship between GSCM and GI, along with any limita–tions identified in the study design or data analysis. A standardized form was used to ensure a consistent approach during the extraction process [87].

The extracted data were analyzed using a meta-analytic framework to compute effect sizes for each study. This approach quantifies the strength of the relationship between GSCM and GI across the different studies included in the analysis. We applied a random-effects model to account for hete–rogeneity among the studies, taking into account variations in sample size, geographical location, and the specific aspects of GSCM and GI under examination. We also used the software JASP to calculate the combined effect size and evaluate potential publication bias. A funnel plot and Egger's test were employed to detect any bias, while heterogeneity was evaluated using the I^2 statistic.

A sensitivity analysis was conducted to ensure the robustness of the meta-analysis results. This analysis involved recalculating the overall effect size by systematically removing one study at a time from the dataset [33]. This process helped identify if any single study disproportionately influenced the overall outcomes. Such a step is crucial to confirm that the findings are not overly dependent on any particular study and to enhance the reliability of the conclusions drawn from the analysis.

Despite these rigorous methods, this meta-analysis has several limitations. The reliance on questionnaire-based studies may introduce response bias, as respondents' perceptions do not always reflect actual practices [87]. Additionally, limiting the included articles to those published in English may exclude relevant studies in other languages, potentially affecting the comprehensiveness of the findings. The heterogeneity of the included studies also poses a challenge, as variations in methodology and focus may impact the generalizability of the results.

This methodology offers a systematic and trans–parent framework for understanding the relation–ship between GSCM and GI. The insights from this meta-analysis can be valuable for academics and practitioners seeking to improve sustainability and foster innovation within supply chain practices.

RESULTS AND DISCUSSION

The search results obtained 24 data that met the research criteria. The data collected for analysis consisted of Fisher's test (*F*), Student's test (*t*), Correlation test (*r*), and the number of research data (N). In this context, we can further analyze data related to GSCM and GI methods by taking specific conditions into consideration. Appendix 1 displays the ES (Effect Size) and SE (Standard Error) values after converting the F and t values from the available data into r values.

A series of hypothesis tests and publication bias tests were then conducted on the collected data. In the meta-analysis process, JASP software was used to analyze the data, and the main focus of inference was on the Z-score (z) and p-value results contained in the coefficient table.

Meta-Analysis Result

Heterogeneity Testing

Q and I^2 statistics were employed to assess the heterogeneity of effect sizes among the studies. A significant *Q* value suggests variations among the sampled studies, while I^2 values, ranging from 0 to 100%, represent the degree of heterogeneity, with higher values indicating greater variability [80]. Greater levels of heterogeneity suggest the possibility of incorporating moderator variables into the study. This indicates that underlying factors may influence differences across studies, and including moderators can help better understand and explain the variability in the observed effects [11], [33].

Table 1. Heterogeneity test results

Industry	K	N	*Q*	τ^2	I^2
Across Industries	24	6.453	606,359*	0,079	95,447
Manufacturing	14	3.047	380,833*	0,079	95,394
Non-Manufacturing	10	3.406	225,500*	0,087	95,848

Note: $^*p < 0.01$; K = number of studies; N = total sample size

The heterogeneity test results in Table 1 indicate substantial variability in the effect sizes across studies on the GSCM–GI relationship. High Q values and I^2 percentages above 95% in all industry categories demonstrate significant heterogeneity, while the τ^2 values confirm moderate between-study variance. Diverse study characteristics influence the observed effect sizes, necessitating the inclusion of moderator variables for further analysis [11], [33]. A random effects model is recommended to account for this variability, as it allows for a more accurate assessment of the relationship across diverse sectors. By considering both within-study and between-study differences, this model helps produce more generalizable conclusions that reflect the variability present in the broader context of different sectors [80].

Hypothesis Testing

The data in Table 2 shows that GSCM and GI are significantly related to each other across industries (rc = 0.521, 95% CI: 0.406–0.637, p < 0.01). This means that Hypothesis 1 is likely to be true (p < 0.05). In the manufacturing industry, GSCM also showed a significant positive correlation with GI (r_c = 0.531, 95% CI: 0.380-0.683, $p < 0.01$); thus, Hypothesis 2 was accepted. Also, in non-manufacturing industries, GSCM has a strong positive relationship with GI (rc = 0.507, 95% CI: 0.320–0.695, p < 0.01), which supports Hypothesis 3. In addition, correlation values of *r* above 0.500 in all three research models indicate a robust correlation [20], [102]. The forest plot image also displays the overall effect size results for clearer visualization.

Table 2. Results of the GSCM–GI relationship

Industry	K	N	r_c	SE	95% CI	Z
Across Industries	24	6.556	0.521***	0.059	0.406 0.637	8.855
Manufacturing	14	3.150	0.531***	0.077	0.380 0.683	6.879
Non-Manufacturing	10	3.406	0.507***	0.096	0.320 0.695	5.304

Note: $^{***}p < 0.01$; K = number of studies; N = total sample size; *rc* = corrected effect size; CI = 95% confidence intervals.

The forest plot in Figure 1 reveals significant variability in the impact size of GSCM on GI across different studies. Wu [105] found the weakest effect in the study, with an effect size of 0.19 (95% CI: 0.09–0.29), indicating a weaker positive relationship. This could be because of the nature of the industry or differences in how GSCM is implemented. In contrast, the study by Shafique et al. [86] shows the highest impact, with an effect size of 1.26 (95% CI: 1.17–1.36), suggesting a robust positive correlation, potentially driven by effective GSCM strategies or favorable contextual factors. These disparities underscore that while the overall pooled effect size of 0.52 (95% CI: 0.41–0.64) confirms a significant positive relationship between GSCM and GI, the effectiveness of GSCM practices can vary widely across different contexts and industries, highlighting the need to consider these factors when assessing the impact of GSCM on innovation.

The forest plots in Figure 2 and Figure 3 provide a comprehensive overview of the impact of GSCM on GI in manufacturing and non-manu–

facturing sectors. In the manufacturing sector (see Figure 2), the pooled effect size of 0.53 (95% CI: 0.38–0.68) indicates a robust and significant positive relationship between GSCM and GI. Most studies in this sector report positive effect sizes, highlighting that effective GSCM practices, such as green purchasing, eco-design, and collaboration with suppliers, significantly contribute to enhancing innovation related to environmental sustainability. The high variability observed, with Shafique et al. [86] showing the highest impact (effect size = 1.26) and Guo et al. [35] the lowest (effect size = 0.23), suggests that contextual factors like industry type, regulatory pressures, and the degree of organizational commitment to sustainability can influence the effectiveness of GSCM strategies.

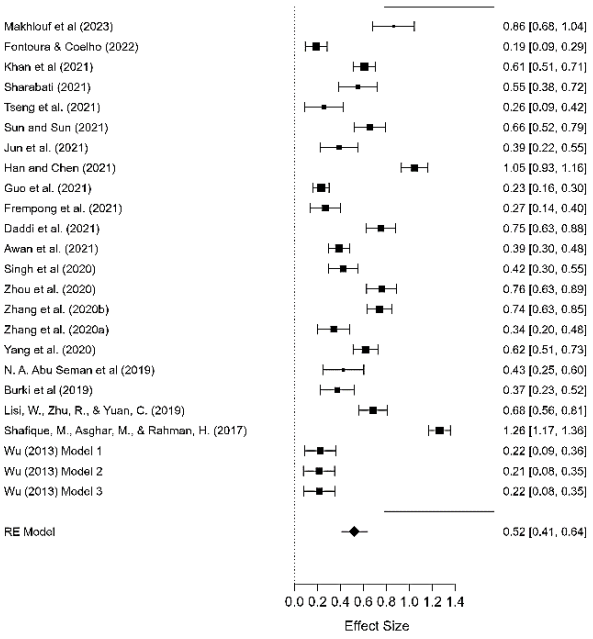

Figure 1. Forrest plot on across industries sector

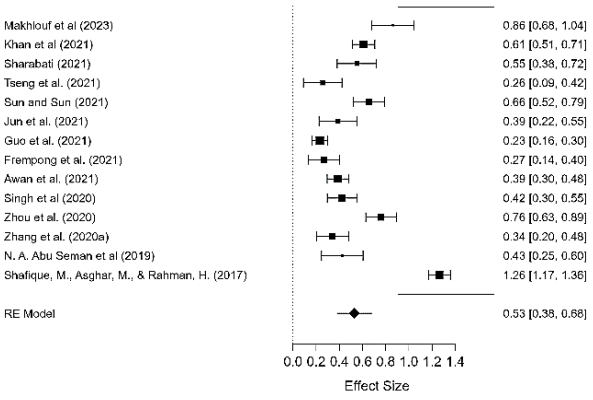

Figure 2. Forrest plot on manufacturing industries sector

In the non-manufacturing sector (see Figure 3), the pooled effect size of 0.51 (95% CI: 0.32–0.69) also indicates a significant positive impact of GSCM on GI. The studies by Han & Chen [37] demonstrate the most robust relationship (effect size = 1.05), potentially due to more proactive adoption of green practices and innovation-driven organizational cultures. On the other hand, the relatively lower effect sizes reported in studies like G. C. Wu [105] suggest that in some non-manufacturing contexts, challenges such as limited resources, lack of regulatory support, or lower prioritization of environmental practices may hinder the full potential of GSCM in driving green innovation.

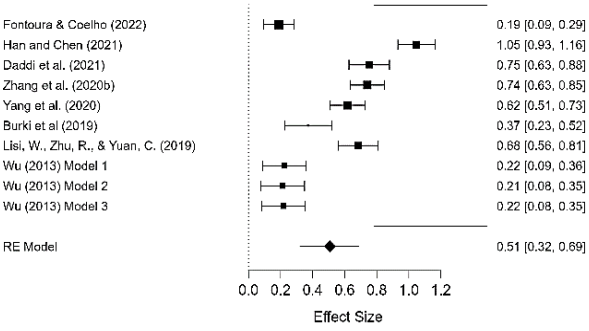

Figure 3. Forrest plot on non-manufacturing industries sector

In the non-manufacturing sector, the pooled effect size of 0.51 (95% CI: 0.32–0.69) also indicates a significant positive impact of GSCM on GI. The studies by Han & Chen [37] demonstrate the most robust relationship (effect size = 1.05), potentially due to more proactive adoption of green practices and innovation-driven organizational cultures. Some studies, like the one by G. C. Wu [105], found smaller effects. This suggests that GSCM may not be able to fully drive green innovation in non-manufacturing settings, where there are problems like a lack of resources, regulatory support, or higher priority for environmental practices.

In the non-manufacturing sector, the pooled effect size of 0.51 (95% CI: 0.32–0.69) also indicates a significant positive impact of GSCM on GI. The studies by Han & Chen [37] demonstrate the most robust relationship (effect size = 1.05), potentially due to more proactive adoption of green practices and innovation-driven organizational cultures. On the other hand, the relatively lower effect sizes reported in studies like G. C. Wu [105] suggest that in some non-manufacturing contexts, challenges such as limited resources, lack of regulatory support, or lower prioritization of environmental practices may hinder the full potential of GSCM in driving green innovation.

These findings collectively highlight that while GSCM is an effective strategy for fostering green innovation in both manufacturing and non-manufacturing sectors, the extent of its impact is highly context-dependent [22], [60]. Factors such as industry characteristics, regulatory environment,

and organizational commitment play crucial roles in determining the success of GSCM initiatives [56], [75]. Future research should explore these moderating factors in greater detail to provide more nuanced insights into how GSCM can maximize its positive effects on green innovation across different sectors. The robust positive association identified in many studies highlights the necessity of using GSCM as a strategic method for attaining sustainability and innovation objectives [3].

Publication Bias Testing

Table 3 presents the results of Egger's Test and Fail-Safe N analysis to assess potential publication bias in the meta-analysis of the relationship between GSCM and GI across three industry categories: across industry, manufacturing, and non-manufacturing. The Egger's test results show that the p-values for all industry categories are more significant than 0.05 (across industry: $p = 0.612$, manufacturing: $p = 0.821$, non-manufacturing: $p = 0.371$), indicating no significant publication bias in the studies analyzed.

Additionally, the Fail-Safe N values for all categories indicate the number of additional studies with null results needed to nullify the significant findings. High Fail-Safe N values indicate that many null studies would be needed to reverse the observed significant association, such as 14,875 for across industry, 5,092 for manufacturing, and 2,551 for non-manufacturing. The results indicate that the positive correlation between GSCM and GI is robust and consistent, with a negligible chance of publication bias influencing the meta-analysis outcomes. [33], [87]

Table 3. Results of the GSCM–GI relationship

Industry	K	*Z*	*p*	*Fail-Safe N*
Across Industry	24	-0.507	0.612	14,875*
Manufacturing	14	-0.227	0.821	5,092*
Non-Manufacturing	10	-0.894	0.371	2,551*

Note: *$p < 0.01$; K = number of studies

The funnel plots in Figures 4, 5, and 6 show publication bias in the meta-analysis of GSCM and GI across industries: manufacturing and non-manufacturing sectors. In a well-balanced meta-analysis, studies should be symmetrically distributed around the pooled effect size at the bottom of the funnel. The plot for the entire industry (Figure 4) shows a relatively symmetrical distribution, indicating minimal publication bias and suggesting that the results are likely robust and reliable [11].

There is a slight asymmetry in the manufacturing sector (Figure 5), with a few studies falling outside the funnel, which may indicate the presence of some publication bias or variability in the study outcomes. However, the overall shape still suggests that the results are generally consistent. For the non-manufacturing sector (Figure 6), the funnel plot is less populated, with most studies clustering near the pooled effect size, but a few are more widely dispersed. This could imply some degree of publication bias or heterogeneity among the studies, potentially due to smaller sample sizes or variations in how GSCM practices are implemented in non-manufacturing contexts [11].

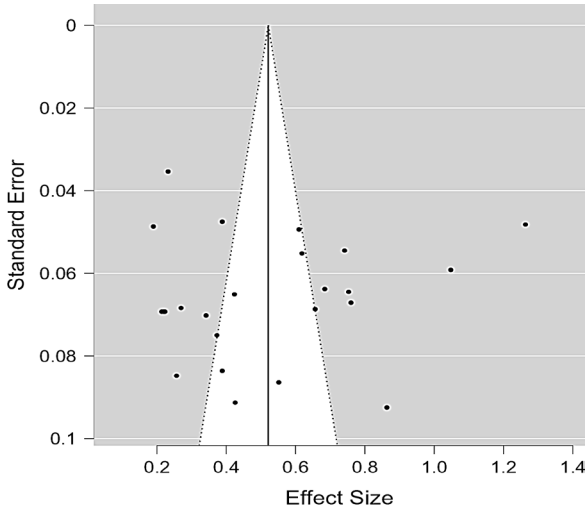

Figure 4. Funnel plot on GSCM-GI for across industries

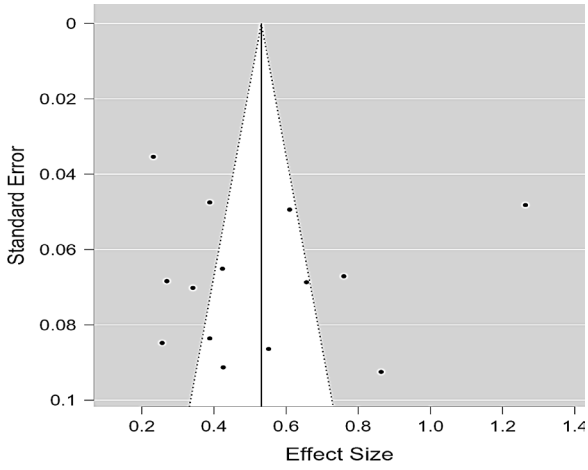

Figure 5. Funnel plot on GSCM-GI for the manufacturing sector

While there may be minor indications of publication bias, the plots' general symmetry suggests that the meta-analysis results are relatively robust, and the observed effect sizes can be considered reliable for concluding the positive relationship between GSCM and GI across different sectors [11], [33].

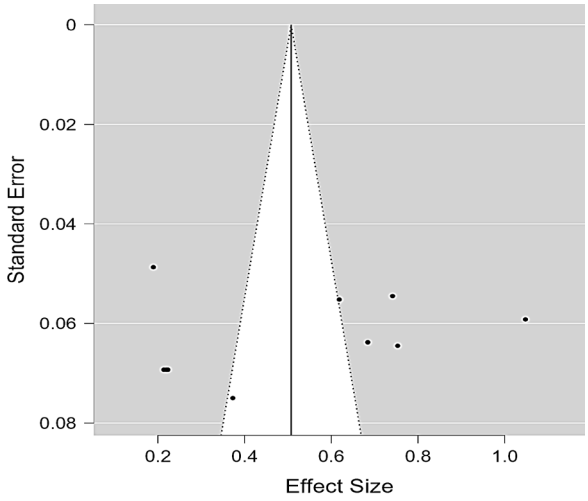

Figure 6. Funnel plot on GSCM-GI for the non-manufacturing sector

This study combines the findings of 24 empirical investigations to investigate the influence of GSCM on GI (H1 accepted). When supply chains adopt green innovations, they develop a sustainable competitive advantage [67]. GI is a dynamic capability that identifies and differentiates GSCM from ordinary supply chains [12]. Developing GI requires knowledge and commitment [35], [89]. Gradual minor improvements, targeted at organizational sustainability through GSCM, lead to the creation of innovative organizational solutions [92]. The organization's production activities will directly impact the environment and society as a whole. GSCM provides insight into increasing product recycling, remanufacturing, and reusing raw materials [7]. The impact of these activities is of more significant concern to governments, regulators, and other civil society groups [27].

GSCM implementation positively correlates with GI in the manufacturing industry (H2 is accepted). Makhlouf et al. [60] stated that GSCM is the primary driver of GI in the manufacturing sector. The manufacturing industry sector has a wide coverage area in implementing GI through various practices. First, by designing green products, choosing product manufacturing methods, and purchasing green raw materials, which are the main components of green supply chain management [2]. Second, by enhancing their green strategic innovation by better understanding various green practices [27]. Collaboration between GSCM and GI practices is highly beneficial for organizations to improve compliance with green product design, manufacturing processes, and environmental impacts [26]. Governments also play an essential role in implementing environmental policies and regulations regarding manufacturing issues [46], [82].

GSCM implementation positively correlates with GI in the non-manufacturing industry sector (H3 is accepted). The non-manufacturing industry sector has a smaller effect size value than the manufacturing industry sector, meaning implementing GSCM is optional for this industry sector [115]. The adoption of environmental innovations by the non-manufacturing sector, especially by Small and Medium Enterprises (SMEs) in developing countries, plays a vital role in driving efforts towards sustainable economic development for a country [35]. This is because SMEs substantially impact the environment and the overall economy [37].

Awareness of environmental issues increases customer concern [83] and pressure from governments and regulators [27] for environmentally friendly products. This condition triggers the application of GSCM not only in the organization's production process but also in pre- and post-production [46]. The availability of skilled human resources and managers' commitment to environmentally friendly practices are the main driving factors for organizations in adopting GI [35]. GSCM integration from the supplier and customer sides has different roles in GI development: suppliers contribute to knowledge combinations, while customers create conditions that support knowledge sharing [105], [119]. Therefore, it is difficult to argue which source of knowledge is more important. Organizations should effectively develop knowledge sharing functions [26] from both the supplier and customer sides to extract the best information about GSCM [21]. Investigating the potential collaborative effects between supplier and customer green management is also essential [78], [113]. The implementation of GSCM that leads to GI will provide a competitive advantage for organizations not only in terms of finances but also in terms of organization performance [16], [46].

Accounting Implications of GSCM and GI

The findings also reveal significant implications for accounting practices, emphasizing the integration of GSCM and GI into environmental reporting and managerial decision-making. The use of GSCM practices generates quantifiable environmental performance metrics, essential for aligning with sustainability reporting frameworks such as the Global Reporting Initiative (GRI) and the Dow Jones Sustainability Index (DJSI) [2], [29]. These metrics facilitate accurate financial disclosures by incorporating environmental costs and savings from waste reduction, energy efficiency, and resource optimization [2].

From a managerial accounting perspective, GSCM and GI enhance cost-benefit analyses and support budgeting for sustainable projects [26], [27]. Operational efficiencies achieved through green

practices directly influence cost structures, allowing firms to allocate resources more strategically while maintaining long-term profitability [21], [67], [86]. Additionally, these practices aid in compliance management by mitigating financial risks associated with regulatory non-compliance, thereby reducing potential liabilities [42], [52].

Green Supply Chain Management (GSCM) and Green Innovation (GI) are also pivotal in enhancing compliance management and mitigating financial risks while simultaneously contributing to intangible value creation. GSCM practices facilitate adherence to environmental regulations, thereby reducing the likelihood of penalties, fines, and legal liabilities [88]. By proactively addressing environmental concerns and integrating sustainable practices into supply chain operations, organizations can circumvent potential financial losses associated with non-compliance [29], [86]. Furthermore, GSCM enables companies to stay ahead of regulatory changes, adopting a proactive stance that is often more cost-effective than reacting to violations [88]. GSCM supports GI in developing compliant technologies and processes, thereby reducing the risks associated with non-adherence to regulatory standards [29], [35].

The implementation of GSCM and GI not only reduces financial liabilities but also enhances operational efficiency and cost savings [29], [86]. Moreover, these initiatives contribute to intangible value creation by enhancing brand reputation, increasing stakeholPr trust, and improving Environmental, Social, and Governance (ESG) scores [21], [60]. These factors are increasingly important indicators of an organization's overall robustness and sustainability, emphasizing the need for accounting practices to evolve and integrate such metrics into financial valuations [21], [26]. The growing emphasis on corporate sustainability requires companies to balance economic growth with environmental protection, leading to a greater focus on transparent reporting and quantifiable sustainability metrics [60].

CONCLUSION

This study provides evidence of a significant and positive relationship between Green Supply Chain Management (GSCM) and Green Innovation (GI) across various industrial sectors. The findings highlight the role of GSCM practices in fostering innovation, improving operational efficiency, and enhancing environmental sustainability within supply chains. Sectoral analysis reveals that manufacturing industries benefit more strongly from the integration of GSCM and GI, driven by structured practices and regulatory compliance. Non-manufacturing sectors, while demonstrating positive impacts, require tailored approaches to maximize the effectiveness of these practices.

The study also underscores the critical accounting implications of GSCM and GI. These practices generate measurable environmental performance metrics that align with global sustainability frameworks such as the Global Reporting Initiative (GRI) and the Dow Jones Sustainability Index (DJSI). These metrics not only enhance the transparency and accuracy of environmental financial disclosures but also enable firms to integrate sustainability considerations into cost management and financial risk assessment. Additionally, GSCM and GI contribute to operational cost efficiencies and risk mitigation by supporting compliance with environmental regulations and thereby safeguarding financial stability.

Moreover, the findings emphasize the value of incorporating Environmental, Social, and Governance (ESG) metrics into accounting systems. These metrics are vital for reflecting the intangible benefits of GSCM and GI, such as improved brand reputation, increased stakeholder trust, and enhanced corporate valuation. By adapting accounting practices to capture these dimensions, organizations can better communicate the economic and reputational advantages of sustainability initiatives to stakeholders.

This study advances the understanding of the GSCM-GI relationship while providing valuable insights for practitioners, policymakers, and accounting professionals. Future research should explore the integration of advanced accounting practices and sustainability frameworks to further enhance the implementation and measurement of GSCM and GI. These efforts will contribute to achieving broader organizational, environmental, and financial sustainability goals.

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APPENDIX

Appendix 1. Article selected from database, 2013-2023

Author	Industry	Country	N	r	ES	SE
Makhlouf et al. (2023)	Manufacturing	France	120	0,6980	0,8634	0,0925
Fontoura & Coelho (2022)	Non- Manufacturing	Portugal	425	0,1873	0,1896	0,0487
Khan et al. (2021)	Manufacturing	Pakistan	413	0,5440	0,6098	0,0494
Sharabati (2021)	Manufacturing	Jordan	137	0,5017	0,5515	0,0864
C. H. Tseng et al. (2021)	Manufacturing	Taiwan	142	0,2510	0,2565	0,0848
Y. Sun & Sun (2021)	Manufacturing	China	215	0,5760	0,6565	0,0687
Jun et al. (2021)	Manufacturing	Pakistan	288	0,3700	0,3884	0,0836
Han & Chen (2021)	Non- Manufacturing	Myanmar	800	0,7810	1,0479	0,0592
Guo et al. (2021)	Manufacturing	China	217	0,2280	0,2321	0,0354
Frempong et al. (2021)	Manufacturing	Ghana	243	0,2632	0,2695	0,0684
Daddi et al. (2021)	Non- Manufacturing	Mixed	447	0,6370	0,7531	0,0645
Awan et al. (2021)	Manufacturing	Pakistan	239	0,3700	0,3884	0,0475
Singh et al. (2020)	Manufacturing	India	46	0,4000	0,4236	0,0651
Zhou et al. (2020)	Manufacturing	China	225	0,6410	0,7599	0,0671
Q. Zhang et al. (2020)	Manufacturing	China	206	0,3290	0,3417	0,0702
Y. Zhang et al. (2020)	Non- Manufacturing	China	340	0,6300	0,7414	0,0545
Yang et al. (2020)	Non- Manufacturing	China	331	0,5500	0,6184	0,0552
Abu Seman et al. (2019)	Manufacturing	Malaysia	123	0,4018	0,4257	0,0913
Burki et al. (2019)	Non- Manufacturing	Turki	181	0,3565	0,3729	0,0750
Lisi et al. (2020)	Non- Manufacturing	China	249	0,5943	0,6842	0,0638
Shafique et al. (2017)	Manufacturing	Pakistan	433	0,8520	1,2634	0,0482
G. C. Wu (2013) Model 1*	Non- Manufacturing	Taiwan	211	0,2192	0,2229	0,0693
G. C. Wu (2013) Model 2**	Non- Manufacturing	Taiwan	211	0,2107	0,2139	0,0693
G. C. Wu (2013) Model 3***	Non- Manufacturing	Taiwan	211	0,2156	0,2191	0,0693

* G. C. Wu (2013) Model 1 uses the supplier integration uncertainty approach as a proxy for GSCM.
** G. C. Wu (2013) Model 2 uses the customer integration uncertainty approach as a proxy for GSCM.
*** G. C. Wu (2013) Model 3 uses the internal integration uncertainty approach as a proxy for GSCM.