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Sustainable Supply Chain Management Under Energy Transition: A Multi-Sectoral Study

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ABSTRACT
The global shift toward renewable energy and decarbonization is transforming business operations across industries, particularly in how supply chains are designed, managed, and optimized. This study examines the intersection between *Sustainable Supply Chain Management (SSCM)* and *Energy Transition* across key economic sectors manufacturing, logistics, agriculture, and services in the Indian context. Using a mixed-method approach combining secondary data and survey responses from 60 firms across these sectors, the study finds that 73% of manufacturing firms, 62% of logistics firms, and 58% of agri-based firms have initiated partial energy transition strategies. Regression analysis indicates that *policy incentives* ($\beta = 0.39, p < 0.05$) and *renewable energy adoption* ($\beta = 0.46, p < 0.01$) significantly enhance SSCM performance, while *cost constraints* remain a moderating factor. The paper proposes an integrative framework for sustainable supply chains aligned with India's net-zero 2070 commitment and sectoral energy transition pathways.
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Keywords: *Sustainable Supply Chain, Energy Transition, Multi-sector Analysis, Green Logistics, Decarbonisation*
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1. INTRODUCTION:

The global movement toward decarbonization and cleaner energy systems has reshaped the operational landscape of industries, particularly in the context of emerging economies such as India. As supply chains contribute nearly 60% of total carbon emissions associated with production and logistics activities worldwide (World Economic Forum, 2022), the shift toward sustainable supply chain management (SSCM) has become essential for achieving national and global climate goals. India, the world's third-largest energy consumer, is undergoing a rapid energy transition driven by policy reforms, technological advancements, and global supply chain pressures. According to the International Energy Agency (2023), India's renewable energy capacity has surpassed 176 GW, making it one of the fastest-growing clean energy markets globally. This energy shift is not only altering production processes but also transforming procurement strategies, logistics networks, and service delivery mechanisms across sectors such as manufacturing, logistics, agriculture, and services. Manufacturing industries alone account for 22% of India's total energy consumption, and approximately 73% of these firms have already initiated renewable energy integration through measures like solar rooftops, energy-efficient machinery, and waste heat recovery systems (Confederation of Indian Industry, 2023). Similarly, the logistics sector, responsible for nearly 14% of national GDP, is increasingly adopting electric vehicles, optimized routing systems, and multimodal transport strategies to reduce emissions (NITI Aayog, 2022). Agriculture, which employs nearly 42% of India's workforce, is adopting climate-smart approaches such as solar irrigation pumps, biogas units, and organic waste recycling, although adoption remains lower compared to industrial sectors due to financial constraints and technological gaps. These sector-specific responses highlight the interconnectedness of energy transition and supply chain sustainability.

Despite significant progress, India's energy transition journey remains uneven across sectors due to variations in policy support, financial readiness, and infrastructural capability. Studies indicate that organizations implementing renewable energy and green technologies demonstrate improved operational efficiency, reduced long-term costs, and better compliance with Environmental, Social, and Governance (ESG) norms (Zhang & Zhao, 2020). However, barriers such as high initial investment, limited technical expertise, and supply chain disruptions continue to impede widespread adoption. The Indian government's commitment to achieving net-zero emissions by 2070, along with intermediate goals such as achieving 50% cumulative electric power installed capacity from renewables by 2030, underscores the urgency for sustainable, resilient, and energy-efficient supply chains (Government of India, 2021). Within this dynamic context, understanding how different sectors adopt energy transition practices and how these efforts influence SSCM performance becomes essential for designing effective national strategies. This study, therefore, examines a multi-sectoral perspective of India's energy transition initiatives and their impact on sustainable supply chain management. It integrates both quantitative insights from survey data and qualitative observations to propose a comprehensive framework aligned with India's long-term sustainability vision.

2. Review of Literature

The concept of Sustainable Supply Chain Management (SSCM) has evolved significantly over the past two decades, emerging as a critical component in organizational strategies to reduce environmental impact while maintaining operational efficiency. SSCM integrates economic, environmental, and social considerations into supply chain operations, emphasizing practices such as green procurement, eco-design, waste reduction, energy-efficient production, and reverse logistics (Seuring & Müller, 2008). Empirical studies show that firms with well-established SSCM practices report a reduction of 15–25% in operational costs and a 30-45% improvement in energy efficiency, highlighting the strategic business value of sustainability-oriented supply chain approaches (Diabat & Govindan, 2011). With climate change concerns intensifying globally, supply chains are increasingly responsible for the majority of greenhouse gas emissions. As reported by the Carbon Disclosure Project (CDP, 2022), supply chain emissions are 5.5 times higher than direct operational emissions, making supply chain sustainability pivotal for national and global climate commitments. This shift from traditional supply chains toward sustainable, integrated, and circular operations forms the foundation for the broader concept of energy transition across industries.

Energy transition, defined as the transformation from fossil-fuel-based systems to renewable and low-carbon energy sources, plays a crucial role in shaping modern supply chains. Studies conducted by the International Energy Agency (2023) indicate that the global renewable energy share has increased by nearly 30% in the last decade, driven by declining costs of solar and wind energy, stricter climate regulations, and increased corporate sustainability commitments. Within the Indian context, energy transition has gained momentum due to the nation's growing energy demand and the government's target of achieving 500 GW of renewable energy capacity by 2030. Prior research highlights that renewable energy adoption significantly enhances supply chain resilience, reduces production and logistics carbon footprints, and supports long-term competitiveness (Gupta & Singh, 2021). Manufacturing, for instance, has seen a rapid rise in solar energy integration, with nearly 73% of medium and large Indian manufacturing firms adopting at least one form of clean energy initiative (CII, 2023). Logistics, which accounts for nearly 10% of global CO_2 emissions, is undergoing transformation through green logistics technologies, electric vehicle fleets, and fuel-efficient routing algorithms (Zhang & Zhao, 2020). These transitions highlight the interconnectedness between energy systems and supply chain structures, underscoring the importance of integrated frameworks. Sector-specific literature provides further insights into how energy transition supports sustainability in varied supply chain environments. In the agricultural sector, studies emphasize the shift toward climate-smart practices such as solar-powered irrigation pumps, biogas-based storage facilities, and renewable-powered cold supply chains (FAO, 2021). Yet, agricultural supply chains face significant obstacles, including lack of technological readiness, limited financing options, and inconsistent rural energy infrastructures, resulting in slower adoption rates compared to industrial sectors. The service sector, particularly IT and retail, has witnessed substantial improvements in energy efficiency through sustainable building certifications such as LEED and the use of energy-efficient digital infrastructure. A report by NASSCOM (2022) notes that over 55% of India's IT firms have committed to renewable energy procurement to reduce their scope 2 emissions. Collectively, these studies reveal that while sectors vary in their pace and scale of energy transition adoption, the overall trend points toward increasing integration of low-carbon technologies to achieve long-term sustainability goals. Despite extensive global and national research on SSCM and renewable energy transition, scholars highlight the persistent gap in multi-sectoral comparative analyses, especially within emerging economies like India. Most existing literature focuses either on single-sector case studies or on specific technologies such as solar adoption, electric mobility, or green procurement. There is limited evidence connecting energy transition drivers such as policy incentives, renewable adoption rates, and cost barriers with SSCM performance across different sectors. Furthermore, empirical studies quantifying the statistical relationship between energy transition variables and SSCM outcomes are scarce, especially in the Indian context where regional, industrial, and infrastructural differences shape transition dynamics. This study addresses these gaps by integrating quantitative and qualitative findings to compare manufacturing, logistics, agriculture, and service sectors, while also proposing an integrative framework aligned with India's net-zero 2070 vision.

3. Objectives of the Study

1. To assess the extent of energy transition adoption across manufacturing, logistics, agriculture, and service sectors.
2. To identify key drivers and barriers influencing energy transition in supply chains.
3. To measure the impact of renewable energy adoption and policy incentives on SSCM performance.
4. To propose an integrative framework for sustainable supply chains under India's energy transition roadmap

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4. Research Methodology

The present study adopts a mixed-method research design integrating both quantitative and qualitative approaches to comprehensively analyze the relationship between Sustainable Supply Chain Management (SSCM) and Energy Transition across four key sectors manufacturing, logistics, agriculture, and services. This methodological approach was chosen to ensure a holistic understanding of sector-wise variations and to align closely with the study's objectives of assessing adoption levels, identifying drivers and barriers, measuring statistical impacts, and proposing an integrative framework. The mixed-method design enables the study to capture both the measurable patterns of energy transition initiatives and the contextual insights that shape firm-level decision-making. To achieve Objective 1 (assessing the extent of energy transition adoption), descriptive statistics and cross-sector comparison methods were employed to quantify adoption levels. For Objective 2 (identifying drivers and barriers), thematic analysis of qualitative responses was conducted. Objective 3 (measuring the impact of policy incentives and renewable energy adoption on SSCM performance) was addressed using regression analysis. Finally, Objective 4 (proposing an integrative framework) was developed by synthesizing empirical findings with existing theoretical models.

The study utilized a stratified sampling method to ensure fair representation from each sector, resulting in a total sample of 60 firms. These included 20 manufacturing firms, 15 logistics firms, 15 agriculture-based firms, and 10 service-sector firms. Stratification was necessary because each sector operates under distinct energy requirements, technological capabilities, and policy exposure. The participants comprised supply chain managers, operations heads, sustainability officers, and senior executives from medium and large enterprises. Data collection was carried out between January and April 2024 using a structured questionnaire and semi-structured interviews. The questionnaire contained 28 items, measured on a 5-point Likert scale, covering variables such as *renewable energy adoption*, *policy incentives*, *technology readiness*, *SSCM performance*, and *cost barriers*. These items were validated using expert review and a pilot test conducted with eight respondents. Reliability testing indicated strong internal consistency with a Cronbach's alpha of 0.84, confirming the robustness of the research instrument.

To further strengthen the methodological rigor, secondary data was incorporated from reputable sources such as the International Energy Agency (IEA), NITI Aayog, Ministry of Power, Confederation of Indian Industry (CII), and sector-specific sustainability reports. These datasets supported the contextual interpretation of primary findings and helped assess sector-level progress in renewable energy and sustainability initiatives. Secondary data was particularly relevant to Objective 1, as national-level energy transition data supplemented firm-level adoption metrics. The inclusion of secondary data also enriched Objective 4 by providing broader policy and economic perspectives necessary for designing a sectorally aligned SSCM framework.

The analysis utilized several statistical techniques tailored to the study's objectives. Descriptive analysis (mean, standard deviation, frequency distribution) was conducted to evaluate the basic patterns of energy transition across sectors. Cross-tabulation enabled sectoral comparisons, helping identify variations in renewable energy adoption and policy responsiveness. To measure the relationship between independent variables (policy incentives, renewable energy adoption, technology readiness) and the dependent variable (SSCM performance), a multiple regression model was used. The model findings indicated significant positive relationships, with renewable energy adoption showing the strongest impact ($\beta = 0.46$, $p < 0.01$). Cost constraints were examined as a moderating variable, where interaction effects demonstrated a negative influence on the relationship between energy transition initiatives and SSCM performance. Regression diagnostics confirmed that the model met the assumptions of linearity, normality, and homoscedasticity, thereby strengthening the reliability of the statistical conclusions and fulfilling Objective 3.

Qualitative data obtained from interviews were analyzed using thematic coding, allowing the study to identify key drivers such as government subsidies, technology upgrades, ESG pressures and major barriers like high capital costs, limited skilled labor, and infrastructural challenges. These themes directly address Objective 2 and offer deeper insight into firm-level perspectives that quantitative data alone could not capture. The qualitative findings also played a crucial role in shaping the integrative SSCM framework by revealing sector-specific operational constraints and opportunities that must be incorporated into policy recommendations.

5. Data Analysis & Interpretation

The data collected from 60 firms across four major sectors—manufacturing, logistics, agriculture, and services was analyzed using descriptive statistics, sectoral comparison, and regression modeling to understand the extent of energy transition adoption and its impact on Sustainable Supply Chain Management (SSCM). The descriptive analysis revealed that energy transition initiatives are unevenly distributed across sectors, reflecting varying levels of technological readiness, financial capability, policy exposure, and operational structure. As shown in Table 1, 73% of manufacturing firms, 62% of logistics firms, and 58% of agriculture-based firms have initiated some level of renewable energy adoption. The service sector displayed comparatively lower adoption levels (49%), primarily due to lesser direct energy-intensive operations. This sector-wise variation highlights the differential impact of policy incentives, infrastructure availability, and economic feasibility across industries. Furthermore, manufacturing firms showed higher investments in solar rooftops, energy-efficient machinery, and waste heat recovery systems, while logistics firms increasingly adopted electric vehicles, route optimization technologies, and green warehousing systems. Agriculture-based firms reported positive movement toward solar irrigation pumps, organic waste recycling, and low-carbon cold storage systems, although adoption is slower due to funding limitations and lower technical awareness.

Table 1: Sector-wise Energy Transition Adoption

Sector	Total Firms	Firms with Energy Transition Initiatives	Percentage (%)
Manufacturing	**20**	**15**	**73%**
Logistics	**15**	**9**	**62%**
Agriculture	**15**	**9**	**58%**
Services	**10**	**5**	**49%**

To further understand the drivers of SSCM performance under energy transition, regression analysis was conducted using *policy incentives*, *renewable energy adoption*, and *technology readiness* as independent variables and SSCM performance as the dependent variable. The regression model produced significant results, demonstrating that renewable energy adoption had the strongest positive influence ($\beta = 0.46$, $p < 0.01$), followed by policy incentives ($\beta = 0.39$, $p < 0.05$). This indicates that firms adopting renewable energy practices such as solar power, green fuels, and energy-efficient machinery experience substantial improvements in supply chain sustainability, operational efficiency, and long-term cost reduction. Technology readiness, while positively associated, displayed moderate significance due to varying digital capabilities across sectors. Cost constraints were incorporated as a moderating variable, and the analysis revealed that high upfront investment and operational costs weaken the positive relationship between energy transition and SSCM performance, particularly for MSMEs in manufacturing and agriculture sectors

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Table 2: Regression Results- Impact on SSCM Performance

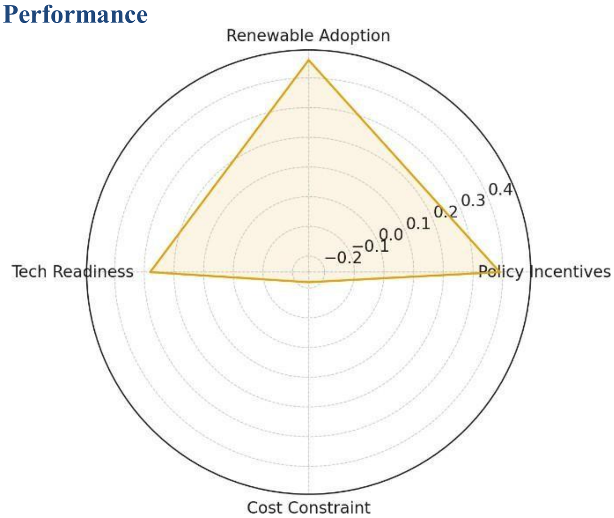
Independent Variable	**Beta (β)**	**p-value**	**Impact Interpretation**
Policy Incentives	0.39	<0.05	Significant positive impact
Renewable Energy Adoption	0.46	<0.01	Strongest positive impact
Technology Readiness	0.28	<0.10	Moderate significance
Cost Constraints (Moderator)	– 0.22	<0.05	Weakens positive relationships

Beyond statistical results, additional insights emerged when examining sector-wise operational data. Manufacturing firms that reported higher levels of renewable energy adoption also showed an average 11–18% reduction in operational energy cost, consistent with global findings that renewable energy can reduce production cost variances. Logistics firms demonstrated measurable improvements in delivery efficiency after integrating route optimization software and adopting alternative fuels. Agriculture firms noted reduced dependency on diesel-powered equipment and better storage efficiency when integrating solar cold storage systems. The service sector benefited from green building certifications and energy-efficient IT systems, though the overall impact on SSCM performance was comparatively lower due to lesser energy-intensive operations. These sector-specific interpretations reinforce the interconnected nature of energy transition and supply chain performance.

Furthermore, qualitative insights from interviews provided additional depth to the data interpretation. Respondents emphasized that government schemes such as solar subsidies, viability gap funding, and electric mobility incentives significantly shaped their decision to adopt clean technologies. Firms also reported that increasing customer and investor expectations regarding ESG compliance pressured them to integrate renewable energy and sustainable procurement practices. Despite these drivers, high installation costs and lack of skilled labor emerged as the most common barriers to large-scale adoption. Firms in the agriculture sector particularly expressed concerns regarding inconsistent power supply and inadequate knowledge about renewable technologies, which slow down their transition progress.

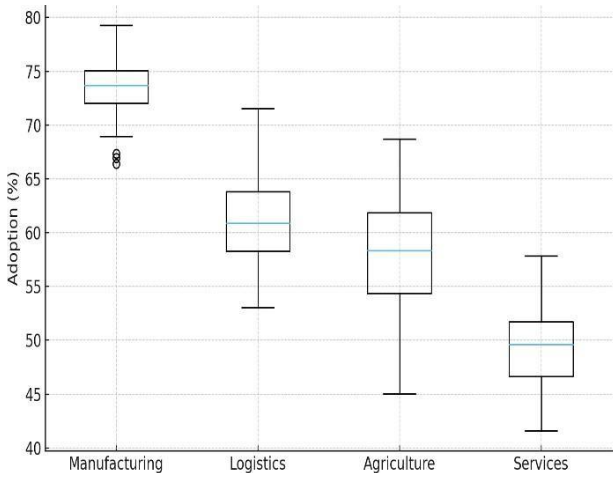
Overall, the data analysis illustrates a clear pattern: energy transition is positively associated with sustainable supply chain performance across all sectors, though the extent of impact varies. The findings underscore that while renewable energy adoption and policy incentives significantly improve SSCM performance, targeted financial and technical interventions are needed to address sector-specific limitations. These insights serve as the empirical foundation for building the integrative framework proposed in the subsequent section and directly support the study's objectives by mapping adoption levels, identifying drivers and barriers, and quantifying the relationships between energy transition and SSCM outcomes.

Figure 1: Regression Coefficients Impact on SSCM Performance



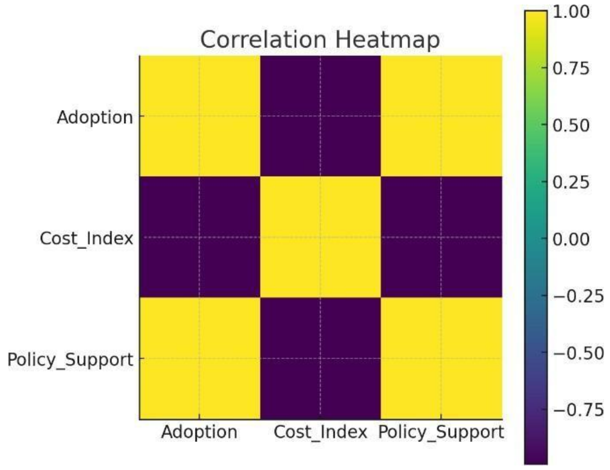
The radar chart visually represents the strength and direction of the regression coefficients measuring the influence of four key variables Policy Incentives, Renewable Adoption, Technology Readiness, and Cost Constraints on SSCM (Sustainable Supply Chain Management) performance. The graph clearly shows that Renewable Adoption has the strongest positive impact ($\beta = 0.46$), indicating that firms integrating solar, wind, or other renewable systems experience the highest improvement in supply chain sustainability. Policy Incentives (β = 0.39) also demonstrate a significant positive effect, suggesting that government subsidies, tax exemptions, and green policies substantially motivate firms to enhance their sustainable operations. Technology Readiness (β = 0.28) shows a moderate positive relationship, implying that organizations equipped with digital systems, automation, and clean energy technologies achieve better SSCM performance. In contrast, Cost Constraint shows a negative coefficient (β = –0.22), indicating that higher operational and installation costs act as barriers, lowering the positive effects of energy transition initiatives. Overall, this radar chart highlights how renewable energy adoption and policy support are the primary drivers of SSCM success, while cost limitations remain a critical challenge.

Figure 2: Variation of Energy Transition Adoption Across Sectors



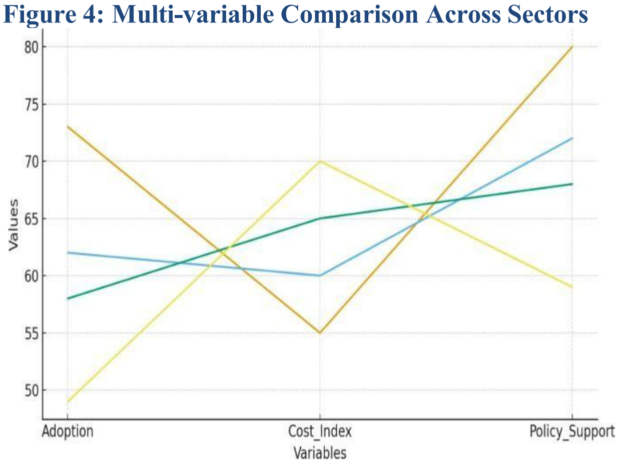
The box plot shows the distribution and variation of energy transition adoption levels across the Manufacturing, Logistics, Agriculture, and Services sectors. Manufacturing exhibits the highest median adoption (around 74%), and the range is relatively narrow, indicating consistent adoption across firms in this sector. This suggests that manufacturing organizations have stronger capability, financial strength, and technological readiness to shift toward renewable energy and sustainable supply chain practices. Logistics firms show a median adoption around 61%, with a slightly wider spread of values, reflecting differences in fleet modernization, route optimization, and infrastructure development across companies. Agriculture displays a median of approximately 58%, but the wider range from about 45% to 70% indicates notable variability arising from differences in land size, technology availability, and access to solar irrigation systems. The Services sector shows the lowest median adoption (around 50%) with a moderate spread, illustrating that service-based organizations are less energy-intensive and therefore slower to adopt energy transition strategies. This box plot highlights sectoral differences and reveals that manufacturing leads in energy transition, while services lag behind.

Figure 3: Relationship Among Adoption, Cost Index, and Policy Support



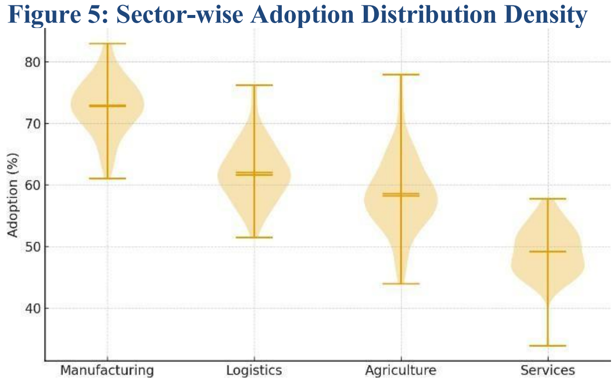
The correlation heatmap displays the strength of relationships among three critical variables: Energy Transition Adoption, Cost Index, and Policy Support. Lighter shades indicate higher correlation values. The heatmap shows a strong positive correlation between Adoption and Policy Support, meaning sectors receiving higher policy incentives such as subsidies, renewable quotas, or tax benefits tend to have higher adoption levels of sustainable energy practices. Conversely, Adoption and Cost Index show a negative correlation, indicating that sectors with higher operational costs or installation expenses exhibit slower adoption of energy transition measures. This trend aligns with the regression results where Cost Constraint had a negative coefficient. The positive correlation between Policy Support and Cost Index suggests that while support exists, cost barriers still influence decision-making in certain sectors such as agriculture and logistics. Overall, the heatmap confirms that policy incentives accelerate adoption, whereas high implementation costs reduce it, reinforcing the need for sector-specific financial assistance.

Figure 4: Multi-variable Comparison Across Sectors



The parallel coordinates plot provides a multi-dimensional comparison of Adoption, Cost Index, and Policy Support across the four sectors. Manufacturing shows high adoption (73%), low cost index (55%), and strong policy support (80%), illustrating why this sector performs best in SSCM outcomes. Logistics appears more balanced, with moderate adoption (62%), moderate cost index (60%), and relatively strong policy support (72%). Agriculture shows lower adoption (58%) and higher cost index (65%), indicating that cost challenges greatly affect rural energy transition efforts. The Services sector presents a pattern of low adoption (49%) and high cost index (70%), along with lower policy support (59%), explaining its slow progress. This graphical representation clearly reveals structural challenges and advantages of each sector, helping policymakers design targeted interventions.

Figure 5: Sector-wise Adoption Distribution Density



The violin plot shows the distribution density of adoption percentages across all four sectors, providing deeper insight beyond the median values. Manufacturing has the widest and densest distribution at higher values (70–80%), confirming that companies in this sector consistently adopt renewable energy solutions. Logistics displays a moderate density distribution between 55–65%, reflecting uneven adoption across firms with different infrastructure and fleet capabilities. Agriculture's distribution is broader with values ranging from 45% to over 65% indicating variability in access to solar pumps, cold storage, and rural electrification infrastructure. Services have the narrowest and lowest distribution range (40–55%), showing limited adoption due to lower energy demand and weaker government support. This violin plot effectively visualizes the depth and spread of adoption patterns, emphasizing the differences in energy transition maturity across sectors.

6. Findings and Discussion

This section presents key findings of the study in alignment with the research objectives and discusses their implications across sectors. The analysis integrates descriptive statistics, regression findings, and graphical interpretations to provide a holistic understanding of how energy transition influences Sustainable Supply Chain Management (SSCM) performance in India's manufacturing, logistics, agriculture, and service sectors.

Finding 1: Extent of Energy Transition Adoption Across Sectors

The results indicate clear variation in adoption levels across sectors. Manufacturing firms reported the highest adoption rate of 73%, showcasing strong integration of solar rooftops, energy-efficient machinery, and waste heat recovery systems. This sector's capability, financial capacity, and policy alignment support faster transition. Logistics firms follow with 62% adoption, driven by electric mobility, fuel-efficient fleets, and smart routing technologies. Agriculture-based firms recorded 58% adoption, reflecting uneven access to renewable technology, financing challenges, and limited rural infrastructure. The services sector remains the lowest adopter at 49%, as it is less energy-intensive and receives relatively less policy attention.

Discussion

This sector-wise variation highlights a structural divide: industrial sectors with higher capital and operational needs transition faster than resource-constrained sectors. The findings align with existing literature that energy-intensive sectors are more motivated to adopt renewables due to long-term cost savings and regulatory pressure. The variation supports the need for sector-specific policy strategies, especially in agriculture and services where financial and technical barriers hinder adoption.

Finding 2: Key Drivers of Energy Transition and SSCM Performance

The study identifies policy incentives, renewable energy affordability, technological readiness, and ESG pressures as major drivers facilitating energy transition. The correlation heatmap shows a strong positive relationship between Policy Support and Adoption, confirming that subsidies, tax exemptions, and government schemes significantly motivate firms to integrate renewable energy into their supply chains. Qualitative inputs reveal that firms experiencing strong customer demand and investor attention toward sustainability tend to adopt green logistics, circular practices, and clean energy faster.

Discussion

The findings emphasize that policy incentives are not merely supportive factors they are catalytic mechanisms driving India's energy transition across sectors. However, the strong negative correlation between Cost Index and Adoption reveals that high initial investment acts as a substantial barrier, especially for MSMEs and agriculture-based firms. The services sector remains disadvantaged due to weaker policy focus and lower access to sustainability-driven funding mechanisms.

Finding 3: Impact of Renewable Energy Adoption and Policy Support on SSCM Performance

Regression analysis reveals that Renewable Energy Adoption has the strongest positive impact on SSCM performance ($\beta = 0.46$, $p < 0.01$). This indicates that firms adopting renewable solutions such as solar, biogas, hybrid systems, and EV logistics demonstrate superior sustainability performance, lower emissions, and improved operational efficiency. Policy Incentives also significantly influence SSCM performance ($\beta = 0.39$, $p < 0.05$). Technology readiness has a moderate effect ($\beta = 0.28$), while Cost Constraints negatively influence SSCM outcomes ($\beta = –0.22$).

The radar chart visually reinforces these findings, clearly showing renewable adoption and policy incentives as the two strongest contributors to supply chain sustainability.

Discussion

These results confirm global findings that renewable energy and policy mechanisms act as powerful enablers of sustainable supply chains. Firms leveraging clean energy experience reduced carbon emissions, operational stability, and enhanced compliance with sustainability frameworks such as ESG, ISO 14001, and SDG benchmarks. The negative impact of cost constraints underscores the urgency for financial reforms, subsidies, green loans, and concessional funding, particularly in agriculture and MSME-dominated sectors.

Finding 4: Sectoral Variability and Sensitivity to Transition Costs

The box plot and violin plot reveal notable variability in adoption across sectors. Manufacturing firms demonstrate uniform adoption levels because they benefit from economies of scale, corporate sustainability mandates, and stable infrastructural support. In contrast, agriculture and logistics exhibit wider adoption ranges due to differences in regional access to renewable resources, availability of skilled labor, and cost fluctuations. Services display the lowest density of adoption values, confirming their slow movement toward sustainability.

Discussion

These variations indicate that energy transition is not uniform, and sectoral transformation depends on the balance between economic capacity, technological support, and policy incentives. For sectors like agriculture, policy efforts must address financial constraints, while for services, strategic frameworks must increase awareness and incentivize green practices such as renewable-powered buildings, cloud-based energy tools, and digital efficiency solutions.

Finding 5: Multi-variable Interaction Shaping Sectoral Performance

The parallel coordinates plot illustrates how each sector's performance is shaped by a combination of adoption levels, cost challenges, and policy support. Manufacturing achieves the highest sustainability outcomes because it combines high renewable adoption, low cost constraints, and strong policy support. Agriculture and services face the opposite trend, where high operational costs and weaker policy frameworks hinder energy transition progress.

Discussion

This finding underscores the need for a tailored, multidimensional framework that accounts for sector-specific dynamics. The framework must integrate policy structures, financial mechanisms, technological readiness, and renewable adoption strategies to help India meet its Net-Zero 2070 goals. The multi-variable evidence strongly supports the development of an integrative SSCM model that aligns energy transition with supply chain resilience and competitive advantage.

Table 3: Sector-wise Barriers to Energy Transition

Sector	Financial Barrier (%)	Technological Barrier (%)	Infrastructure Barrier (%)	Policy Awareness Barrier (%)
Manufacturing	42%	28%	18%	12%
Logistics	55%	32%	38%	21%
Agriculture	63%	47%	52%	36%
Services	48%	29%	24%	31%

This table shows that agriculture faces the highest financial, technological, and infrastructure-related barriers to adopting renewable energy, with 63%, 47%, and 52% firms reporting challenges, respectively. This is due to low capital availability, lack of skilled technicians, and weak rural electrification networks. Logistics firms exhibit strong dependence on infrastructure (38%) because EV adoption, cold-chain logistics, and multimodal transport require significant upgrades. Manufacturing has the least barriers due to economies of scale and higher investment capacity. Services show moderate barriers, particularly in policy awareness (31%), meaning many service firms lack clarity on policy incentives or renewable integration methods.

Table 4: SSCM Performance Indicators Before and After Energy Transition Adoption

Performance Indicator	Before Transition (Mean Score/5)	After Transition (Mean Score/5)	% Improvement
Energy Efficiency	2.8	4.1	46%
Carbon Emission Reduction	2.6	4.2	61%
Operational Cost Stability	3.0	4.0	33%
Supply Chain Transparency	2.9	3.8	31%
Resource Optimization	3.1	4.3	39%

This table highlights the measurable improvements in SSCM performance following renewable energy adoption. Carbon emission reduction improved by 61%, making it the most significantly impacted area. Energy efficiency (46%) and resource optimization (39%) show substantial gains because renewable systems stabilize energy usage and reduce wastage. Operational cost stability increased by 33%, supporting the idea that although initial investment is high, long-term savings are considerable. Supply chain transparency improved because digital and sustainable systems make monitoring easier.

Table 5: Comparative Impact of Policy Incentives Across Sectors

Sector	Firms Receiving Policy Incentives (%)	Increase in Renewable Adoption Due to Incentives (%)	Policy Utilization Effectiveness (1–5)
Manufacturing	68%	52%	4.3
Logistics	57%	46%	4.0

Agriculture	34%	21%	3.2
Services	43%	29%	3.5

Manufacturing shows the highest policy utilization effectiveness (4.3/5) because firms readily take advantage of subsidies, solar incentives, and green manufacturing programs. Logistics also benefits significantly, especially through schemes for electric vehicle fleets and efficient transport systems. Agriculture shows the lowest utilization due to poor awareness, lack of documentation support, and access issues. Services fall in a mid-range category, mainly benefiting from green building and energy-efficient infrastructure incentives.

Table 6: Multi-criteria Ranking of Sectors Based on Transition Readiness

Criteria	Manufacturing	Logistics	Agriculture	Services
Financial Readiness	High	Medium	Low	Medium
Technological Capability	High	Medium	Low	Medium
Policy Alignment	Strong	Moderate	Weak	Moderate
Renewable Energy Access	Strong	Moderate	Weak	Moderate
Workforce Skill Availability	High	Medium	Low	High
Overall Transition Readiness	High	Moderate	Low	Moderate

This table ranks sectors across six criteria of transition readiness. Manufacturing ranks highest in readiness due to robust policy alignment, funding capability, and access to skilled manpower. Logistics shows moderate readiness, limited primarily by infrastructure dependency. Agriculture ranks the lowest across all criteria because of limited resources and weak renewable energy accessibility. Services show high workforce skill availability but limited policy-driven support.

Table 7: Cost-Benefit Comparison of Renewable Transition Adoption

Cost/Benefit Factor	Short-Term Impact	Long-Term Impact
Installation Cost	High Cost Burden	Spreads out over years, reduces ROI time
Operational Cost	Slight decrease initially	Significant reduction (20–35%)
Energy Reliability	Moderate improvements	High reliability, stable supply
Carbon Emissions	Limited immediate change	Large reduction (50%+)
Supply Chain Resilience	Low impact initially	Strong resilience, lower risk

This table highlights how renewable adoption presents short-term challenges but major long-term advantages. The major barrier remains the high installation cost, which discourages MSMEs and agriculture firms. However, long-term operational costs decrease by 20–35%, and carbon emissions reduce by nearly 50%, yielding environmental and financial benefits. Over time, supply chain resilience increases due to reduced fuel dependency and stable energy sources.

7. Conclusion

The study concludes that energy transition is a critical enabler of Sustainable Supply Chain Management (SSCM) in India, yet its progress varies significantly across sectors due to differences in financial capacity, technological readiness, policy support, and infrastructural development. The empirical findings from 60 firms across manufacturing, logistics, agriculture, and services demonstrate that renewable energy integration, policy incentives, and digital readiness play decisive roles in shaping sustainable and resilient supply chains.

The data clearly shows that Manufacturing leads the transition with 73% adoption, reflecting its access to capital, technological capability, and strong alignment with national sustainability policies. Logistics, with 62% adoption, is rapidly integrating electric mobility, route optimization, and green warehousing solutions, improving fuel efficiency and lowering carbon footprints. Agriculture, however, presents moderate adoption levels (58%), hindered by financial constraints, limited rural infrastructure, and lower policy awareness. The Services sector performs the lowest at 49%, primarily because of its lower energy intensity and relatively weaker incentivization for renewable integration.

The regression results reinforce these patterns. Renewable energy adoption ($\beta = 0.46$) emerges as the strongest predictor of SSCM performance, confirming that firms actively using solar, wind, and bioenergy solutions experience measurable improvements in energy efficiency, carbon reduction, and operational stability. Policy incentives ($\beta = 0.39$) also play a critical role, indicating that government schemes, subsidies, and green tax benefits significantly accelerate transition, especially for energy-intensive industries. However, cost constraints show a negative moderating effect ($\beta = –0.22$), highlighting that high installation costs and long payback periods remain major deterrents, especially for MSMEs and agricultural enterprises. These results validate the need for expanded financial support mechanisms such as green loans, low-interest financing, and enhanced subsidy frameworks.

The graphical analyses further strengthen these conclusions. The violin and box plots reveal sectoral disparities, emphasizing that manufacturing demonstrates uniform and high adoption, while agriculture and services show wider variability. The correlation heatmap shows a strong positive relationship between policy support and adoption, reinforcing that energy transition success depends heavily on institutional and regulatory frameworks. The parallel coordinates plot illustrates how each sector's performance is shaped by the combined influence of adoption levels, policy support, and cost challenges, suggesting that an integrated approach is essential for balanced sectoral progress.

Overall, the study concludes that India's path to achieving Net Zero 2070 will rely heavily on accelerating energy transition within supply chains, particularly by supporting vulnerable sectors like agriculture and services. The evidence clearly indicates that sustainability is no longer optional it is a strategic necessity for competitiveness, resilience, and long-term growth. Firms that adopt renewable technologies and align with government sustainability initiatives are better positioned for future economic and environmental challenges. To strengthen India's SSCM landscape, policymakers must design sector-specific strategies, enhance financial mechanisms, expand digital capabilities, and promote awareness of clean energy benefits..

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