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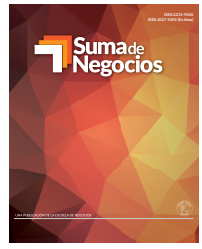

Research Article

Navigating sustainability: The impact of green innovation strategies on firm performance

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ABSTRACT

Introduction/objective: this study examines the impacts of green innovation strategies—product, process, and service—on firm performance and the moderating roles of supply chain risk, stakeholder engagement, and managerial commitment to sustainability initiatives.

Methodology: the study adopted a quantitative method with PLS-SEM using SmartPLS. Data were obtained from 468 companies across different industries such as retail, healthcare, education, finance, and technology, stratified for representation. Path analysis and reliability statistics tested our hypothesis.

Results: results show Green product ($\beta = 0.432$, $p < 0.001$), process ($\beta = 0.356$, $p < 0.001$), and service innovation ($\beta = 0.290$, $p < 0.005$) were found to positively influence firm performance. Supply chain risk has a negative effect on firm performance (coefficient = -0.215, $p < 0.003$). However, stakeholder engagement (coefficient = 0.412, $p < 0.000$) and managerial commitment (path coefficient = 0.378, $p < 0.000$) have a positive influence. The R-squared of 0.682 shows that these variables explain 68.2% of the variance in firm performance.

Conclusions: businesses have to invest in Green innovation at a short-term cost for long-term benefits such as market differentiation, efficiency, and loyalty. Stakeholder engagement and management commitment are important for integrating sustainability into business strategy. New technologies such as blockchain can also reduce supply chain risks. This study offers evidence of the double benefits of Green innovation, environmental sustainability and improved firm performance. It emphasises managerial dedication and stakeholder engagement in influencing sustainable conduct, which the existing literature does not address.

Palabras clave:
Innovación verde,
participación de los grupos de interés,
desempeño empresarial,
riesgo en la cadena de suministro,
compromiso gerencial.

Navegando la sostenibilidad: el impacto de las estrategias de innovación verde en el desempeño empresarial

RESUMEN

Introducción/objetivo: este artículo examina los impactos de las estrategias de innovación verde —en productos, procesos y servicios— sobre el desempeño empresarial, así como el papel moderador del riesgo en la cadena de suministro, la participación de los grupos de interés y el compromiso gerencial con las iniciativas de sostenibilidad.

Metodología: se adoptó un enfoque cuantitativo mediante PLS-SEM utilizando SmartPLS. Los datos se recopilaron de 468 empresas de diferentes sectores como comercio minorista, salud, educación, finanzas y tecnología, con muestreo estratificado para asegurar representatividad. El análisis de trayectorias y las pruebas de fiabilidad se aplicaron para contrastar las hipótesis.

Resultados: los resultados muestran que la innovación verde en productos (β = 0.432, p < 0.001), procesos (β = 0.356, p < 0.001) y servicios (β = 0.290, p < 0.005) influyen de manera positiva en el desempeño empresarial. El riesgo en la cadena de suministro tiene un efecto negativo (coeficiente = -0.215, p < 0.003). No obstante, la participación de los grupos de interés (coeficiente = 0.412, p < 0.000) y el compromiso gerencial (coeficiente de trayectoria = 0.378, p < 0.000) muestran una influencia positiva. El R-cuadrado de 0.682 indica que estas variables explican el 68.2% de la varianza en el desempeño empresarial.

Conclusiones: las empresas deben invertir en innovación verde, asumiendo un costo en el corto plazo, para obtener beneficios a largo plazo como diferenciación en el mercado, eficiencia y lealtad. La participación de los grupos de interés y el compromiso de la alta dirección son fundamentales para integrar la sostenibilidad en la estrategia empresarial. Asimismo, nuevas tecnologías como blockchain pueden contribuir a reducir riesgos en la cadena de suministro. Este estudio ofrece evidencia de los beneficios duales de la innovación verde: sostenibilidad ambiental y mejor desempeño empresarial. Además, enfatiza el papel de la dedicación gerencial y la participación de los grupos de interés en la adopción de conductas sostenibles, un aspecto poco abordado en la literatura existente.

Introduction

Background and context

The business landscape transforms rapidly which has led sustainability to become fundamental for corporate strategy development. Current global sustainability issues such as climate change and resource constraints and rising ecological product interest make companies transform their operational methods. Organisations face pressure from governments as well as consumers and investors to be environmentally responsible thus driving companies to adopt sustainable business practices. Sustainability has gained prominence among businesses because authorities have adopted new rules and companies see sustainable conduct as an opportunity to secure greater business performance and stability.

The concept of Green innovation

New and enhanced products and processes and services under the classification of Green innovation serve dual objectives for lower environmental strain and drive economic success. Three areas define Green innovation: creation of Green product innovation that benefits the environment and the creation of efficient processes through Green process innovation as well as the delivery of sustainable services through Green service innovation. Environmental and social innovations demonstrate substantial capabilities to boost company performance by reducing expenses and creating unique market offerings and boosting compliance with regulatory requirements. Tesla along with Patagonia have proven that sustainable innovation results in sustainable profitability by establishing new industry standards around the world.

Research problem and knowledge gap

Active scholarly interest in Green innovation has not resulted in sufficient clarity regarding its effects on company performance metrics. Little evidence exists about sustainability initiatives which explore crucial success elements such as supply chain risks and stakeholder collaboration and managerial dedication. Previous studies analysed single components of Green innovation but did not explain how

these elements produce organisational outcomes together. The present situation demands practical evidence which companies need to utilise for designing practical Green innovation tactics which unite environmental goals with financial targets.

Research objectives

The research explores the performance effects of Green innovation strategies consisting of innovation in Green products, Green service and Green process innovation. The research will investigate two secondary elements: first it will study how supply chain risk impacts organisational performance and second it will evaluate how stakeholder involvement with managerial dedication builds better business results. These research objectives guide the study towards complete knowledge of the elements that support sustainable business achievement.

Research questions

1. How do Green products, processes, and service innovations affect firm performance?
2. What is influence of supply chain risk on firm performance?
3. How do stakeholder engagement and managerial commitment influence firm performance?

These questions are designed to uncover the association between Green innovation strategies and firm performance while considering the moderating effects of supply chain dynamics and organisational commitment.

Significance of the Study

The research contributes to the theoretical knowledge of Green innovation since this study provided a broad model which looks at the synergetic effects of Green product, Green process and Green service innovation on corporate performance. In addition, it adds to existing literature by evaluating the moderating effect of stakeholder engagement and managerial commitment as two important organisational variables that are ignored in the previous empirical research. Such results provide new ideas on the possibilities of introducing sustainability efforts into business strategies. This study helps decision-makers in public services and industry and scholars by combining previous research data with practical findings which enables them to handle complex sustainable business management systems.

Literature review

Green innovation has attracted attention in academia and industry in recent times as firms try to balance economic development with environmental sustainability (Burbano-Figueroa, 2023). It involves practices that reduce environmental pressure and improve firm performance. This research examines Green innovation dimensions —process, product, and service—and their relationships with supply chain risk, stakeholder engagement, and managerial commitment (Yang & Lin, 2020).

Green product innovation

This represents the development of ecological products which contribute to using fewer resources and emitting fewer pollutants while also including recyclable elements. The research conducted by Al-Khatib (2023), confirms that businesses implementing this method gain enhanced market outcomes together with customer loyalty. Growing environmental concern combined with regulations lead customers to choose environmentally friendly products (Al-Khatib, 2022). Research indicates that Tesla along with Patagonia employs Green product innovation to gain competitive market advantages. Harder challenges emerge from product adoption of Green products because of initial expense barriers and distrust of environmental advantages (Cutipa-Limache et al., 2022). In spite of these difficulties, empirical research indicates that companies investing in Green product innovation realise superior long-term financial performance, as they seize new market segments and establish a reputation for sustainability.

Green process innovation

Green process innovation aims at enhancing production while reducing the environmental effect without affecting efficiency or quality (Díaz Pacheco et al., 2023). The implementation of technologies enables the management of waste production together with the control of energy consumption and pollution levels. The adoption of industrial innovation leads firms to reduce their environmental impact alongside lowering resource costs as noted by (Alhmeidiyeen et al., 2024). Toyota integrates a lean production system with Green principles in order to minimise waste. Becoming Green, however, involves a heavy investment in training and technology, which may be prohibitive for smaller firms (Gómez-Alvarez & Ochoa-Avila, 2024). Despite these setbacks, research shows that Green innovation enhances performance and efficiency, especially in sectors where resources are limited.

Green service innovation

This deals with creating environmentally sustainable services. It includes sustainable logistics, Green maintenance, and online platforms that minimise the use of resources. It is, as per Alkaraan et al. (2025), important in promoting sustainability through the reduction of the environmental footprint of service delivery. Uber and Lyft provide carpooling to reduce transport emissions. Green service innovation enhances customer satisfaction and brand image but requires coordination with suppliers and regulators for sustainability alignment (Block et al., 2024). Research has exposed that firms with Green service innovation enjoy better customer relationships and improved financial performance.

Supply chain risk

To a great extent supply chain risk determines the performance of companies, particularly when it comes to sustainability. The implementation of Green strategies by companies increases supply chain complexity since businesses

need to obtain environmentally friendly materials and follow sustainability standards. Gao et al. (2024) reported that supply chain-related risks significantly affect the success of Green innovation implementations but external material shortages along with regulatory changes are the major factors that influence the outcome. Operating a stable sustainable supply chain becomes more difficult for companies due to geopolitical instability together with global trade tensions (González-Argote et al., 2024). Companies actively utilise blockchain technology together with supplier diversification practices and local procurement policies in order to protect themselves from threats. Supply chain risk management stands as a massive issue which multinational corporations face throughout their operation in various markets.

Stakeholder engagement

Green innovation strategies need participation from all stakeholders in order to achieve their goals. Businesses need to collaborate with customers and employees and suppliers and regulators to achieve alignment regarding sustainable initiatives. According to Gao et al. (2025) research organisations must gain stakeholder support to achieve sustainable Green innovation success in the long run. Sustainability initiatives that involve employees lead to higher job satisfaction along with enhanced commitment in the retailing and hospitality sectors (López-Lemus & De la Garza Carranza, 2020). In addition to increasing a company's market presence, initiatives that promote Green practices help them win over more customers. It becomes difficult to manage stakeholder expectations, so organisations must use open communication techniques and participatory decision-making.

Managerial commitment

Green innovation requires managerial commitment in order to achieve supply chain risk reduction. Leaders who are committed to sustainability are likely to allocate funds, establish goals, and promote ecologic accountability. Research by Hu and Chen (2023) indicates that firms with strong sustainability commitment perform better financially and environmentally. Firms such as Unilever under the leadership of visionary managers, have reduced their carbon footprint while expanding financially (Pérez-Moure, 2025).

According to Figure 1 the diagram presents an analysis of the factors that influence firm performance. This model contains three main hypotheses connections that describe how different factors relate to firm performance levels (Junaid et al., 2022).

H1: Green Product Innovation →Firm Performance

The innovation of Green products create eco-friendly items which attract consumers concerned about the environment thus raising product prices and driving up sales and consumer loyalty and brand reputation (Li et al., 2024).

H2: Green Process Innovation → Firm Performance

Green innovation works to increase efficiency for minimising environmental effects including energy consumption and waste as well as emissions. Green practices decrease costs while enhancing resource utilisation and avoiding fines which leads to both monetary savings and performance growth and operational risk reduction (Luo & Zhang, 2024).

H3: Green Service Innovation → Firm Performance

Green service innovation provides environmentally friendly services that minimise carbon footprints. They appeal to Green customers, increase satisfaction, and increase competitiveness and hence, result in enhanced retention, referrals, and finances (Mahar et al., 2025).

H4: Supply Chain Risk → Firm Performance

Supply chain risk encompasses sourcing, manufacturing, and distribution uncertainty coming about due to geopolitical incidents, natural catastrophes, or breakdowns in supplies. Such a risk results in delayed deliveries, stockouts, and compromised quality, resulting in foregone sales, increased costs, and reputational damage. Accordingly, supply chain risk, in turn, adversely affects the performance of the firm (Nguyen et al., 2020).

H5: Stakeholder Engagement → Firm Performance

Stakeholder engagement creates robust relationships among customer, employee, supplier, regulator, and community relationships. Building engagement with stakeholders helps organisations obtain guidance while creating champions that increase both trust levels and decision-making strength and help resist change when it occurs and boost overall performance results (Ning et al., 2025).

H6: Managerial Commitment → Firm Performance

The concept of managerial commitment requires leaders to establish sustainability within business operations. The process of goal-sustainable practice alignment and resource optimisation managed by executives brings both innovation and risk mitigation and long-term value creation that results in performance improvement (Nureen et al., 2023).

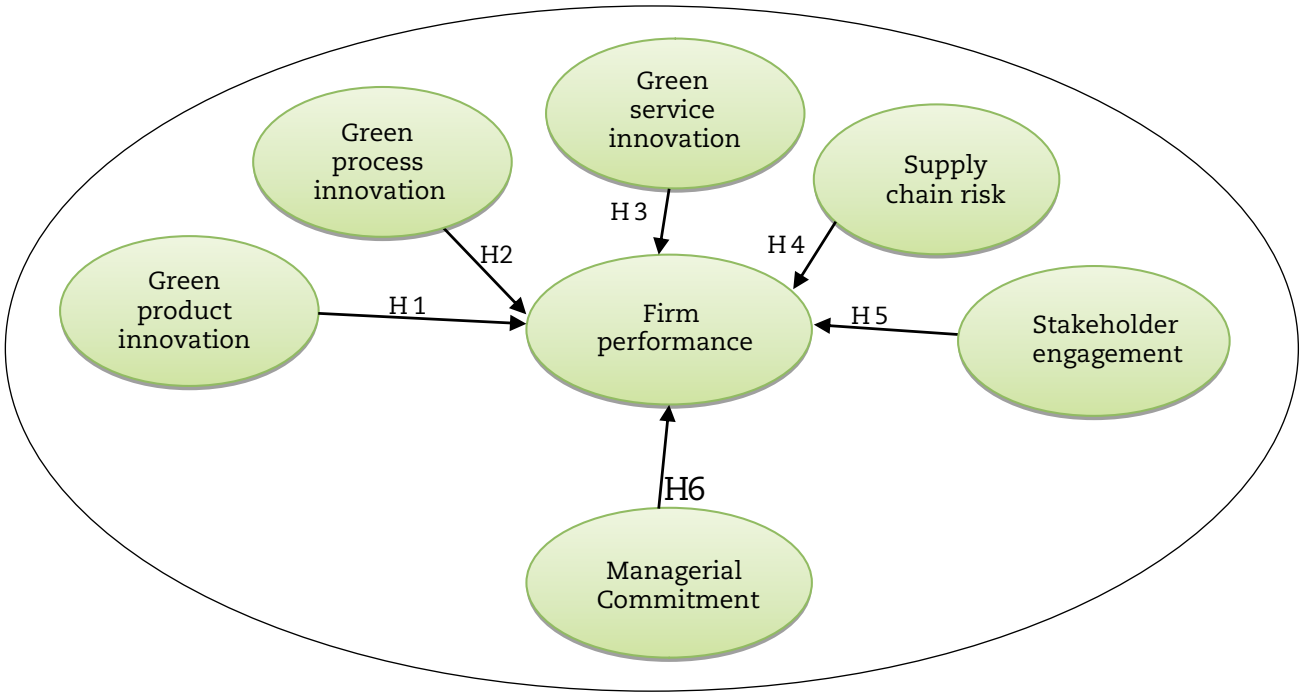

Figure 1. Hypotheses diagram
Source: Own elaboration.

Methodology

Research design

The research design used in this study is a quantitative research design that seeks to examine how Green innovation strategies product, service, and process influence firm performance bearing in mind the moderating effects of the supply chain risk level, the level of stakeholder involvement, and the level of managerial commitment (Wang et al., 2025). In particular, non-experimental, correlational research design has been utilised, since there has been no intervention in the relations between variables to be identified. This suits the purpose of the study that is to test a hypothesis and to generalise on the basis of empirical data (Roh et al., 2022).

The study is both explanatory and predictive since the study intends to establish how Green innovation strategies affect the performance of firms and make predictions using the relationships established. The choice of the design was made to assure that the study provides not only theoretical knowledge but also practical implications that are applied by businesses who want to adopt sustainability in their operations.

Data description and collection

Quantitative research was based on primary data obtained with the help of structured questionnaires sent to professionals and decision-makers in the companies representing different sectors: retail, healthcare, education, finance, and technology. The questionnaire was developed to ascertain the respondent's perception as to implementation of Green innovation strategies and their effect on the performance of the firms. This data was retrieved via an online survey tool so that it reached as many people as possible, as well as being convenient to participate. A pilot sample of 50 participants was used as a trial sample to determine the clarity, validity and reliability of the questionnaire before the entire sample was used. The data collection was carried out during three months (January-March 2025) to provide appropriate response rates and the relevance of information based on the recent data.

To represent firms among various firms of various sectors and sizes (small, medium, and large) in proportional representation, stratified sampling technique was employed. To increase the scope of generalisability of the results the stratification was conducted by the prevalence of the industries in the target population (Rehman et al., 2024). The professionals working in firms where there is implementation of Green innovation strategies are inclusion criteria. Study included the criteria of the executives directly involved in the decision-making process or participation in the sustainability programs within their institutions. Respondents who were not included in the predefined categories as excluded criteria and those who gave partial and inconsistent answers were excluded.

468 of the responses obtained were considered as valid and sufficient to conduct the structural equation modelling (SEM) through PLS-SEM since a minimum amount of sample size is required in the conduct of such models. In order to maintain construct validity, the items of the measurements were adapted using those of the already established scales in previous literature. Confirmation factor analysis (CFA) was performed in SmartPLS 4 and the good convergent and discriminant validity has been identified (see Tables 2 and 6). Cronbach Alpha, Composite Reliability and mean variance extracted (AVE) were used in gauging reliability. Constructs procured within the recommended limits (Cronbach Alpha > 0.70, Composite Reliability > 0.70 and AVE > 0.50) meaning that the internal consistencies and reliabilities of measurement instruments were high.

Research procedure

Questionnaire items were based upon matched scales in the literature. Face and content validity was checked by a panel of experts in sustainability and innovation management of the instrument. The questionnaire was nearly finalised and given to 50 professionals in order see how clear and understood it was, and whether it had flow. The instrument was refined with the help of feedback. The final questionnaire was supplied through social media and email as well reaching out to the professionals in the concerned areas. The survey was voluntary and prior to the survey, informed consent was sought. The completeness, consistency, and outliers of responses were screened. The analysis was not made of cases with missing information or irregularities in patterns. The analysis of data was performed in the SmartPLS 4 software, which is specifically used to conduct PLS-SEM. The technique was selected because it was appropriate to use complex models with multiple latent variables and because it deals well with non-normal data.

Data analysis techniques

The analysis applied Partial Least Squares Structural Equation Modelling (PLS-SEM) with the SmartPLS 4 statistical application to check the hypotheses and test the association between the constructs. The choice of PLS-SEM was due to its capacity to deal with complex models, robustness with a smaller sample set and the consideration of precision in predictions.

Regarding Measurement Model Tests, all items loaded higher than 0.70 to imply that they were strongly related with constructs. Internal consistency and convergent validity were measured using Cronbach Alpha, Composite Reliability and AVE. The Fornell-Larcker criterion of discriminant validity and the HTMT ratio as well as Tables 5 and 6 confirmed discriminant validity (Tables 5 and 6).

The Path coefficients and the bootstrapping procedure (5,000 resamples) were used to test the Assessment of Structural Model hypotheses by estimating the t-values and *p*-values. The SRMR, NFI, and Chi-square goodness-of-fit statistics were used to evaluate the test of the overall model (Table 9). The Q-square and F-square values were obtained to define the model predictive relevance and the effect size.

Ethical considerations

Before taking this survey, the participants were made aware of the study purpose and their right to withdrawal at any given moment as well as the confidentiality of their answers. None of the data were collected using names, and no personal identifiers were registered. Data were kept secure in a place that only the research team had access to. All of the authors state that they have no conflict of interest concerning this research. Ethical approval was registered by the Institutional Review Board (IRB) of Sichuan University with a reference number of IRB-2025-003. This research study did not consider any secondary data. All information was gathered directly from the participants by means of the original survey tool.

Results

Data analysis is employed quantitative technique to comprehensively evaluate the collected data. For quantitative analysis, software such as SmartPLS is utilised to conduct structural equation modelling (SEM), enabling the assessment of relationships between constructs through path analysis. The statistical method included evaluating path coefficients, significance levels (using bootstrapping), and model fit indices (such as R-squared values).

Table 1. Descriptive statistics

Variable	Categories / Stats	Frequency	Percentage (%)
Gender	Male	248	52.99
	Female	220	47.01
Education	PhD	135	28.85
	Master	124	26.50
	High School	105	22.44
	Bachelor	104	22.22

(*Continued*)

Variable	Categories / Stats	Frequency	Percentage (%)
Experience (Years)	N	468	-
	Mean	20.28	-
	Std. Dev.	11.93	-
	Min	0	-
	25th Percentile	9	-
	Median (50th Percentile)	21	-
	75th Percentile	30	-
	Max	40	-
Job Position	Senior Level	104	22.22
	Manager	94	20.09
	Mid-Level	93	19.87
	Executive	90	19.23
	Entry Level	87	18.59
Industry Type	Retail	107	22.86
	Healthcare	96	20.51
	Education	95	20.30
	Finance	90	19.23
	Technology	80	17.09
Industry Size	Medium	167	35.68
	Large	159	33.97
	Small	142	30.34

Source: Own elaboration.

Table 2. Construct, Statement, Factor Loading

Construct	Item	Statement	Factor Loading
Green Product Innovation	GPI1	The company introduces new environmentally friendly products through its regular scheduling.	0.825
	GPI2	Sustainability plays a primary role in material selection during product development at our company.	0.798
	GPI3	Product designs from our company exist to reduce environmental impacts.	0.841
Green Process Innovation	GPRI1	Our production system exists to minimise energy usage during manufacturing operations.	0.863
	GPRI2	Our factory utilises various methods to lower manufacturing waste output.	0.815
	GPRI3	The present operations of our organisation depend on renewable energy sources.	0.832
Green Service Innovation	GSI1	Our business provides sustainable practice promotion services to clients.	0.778
	GSI2	Service delivery methods at our organisation work to reduce carbon emissions.	0.754
	GSI3	We give training sessions about sustainability to the members of our service team.	0.790
Supply Chain Risk	SCR1	The current design of our supply chain makes it susceptible to disruptions which stem from geopolitical factors.	0.689
	SCR2	Our business struggles to secure sustainable materials with consistent reliability.	0.654
	SCR3	The supply chain operations of our organisation experience substantial changes when regulatory laws evolve.	0.701
Stakeholder Engagement	SE1	Stakeholders receive continuous updates about our sustainability targets from our company.	0.812
	SE2	Sustainable decision-making at our organisation involves extensive stakeholder participation.	0.835
	SE3	The company receives ongoing stakeholder feedback about our current environmental programmes.	0.803
Managerial Commitment	MC1	The leadership team at our organisation demonstrates sustained backing of all sustainability projects.	0.879
	MC2	Managers use specific organisational targets to enable sustainability implementation within business operations.	0.856
	MC3	Strategic planning at our organisation bases its decisions on sustainability elements.	0.868
Firm Performance	FP1	Our organisation achieved higher revenue levels because of our approach to Green innovations.	0.851
	FP2	The implementation of sustainable practices led to better customer satisfaction results.	0.839
	FP3	Our market share has grown since applying Green strategies.	0.847

Note: All factor loadings are statistically significant ($p < 0.001$).
Source: Own elaboration.

The Table 1 sample of 468 individuals consists of 52.99% males (248) and 47.01% females (220). The employee survey revealed that 28.85% earned a Doctorate degree while 26.50% had Master's qualifications and 22.44% graduated from high school and 22.22% received their Bachelor's degree. Participants spent an average of 20.28 years in the workforce with a data spread of 11.93 years extending from 0 to 40 years; their median employment period was 21 years and the calculation showed 9 years and 30 years as the lower and upper quartile values. Job positions are fairly evenly distributed, with Senior Level employees representing 22.22%, Managers 20.09%, Mid-Level 19.87%, Executives 19.23%, and Entry Level 18.59%. In terms of industry type, 22.86% work in Retail, 20.51% in healthcare, 20.30% in Education, 19.23% in Finance, and 17.09% in Technology. Finally, the industry size distribution shows 35.68% in medium-sized companies, 33.97% in large companies, and 30.34% in small companies, reflecting a balanced representation across different organisational scales.

Table 2 presents constructs, items, statements, and factor loadings measuring the impacts of Green innovation strategies on firm performance. It comprises six constructs: supply chain risk, Green product, Green process, and Green service innovation, Stakeholder Engagement, and Managerial Commitment, and includes three items in each of them. For example, Green Product Innovation comprises items like "Our company constantly releases environmentally friendly products" (GPI1) and "Our product designs attempt to reduce environmental footprint" (GPI3) with loadings of 0.825 and 0.841, reflecting strong connections. Likewise, Managerial Commitment and Firm Performance also have high loadings of 0.839 and 0.879, showing that they have good psychometric properties. All the constructs exhibit loadings of more than 0.7, supporting the reliability of the model in the measurement of firm performance and Green innovation.

Complementing this analysis, the VIF (Variance Inflation Factor) Table 3 assesses multicollinearity among the predictor constructs. The VIF values in this model fall under the accepted limit of 5 and show a range from 1.067 for Stakeholder Engagement to 1.456 for Green Process Innovation. The model results demonstrate that multiple predictor constructs maintain independence in their contributions to firm performance thus preventing any negative impact from variable correlation. Together, these Tables provide robust evidence for the model's validity and reliability in exploring the association between Green innovations and firm performance.

Table 4 illustrates measures of Green innovation constructs, supply chain risk, stakeholder engagement, managerial commitment, and firm performance. Reliability measures show high internal consistency in the shape of Cronbach's Alpha, Average Variance Extracted (AVE), and Composite Reliability (ρc). Cronbach's Alpha measures of 0.77 (Supply Chain Risk) to 0.86 (Managerial Commitment) show good and high levels of consistency. Composite Reliability of (0.85 to Supply Chain Risk, Managerial Commitment at 0.91) supports measure reliability. Average Variance Extracted (AVE) is above the minimum of 0.5 at Green Process Innovation (0.76) and Supply Chain Risk (0.60). These measures support strong psychometric properties, hence the research.

Table 3. VIF (Variance Inflation Factor)

Predictor Construct	VIF Value
Green Product Innovation	1.234
Green Process Innovation	1.456
Green Service Innovation	1.345
Supply Chain Risk	1.112
Stakeholder Engagement	1.067
Managerial Commitment	1.289

Note: Variance Inflation Factor (VIF) values below 5 shows acceptable multicollinearity levels among predictor constructs.
Source: Own elaboration.

Table 4. Reliability statistics

Construct	Cronbach's Alpha	Composite Reliability (ρc)	Average Variance Extracted (AVE)
Green Product Innovation	0.83	0.90	0.75
Green Process Innovation	0.86	0.90	0.76
Green Service Innovation	0.82	0.89	0.74
Supply Chain Risk	0.77	0.85	0.60
Stakeholder Engagement	0.81	0.88	0.72
Managerial Commitment	0.86	0.91	0.78
Firm Performance	0.82	0.88	0.77

Source: Own elaboration.

Table 5 illustrates that Fornell-Larcker Criterion Green Product Innovation and Firm Performance, for instance, have diagonal elements of 0.866 and 0.892, which surpass their correlation of 0.587, demonstrating distinctness. Supply Chain Risk, however, indicates negative correlation, supporting distinctness. Table 3 generally illustrates high discriminant validity, thereby ensuring that diverse model elements are captured. This supports hypothesis testing and theory building and makes the findings of the study valid and reliable.

Table 6 illustrates high HTMT ratios of Green Product Innovation (0.623) and Green Process Innovation (0.654) which indicate moderate common variance, while low HTMT ratios of Supply Chain Risk and others (0.321 and 0.278) indicate high discriminant validity. Generally, constructs relate, but HTMT ratios remain below the 0.85 or 0.90 benchmark, establishing the discriminant validity model.

The path coefficients Table 7 displays essential information about construct-to-performance relationships which demonstrates both the strength and significance of their connectedness. The path coefficient values provide dual information about the relationship direction and strength where positive numbers show performance boosting effects and negative numbers show performance toxic effects. The association between Green Product Innovation and Firm Performance displays both statistical and theoretical strength because it yields a coefficient value of 0.432 and t-statistic of 5.678 with a *p*-value of 0.000. Two evaluative models confirm that Green Process Innovation (0.356) and Stakeholder Engagement (0.412) have perceptible positive relationships to firm performance based on Figure 2 results. The research shows Supply Chain Risk resulting in -0.215 path coefficient which performs significantly negative for firm performance at $p = 0.003$. These paths validate the hypotheses about Green innovation and firm performance because their related t-statistics exceed the threshold for significance. The Table shows that firm success in an environmentally conscious industry depends heavily on Green innovations and managerial practices which drive business achievement in today's competitive market.

Table 5. Fornell-Larcker Criterion

Construct	Green Product Innovation	Green Process Innovation	Green Service Innovation	Supply Chain Risk	Stakeholder Engagement	Managerial Commitment	Firm Performance
Green Product Innovation	0.866	0.623	0.654	-0.321	0.512	0.601	0.587
Green Process Innovation	0.623	0.873	0.598	-0.278	0.487	0.542	0.562
Green Service Innovation	0.654	0.598	0.845	-0.210	0.532	0.590	0.578
Supply Chain Risk	-0.321	-0.278	-0.210	0.775	-0.190	-0.300	-0.256
Stakeholder Engagement	0.512	0.487	0.532	-0.190	0.846	0.601	0.618
Managerial Commitment	0.601	0.542	0.590	-0.300	0.601	0.883	0.652
Firm Performance	0.587	0.562	0.578	-0.256	0.618	0.652	0.892

Source: Own elaboration.

Table 6. Heterotrait-Monotrait (HTMT) Ratio

Construct	Green Product Innovation	Green Process Innovation	Green Service Innovation	Supply Chain Risk	Stakeholder Engagement	Managerial Commitment	Firm Performance
Green Product Innovation	-						
Green Process Innovation	0.623	-					
Green Service Innovation	0.654	0.598	-				
Supply Chain Risk	0.321	0.278	0.210	-			
Stakeholder Engagement	0.512	0.487	0.532	0.190	-		
Managerial Commitment	0.601	0.542	0.590	0.300	0.601	-	
Firm Performance	0.587	0.562	0.578	0.256	0.618	0.652	-

Source: Own elaboration.

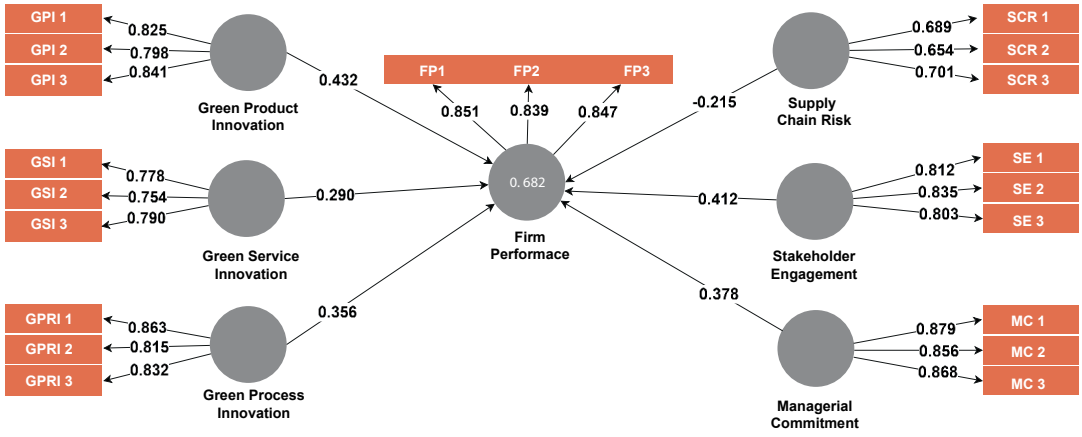

Figure 2. SmartPLS Result
Source: Own elaboration.

Table 7. Path Coefficients

Path	Path Coefficient	t-Statistic	*p*-Value	Significance
Green Product Innovation → Firm Performance	0.432	5.678	0.000	Significant
Green Process Innovation → Firm Performance	0.356	4.234	0.001	Significant
Green Service Innovation → Firm Performance	0.290	3.456	0.005	Significant
Supply Chain Risk → Firm Performance	-0.215	2.987	0.003	Significant
Stakeholder Engagement → Firm Performance	0.412	5.123	0.000	Significant
Managerial Commitment → Firm Performance	0.378	4.567	0.000	Significant

Source: Own elaboration.

Table 8 provides R-Squared, Q-Square, and F-Square statistics of Firm Performance, which are indicators of the predictive power of the model. A statistic of R-Squared equal to 0.682 suggests that 68.2% of the variation in the independent variables explain the firm's performance, indicating high explanatory power. The strong R-Squared value establishes that Green innovation strategies together with supply chain risk and stakeholders' involvement and managerial support substantially impact firm performance. The Q-Square value reaches 0.561 to confirm predictive relevance exceeding 0.5 with satisfactory out-of-sample prediction capabilities. When F-Square reaches 0.360 then the model loses 36% of its ability to explain performance outcomes. The structural equation model displays strong predictive power to forecast firm outcomes because Green innovation strongly influences performance which is confirmed by these prediction numbers.

Table 8. R-Squared, Q-Square, and F-Square Values

Construct	R-Squared Value	Q-Square Value	F-Square Value
Firm Performance	0.682	0.561	0.360

Source: Own elaboration.

Table 9 shows the main indicators for assessing the fit of the structural equation model to observed data. The SRMR is 0.045, which is less than 0.08, suggesting a good fit. The NFI is 0.910, which is above the 0.90 cut-off, confirming a strong fit. The Chi-square (χ^2) statistic is 120.45, but its usefulness could be low for models with repeated indicators. d_ULS and d_G (0.250 and 0.180) need bootstrap tests for significance. In all, these indices confirm the model's strength in representing relationships pertaining to Green innovation and firm performance in satisfying fit criteria.

Table 9. Model Fit Indices

Fit Measure	Value	Threshold	Interpretation
SRMR	0.045	< 0.08	Good fit
NFI	0.910	> 0.90	Good fit
Chi-square (χ^2)	120.45	-	Not applicable for all models
d_ULS	0.250	-	Bootstrap-based test needed
d_G	0.180	-	Bootstrap-based test needed

Note: d_ULS = Discrepancy as a result of Unweighted Least Squares; d_G = Geodesic Discrepancy. The smaller values determine a better fit of the models.
Source: Own elaboration.

Table 10 presents the important bootstrap confidence intervals of d_ULS and d_G, important for model fit. [0.200,0.300]

in the case of the interval of d_ULS encompasses the original value, demonstrating a good fit. So also, the [0.150,0.220] in the case of the interval of d_G encompasses the original value, supporting the good fit. These intervals capture model fit by eliminating the effects of sampling fluctuation. Incorporation of d_ULS and d_G in its respective intervals supports the efficacy of the model in describing the association of Green innovation and company performance, supporting the findings of research.

Table 10. Bootstrap-Based Model Fit Summary

Fit Measure	Bootstrap Confidence Interval (95%)	Interpretation
d_ULS	[0.200, 0.300]	Original value within interval indicates good fit
d_G	[0.150, 0.220]	Original value within interval indicates good fit

Source: Own elaboration.

Discussion

The analysis reveals compelling evidence supporting the influence of Green innovation strategies on firm performance. Green product innovation (path coefficient = 0.432, $p < 0.001$), Green process innovation (path coefficient = 0.356, $p < 0.001$), and Green service innovation (path coefficient = 0.290, $p < 0.005$) all exhibit significant relationships with firm performance, underscoring their critical role in driving economic and environmental benefits. The R-squared value of 0.682 indicates that these factors collectively explain 68.2% of the variance in firm performance, highlighting their substantial explanatory power. However, supply chain risk emerges as a significant barrier, with a negative path coefficient of -0.215 ($p < 0.003$), demonstrating its detrimental effect on firm performance. Conversely, stakeholder engagement (path coefficient = 0.412, $p < 0.000$) and managerial commitment (path coefficient = 0.378, $p < 0.000$) play pivotal roles in enhancing firm performance. The model's predictive relevance is further validated by the Q-square values, especially with regard to firm performance (Q-square = 0.561, categorised as strong). These findings align with prior research, reinforcing the importance of integrating sustainability into business practices.

Interpretation of Hypotheses

Hypothesis H1 Green product innovation positively impacts firm performance by enabling firms to differentiate themselves in competitive markets. Companies such as Patagonia and Tesla have capitalised on eco-friendly products to build loyal customer bases and achieve premium pricing. For example, the automotive industry has been disrupted by Tesla's electric vehicles while enhancing brand reputation and market share.

Hypothesis H2 Green process innovation enhances firm performance by reducing operational costs and improving resource efficiency. Toyota's integration of lean manufacturing principles with Green practices exemplify how firms can minimise waste and energy consumption while maintaining high productivity. With a path coefficient of ($\beta = 0.356$), Green process innovation demonstrates its ability to drive operational efficiencies and cost reductions, making it a vital component of sustainable business strategies.

Hypothesis H3 Green service innovation fosters customer satisfaction and competitive advantage by delivering environmentally sustainable services. Examples include Uber and Lyft's carpooling initiatives, which reduce carbon emissions while appealing to eco-conscious customers. The above observation is attributed to the fact that consumers tend to relate environmental responsibility more aptly to tangible products than to services, hence the stronger impact of Green product innovation ($\beta = 0.432$) induces a stronger impact than Green service innovation ($\beta = 0.290$). This implies that companies interested in immediate market differentiation can get more out of the investment in Green product production.

Hypothesis H4 Supply chain risks, such as disruptions caused by geopolitical instability or regulatory changes, negatively affect firm performance. The path coefficient of ($\beta = -0.215$) illustrates the adverse impact of supply chain vulnerabilities on operational continuity and profitability. To mitigate these risks, firms are adopting strategies such as supplier diversification and blockchain technology, which enhance transparency and resilience in global supply chains.

Hypothesis H5 Stakeholder engagement has an important role in achieving sustainability goals and improving firm performance. Studies show that employee engagement in sustainability programmes boosts job satisfaction and organisational commitment, while transparent communication with customers enhances brand loyalty. With a path coefficient of ($\beta = 0.412$), stakeholder engagement is a main driver of organisational success, underscoring the importance of collaboration and trust-building.

Hypothesis H6 Managerial commitment is foundational to embedding sustainability into business strategies and driving firm performance. Companies such as Unilever and Interface demonstrate how leadership dedication to sustainability leads to significant reductions in carbon footprints while maintaining robust financial growth. The path coefficient of ($\beta = 0.378$) highlights the transformative role of managerial commitment in fostering innovative solutions and long-term value creation.

Contribution to theory

This study advances existing theories on Green innovation and sustainability by elucidating the interplay between many Green innovation strategies and firm performance. It extends the understanding of how Green product, process, and service innovations align with economic and environmental objectives, offering new insights into their collective

impact. Furthermore, the findings underscore the critical roles of stakeholder engagement and managerial commitment in fostering sustainable practices. By addressing gaps in prior literature, this research provides a comprehensive framework for examining drivers of sustainable firm performance and contributes to the rising body of knowledge on Green innovation.

Practical implications

The findings offer actionable recommendations for firms seeking to implement Green innovation strategies. First, firms should invest in Green product and process innovations despite initial costs, as these provide long-term advantages in terms of market differentiation and operational efficiency. Second, stronger stakeholder engagement and transparent communication are essential for aligning interests and ensuring the viability of sustainability initiatives. Third, managerial commitment must be prioritised to integrate sustainability into core business strategies effectively. Finally, firms should adopt advanced technologies such as blockchain to mitigate supply chain risks and enhance resilience. These strategies can help organisations navigate sustainability challenges while achieving superior financial performance.

Limitations

The sample size and industry diversity may restrict how broadly the results can be applied, particularly for smaller or underrepresented sectors. Self-reported data could introduce response bias, which could compromise the results' accuracy. Furthermore, the study's cross-sectional design restricts causal inferences, necessitating caution when interpreting the relationships among variables. It should be noted that it was possible to employ self-reported data and that such may impose a certain bias on a response that has to be high, especially by subjecting the respondent to exaggerate their involvement in Green innovation practices. To reduce the effects of the same we assured that the survey is anonymous and the study was to be used academically and hence the greater need to give honest answers was stated. In the future, it may be good to supplement self-reporting with objective performance to provide more validity.

Directions for future research

Future research should consider the long-term effects of Green innovation through longitudinal designs, enabling a greater comprehension of its sustained effects on firm performance. Sector-specific differences in Green innovation adoption warrant further investigation, as do cultural and regional influences on sustainability practices. Additionally, integrating technologies such as the Internet of Things (IoT) and artificial intelligence (AI) into Green innovation frameworks present an exciting avenue for exploration. Such research could uncover novel approaches to enhancing sustainability and firm performance in an increasingly complex business environment.

Conclusion

The findings of the study emphasise the critical role of Green innovation in advancing sustainable business practices. By demonstrating the positive impact of Green product, process, and service innovations on firm performance, this research provides compelling evidence that sustainability is not merely an ethical responsibility but also a strategic imperative for businesses. The results highlight how firms can achieve a competitive edge by aligning their operations with environmental goals, thereby addressing both consumer demands and regulatory pressures. Furthermore, study emphasises the importance of mitigating supply chain risks and fostering stakeholder engagement and managerial commitment to ensure the successful operation of Green strategies.

The dual benefits of Green innovation—environmental responsibility and enhanced firm performance—are evident throughout the analysis. Green innovation enables firms to decrease their ecological footmark while simultaneously refining financial outcomes, operational efficiency, and market positioning. For instance, companies such as Tesla and Patagonia have shown that prioritising sustainability can lead to significant economic gains, including increased market share and customer loyalty. These examples reinforce the idea that environmental stewardship and profitability are not mutually exclusive but rather complementary objectives that can drive long-term success.

Looking ahead, businesses play a crucial part in driving global sustainability efforts. As climate change and resource scarcity continue to pose significant challenges, organisations must take bold steps to integrate sustainability into their core strategies. By investing in Green innovation, fostering collaboration with stakeholders, and committing leadership to environmental goals, firms can contribute to a more sustainable future while securing their own resilience and growth. The transition to a greener economy is not only an opportunity for businesses to thrive but also a responsibility they must embrace to ensure the well-being of future generations.

On the policy side, governments can assist the firms in terms of tax incentives of Green innovation investments, encouraging business-research institution collaboration, and increasing transparency in the supply chain using digital technologies such as blockchain. Governance systems, which favours sustainable practices and punishes unethical behaviours towards the environment also helps fast track the spread of Green practices in various sectors. The present study is both theoretically and practically valuable in terms of the sphere of sustainable business management. Theoretically, it broadens the knowledge pertaining to the overall impacts of the Green innovation strategies about products, processes and services on the performance of firms which is much greater when the moderators of stakeholder-engagement and managerial commitments are taken into consideration. In practice, it gives practical information to insti-

tutions that need to balance environmental responsibility and economical gains by investing strategically in sustainability. In conclusion, the path forward requires a collective effort from businesses, policymakers, and society to create a world where economic progress and environmental sustainability go hand in hand.

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Authors' contribution

Shah Mehmood Wagan: conceptualisation, formal analysis, research, Visualisation, methodology, writing (original draft); Xinli Zhang: conceptualisation, formal analysis, research, methodology, writing (original draft); Sidra Sidra: conceptualisation, formal analysis, research, methodology, writing (original draft), writing (refereeing and editing corrections), Writing – review & editing.

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