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An empirical investigation of green supply chain management (GSCM) and environmental sustainability in Saudi manufacturing SMEs: The mediating role of operations analytics

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A B S T R A C T

Incorporating sustainability principles into Supply Chain Management (SCM) has received considerable attention in recent years, with a particular emphasis on Green Supply Chain Management (GSCM), which aims to reduce environmental consequences. Saudi Arabia has launched sustainability initiatives; however, the application of green SCM methods in SMEs in Saudi Arabian manufacturing has yet to be explored. Therefore, this research aimed to empirically assess the effect of GSCM in promoting environmental sustainability in Saudi manufacturing SMEs, focusing on the mediating function of operations analytics. Therefore, this study used a quantitative research technique to discover the link between the study variables—a rigorous questionnaire obtained primary data from managers and team leaders. SPSS was used for descriptive statistics, while SMARTPLS was used for structural equation modelling. The measurement model, path analysis, and indirect impact analysis were used to validate the research constructs and analyze the hypothesized associations. The findings support the evidence of direct positive links between green manufacturing, green business practices, eco-design and environmental sustainability in Saudi manufacturing SMEs. Conversely, no evidence was found to support the function of operations analytics as a bridge between green SCM and environmental sustainability. Although operations analytics can improve green SCM processes, more studies are needed to understand its full impact on environmental sustainability outcomes.

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1. Introduction

There is an increasing acknowledgment of the necessity of implementing sustainability principles into supply chain management (SCM) initiatives (Burke et al., 2021). One specific area of focus under this is Green Supply Chain Management (GSCM). GSCM refers to incorporating environmentally responsible techniques throughout the supply chain (Meera and Chitramani, 2014). Meanwhile, Green SCM attempts to reduce the negative environmental consequences of manufacturing processes, distribution, and logistical operations (Teixeira et al., 2018). Similarly, environmental sustainability has evolved as a critical worldwide problem, encompassing the preservation of natural resources, waste reduction, and reduction of greenhouse gas emissions (Gorman & Dzombak, 2018). Achieving environmental sustainability is a complicated and multifaceted goal requiring collaborative efforts from various stakeholders, including corporations. Saudi Arabia has taken green initiatives to promote sustainability, including green environmental protection, a stable echo system, and energy transition (Almulhim & Al-Saidi, 2023). However, the current condition of Saudi manufacturing SMEs regarding GSCM and environmental sustainability varies. While there is a growing understanding and acceptance of the importance of environmental sustainability among Saudi SMEs, implementing green SCM practices and attaining environmental sustainability targets still need improvement (Wasiq et al., 2023). According to Abualfaraa et al. (2022), Saudi Arabia still has

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a long way to go in completely incorporating green SCM principles into its manufacturing SMEs. Limited resources, a lack of experience, and insufficient access to technology and finance impede the implementation of ecologically friendly practices.

Furthermore, there needs to be more data-driven decision-making. Manufacturing SMEs in Saudi Arabia contributed considerably to economic growth in 2021, accounting for over 32% of non-oil GDP and employing approximately 70% of the private sector workforce (East and Initiative, 2022). Given the importance of manufacturing SMEs to Saudi Arabia's economic growth, it is critical to investigate how Green SCM could enhance its environmental sustainability performance. Green SCM and environmental sustainability are linked since both can result in less resource usage, waste output, and carbon emissions. Another critical factor to examine is the function of operations analytics in mediating the link between green SCM and environmental sustainability (Khan et al., 2022). Operations analytics uses data-driven methodologies and analytical tools to enhance operational efficiency and decision-making. Manufacturing SMEs obtain essential insights into their supply chain operations and find opportunities for improvement in environmental performance using data analytics (Long, 2018). Operations analytics give SMEs real-time visibility into their supply chains. It allows SMEs to make educated decisions about resource utilization, waste reduction, and emissions management (Khan et al., 2021). With the growing worldwide concern for environmental sustainability and the pressing necessity for enterprises to encirclement green practices, there is a growing interest among scholars in learning how green SCM methods are efficiently applied (Moshood et al., 2021). Therefore, the proposed study emphasizes determining the context of Saudi SMEs. Furthermore, including operations analytics, which involves applying proficient data analytics techniques in operations management, may give valuable insights into optimizing green SCM processes and improving environmental performance. However, most studies concentrate on the links between green SCM techniques and environmental sustainability or on operations analytics in the larger context of SCM (Kholaif et al., 2022). Research on the combined benefits of green SCM, operations analytics, and environmental sustainability in Saudi manufacturing SMEs is lacking. Furthermore, empirical research on the function of operations analytics in mediating the link between GSCM and environmental sustainability in the context of Saudi manufacturing SMEs is insufficient.

The current investigation intends to empirically assess the function of GSCM in promoting environmental sustainability in Saudi manufacturing SMEs, with a specific emphasis on the mediating role of operations analytics. Hence, this research is motivated by the global concern for environmental issues and the recognition of SCM as a vital driver for sustainable business practices (Saeed and Kersten, 2019). Considering this, the study first examines the characteristics that encourage implementing green SCM methods in Saudi manufacturing SMEs. Secondly, the objective of the proposed inquiry is to empirically examine the impact of green SCM determinants on environmental sustainability that results in Saudi manufacturing SMEs. The study proposes to contribute to the current body of information on the influence of sustainable supply chain practices on environmental performance by exploring the link between green SCM practices and environmental sustainability. Finally, the proposed study emphasized examining the function of operations analytics in mediating the association between GSCM and environmental sustainability in Saudi manufacturing SMEs. Operations analytics is intended to help adopt and monitor green SCM practices, favorably affecting environmental sustainability results (Jum'a et al., 2022). Understanding operations analytics' mediating function can give insights into the processes through which green SCM techniques impact environmental sustainability (Fontoura and Coelho, 2022). The study is essential since the research findings can enlighten Saudi officials and practitioners about the variables that drive the adoption of green SCM practices and their influence on environmental sustainability. Moreover, this study gives evidence-based insights that can help develop effective policies and guidelines to promote sustainability in the industrial sector, resulting in a greener and more sustainable economy.

2. Literature Review

2.1 Green Supply Chain Management

The name Green Supply Chain Management (GSCM) describes implementing environmentally friendly practices across the supply chain. A product's supply chain must take the environment's effects into account at every stage of manufacturing, from initial concept to final disposal, for it to be sustainable. According to Raut et al. (2021), green supply chain management's primary objective is to lessen the harm of product manufacture and distribution due to the environment. Energy efficiency, waste minimization, reduced carbon emissions, responsible material procurement, and renewable resource utilisation are all considered in this method. Pollutants, deforestation, ozone depletion, and global warming are all detrimental to the environment, but sustainable supply chains work to mitigate these effects (Sarkis, 2012). On the other side, intelligent packaging, by avoiding the use of enormous boxes such as employing the correct size packaging boxes for smaller shipments or the use of recyclable paper pads in place of plastic packaging, are two possible approaches. Using electric fleets instead of fleets powered by fossil fuels to reduce carbon emissions is another major revolution slowly gaining traction (Fahiminia et al., 2015). Sustainability in the supply chain is thinking about how a product will affect the environment at every level of the process, from initial concept to final disposal (Green et al., 2012). The manufacturing sector incorporates environmental consciousness as a consideration or measure for supplier selection by working with vendors with a track record of integrating green practices in their offices and operations.

2.1.1 The effect of green manufacturing on environmental sustainability

In current years, there has been a rise in scholarly interest in environmental problems in both developed and developing nations. Its negative consequences on the country's economic standing and national policies are expanding its significance. Moreover, protecting natural ecosystems has recently become a pressing concern (Seth et al., 2018). These serious environmental problems need manufacturers to implement green practices. In the industrial sector, in particular, efforts have been focused on minimising waste and improving the environmental sustainability of production. Al-Hakimi et al. (2022) used the resource-based view (RBV) of the company and the ecological modernization theory (EMT) to explore the link between green innovation (GI) and organisation sustainable performance. Green manufacturing practices (GMPs) aim to produce goods using ecologically friendly methods.

Few research studies have specifically addressed GMP in SMEs despite major attempts to adopt GMPs in big, well-established enterprises, notably in the food, auto, and chemical industries (Ahmad et al., 2019). The primary reason for adopting these practices by large-size organisations is because they are well established, have better organisational management, and have more solid finances. Large companies are under more pressure to implement GMP than SMEs. Nevertheless, SMEs provide a favourable setting for GMP investigations for several reasons. One of the critical issues is the typical absence of actual GM best practices knowledge among SMEs. That is because there are insufficient resources, such as qualified personnel, enough time, and enough money (Al-Hakimi et al., 2022). However, academics contend that industrialization and global competition force SMEs to improve their organisational structures and adopt standards, norms, and production methods that are environmentally friendly.

Even though both big and small businesses benefit from adhering to GMP, SMEs are slower to transition, especially in developing nations (Aityassine et al., 2021). There is a rising need to safeguard the environment and manage its risks. For this instance, Saudi Arabia's government, which has emerged as one of the most active emerging nations in economic growth in the Gulf area, has developed policies that reflect this. The energy industry in Saudi Arabia is wholly reliant on fossil fuels, making oil the country's primary export (Bai et al., 2021). As a result, the country has a particular problem with CO2 emissions. Therefore, the need to adopt environmentally friendly practices is growing with time. The Saudi Vision 2030 lays a heavy focus on supporting environmentally friendly firms and developing socially wide-ranging enterprises as part of the government's action plan for a more viable and diversified economy. The Saudi government aims to lessen its dependence on oil and contribute to a worldwide initiative to decrease carbon dioxide discharges by 2030 as part of its Saudi Vision 2030 goal to enhance sustainable development. By 2030, SMEs will contribute 35% of Saudi Arabia's GDP, up from 20%, according to Delbeke and Lamas (2021). Supporting green efforts (such as GMP and GI) among SMEs is essential, according to proponents of sustainable development, in order to achieve this goal. Therefore, we have

H_1: *Green Manufacturing in SMEs directly affects environmental sustainability.*

2.1.2 The effect of green purchasing in SMEs on environmental sustainability

Small and medium-sized enterprises (SMEs) may considerably improve the environment by managing green purchases. Although essential to the economy, SMEs can damage the environment through their buying practices. The organization's internal and external factors must support green supply chain management. Purnomo et al. (2024) highlight exogenous pressures such as governmental regulation, strategic direction, community needs, and consumer behaviour. Jermsittiparsert et al. (2019) list several internal driving factors, including organisational strategy, top management support, green knowledge management capabilities, and internal environment management. To "go green" means making environmentally friendly purchases and consuming fewer natural resources. SMEs may directly impact resource conservation and waste reduction by selecting energy-efficient equipment, recycled materials, or sustainable packaging.

Consumers who care about environment-free products choose products with lower carbon footprints. By reducing their greenhouse gas emissions by switching to more fuel-efficient cars or converting to renewable energy sources for business operations, SMEs may contribute to the fight against climate change (Mishra et al., 2019). Small and medium-sized businesses may build their brands and attract environmentally-conscious clients by making green purchases. Businesses that care about the environment and its impact have a finer chance of succeeding in the market and attracting clients. Meng et al. (2021) state that "green supply chain management" considers the environment throughout a company's activities, from procuring raw materials to delivering completed goods. The management of a green supply chain consists of a number of procedures. The first is "green purchasing," which comprises making purchases in compliance with relevant legal requirements and environmental best practices. According to Ninlawan et al. (2010), green logistics and green packaging are two additional aspects of green distribution. Timeliness and volume of consumer purchases, fuel efficiency, and transportation capacity optimisation are all part of what we mean when we say "green distribution." Reuse, the third strategy, curtails waste throughout the production process. There are several international policies and standards in place to encourage eco-friendliness.

Through green buying, SMEs may ensure compliance with these rules and align with sustainability goals. It lessens the potential for fines, legal trouble, and brand harm from failing to comply (Wasiq et al., 2023). SMBs may save money in the long run by making greener purchasing decisions. Reducing trash and using less energy-intensive appliances may help save money in many ways, including on utility bills and the cost of disposal and raw materials. SMEs may reap environmental and

financial rewards by investing in sustainable solutions. Yang et al. (2020) concluded that a company's performance will improve due to its efforts to embrace GSCM.

Further, GSCM has been shown to improve the environmental performance of SMEs (Dzikriansyah et al., 2023). The results showed that interior issues did not hinder environmental performance when GSCM was implemented. However, using GSCM may help mediate government laws to enhance SMEs' environmental performance. Thus, we propose the following hypothesis:

H_2: *Green Purchasing in SMEs directly influences environmental sustainability.*

2.1.3 The effect of eco-design in SMEs on environmental sustainability

Previous talks have proven that GSCM significantly improves environmental operations. There are several ways in which eco-design at SMEs (or medium and small businesses) affects environmental sustainability (Deutz et al., 2013). Environmentally responsible design is at the heart of eco-design, which also goes by the names sustainable design and eco-friendly design. From gathering raw materials to the final product disposal, the ecological design attempts to lessen its adverse environmental effects. SMEs may reduce their environmental impact by designing goods with energy efficiency, material selection, waste reduction, and recyclable components in mind (Wasiq et al., 2023). Eco-design prioritises robustness and lifespan. SMEs can save money by reducing the frequency of product replacements by creating items that endure a long time and can be fixed, reconditioned, or updated (Dzikriansyah et al., 2023).

Further, it aids in reducing the waste created and environmental damage caused by the manufacturing and disposal of items with a limited lifespan. In the United States, 159 manufacturing firm managers were polled by Green et al. (2012), while 248 manufacturing enterprises in the United Kingdom were polled by Cousins et al. (2019). According to both findings, GSCM significantly influences environmental performance. Although research has shown a connection between intellectual capital and environmental performance, it has also been shown that GSCM may attenuate this connection, at least in part. (Khan et al., 2021). As a way of incorporating sustainability concepts into product development processes, the literature highlights the importance of eco-design in SMEs. It emphasises SMEs' particular contribution to environmental sustainability through adaptability, innovation potential, and speedy response to shifting market needs. Researchers have found that SMEs can profit monetarily from eco-design (Deutz et al., 2013). Reduced resource consumption, higher energy efficiency, waste reduction, and increased market competitiveness can lead to long-term cost benefits, offsetting the original investment in sustainable design practices.

Green buying and eco-design are two examples of GSCM practices that have been presented to have a detrimental effect on environmental performance, particularly in terms of economic performance. GSCM practices (such as green buying and eco-design) were shown to be unimportant by Khan and Qianli (2017). The idea of the circular economy, which stresses efficiency and resource conservation, is consistent with eco-design. Designing for disassembly, recyclability, and using recycled materials are all ideas that SMEs may use to help speed up the shift to a circular economy. Products with an eco-friendly design can encourage shoppers to make greener decisions. Environmentally friendly product development by SMEs may help educate customers on the value of sustainability and inspire them to make ethical purchases (Wasiq et al., 2023). Internal variables, including administration commitment, partnerships with suppliers, and regulatory and customer pressure, all play a role in the uptake of environmentally friendly purchasing practices, and there is a definite correlation between the two. The use of green and limited materials in product design and reductions in water, energy, and other raw material use are all examples of GI practices that may be adopted and put into action (Mishra et al., 2019). Eco-design concepts should be incorporated at various points during product development, as discussed in the literature. Among these are the product's durability, simplicity of disassembly, recyclability, energy efficiency, waste reduction, and reusability.

H_3: *Eco-design in SMEs directly impacts environmental sustainability.*

2.1.4 The mediating effect of operational analysis between green SCM and environmental sustainability

Geng et al. (2017) said GSCM practices led to better social, environmental, operational, and economic performance. Additionally, the data indicates that certain GSCM practice-performance links are influenced by the industry, organisation size, ISO certification, and export orientation. In addition, the research outcomes of Geng et al. (2017) provide managers and policymakers with further evidence that GSCM practices may boost business results. Operations analytics describes cutting-edge analytic techniques and technologies to improve operational performance and judgement. Green SCM is a strategic management framework prioritising sustainability (Altassan, 2024). In order to get insight into the environmental performance of supply chain activities, activities Analytics employs data gathering, analysis, and visualisation approaches. Energy consumption, emissions, trash production, and water usage are just a few of the leading sustainability indicators that can be monitored and measured to help decision-makers make educated decisions and locate places for improvement (Wang et al., 2020). This data-driven strategy promotes foresight in decision-making and streamlines the introduction of efficient, environmentally friendly practices.

Big data analytics (BDA) and other ICT innovations may be used to get new understandings that can identify unsustainable supply chain activities and the components and actors involved (Liu et al., 2020). The study of sustainable supply chain

management (SSCM) is growing in popularity, but a minor has been identified about how business data analytics (BDA) may affect SSCM when applied to industrial supply chains. According to Mageto (2021), data administering, integration, reporting, analytics, security, and economics are the constituents of big data analytics. Openness, a culture of sustainability, strategic business goals, and risk management are all aspects of sustainable supply chain management. It is commonly known that BDA improves SSCM in the industrial sector. One of the obstacles to BDA adoption is the lack of qualified IT professionals and the prevalence of cyberattacks (Mageto, 2021). Predictive modelling tools available in operations analytics may be used to look into the future and adjust the supply chain in light of those predictions.

Predictive models may aid in optimizing transportation routes, inventory management, production planning, and facility layout design by considering environmental issues like carbon emissions, energy use, and waste creation (Mageto, 2021). As a result of this optimisation, the environmental effect, resource conservation, and sustainability performance are enhanced. Organisations can proactively detect vulnerabilities connected to environmental issues like natural catastrophes, climate change, or regulatory changes by analysing data and using risk assessment models (Raut et al., 2021). BDA paves the way for the creation of tactics to lessen the likelihood of adverse outcomes, as well as backup plans and steps to increase resilience in the event of an interruption.

H_4: *Operations Analytics positively mediates the association between Green SCM and environmental sustainability.*

Fig. 1 shows the conceptual framework of the proposed study.

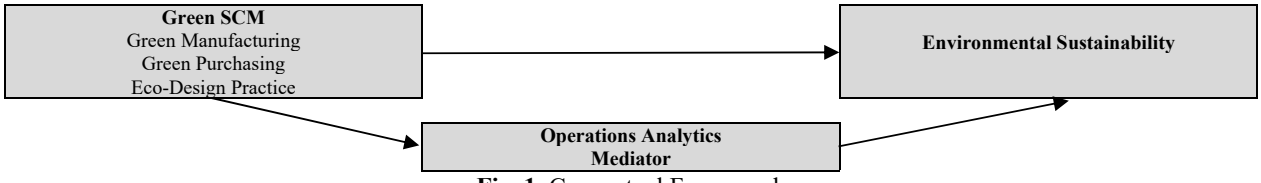

Fig. 1. Conceptual Framework

3. Methodology

The research methodology used in the proposed investigation is described in this section. A quantitative research design investigated the association between green SCM, environmental sustainability, and the mediating character of operations analytics. This method is advantageous because it permits the systematic collection of the data and its analysis, enabling the researcher to present statistically significant relationships and generalize outcomes to a larger population (Mohajan, 2020). This method was employed since the research aimed to ascertain how much green SCM practices in Saudi manufacturing SMEs impact environmental sustainability and how substantially operations analytics functions as a mediating factor.

In addition, primary data was collected for this study due to its focus on Saudi SME manufacturers. Primary data permits the collection of novels, direct information from the target population. It allowed the researcher to appropriately alter the questionnaire and data collection instruments to the research's context and requirements, improving the findings' validity and reliability (Kumari, 2022). Furthermore, primary data collection allows for evaluating variables and constructs that have not been thoroughly investigated in earlier research, making a unique addition to the field of study (Pedersen, 2021). A questionnaire was created to gather primary quantitative data. The questionnaire was meticulously constructed to elicit essential information on green SCM practices, environmental sustainability, operations analytics, and their interrelationships. It included Likert-scale items and closed-ended questions to guarantee a brief investigation of the study variables. This study's participants were managers and team leaders from Saudi manufacturing SMEs. Their direct engagement in supply chain management procedures and decision-making contributed to their selection. A power analysis was used to select a sample size of 350 participants to assure statistical validity and representativeness of the target population. A high enough sample size allows for rigorous statistical analysis and improves the findings' generalizability to the larger population of Saudi manufacturing SMEs (Ong and Puteh, 2017).

SPSS and SMART PLS were used to analyze the data for this study. SPSS was employed for descriptive statistics, data cleansing, and exploratory data analysis. It enables the computation of means, frequencies, correlations, and regression analysis. These statistical analyses are necessary to examine the connections between variables and evaluate hypotheses (Landau and Everitt, 2003). Because of its aptitude for complicated structural equation modelling, SMART PLS was chosen as the major statistical approach (Sarstedt et al., 2019). It facilitates the study of mediating effects and yields reliable results even with small sample numbers. SMART PLS also dealt with non-normal data distributions and did not need the fulfilment of severe assumptions, as maximum likelihood-based approaches do (Cheah et al., 2020). These benefits make SMART PLS an appropriate choice for this study, allowing for a thorough examination of the claimed links between green SCM, environmental sustainability, and operations analytics.

The measurement model with PLS was utilized to determine the validity and dependability of the proposed research. The path analysis investigated direct links, whereas the indirect effect looked at the function of operations analytics as an intermediary. These investigations revealed connections between green SCM, environmental sustainability, and operations analytics

(Iftikhar et al., 2022). The model's statistical quality and predictive ability were examined using the quality criteria and predictive relevance metrics (Hair et al., 2020). These tests confirmed that the assessment items properly represented the ideas, identified causal pathways, investigated mediating effects, and evaluated the model's overall performance.

4. Results

4.1 Demographic Analysis

Table 1 represents the demographic traits of the sample profile of the current research, including gender, age, and designation. Notably, most of the responses are collected from male participants, which is 69.7%, while female participants are observed to be 30.3%. Moreover, it also represents a mixed age of participants, as 22% of participants fall in the range of 20 to 28 years, 26.6% fall in the age of 29 to 35 years, 32.9% fall in 36 to 49 years, and 18.6% are found to be 50 above 50. Finally, referring to the designation of the participants, 51.7% are Managers and 48.3% are Team lead.

Table 1
Demographic Analysis

Attributes	Distribution	Frequency (n =350)	Percent
Gender	Male	244	69.7
	Female	106	30.3
Age	20 - 28 years	77	22.0
	29 – 35 years	93	26.6
	36 – 49 years	115	32.9
	50 and Above 50 years	65	18.6
Designation	Manager	181	51.7
	Team Lead	169	48.3
	Total	350	100.0

4.2 Descriptive Analysis

Table 2 summarises the latent variables involved in this study based on a 5-point Likert scale. The mean value of green manufacturing is 3.54, indicating that participants' average response toward agreement. The mean score of green processing is also identified as 3.95, indicating that average respondents are inclined to agree. Moreover, the mean value of eco-design was also found to be 3.85, demonstrating that average respondents are inclined to agree. Further operation analytics has also been considered as a mediator for analysing its influence on environmental sustainability. However, the statements in the questionnaire were determined to agree. Lastly, the mean value of environmental sustainability is 3.72, which depicts that an average number of participants agreed with the variable's latent items.

Table 2
Descriptive Statistics Analysis

	N	Minimum	Maximum	Mean	Std. Deviation
Green Manufacturing	350	1.00	5.00	3.54	0.81
Green Processing	350	1.00	5.00	3.95	0.69
Eco-design Practice	350	1.00	5.00	3.85	0.71
Operation Analytics	350	2.00	5.00	3.92	0.60
Environmental Sustainability	350	1.00	5.00	3.72	0.76
Valid N (listwise)	350				

4.3 Measurement Model

Confirmatory Factor Analysis (CFA) was used to determine the constructs' validity and reliability, consisting of Cronbach's alpha, outer loadings, composite reliability, and average variance extracted (AVE). The outer loading, also known as factor loading, evaluates the relationship between each indicator (item) and its concept, and it should surpass 0.7 for the legitimacy of the construct (Noonan, 2017). In empirical research, a value larger than 0.5 can also be considered appropriate (Purwanto, 2021). However, all values of outer loading are above 0.7, which indicates that each item used to measure the construct is valid for analysis. Cronbach's alpha is also employed to ensure the internal consistency of the construct involved in the model. All values of Cronbach's are above the threshold of 0.7, which is the minimum criterion for the reliability of the constructs (Purwanto et al., 2020).

Further, the composite reliability (CR) values were also considered, as all values were between 0.826 and 1.089, higher than the minimum criterion of 0.7 **(**Hair et al., 2014**).** Lastly, referring to the AVE tests of the SEM model, it can be observed that all values are found to be higher than 0.50, which acknowledges the convergent validity of the model (Hult et al., 2018). Thus, it indicated that all constructs measured in the current model are appropriate and accurate for analysis.

Table 3
Convergent Validity and Reliability

Latent Constructs	Indicators	Outer loadings	Cronbach's alpha	Composite reliability	Average variance extracted (AVE)
Eco-Design Practice	EDP1	0.909	0.884	0.909	0.810
	EDP2	0.926			
	EDP3	0.864			
Environmental Sustainability	ES1	0.913	0.899	0.901	0.833
	ES2	0.931			
	ES3	0.893			
Green Manufacturing	GM1	0.791	0.815	0.826	0.731
	GM2	0.896			
	GM3	0.874			
Green Purchasing	GP1	0.906	0.905	0.905	0.841
	GP2	0.932			
	GP3	0.912			
Operations Analytics	OA1	0.948	0.888	1.089	0.805
	OA2	0.934			
	OA3	0.802			

Discriminant validity was also examined using the Heterotrait–Monotrait ratio (HTMT). It can be observed from Table 4 that all values are computed to be less than 0.85, which is the maximum criterion for the legitimacy of discriminant validity. Thus, it indicated that the dataset had discriminant legitimacy**.**

Table 4
Discriminant Validity HTMT (Heterotrait–Monotrait) ratio

	EDP	ES	GM	GP
Environmental Sustainability (ES)	0.462			
Green Manufacturing (GM)	0.310	0.458		
Green Purchasing (GP)	0.512	0.507	0.270	
Operations Analytics (OP)	0.059	0.050	0.149	0.060

5. Structural Equation Model and Hypothesis Testing

The SEM model has been constructed, as indicated in Fig. 2, to evaluate the associations between variables of interest and accomplish the research goals. However, for hypothesis testing, SEM was tested in two ways. First, bootstrapping samples were used to analyse the significance of direct path analysis, and then indirect effects (mediation effects) of operations analytics on green SCM and environmental sustainability were investigated.

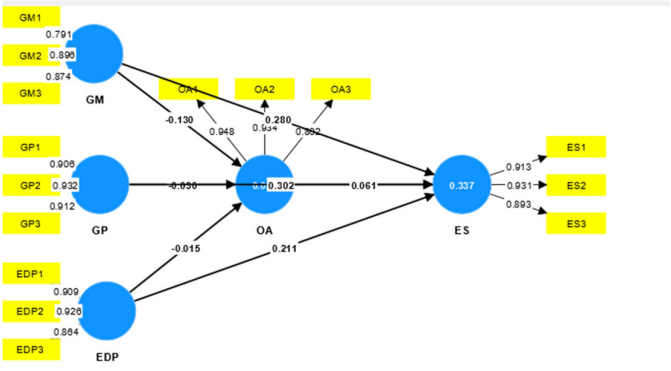

Fig. 2. SEM Model

Table 5
R-square and Adjusted R-Square

	R-square	R-square adjusted
ES	0.337	0.329
OA	0.021	0.013

However, before SEM testing, R-squared and adjusted R-square were used to measure the ability of the structural model. From Table 5 above, a 33.7% variance in environmental sustainability is predicted due to variance in green SCM practices. Further, it also demonstrated that only 2.1% of changes in the operations analytics are predicted due to the variance in the green SCM practices.

Table 6
Bootstrapping Result - Path Coefficients

	Path Coefficient	T statistics	P values
EDP → ES	0.211***	2.798	0.005
GM → ES	0.280***	5.338	0.000
GP → ES	0.302***	4.729	0.000

*** indicating significant at 5%, *** indicating significant at 1%*

The above table of path coefficients shows that eco-design practice positively and significantly impacts environmental sustainability (t = 2.798, B = 0.211, P < 0.01). Similarly, green manufacturing positively and significantly influences environmental sustainability (t = 5.338, B = 0.280, P < 0.01). Lastly, green purchasing also positively and significantly influences environmental sustainability (t = 4.729, B = 0.302, P < 0.01). Thus, findings revealed that green SCM practices in SME manufacturing firms in Saudi Arabia positively influence environmental sustainability.

Table 7
Bootstrapping Result - Indirect Impacts

	Path Coefficient	T statistics	P values
EDP → OA → ES	-0.001	0.182	0.856
GM → OA → ES	-0.008	1.171	0.242
GP → OA → ES	-0.002	0.356	0.722

** indicating significant at 5%, *** indicating significant at 1%

Table 7 above illustrates the mediating effects of operations analytics on green SCM practices and environmental sustainability. Notably, results indicated that green SCM practices (eco-design, green manufacturing, and green purchasing) do not considerably influence environmental sustainability through operations analytics, as p > 0.1.

Hence, based on the findings in the current research, H1 (GM → ES), H2 (GP → ES), and H3 (EDP → ES) are found to be supported, and H4 (GSCM → OA → ES) is rejected, as shown in the table below:

	Hypothesis	Accepted/Rejected
H1	Green Manufacturing in SMEs directly influences environmental sustainability.	Accepted
H2	Green Purchasing in SMEs directly influences environmental sustainability.	Accepted
H3	Eco-design practices in SMEs directly influence environmental sustainability.	Accepted
H4	Operations Analytics positively mediate the association between green SCM and environmental sustainability.	Rejected

6. Discussion

This research examined green SCM and environmental sustainability for Saudi manufacturing SMEs and the mediating role of operations analytics. The study developed the above four hypotheses, which were tested, and the results were evaluated. Green SCM has been examined to determine whether it plays a critical role in the environmental sustainability of SMEs. Companies use various methods and strategies to implement green SCM and be environmentally sustainable. However, there are challenges, too, which have been examined briefly in the literature. The mediating role of operations analytics in green SCM and environmental sustainability for SMEs in Saudi Arabia has been evaluated. Further, this section's primary discussion topics are the GSCM and environmental sustainability hypotheses in the context of Saudi SMEs. According to the study's findings, one hypothesis concerning the mediating function of operations analytics was rejected, whereas three hypotheses indicating direct links were confirmed. The approval of H1 (Green manufacturing in SMEs directly impacts environmental sustainability) demonstrates the beneficial correlation between environmentally friendly production methods and environmental sustainability in Saudi manufacturing SMEs. Green manufacturing uses environmentally friendly production techniques, such as waste reduction, increased energy efficiency, and sustainable materials (Paul et al., 2014). Green manufacturing techniques can help SMEs lessen their environmental impact and support larger sustainability initiatives. The results are consistent with earlier studies emphasizing the value of green manufacturing in achieving environmental sustainability goals (Wasiq, 2023). The approval of H2 (Green business practices directly affect the environment's viability) lends credence to the idea that environmentally friendly purchasing practices directly impact environmental sustainability in Saudi manufacturing SMEs. Green purchasing is obtaining materials and parts from companies that uphold sustainable business. SMEs may help encourage using renewable resources, reduce carbon emissions, and create sustainable supply chains by prioritizing green purchasing. The results underline how crucial it is for SMEs to adopt green purchasing methods to improve environmental sustainability (Khan, 2021). The approval of H3 (Environmental sustainability is directly influenced by eco-design practices in SMEs) suggests that eco-design methods benefit Saudi manufacturing SMEs' commitment to environmental sustainability. Incorporating environmental factors into product design, such as using sustainable materials, energy-efficient construction, and end-of-life disposal considerations, is known as eco-design. Using eco-design concepts, SMEs may create goods with a lower environmental effect throughout their lifecycle. The results highlight eco-design's importance as a proactive method of accomplishing environmental sustainability goals in the manufacturing industry (Khan and Qianli (2017). Contrary to predictions, the study's findings disprove hypothesis H4 (operations analytics moderate the interaction between sustainable business practices and the environment favorably), which held that operations analytics mediates the relationship between environmentally friendly supply chain management and environmental sustainability. This shows that the association between green SCM practices and environmental sustainability results in Saudi manufacturing SMEs is not mediated directly by operations analytics alone. The study could not discover evidence to support operations analytics' mediating role even though it can offer insightful information for process optimization and improving environmental performance. The fact that H4 was disregarded shows that operations analytics is unnecessary in mediating the interaction between green SCM and environmental sustainability. It is significant to remember that operations analytics can still directly improve environmentally sustainable business practices and green SCM. SMEs may optimize their supply chain processes,

spot areas for improvement, and make data-driven decisions to progress their environmental performance by utilizing operations analytics Delbeke and Lamas (2021). The results emphasize the need for more investigation into how operations analytics contribute to driving environmental sustainability outcomes within the framework of green SCM. Future research could focus on how operations analytics can help with green SCM, like spotting inefficiencies, maximizing resource allocation, and anticipating environmental effects. SMEs looking to boost their environmental sustainability performance would benefit greatly from understanding how operations analytics can improve the efficiency of green SCM initiatives. The study's findings support the direct, beneficial linkages between environmentally sustainable manufacturing, green buying, and eco-design practices in Saudi manufacturing SMEs. The findings, however, did not support the idea that operations analytics might mediate the connection between green SCM and environmental sustainability. These results indicate the necessity for more investigation into the function of operations analytics in this situation while also adding to the body of information regarding the importance of green SCM practices in achieving environmental sustainability goals.

7. Conclusion

The primary objective of this study was to examine the issues that promote GSCM in Saudi manufacturing SMEs to empirically analyze the impact of these green SCM factors on environmental sustainability in Saudi manufacturing SMEs and to anticipate the role of operations analytics as a mediator in the association between green SCM and environmental sustainability in Saudi manufacturing SMEs. Considering this, the proposed research investigated the correlation among GSCM, environmental sustainability, and the intermediary function of operations analytics in manufacturing SMEs in Saudi Arabia. The research findings indicated that implementing GSCM is a significant factor in advancing ecological sustainability for SMEs. The research findings validated three hypotheses that establish direct associations: firstly, green manufacturing exerts a direct influence on environmental sustainability; secondly, green business practices have a direct impact on the feasibility of the environment; and thirdly, eco-design practices directly affect environmental sustainability. The results mentioned above highlight the significance of implementing eco-friendly manufacturing techniques, adopting green procurement strategies, and integrating environmental considerations into product development to augment sustainability within the manufacturing sector.

Nevertheless, the research did not discover evidence to substantiate that operations analytics mediate the association between GSCM and ecological sustainability. While operations analytics offer significant insights for enhancing process optimization and environmental performance, it is not a prerequisite for moderating the correlation between GSCM practices and environmental sustainability outcomes. However, operations analytics could enhance environmentally sustainable business practices and GSCM by facilitating supply chain optimization and data-driven decision-making.

Based on the findings of the proposed study, Saudi manufacturing SMEs must adopt and integrate green SCM practices into their operations to enhance environmental sustainability. It includes implementing renewable energy sources, improving transportation routes, and using eco-friendly packaging materials. Secondly, SMEs should leverage operations analytics to gather real-time data and insights. It will enable them to make informed decisions regarding sustainability practices and performance improvement. It includes using analytics to monitor energy consumption, waste management, and carbon emissions. Moreover, collaboration and knowledge sharing among SMEs, industry associations, and governmental bodies should be encouraged to foster a supportive ecosystem for green SCM implementation. It includes establishing platforms for sharing best practices, providing training programs, and offering incentives for sustainable initiatives.

Despite the valuable insights from the findings of the proposed study, the current study has certain drawbacks. Firstly, the study is limited to Saudi manufacturing SMEs, restricting generalizability to other industries or nations. Secondly, the study depends heavily on self-reported data, which induces response bias. Thirdly, the study only looks at the function of operations analytics as a mediator, leaving the potential for further research into other variables that influence the link between green SCM and environmental sustainability. Considering this, future studies should widen the scope to cover different industries and countries, investigate operations analytics approaches, and investigate the challenges SMEs experience while using green SCM. The integration of new technologies like IoT and blockchain must also be investigated. Lastly, long-term impact studies and a multidisciplinary approach should be the focus of fellow researchers to handle problems in manufacturing SMEs.

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Appendix A

Section 1				
Demographics				
Gender:	1 = Male		2 = Female	
Designation:	1 = Manager		2 = Team Lead	
Age:	1 = 20 - 28 years	2 = 29 – 35 years	3 = 36 – 49 years	4 = 50 and Above 50 years

Appendix B

Section 2						
Please choose the best option according to your understanding						
Statement		1	2	3	4	5
Green Manufacturing (Independent Variable)						
GM1	Your firm complies with all requirements and regulations designed by a waste management program.					
GM2.	Please indicate to what extent you agree that your firm uses optimal allocation of resources in manufacturing products.					
GM3.	Your firm prioritises the reuse of recycled materials.					
GM4.	Harmful waste and pollution are kept identified and minimised during the manufacturing process.					
Green Purchasing (Independent Variable)						
GP1.	Our firm collaborates with vendors to accomplish environmental goals.					
GP2.	Environmental parameters are also considered when choosing suppliers to purchase products.					
GP3.	All products are eco-labelled.					
GP4.	Green purchasing is highly prioritised while making purchasing decisions.					
Eco-Design Practice (Independent Variable)						
EDP1.	Our firm allows the recycling, reuse, and recovery of raw materials.					
EDP2.	Our organisation pays high attention to eco-design practices in designing and packaging products.					
EDP3.	Our firm intends to maintain the product design to restrict the usage of hazardous goods and production processes.					
EDP4.	The company adheres to the safety of raw materials and efficient use of allocation of resources.					
Operations Analytics (Mediating Variable)						
OA1.	Operations analytics can help streamline the efficient allocation of resources.					
OA2.	Operational analytics also helps forecast and perform preventative maintenance.					
OA3.	Operational analytics also ensure efficiencies in supply chain management.					
OA4.	Operations analytics helps promote Green SCM practices and environmental sustainability.					
Environmental Sustainability (Dependent Variable)						
ES1.	Please indicate to what extent you agree that the company has strict rules for environmental sustainability in different areas.					
ES2.	Green SCM also helps decrease the consumption of hazardous or toxic materials.					
ES3.	Green SCM ensures a reduction in climate change and promotes environmental sustainability.					
ES4.	Implementing Green SCM practices is considered corporate responsibility to the environment.