



# Green technology, policy and sustainable finance nexus with SDG-12: Moderating effects of stakeholder awareness

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## ABSTRACT

The world is currently grappling with unparalleled environmental and social challenges that threaten sustainable development. Among these challenges, the attainment of Sustainable Development Goal-12 (SDG-12), which focuses on responsible consumption and production, is especially crucial. Thus, this study aims to investigate the impact of key factors, including green technology, policy and governance, access to sustainable finance, and stakeholder awareness, on SDG-12 by collecting 359 responses from pharmaceutical companies in Bangladesh. Employing a multi-method approach that integrates Structural Equation Modeling (SEM) and Artificial Neural Networks (ANN), the research investigates both direct effects and moderating influences of stakeholder awareness on the relationships among the variables. The results demonstrate significant direct effects of all predictor variables on SDG-12, with access to sustainable finance exhibiting the highest impact, followed closely by green technology, stakeholder awareness, and policy and governance. Furthermore, the moderating analysis reveals that stakeholder awareness significantly strengthens the relationships between the predictor variables and SDG-12, highlighting its crucial role in promoting sustainable practices. The ANN results rank sustainable finance as the most critical factor, affirming the consistent importance of these variables across different analytical frameworks. This research contributes to the literature by offering insights into the moderating effects of stakeholder awareness within the context of stakeholder theory, providing valuable theoretical and practical implications for policymakers and practitioners in advancing sustainability initiatives.

## 1. Introduction

The world faces unprecedented environmental and social challenges that threaten sustainable development [1,2]. Among these, achieving SDG-12 on responsible consumption and production is particularly critical [3,4]. The current global consumption patterns are unsustainable, putting immense pressure on natural resources and ecosystems [5]. Developing countries like Bangladesh are especially vulnerable to the consequences of unsustainable consumption and production practices due to limited resources, high population density, and economic dependencies on industries with heavy environmental footprints, such as textiles and agriculture [6,7]. Thus, addressing SDG-12 in Bangladesh is essential for the country's sustainable future and can also serve as a model for other developing nations facing similar pressures.

Green technologies, sustainable finance, and robust policy and governance mechanisms are widely recognized as pivotal tools in

addressing the challenges of sustainable development [7–9]. Green technology innovations can reduce resource consumption and waste, promoting more sustainable production processes [11]. Similarly, sustainable finance is necessary to provide the capital required for green investments, bridging the gap between financial resources and environmentally friendly practices [12]. Policy and governance frameworks play a crucial role in enforcing sustainable practices by establishing regulations, standards, and incentives [9]. These mechanisms collectively address the global pressures on sustainable consumption and production, but their impact can be limited if not implemented effectively [3,13–16].

The role of stakeholder awareness becomes vital here, especially when viewed through the lens of stakeholder theory, which posits that stakeholders' interests and engagement are fundamental to organizational success [5,17]. Stakeholder awareness may significantly enhance the impact of green technologies, finance, and policies on SDG-12 but is

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unexplored in the existing studies. Engaged stakeholders, from consumers to investors, drive demand for sustainable products and services, support green financing, and encourage compliance with governance policies [5]. Therefore, this study explores how stakeholder awareness acts as a moderating factor, potentially amplifying the effectiveness of the investigated relationships' interventions on SDG-12.

While extensive research has been conducted on green technology, sustainable finance, and governance in sustainable development, few studies have simultaneously examined these elements in relation to SDG-12 [2,4,7,10,12,16,18–21]. Existing studies often focus on parallel concepts, such as the impact of green technology on environmental sustainability, the role of sustainable finance in promoting renewable energy, or the influence of policy on resource conservation [5,7,9,22]. However, no prior research has integrated these elements within a comprehensive framework focused on SDG-12, especially with stakeholder awareness as a moderating variable. This study, therefore, fills this gap by developing a novel conceptual model that combines these factors with stakeholder theory to examine the nexus of green technology, governance, and sustainable finance for SDG-12.

This study is essential as it addresses a pressing need to understand how to foster responsible consumption and production more effectively, especially in the context of developing economies. The research aims to examine the interactions among green technology, governance, and sustainable finance in promoting SDG-12, with a specific focus on how stakeholder awareness moderates the investigated relationships. To achieve this, the study seeks to answer the following research questions: “How do green technology, policy and governance, and sustainable finance affect responsible consumption and production?” “How does stakeholder awareness influence the effectiveness of the investigated factors in achieving SDG-12?” A SEM-ANN approach is applied to investigate these relationships and test the proposed model.

The contributions of this study are fivefold: Firstly, this study presents a novel conceptual model linking green technology, governance, and sustainable finance for achieving SDG-12. Secondly, we introduce stakeholder awareness as a moderating factor, providing a novel concept to the investigated variables. Thirdly, this study leverages stakeholder theory to underpin these relationships, contributing to theoretical advancements in sustainable development literature. Fourthly, we employ multi-method approaches (SEM-ANN) to make robustness of the results. Finally, this study offers practical policy recommendations, including policy dialogues, to guide the implementation of sustainable practices for SDG-12.

The structure of this paper is as follows: [Section 1](#) presents the introduction; [Section 2](#) provides a literature review and theoretical foundation; [Section 3](#) details the methodology; [Section 4](#) covers the results and discussion; and [Section 5](#) concludes with implications, limitations, and future research directions.

## 2. Literature review and hypothesis development

### 2.1. Green technologies and SDG-12

Green technology encompasses environmentally-friendly innovations that promote resource efficiency, waste reduction, and emission mitigation in production and consumption processes [23,24]. From renewable energy sources to energy-efficient manufacturing and recycling technologies, green technologies support the shift toward responsible consumption and production [25]. Within the SDG-12 framework, green technology is viewed as essential for reducing resource intensity and enabling more sustainable industrial processes that align with ecological limits.

Energy-efficient machinery in manufacturing and its adoption leads to significant energy reductions, linking green technology with sustainable production practices [26]. Waste management technology shows how advanced recycling systems reduce landfill contributions and enhance resource recovery, essential for responsible consumption [24].

Renewable energy technology, particularly in the power generation sector, indicates that the shift to solar and wind sources significantly lowers carbon emissions, thus reducing the environmental impact of energy consumption [27]. In addition, green product design, such as the development of biodegradable packaging materials, indicated that such innovations promote responsible consumer behavior by reducing waste [23]. Water conservation technology in agriculture observed that implementing drip irrigation and soil moisture monitoring systems conserves water and promotes sustainable agricultural production.

Further, green building technologies, such as energy-efficient insulation and solar heating, can reduce energy use in residential and commercial buildings, promoting responsible consumption [25]. While focusing on the construction sector, green technology can highlight the significance of green technology in reducing resource intensity at the point of end-use [24,26]. Lastly, digital technologies, like smart meters and IoT-enabled monitoring, improve energy and resource efficiency by enabling real-time consumption tracking and waste management. The digital side of green technology reinforces the idea that technological innovation can drive responsible consumption by informing users about sustainable practices [28].

Each of these studies highlights various applications of green technology in promoting sustainability and innovation, either through reducing resource use, lowering emissions, or managing waste. However, these studies often focus on sector-specific impacts rather than an integrated perspective on responsible consumption and production. Addressing this gap justifies a more comprehensive investigation, leading to hypothesis 1:

**H1.** Green technology positively influences responsible consumption and production.

### 2.2. Policy, governance, and SDG-12

Policy and governance play a crucial role in promoting sustainable practices by creating regulatory frameworks, guidelines, and incentives that encourage both responsible production and consumption [16,24]. Governance and policy may include environmental regulations, waste management policies, carbon pricing, and subsidies for green practices, which shape corporate behavior and consumer habits alike [9,29]. Within the scope of SDG-12, effective policy and governance create an enabling environment for sustainable actions across industries and communities, guiding organizations and individuals toward practices that minimize environmental impacts.

The impact of emission-reduction regulations on manufacturing firms has shown that stricter policies lead to significant reductions in pollutants and increased investment in eco-friendly production processes, highlighting the direct influence of policy on sustainable production [6,13]. Additionally, citywide recycling programs have been found to significantly decrease landfill waste and encourage resource recovery, illustrating how local governance can drive responsible consumption through initiatives that promote waste minimization [3,24]. Moreover, companies subject to carbon pricing have been observed to adopt cleaner technologies and more sustainable practices to minimize costs, demonstrating how market-based policies can incentivize organizations to pursue responsible production methods [9,15].

Government subsidies for renewable energy projects have been shown to accelerate the adoption of green technologies in industry, highlighting the potential of financial incentives within governance to foster sustainable production [13,14]. Extended producer responsibility policies also play a significant role by making manufacturers accountable for the lifecycle of their products, leading to more sustainable product design and increased recycling rates [3,30]. While policies clearly encourage responsible production, their focus is primarily on waste management in consumer goods rather than production practices across various industries. Additionally, urban policies aimed at promoting public transportation and reducing private car usage effectively

support responsible consumption by decreasing fuel dependency and emissions [16,24].

Each of these studies illustrates the impact of specific policies or governance approaches on sustainability [3,6,9,13–16,24,30,31]. However, most focus on isolated regulatory measures rather than a comprehensive approach to responsible consumption and production. This gap underscores the need for an integrated view of policy and governance as holistic drivers of SDG-12 outcomes. Thus, H2 is proposed:

**H2.** Policy and governance positively affect responsible consumption and production.

### 2.3. Sustainable finance and SDG-12

Sustainable finance encompasses funding mechanisms that prioritize environmental, social, and governance (ESG) considerations, aiming to support projects and businesses that promote sustainable development [7,9,10,12]. Through avenues such as green bonds, ESG investments, and sustainable loans, sustainable finance provides the necessary capital for organizations to adopt environmentally-friendly practices, invest in green technology, and pursue responsible production [8,9]. Within the scope of SDG-12, access to sustainable finance enables companies and industries to adopt practices that reduce resource intensity, cut emissions, and foster a circular economy, thus supporting responsible consumption and production.

Green finance has been found to facilitate large-scale environmental projects, such as renewable energy infrastructure, thereby supporting sustainable production practices [12,8]. This highlights the potential of sustainable finance to advance green initiatives, although the focus remains primarily on energy projects, leaving room for exploration of broader aspects of responsible production [12,16]. Research into ESG investing reveals that companies with strong ESG practices attract more investment and are better positioned to adopt sustainable practices, aligning with responsible production by incentivizing improvements in environmental and social impacts [9,7]. However, this study mainly addresses investor behavior without examining the specific impacts on consumption or production. Additionally, access to green loans has been shown to enhance corporate environmental performance by enabling firms to invest in resource-efficient technologies and waste management systems [13,19].

Microfinance institutions have been shown to provide small loans for eco-friendly agricultural practices, thereby supporting responsible consumption in rural communities [12,13]. However, this focus is limited to small-scale applications, with little attention given to the broader impact of sustainable finance on industrial production. Additionally, research on impact investing indicates that companies receiving funds from impact investors are more likely to adopt sustainable production practices, such as reducing emissions and implementing fair labor practices. While this study establishes a connection between finance and sustainability, it primarily emphasizes social aspects rather than resource efficiency in production [12,8]. Furthermore, green venture capital funding has been found to enable startups to develop innovative, eco-friendly products, fostering responsible consumption by providing consumers with sustainable alternatives. However, this research does not address production practices in established industries. Finally, government-backed green finance programs have been shown to positively impact small and medium enterprises by enabling them to adopt sustainable production practices [13,19,16]. Moreover, existing studies tend to focus on financing mechanisms independently, without examining how sustainable finance interacts with other drivers like policy and stakeholder awareness to achieve SDG-12 outcomes [7–10,12,13,16,19]. Addressing this gap, we postulated H3:

**H3.** Access to sustainable finance has a positive relationship with responsible consumption and production.

### 2.4. Stakeholder awareness and SDG-12

Stakeholder awareness involves the knowledge, engagement, and concern of different groups—consumers, employees, investors, regulatory bodies, and the broader community—regarding sustainability issues [14,32–34]. High levels of awareness can drive stakeholders to adopt sustainable practices, support eco-friendly products, or demand environmentally responsible policies from organizations [6,32,34,35]. Within the scope of SDG-12, stakeholder awareness is crucial for fostering responsible consumption and production by influencing organizations to prioritize sustainable practices and motivating consumers to make eco-conscious choices.

Consumer awareness campaigns have demonstrated that consumers who are informed about environmental impacts are more likely to purchase eco-friendly products, thereby directly supporting responsible consumption [6,36]. However, this research focuses primarily on consumer behavior, neglecting the broader impact of stakeholder awareness across other groups. Similarly, studies on investor awareness indicate that those informed about ESG issues are more inclined to support companies committed to sustainable practices, incentivizing firms to enhance their production processes [7,9,33,37]. While this highlights the link between stakeholder awareness and responsible production, it mainly concentrates on investor behavior without considering the perspectives of other stakeholders [6,14,33,37]. Research on employee awareness of sustainability has found that employees who are knowledgeable about environmental issues tend to support green initiatives within their organizations, contributing to sustainable production practices [33,34,36].

Community awareness programs focused on waste management have been shown to engage communities in sustainability education, leading to reduced waste and increased recycling, thus supporting responsible consumption [6,32,34]. However, while this research emphasizes community involvement, it does not explore how stakeholder awareness might influence production behaviors within organizations [33,37]. Additionally, the influence of media coverage on sustainability awareness has been examined, revealing that increased exposure to environmental issues motivates both consumers and corporations to adopt more sustainable practices [14,35,36]. Finally, research on supply chain awareness indicates that companies aware of stakeholder concerns regarding sustainable sourcing are more likely to adopt responsible production practices [6,32,34,37]. Therefore, existing studies often address awareness in isolation, rather than considering how it might interact with other factors like policy or sustainable finance to enhance SDG12 outcomes. Addressing this gap, we propose H4:

**H4.** Stakeholder awareness positively influences responsible consumption and production.

### 2.5. Moderating effect of stakeholder awareness

The moderating role of stakeholder awareness in the relationship between green technology, policy and governance, and access to sustainable finance with responsible consumption and production presents a novel area of exploration with significant potential. Stakeholder awareness can significantly impact how effectively organizations adopt green technologies, comply with governance frameworks, and leverage sustainable finance to promote responsible practices [32,37]. For instance, higher stakeholder awareness may lead to increased demand for accountability and transparency, compelling organizations to adopt more rigorous sustainable practices, thereby enhancing or weakening the direct relationships depending on the level of engagement and expectation from stakeholders [14,36,37]. Given this gap in the literature, the proposed hypotheses explore the potential for stakeholder awareness to strengthen the investigated relationships, highlighting its critical role in the dynamics of sustainable development.

**H5a.** Stakeholder awareness strengthens the relationship between

green technology and responsible consumption and production.

**H5b.** Stakeholder awareness strengthens the relationship between policy-governance and responsible consumption production.

**H5c.** Stakeholder awareness strengthens the relationship between access to sustainable finance and responsible consumption production.

### 3. Conceptual and theoretical understanding of this research

Broderick and Usher [38] emphasize the importance of conscious consumer choices as a means of promoting sustainable practices, urging individuals to think critically before purchasing. This theme resonates with Jacob-John et al. [39], who review the synergistic interactions among different SDGs in food supply chains. They find that responsible consumption and production are interconnected, influencing not only environmental outcomes but also social and economic factors. In this context, the principles outlined by Gasper et al. [40] provide a foundational understanding of how sustainable consumption and production are framed within SDG-12, advocating for a comprehensive approach to policy and practice.

Stakeholder theory posits that organizations should consider the interests and well-being of all parties affected by their operations, including employees, customers, suppliers, investors, and the community at large [32]. This theory, developed by R. Edward Freeman, challenges the traditional notion that a company's primary responsibility is to maximize shareholder profit. Instead, it emphasizes the interconnectedness of stakeholders and recognizes that a firm's long-term success is contingent upon effectively managing these relationships and addressing their concerns [36]. By prioritizing stakeholder interests, organizations can enhance their reputation, foster loyalty, and create value that transcends financial metrics [34,36]. Stakeholder theory provides a framework for understanding the dynamics between businesses and their external environments, particularly in the context of sustainability and responsible practices.

In the context of this study, stakeholder theory is particularly relevant as it underpins the relationships between green technology, policy and governance, access to sustainable finance, and responsible consumption and production. By exploring how stakeholder awareness influences the investigated relationships, the study highlights the necessity for organizations to engage with their stakeholders to drive sustainable outcomes. For example, heightened stakeholder awareness may compel organizations to adopt green technologies and comply with

environmental policies, ultimately promoting responsible consumption and production practices [33,36]. This investigation can contribute to a deeper understanding of how stakeholder dynamics shape sustainability efforts, providing empirical evidence that supports stakeholder theory in practical contexts. By examining these interconnected relationships, the study emphasizes the importance of stakeholder engagement as a catalyst for achieving SDG-12 and advancing sustainable development goals. Therefore, Fig. 1 is developed as a conceptual research model.

### 4. Materials and methodology

#### 4.1. Data and sample

This study gathers data from 359 responses obtained from pharmaceutical companies in Bangladesh, selected for their significant contribution to the country's industrial landscape and their potential influence on sustainable practices, particularly in alignment with SDG-12. The pharmaceutical sector is vital to Bangladesh's economy, playing a crucial role in enhancing public health outcomes and generating export revenue. Consequently, it serves as an important context for investigating the adoption of green technologies, the effectiveness of policy frameworks, and access to sustainable finance [6].

We use the "rule of ten times," which states that the minimum sample size should be at least ten times the number of items included in the measurement model of the study [10,41]. With the measurement model comprising 20 items, the minimum required sample size would be 200. Thus, the 359 responses collected not only exceed this threshold but also provide a robust foundation for conducting comprehensive statistical analyses and yielding reliable results. This adequate sample size enhances the validity of the study's findings and strengthens the implications for sustainable practices within the pharmaceutical industry.

Table 1 presents a comprehensive demographic profile of the respondents from pharmaceutical companies in Bangladesh, detailing essential characteristics such as gender, age, education level, job position, and years of experience. The majority of respondents are male, comprising 66.20% of the sample, while females represent 33.80%. Age distribution reveals that the largest group falls within the 30–39 years range (43.70%), followed by participants aged 40–49 years (27.00%), indicating a workforce that is predominantly in their prime working years. Regarding educational attainment, more than half of the respondents possess a Master's Degree (54.90%), with those holding a Bachelor's Degree accounting for 37.90%, and a smaller fraction having obtained a Ph.D. or Doctorate (7.20%). The job position distribution

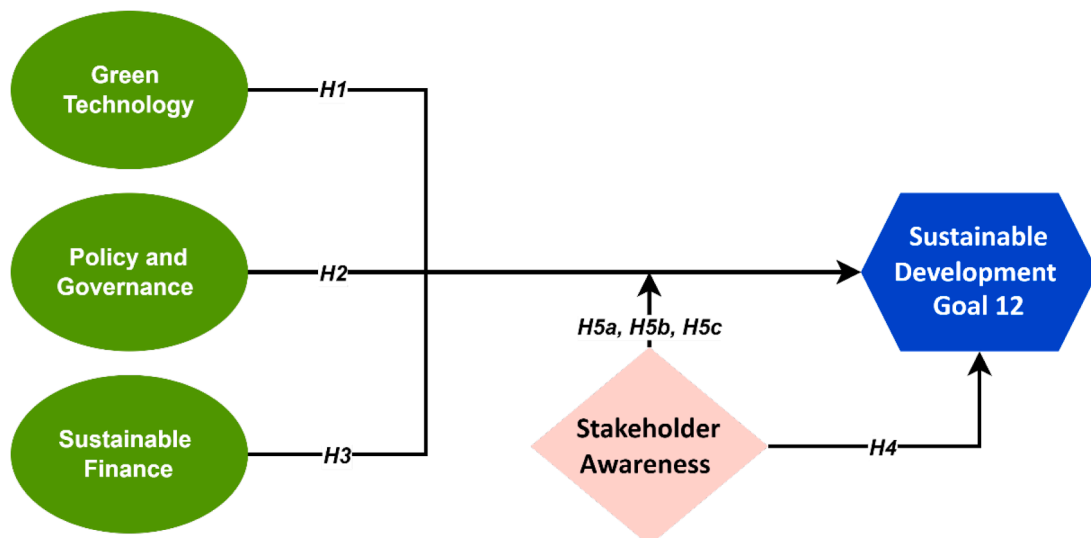


Fig. 1. Research model constructed by the authors.



**Table 1**  
Demographic profile of participants.

Demographic Variable	Category	Frequency (n = 359)	Percentage (%)
Gender	Male	238	66.20%
	Female	121	33.80%
Age	20–29 years	80	22.30%
	30–39 years	157	43.70%
	40–49 years	97	27.00%
	50 years and above	25	6.90%
Education Level	Bachelor’s Degree	136	37.90%
	Master’s Degree	197	54.90%
	Ph.D./Doctorate	26	7.20%
Job Position	Junior/Entry-Level	95	26.50%
	Mid-Level	158	44.00%
	Management		
	Senior Management	89	24.80%
	Executive/C-Suite	17	4.70%
Years of Experience	Less than 5 years	80	22.30%
	5–10 years	136	37.90%
	11–15 years	97	27.00%
	More than 15 years	46	12.80%

indicates that nearly half of the respondents occupy mid-level management roles (44.00%), while junior/entry-level positions comprise 26.50%, senior management roles make up 24.80%, and executive/C-suite positions account for 4.70%. Lastly, in terms of professional experience, a significant proportion of respondents have between 5 and 10 years of experience (37.90%), followed by those with 11 to 15 years (27.00%), less than 5 years (22.30%), and more than 15 years (12.80%). This diverse range of professional backgrounds enriches the study’s findings and insights into sustainable practices within the pharmaceutical sector.

4.2. Operationalization of variables

Green technologies (GTEC) are measured through various items that capture the adoption and integration of environmentally friendly technologies within organizations [8,11,42]. Specifically, this includes evaluating the extent to which companies implement energy-efficient technologies (GTEC1), invest in renewable energy sources like solar and wind (GTEC2), utilize sustainable materials in production (GTEC3), and adopt technologies aimed at enhancing resource efficiency (GTEC4). Each item facilitates a thorough assessment of the implementation of green technologies and their effectiveness in promoting sustainability.

Policy and governance frameworks (PGF) are assessed by analyzing the effectiveness of policies and governance structures that support sustainability objectives [3,4,9,16]. This involves evaluating adherence to national and international environmental regulations (PGF1), the presence of effective policies that promote sustainability and minimize environmental impacts (PGF2), the frequency of reviews and updates to governance frameworks (PGF3), and stakeholder engagement in the development and implementation of environmental policies (PGF4). These measures capture the extent to which governance frameworks are integrated into organizational practices and their role in fostering sustainable development.

Access to sustainable finance (ASF) is operationalized by examining the availability and utilization of financial resources allocated to green and sustainable projects [8,12,16,19]. This includes assessing whether companies have access to financing specifically for sustainability initiatives (ASF1), receive funding for projects aimed at reducing environmental impact (ASF2), benefit from financial incentives for adopting sustainable practices (ASF3), and are supported by investors or financial institutions prioritizing sustainability (ASF4). These measures provide insights into how access to sustainable finance influences the implementation of environmentally friendly practices.

Stakeholder awareness (SKAW) is operationalized by evaluating

consumer knowledge and its impact on purchasing behavior [32–34, 37]. This involves assessing whether consumers are aware of the environmental impacts of products (SKAW1), demand sustainable and environmentally friendly options (SKAW2), seek information on companies’ sustainability practices before purchasing (SKAW3), and are willing to pay a premium for sustainable products (SKAW4). These items reflect variations in consumer awareness and behavior, shedding light on how these factors moderate the relationship between corporate social responsibility practices and SDG-12.

Finally, SDG-12 is operationalized by measuring the extent of an organization’s practices that contribute to responsible consumption and production [11,18,22,43]. This includes evaluating practices related to waste reduction and recycling (RCP1), enhancing resource efficiency throughout the supply chain (RCP2), minimizing environmental impact during production processes (RCP3), and promoting sustainable consumption patterns among consumers (RCP4). Each item is assessed to determine the organization’s alignment with SDG-12 goals and to identify areas for improvement.

The study employs a 7-point Likert scale to measure these items. A 7-point scale offers finer granularity compared to a 5-point scale, allowing for more nuanced distinctions in respondents’ levels of agreement or disagreement [6,41]. This increased granularity enhances the accuracy and reliability of the collected data by capturing subtle differences in attitudes and perceptions. Furthermore, utilizing a 7-point scale minimizes central tendency bias, encouraging respondents to provide more precise evaluations rather than defaulting to neutral or mid-range responses [6,10,35].

4.3. Empirical methodology

This study employs a multi-method approach, utilizing PLS-SEM in conjunction with ANN to rigorously test the proposed hypotheses. PLS-SEM is preferred over Covariance-Based SEM (CB-SEM) due to its suitability for exploratory research, particularly when the research model is complex and involves a limited sample size, as is the case in this study [41]. PLS-SEM is adept at handling non-normal data distributions and allows for the evaluation of both reflective and formative constructs, making it particularly advantageous for understanding the intricate relationships between variables in sustainability research [41]. Following PLS-SEM, ANN is employed to further enhance the analysis by capturing non-linear relationships and interactions between variables that traditional linear modeling may overlook [30,44]. ANN’s ability to model complex patterns and interactions provides a robust framework for validating the findings from PLS-SEM, ensuring a comprehensive understanding of the factors influencing responsible consumption and production [44].

5. Results and discussions

5.1. Structural equation modelling

In PLS-SEM, the first step involves analyzing the measurement model to confirm the reliability and validity of the constructs [41]. This process ensures that each construct is accurately represented by its respective indicators [6]. Table 2 summarizes the reliability and validity metrics for each construct. In the measurement model assessment, each indicator’s factor loading, Cronbach’s Alpha, Composite Reliability, and Average Variance Extracted (AVE) are analyzed to determine if they meet the recommended thresholds [41]. Specifically, a factor loading above 0.70 is considered satisfactory, as it indicates that each item reliably contributes to its construct [41].

As shown in Table 2, all reliability and validity measures meet or exceed the required thresholds. Cronbach’s Alpha values are above 0.70 for each construct, demonstrating internal consistency, while Composite Reliability values also surpass the minimum threshold of 0.70, indicating that the constructs are measured reliably [41]. Furthermore, the

**Table 2**  
Reliability and validity measures.

Constructs	Items	Factor Loading	Cronbach's Alpha	Composite Reliability	AVE
Green Technologies (GTEC)	GTEC1	GTEC1	0.82	0.89	0.62
	GTEC2	GTEC2	0.87		
	GTEC3	GTEC3	0.90		
	GTEC4	GTEC4	0.78		
Policy and Governance Framework (PGF)	PGF1	PGF1	0.80	0.88	0.61
	PGF2	PGF2	0.83		
	PGF3	PGF3	0.84		
	PGF4	PGF4	0.80		
Access to Sustainable Finance (ASF)	ASF1	ASF1	0.84	0.90	0.73
	ASF2	ASF2	0.88		
	ASF3	ASF3	0.89		
	ASF4	ASF4	0.80		
Stakeholder Awareness (SKAW)	CAB1	SKAW1	0.78	0.87	0.70
	CAB2	SKAW2	0.85		
	CAB3	SKAW3	0.81		
	CAB4	SKAW4	0.80		
Responsible Consumption and Production (RCP)	RCP1	RCP1	0.84	0.92	0.64
	RCP2	RCP2	0.87		
	RCP3	RCP3	0.90		
	RCP4	RCP4	0.79		

AVE values for each construct exceed the recommended 0.50 threshold, confirming that each construct captures a sufficient amount of variance from its indicators [41]. These results validate the measurement model, supporting its suitability for further structural analysis in PLS-SEM, and ensuring the constructs can be confidently used to test the hypothesized relationships within the structural model.

Discriminant validity is confirmed in the model through the Heterotrait-Monotrait (HTMT) ratio analysis, as shown in Table 3. The HTMT values for each construct pairing are below the threshold of 0.90, which indicates that each construct is distinct from the others [41]. This result supports the adequacy of discriminant validity, ensuring that the constructs are well-differentiated and that each variable measures a unique dimension in the model. This distinction among constructs enhances the model's overall reliability and validity, permitting meaningful analysis of the relationships between constructs.

The model evaluation metrics indicate a robust fit and predictive relevance for the dependent variable, RCP. The R<sup>2</sup> value of 0.72 suggests that 72% of the variance in RCP is explained by the predictor variables, demonstrating a substantial explanatory power of the model. Additionally, the Q<sup>2</sup> predictive relevance score of 0.48 confirms that the model has strong predictive accuracy, indicating its effectiveness in achieving RCP. The goodness of fit measures further support the model's adequacy; specifically, the Standardized Root Mean Square Residual

**Table 3**  
HTMT ratio.

Constructs	GTEC	PGF	ASF	SKAW	RCP
GTEC					
PGF	0.78				
ASF	0.74	0.76			
SKAW	0.65	0.68	0.66		
RCP	0.76	0.72	0.77	0.69	

(SRMR) is 0.071, which falls below the threshold of 0.08, indicating an acceptable model fit [41]. Although the Tucker-Lewis Index (TLI) value of 0.87 is slightly below the conventional threshold of 0.90, it still indicates a reasonably good model fit given the complexity and exploratory nature of the model [41]. Therefore, these metrics suggest that the model is well-specified and suitable for analyzing the hypothesized relationships effectively.

Table 4 shows the results that demonstrate the significant direct effects of the investigated variables on SDG-12, indicating that each factor positively contributes to responsible consumption and production practices. Specifically, green technologies show a strong positive effect on SDG-12 (coefficient = 0.365, t-value = 12.98,  $p < 0.001$ ), suggesting that adopting environmentally friendly technologies significantly enhances sustainable practices within organizations, thereby supporting H1. The positive influence of policy and governance frameworks (coefficient = 0.295, t-value = 11.56,  $p < 0.001$ ) supports H2, emphasizing the importance of regulatory support and governance structures in promoting sustainable practices. Access to sustainable finance has the highest positive impact (coefficient = 0.422, t-value = 14.75,  $p < 0.001$ ), underscoring that financial resources dedicated to sustainability initiatives are crucial for achieving responsible consumption and production, affirming H3. Lastly, stakeholder awareness has a significant positive impact (coefficient = 0.336, t-value = 12.87,  $p < 0.001$ ), indicating that increased awareness among stakeholders can drive responsible consumption and production, aligning organizational actions with sustainability goals, thus confirming H4.

Further, the results in Table 4 demonstrate significant moderating effects of stakeholder awareness on the relationships between green technologies, policy and governance framework, access to sustainable finance, and SDG-12, indicating that stakeholder awareness strengthens these relationships, thereby supporting H5a, H5b, and H5c. Specifically, the interaction between green technologies and stakeholder awareness positively influences SDG-12 (coefficient = 0.146, t-value = 11.23,  $p < 0.001$ ), suggesting that higher stakeholder awareness reinforces the positive impact of green technology adoption on responsible consumption and production. This underscores the role of stakeholder awareness in amplifying green technology initiatives towards sustainable practices.

Similarly, policy and governance framework, when moderated by stakeholder awareness, also shows an enhanced positive effect on SDG-12 (coefficient = 0.179, t-value = 12.12,  $p < 0.001$ ), supporting H5b and highlighting that greater awareness among stakeholders strengthens the role of policy and governance in promoting sustainable practices. Finally, access to sustainable finance moderated by stakeholder awareness exhibits the strongest moderating effect (coefficient = 0.204, t-value = 13.02,  $p < 0.001$ ), supporting H5c and indicating that

**Table 4**  
Impact on SDG-12.

Relationships	Coefficient	t-value	p-value	Comment
<b>Direct Effects</b>				
H1. Green Technologies → SDG-12	0.365	12.98	0.000	Supported
H2. Policy and Governance → SDG-12	0.295	11.56	0.000	Supported
H3. Access to Sustainable Finance → SDG-12	0.422	14.75	0.000	Supported
H4. Stakeholder Awareness → SDG-12	0.336	12.87	0.000	Supported
<b>Moderating Effects</b>				
H5a. Green Technologies × Stakeholder Awareness → SDG-12	0.146	11.23	0.000	Supported
H5b. Policy and Governance Framework × Stakeholder Awareness → SDG-12	0.179	12.12	0.000	Supported
H5c. Access to Sustainable Finance × Stakeholder Awareness → SDG-12	0.204	13.02	0.000	Supported

stakeholder awareness further boosts the role of sustainable financial resources in achieving responsible consumption and production.

5.2. Artificial neural network (ANN)

Following the SEM analysis, an Artificial neural network (ANN) approach is applied to further validate and capture the nonlinear relationships among the key variables influencing SDG-12 outcomes [35, 9]. The ANN method uses latent variable scores obtained from the SEM results as input data, which ensures that the model leverages well-calibrated, underlying constructs to achieve a more robust predictive analysis [30,44]. This calibration step ensures that the latent scores accurately reflect the impact of green technology, policy and governance, sustainable finance, and stakeholder awareness on responsible consumption and production.

A ten-fold cross-validation strategy is implemented in this ANN analysis, as proposed by Jilani et al. [30] and Sun et al. [9], to mitigate overfitting and enhance model reliability. This technique partitions the data into ten subsets, where each folds iteratively uses 90% of the dataset for training and 10% for validation [30]. This approach not only improves the model’s generalizability but also optimizes its predictive performance. The resulting ANN model is designed with an input layer comprising four primary variables—green technology, policy and governance, sustainable finance, and stakeholder awareness—and an output layer dedicated to the SDG-12 outcome. This structure enables a focused, data-driven assessment of how these factors collectively and individually contribute to sustainable consumption and production.

Table 5 shows the root mean square error (RMSE) metrics derived from the artificial neural network training and testing phases, providing essential insights into the model’s predictive performance. The RMSE values for the training phase range from 0.082 to 0.090, while the testing phase shows values between 0.066 and 0.112 (see Fig. 2). These metrics suggest a commendable level of precision and robustness in the ANN’s ability to capture the relationships between the predictor variables and the SDG-12 outcomes. The analysis of RMSE values indicates that all metrics fall below the critical threshold of 0.50, demonstrating the model’s accuracy and reliability [9,30]. Furthermore, the proximity of RMSE values between training and testing datasets reinforces the model’s consistency and capacity to generalize effectively. Overall, the results underscore the ANN’s potential as a powerful tool for understanding and predicting the impacts of various factors on responsible consumption and production, as outlined by SDG-12.

Sensitivity analysis is essential in predictive modeling as it assesses the impact of input variable variations on model outputs, helping identify which factors most significantly influence the dependent variable, in this case, SDG-12 [9,30]. By quantifying the relative importance of predictors, sensitivity analysis enables researchers to prioritize resources and strategies towards the most influential variables, thereby enhancing decision-making in policy and governance frameworks.

Table 5  
ANN-RMSE values.

Networks	Training			Testing			Total Samples
	SSE	RMSE	N	SSE	RMSE	N	
ANN1	2.217	0.083	323	0.256	0.084	36	359
ANN2	2.192	0.082	325	0.260	0.087	34	359
ANN3	2.606	0.090	324	0.154	0.066	35	359
ANN4	2.316	0.085	322	0.464	0.112	37	359
ANN5	2.324	0.085	320	0.177	0.067	39	359
ANN6	2.272	0.083	326	0.301	0.095	33	359
ANN7	2.168	0.082	324	0.415	0.109	35	359
ANN8	2.195	0.083	321	0.207	0.074	38	359
ANN9	2.310	0.085	323	0.254	0.084	36	359
ANN10	2.303	0.085	319	0.199	0.071	40	359
Mean	2.290	0.084		0.269	0.085		
SD	0.119	0.002		0.096	0.016		

Additionally, it evaluates the robustness of the model by revealing how stable predictions are to changes in inputs, thereby increasing the model’s credibility. Ultimately, this analysis deepens our understanding of the complex interdependencies among variables, providing valuable insights for effective interventions aimed at achieving sustainable development goals.

Table 6 presents the results of the sensitivity analysis conducted on the artificial neural network model, illustrating the normalized importance of various predictor variables—policy and governance, stakeholder awareness, green technology, and sustainable finance—in influencing SDG-12 outcomes. Each variable is assigned a normalized importance score, expressed as a percentage, reflecting its relative significance in the model. The analysis reveals that sustainable finance emerges as the most critical factor, achieving a normalized importance of 100%, followed closely by green technology (97%), stakeholder awareness (96%), and policy and governance (67%). These rankings underscore the hierarchical influence of these variables on responsible consumption and production practices. The results affirm the unity of the structural equation modeling findings, as shown in Table 4, reinforcing the reliability and consistency of the model’s outcomes.

5.3. Discussions

The findings of this study highlight the significant impact of green technologies, policy and governance, sustainable finance, and stakeholder awareness on SDG-12, which focuses on responsible consumption and production. Specifically, the results demonstrate that each of the investigated variables positively affects sustainable practices within organizations (see Fig. 3). Green technologies are shown to directly facilitate the adoption of environmentally friendly practices, while policy and governance frameworks provide essential regulatory support that fosters sustainability. Furthermore, access to sustainable finance emerges as a crucial enabler, underscoring the importance of financial resources dedicated to sustainability initiatives. Lastly, the role of stakeholder awareness emphasizes that informed and engaged stakeholders can drive organizations toward aligning their operations with sustainability goals, collectively reinforcing the importance of integrating these factors in strategies aimed at achieving SDG-12.

In examining the moderating effects, the analysis reveals that stakeholder awareness significantly strengthens the relationships between the predictor variables and SDG-12. The interaction between green technologies and stakeholder awareness shows a positive moderation effect (see Fig. 4). This indicates that as stakeholders become more informed and engaged, the effectiveness of adopting green technologies is enhanced. Increased awareness leads to a deeper understanding of the benefits and functionalities of environmentally friendly practices, thereby fostering greater acceptance and implementation within organizations. Stakeholders who are well-educated about green technologies are more likely to advocate for their adoption, leading to more innovative solutions and collaborative efforts to integrate sustainable practices into business operations. Thus, the presence of informed stakeholders can act as a catalyst for the successful deployment of green technologies, ultimately resulting in improved sustainability outcomes.

Similarly, the policy and governance framework exhibits a substantial positive interaction with stakeholder awareness (see Fig. 5). Informed stakeholders are better equipped to advocate for and support regulatory measures that promote sustainable practices. This heightened awareness allows stakeholders to engage more effectively with policymakers, fostering a collaborative environment where sustainable development initiatives can thrive. Moreover, active stakeholder participation can lead to the identification of gaps in existing policies and governance structures, enabling the development of more effective frameworks tailored to meet the specific needs of various sectors. As stakeholders become more knowledgeable about the implications of policy decisions on sustainability, their ability to influence policy-

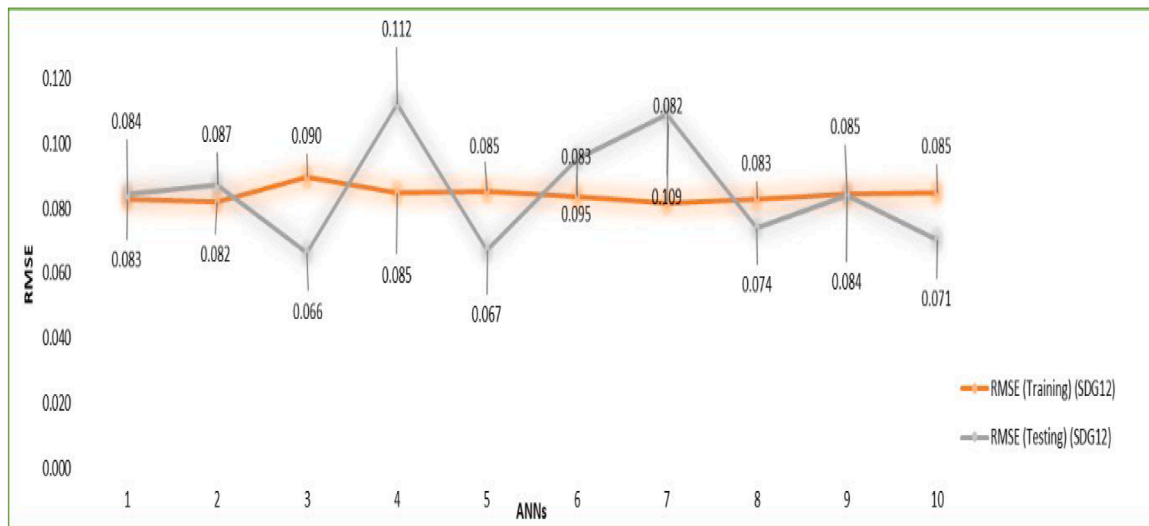


Fig. 2. RMSE values.

**Table 6**  
Sensitivity analysis.

ANN	Policy and Governance	Stakeholder Awareness	Green Technology	Sustainable Finance
ANN1	0.567	1.000	1.000	1.000
ANN2	0.484	1.000	1.000	1.000
ANN3	0.502	1.000	1.000	1.000
ANN4	0.704	0.797	0.432	1.000
ANN5	0.929	0.987	1.000	0.851
ANN6	0.690	1.000	1.000	1.000
ANN7	0.628	0.980	1.000	0.918
ANN8	1.000	0.831	1.000	1.000
ANN9	0.236	1.000	1.000	0.930
ANN10	0.784	0.725	1.000	1.000
Average	0.653	0.932	0.943	0.970
Importance Normalized Importance (%)	67%	96%	97%	100%
Ranking	4	3	2	1



Fig. 3. Direct impact on SDG-12.

making processes increases, thereby reinforcing the importance of governance in achieving responsible consumption and production.

Finally, the interaction between access to sustainable finance and stakeholder awareness further illustrates the importance of informed stakeholders in leveraging financial resources effectively (see Fig. 6). When stakeholders are well-informed about sustainable finance options, they can make more strategic decisions regarding the allocation of financial resources to sustainability initiatives. This informed approach not only enhances the visibility of available funding opportunities but also encourages greater investment in sustainable projects. As stakeholders advocate for sustainable finance, organizations are better positioned to access necessary funding, leading to innovative projects and practices that align with SDG-12. In essence, the presence of knowledgeable and engaged stakeholders amplifies the positive impact of financial resources on responsible consumption and production, demonstrating that the interplay between stakeholder awareness and financial access is crucial for achieving sustainability goals.

The results of ANN analysis provide compelling evidence that substantiates the findings from the structural equation modeling approach. In this analysis, sustainable finance is identified as the most critical factor influencing responsible consumption and production practices related to SDG-12. This prioritization underscores the essential role that financial resources play in driving sustainability initiatives; without adequate access to sustainable finance, organizations may struggle to implement effective green technologies. Following sustainable finance, green technology ranks as the second most important factor, highlighting the necessity of adopting environmentally friendly technologies to achieve sustainability objectives. The rankings of stakeholder awareness and policy and governance, which follow closely in third and fourth place, further emphasize the importance of informed stakeholders and robust regulatory frameworks in facilitating successful sustainability initiatives. The alignment of the ANN and SEM results reinforces the validity of the model presented in this study, confirming that the relative importance of these variables remains consistent across different analytical approaches. This coherence enhances the robustness of the findings, providing a comprehensive understanding of how financial, technological, regulatory, and social dimensions interact to promote sustainable development practices. The unity between the SEM and ANN findings serves to validate this research, indicating that the conclusions drawn are not mere artifacts of a single analytical method.



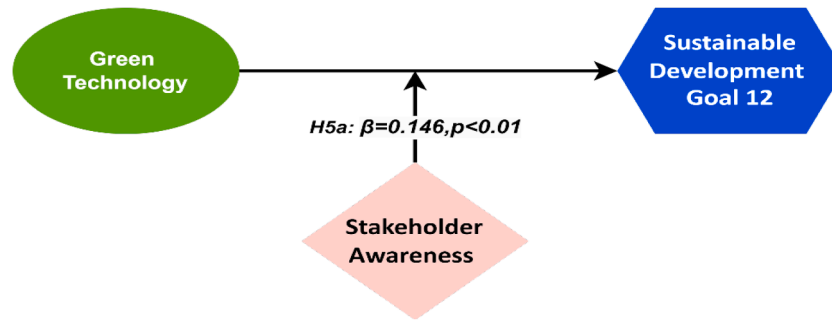


Fig. 4. Relationship between green technology and SDG-12 is moderated by stakeholder awareness.

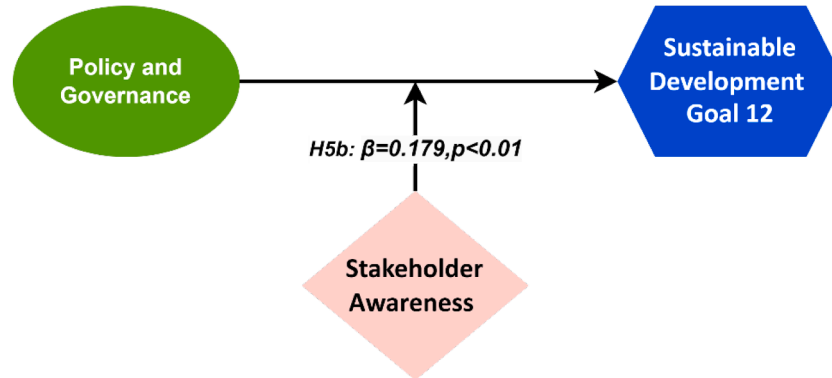


Fig. 5. Relationship between policy and governance and SDG-12 is moderated by stakeholder awareness.

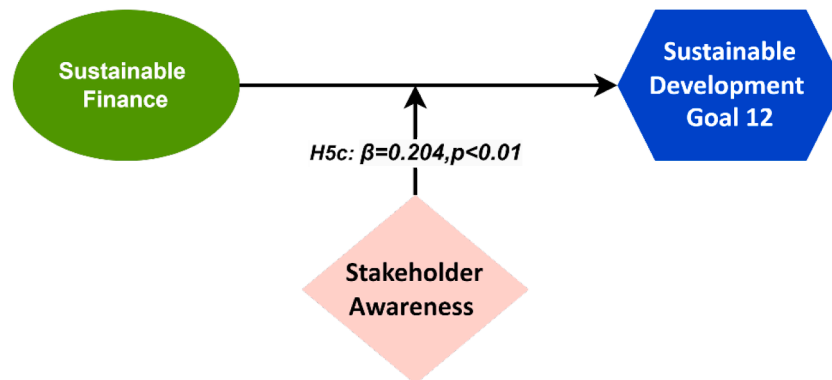


Fig. 6. Relationship between sustainable finance and SDG-12 is moderated by stakeholder awareness.

## 6. Conclusion, implications, and limitations

### 6.1. Conclusion

This study explores the critical relationship between various factors—green technology, policy and governance, access to sustainable finance, and stakeholder awareness—and their impact on SDG-12, which focuses on responsible consumption and production. The research aims to provide a comprehensive understanding of how these variables interact to influence sustainability outcomes. Utilizing a mixed-methods approach, the study integrates SEM and ANN to analyze the direct effects of each factor on SDG-12. The results reveal that all four factors significantly contribute to achieving sustainability objectives, with access to sustainable finance exhibiting the highest positive impact, followed by green technology, stakeholder awareness, and policy and governance.

Additionally, the study investigates the moderating role of

stakeholder awareness, which strengthens the relationships between the predictor variables and SDG-12 outcomes. The interactions indicate that increased stakeholder awareness enhances the effectiveness of green technologies and bolsters support for policy and governance frameworks, while also leveraging access to sustainable finance more effectively. Furthermore, the ANN analysis ranks the importance of the predictor variables, confirming the consistent influence of sustainable finance, green technology, stakeholder awareness, and policy and governance across both analytical methods. This alignment between SEM and ANN results emphasizes the interconnectedness of financial, technological, regulatory, and social dimensions in promoting sustainable development practices, reinforcing the validity of the research model presented in this study.

### 6.2. Theoretical implications

The findings of this research extend existing theoretical frameworks

by offering valuable insights into the role of stakeholder theory in sustainability. The significant impact of stakeholder awareness on the effectiveness of green technology, policy and governance, and access to sustainable finance highlights the importance of informed stakeholder engagement in driving responsible consumption and production. This study posits that organizations must consider stakeholder theory and actively involve them in sustainability initiatives, thereby enriching stakeholder theory with empirical evidence that emphasizes the dynamic interplay between stakeholders and sustainability practices. By demonstrating how awareness can amplify the effects of key sustainability factors, the research contributes to a deeper understanding of stakeholder roles in achieving sustainable development goals.

### 6.3. Practical implications

From a practical standpoint, this study offers actionable insights for policymakers, organizations, and practitioners aiming to promote sustainable development. The findings highlight the necessity of fostering an enabling environment for sustainable finance, as financial resources are identified as a key driver of sustainability initiatives. Policymakers should prioritize regulatory frameworks that support access to sustainable finance, which can, in turn, empower organizations to adopt innovative green technologies. Additionally, the research emphasizes the significance of stakeholder awareness; organizations should invest in educational and engagement initiatives to inform stakeholders about sustainability practices. By doing so, they can enhance stakeholder involvement, leading to more effective implementation of sustainable strategies and better alignment with SDG-12 objectives.

### 6.4. Methodological implications

This study employs a mixed-methods approach, utilizing both SEM and ANN, which enhances the robustness of the analysis and offers a comprehensive understanding of the research problem. The integration of these methodologies not only provides a nuanced perspective on the relationships among the variables but also demonstrates the value of using advanced analytical techniques in sustainability research. The sensitivity analysis conducted within the ANN framework serves to further validate the importance of the identified variables. Future research may build upon this methodological foundation by exploring other advanced modeling techniques or incorporating additional variables to enrich the understanding of factors influencing sustainable development.

### 6.5. Limitations and future research scope

The reliance on self-reported data may introduce bias and affect the generalizability of the findings. Additionally, the research is context-specific, focusing primarily on particular industries or regions, which may limit its applicability to other settings. Future research should consider longitudinal studies that examine the effects of these variables over time, as well as explore additional factors that could influence SDG-12 outcomes, such as technological advancements or cultural dimensions. Furthermore, expanding the geographical scope of the study could provide a more comprehensive understanding of how these dynamics play out in different contexts.

### CRediT authorship contribution statement

**Md. Mominur Rahman:** Writing – original draft, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Md. Emran Hossain:** Writing – review & editing, Writing – original draft, Visualization, Validation, Data curation, Conceptualization.

### Declaration of competing interest

No conflict of interest.

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None.

### Data availability

Data will be made available on request.

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