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The Importance of Supply Chain Integration in Environmental Performance: A mediation-moderation model of Knowledge Combination, Resilience and Green Innovation

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Abstract

Nowadays, Green Supply Chain (GSC) networks are developed as essential components in the commerce strategy. Producing green products is an instance of environmental achievements worldwide, such that ecological statistics show that consumers avoid buying products that emit pollution during production. Therefore, pursuing sustainability approaches in Supply Chain Management (SCM) turns into a fundamental issue. In the present article, we discuss the role of supply chain integration on the environment using Knowledge Combination (KC), Green Innovation (GI), and the mediating role of reactive and Proactive Dimensions (PDs) of resilience. The current study is a quantitative descriptive-correlational research with an applied purpose. The research population analysis is available to experts in the supply chain field. The research findings are expressed in the variance-based structural equation approach and the Radial Basis Function (RBF) neural network approach. Accordingly, supplier integration improves resilience and environmental performance by employing knowledge synthesis. Innovation moderates environmental performance and supplier integration. The results illustrate that reactive and preventive dimensions of Supply Chain Resilience (SCR) have a decisive role in environmental performance.

Keywords: Supply chain integration, Environmental performance, Knowledge combination, Resilience, Innovation, Green supply chain.

1 | Introduction

In recent decades, environmental issues have gained significant importance from the industry perspective [1]. Environmental damage, including water pollution and global warming, is spreading globally. Following these

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damages, companies in developed and emerging economies improve their productivity by using sustainable and efficient resources to deal with environmental damage and improve the supply chain [2].

Supply chain and logistics are among the primary activities in the economic field. In periods of environmental change, having a stable, effective, and efficient supply chain due to reduced costs and improved service levels is essential. It is considered to be a sustainable competitive advantage. Organizations are now using analytical methods focusing on improving the efficiency of their Supply Chain Management (SCM). Network design is one of these important analytical methods in SCM. New research shows that a strategic network design can reduce an organization's costs by 60% [3], [4].

Green Supply Chain (GSC) management integrates sustainable environmental processes into the supply chain [5]. The production of green products is an example of environmental achievements globally. Today, in addition to increasing the social responsibility of companies, it is considered an essential part of business strategies. Despite numerous research studies on the supply chain's impact on global warming, scientific articles in this field still have limitations [6]. Research in green product production and sustainable innovation emphasizes its strategic effects on companies to achieve competitive goals and protect the environment. Environmental values show that consumers avoid buying a product that causes environmental pollution in its production process, even if it has all the expected criteria. In other words, environmental values are described as the first step towards green consumption before other variables in the purchase process [7].

Although integrating supply chain partners is a fundamental option in Green Innovation (GI), it may increase coordination costs [8]. Also, GIs are considered essential in transforming a conventional supply chain into a GSC [9]. They are considered a source of competitive advantage to reduce adverse effects on the environment. GI generally refers to creating new ideas, products, processes, services, technologies, and management systems related to environmental issues [10]. In other words, GI refers to developments that comply with ecological rules and principles, save resources and energy, and prevent pollution and environmental damage during production [11]. Also, innovation refers to creating new knowledge and skills that result from challenges and skills related to developing technology, causing changes in the market and international competition of companies. One of the critical factors in realizing innovation is the combination of knowledge. Knowledge synthesis is an interactive process in which firms collect and absorb new knowledge [12].

Nowadays, according to government environmental regulations and customers' attention to the environment, economic enterprises have made improving environmental performance a top priority of their work [13]. Implementation strategies to improve this situation include implementing internal environmental management [14], making GIs, and investing in information technologies [15]. However, due to limited resources and capabilities in an enterprise, more than improving environmental performance is needed [16]. For this purpose, companies should have integrated supply chain partners in internal environmental practices [2]. In this regard, companies should plan and try to share their knowledge and information with other suppliers or customers, given the fear of opportunistic behavior or exploitation of information by business partners for personal gain, provided that there is a guarantee that There is no release of it to competitors.

Supply Chain Resilience (SCR) focuses on the system's ability to cope with temporary disruptive events. The constituent elements of resilience show how the supply chain can prepare, respond, and recover from an event. Soni et al. [17] study identified ten key factors contributing to achieving resilience. These factors include agility, collaboration between actors, information sharing, sustainability, risk and revenue sharing, trust between actors, transparency, risk management culture, adaptability, and supply chain structure. Also, resilience should encompass all supply chain processes, relationships, and resources that lead to creating capabilities to overcome disruptions. Increasing the degree of capabilities and reducing vulnerability improves the supply chain's resilience. One of the essential prerequisites for creating and improving resilience in the supply chain is knowing and understanding the network that connects the business to suppliers and customers. Mapping tools can help identify critical paths and bottlenecks, often known as bottlenecks. The capacity is limited at these points, and alternative options are unavailable [18].

SCR has a mediating role in the relationship between green supplier integrity and environmental performance. According to the knowledge-based and natural resource perspectives, companies should seek the knowledge, resources, and capabilities needed to increase supply chain flexibility among their partners. In this study, SCR includes preventive and Reactive Dimensions (RD). Proactive resilience allows organizations to respond quickly and most effectively after a disaster. Claver et al. [19] have emphasized the need to adopt pollution prevention or preventive measures because it reduces the cost of environmental productivity. Also, production costs are significantly reduced when less natural resources and energy are consumed as raw materials. Companies should pioneer technological innovations in the field of pollution prevention methods to meet expectations related to reducing waste and resource productivity and increasing company profits. From the point of view of natural resources, resilience and the combination of knowledge in the supply chain as a pollution prevention strategy can improve environmental performance [20], [21].

Therefore, supply chain flexibility is proposed to moderate the relationship between green supplier integrity and environmental performance. A research gap is that most previous studies need to pay more attention to the conditions under which green supplier integration works effectively. Despite the importance of green supplier integration, these values can only be created if suppliers' internal knowledge is combined as a tool with new knowledge. In addition, knowledge integration provides green supplier resilience capabilities in the supply chain. Therefore, in this study, knowledge synthesis strengthens the positive relationship between green supplier integrity and SCR.

This paper examines the topic of the research in 5 parts. In the first part, the problem and necessity of the research is discussed. The second part includes theoretical foundations related to theoretical literature, variables and research gaps. The third part of the research method, the population and the statistical sample and the reasons for using analysis methods are described. Section 4 describes and compares the research findings in the two introduced methods. And finally, in section 5, discussion and conclusions are made.

2 | Literature Review

2.1 | Green Supply Chain

A supply chain model involves dynamic networks of purposeful coordination and cooperation among all chain partners. This multi-faceted issue arises from the execution of environmental operations in an organization. Environmental management principles involve how organizations pay attention to the environment and minimize its harmful effects. They also include policies and implementing protocols to minimize waste or greenhouse gases. These principles are usually presented in the form of standards, such as the international standard ISO14000. These standards provide a framework for organizations to implement an Environmental Management System (EMS) [22]. The GSC is a company's responsibility from raw materials to final consumption and disposal [23]. Operational activities lead to the consumption of natural resources and the creation of carbon and inevitable pollution. According to the literature, the foremost objective of the GSC process is to excrete various types of waste and reduce ecological impacts at different stages [24]. Applying an environmental management strategy and approach makes a GSC out of a regular supply chain [25]. The literature also underlines the main contrast between a typical supply chain and a green one: the former focuses primarily on economic and commercial factors. In contrast, new supply chains mix profitability with accomplishing long-run environmental objectives [26]. Overall, the present article describes the GSC as environmental processes including reverse logistics, design, manufacture, consumption, and production [27], [9].

2.2 | Green supply chain Integration

GSC integration concerns strategic cooperation between partners and companies and their collaborative management [8]. Internal integration is a strategic path by which companies implement environmental goals in their management strategies and processes. Using this method allows allocating companies' internal resources in an electronic process. Accordingly, companies tend to execute environmental management throughout the organization's operations and focus on its continuous tracking and monitoring. Green internal integration covers three major sectors: 1) merging ecological targets and authorities into business practices and managerial rewards, as well as maintaining a balance between business and ecological targets; 2) creating an integrated system that aligns environmental goals in the business decisions and human resources for its various purposes; and 3) interoperability, coordination, and cooperation across the supply chain network tiers as effective measures in reducing ecological pollutions. The green suppliers are integrated to regulate the relationship with suppliers based on the implementation of green management. As a result, the suppliers can develop the company's sustainability approaches while participating in the realization of environmental goals [28], [29]. By analyzing the literature connected to GSC integration, the relevant research covers three main areas: The first category evaluates suppliers from an environmental point of view. It means that companies select suppliers according to environmental criteria. In this category, the regular performance of suppliers is evaluated according to environmental requirements [30]. The second category includes the development of ecological culture through the provision of targeted instructions and guidance, conducting workshops, conferences, and educational seminars and alerting suppliers, notifying them about the advantages of green production alternatives and technologies, and visiting sites of teams' environmental suppliers to strengthen the green orientation in supply methods and direct them to develop environmental programs. The third category includes green cooperation with suppliers, in which the manufacturers call suppliers to take part directly in its environmental activities [31]. Chiou et al. [32] defined the supplier's environmental guidance and assessment as a green supplier. According to the literature, the prime dimensions of this issue are the use of greenness of suppliers and green collaboration with them [33].

2.3 | Supply Chain Resilience

SCR specifies adaptability to recuperate from an unsatisfactory performance level to a planned performance level and aims to reduce the effects of disruption and recuperation as quickly as possible. Readiness, agility, and alertness are the three main components of SCR [34]. Adaptation speed takes many forms in the supply chain. In resilience, speed is regarded as the speed of recovery or adaptation after a disruption. Higher speeds lead to faster tactical, operational, and strategic decisions and faster adaptation to market changes [6], [35].

Regarding the importance of flexibility, the resilient supply chain is an essential topic in research in this field. SCR is the ability to proactively plan and design the supply chain network to anticipate unpredicted disruptions and give an adaptive response to the disruptions simultaneously by controlling the structures and functions. Beyond that, to a stable state or in case it is possible to reach a more favorable state, the result of resilience is gaining a competitive advantage. In this respect, Hamidieh and Arshadi [34] reinforce the SCR against the increasing uncertainty of demand by considering the safety stock in strategic warehouses and strategic inventory in the regional distribution hubs. Besides, these authors significantly reduce energy consumption in the field of network logistics. Shin and Park [36] have proposed a model based on leader interactions with supply chain members to describe the critical effect of supply chain leadership on resilience capabilities. Capabilities, including alertness, agility, flexibility, and efficiency, are the main dimensions of resilience. Qadir et al. [37] studied the impact of Industry 4 technologies on supply chain performance. They stated that supply chain visibility strengthens the SCR and applies a moderating impact between SCR and technologies related to Industry 4. Also, these technologies improve supply chain performance through SCR.

Belhadi et al. [38] presented a model to study the impact of developing dynamic capabilities on the resilience and efficiency of the supply chain. These capabilities included sensing, reconfiguring, and resizing. They also stated that additional manufacturing technology lays the foundation for developing dynamic capabilities and provides a synergistic improvement of the SCR and efficiency. SCR relies on proactive and reactive approaches. Supply chains must enhance their compatibility capacity to be prepared for unexpected and hazardous events. Since the early 2000s, researchers have proposed procedures to advance resilience by upgrading versatility, efficiency, adaptability, and coherence [39].

According to the existing literature, while measuring the amount of profit, we assessed a four-point scale from Cheng and Lu [15] for the reactive and proactive aspects. In sample cases, we can again meet the customer's needs to guarantee that the supply chain will always function properly.

2.4 | Green Supplier Integration and Supply Chain Resilience

Supply chain partners are better integrated. The supplier is at the beginning of the supply chain. In this regard, there are various methods for supplier management, such as evaluating and selecting suppliers [22], cooperating with suppliers, and increasing them [40]. However, most of these methods have focused on the manufacturers and do not consider the participation of suppliers. The consensus between the company and its suppliers has made the researcher consider the integration of green suppliers [41].

A company cannot achieve SCR independently because it needs suppliers' support. In this study, we hypothesize that supplier integration positively affects proactive and RDs. Organizations need knowledge and data to develop creative ideas for ecological disasters [42]. From the knowledge-based perspective, information is the company's primary resource and provides the basis for winning in the market. One of the main processes for GSI is to help companies coordinate the deployment of valuable resources and know-how across organizational boundaries [43].

Integrating suppliers encourages interaction. In addition, GSI helps settle disputes between the company and suppliers, thereby improving the company's efficiency in dealing with environmental issues. Hence, companies can improve environmental issues with SCR and supplier integration.

2.5 | Environmental Performance

With an increase in attention to environmental issues, there is a growing demand for environmentally friendly goods. Along with the environmental responsibility of the manufacturer, the environmental responsibility of companies has also become a principle for the supply chain. Companies may benefit from consumer rewards for supporting environmental programs in this respect. In practice, many retailers are responsible for environmental issues [44].

Research has shown that specific environmental ideas greatly encourage sustainable development. First, specific environmental ideas reinforce the sustainability approach throughout the GSC. These ideas are classified into three axes: 1) the development of new products with the ability to recycle; and 2) environmental innovations that lead the supply chain toward clean operations; and green process innovations that improve environmental performance [45]. Companies must adopt appropriate governance and regulations unless they cannot effectively foster environmental innovation through partnerships with green suppliers. Most companies prefer a controllable agreement because they can ensure cooperation with suppliers under different circumstances.

Furthermore, social responsibility programs in the GSC pursue integrating economic and social issues and developing environmental programs with stakeholders. Hence, environmental performance is considered the main approach to corporate social responsibility [46]. Environmental performance is formed based on the convergent development of the company's economic and environmental interests, which creates a competitive advantage for companies in the market. Therefore, developing environmental performance evaluation criteria improves the position of the final product in the market. Regarding the mentioned points, organizations are trying to improve environmental performance based on the missions, goals, and environmental criteria according to the structure of their GSC.

2.6 | Knowledge Combination

Knowledge management is among the main factors of competitive advantage in economic enterprises. This concept includes a set of technologies and resources that transform information and data into sustainable value through transfer, production, combination, and organization [47]. However, its crucial effect on the supply chain is the effective organization of customer-supplier communication and support of decision-making processes, thereby leading to supply chain integration. The competitive advantage of organizations is directly influenced by knowledge creation, identification, sharing, and use of knowledge [48]. The creation and production of knowledge are among the primary processes of knowledge management in the supply chain. These factors are estimated based on the level of development of knowledge resources throughout the operational and task levels of supply chain networks. Overall, these resources are classified into two types: implicit and explicit.

Explicit knowledge is a piece of documented knowledge that can be accessed, transferred, coded, and recorded in databases. On the other hand, implicit (tacit) knowledge is rooted in the experiences, skills, and personal knowledge of the organization's people. In general, four methods (i.e., socialization, externalization, internalization, and combination) have been proposed for creating and sharing knowledge [49]. Individual sharing and transfer of knowledge at the organizational level imply socialization. To facilitate knowledge dissemination at the organizational level, it is imperative to focus on externalizing knowledge. However, sorting and combining the applied sources of knowledge accelerates the process of creating and developing knowledge at the organizational level. Furthermore, shared across the supply chain network or organization and becomes a part of the knowledge of various organizational roles [50].

Improper sourcing, the bullwhip effect, and the destruction of supply chain integration are among the effects of non-optimal use of knowledge integration at different supply chain levels. Hence, combining and classifying knowledge improves supplier selection processes and develops optimal sourcing [51]. Thus, combining knowledge helps companies benefit more from integrating green suppliers. In this context, a firm's knowledge seems to be an essential complement to the integrity of its green supplier. A company with a high ability to combine knowledge and GSI is more successful in SCR.

2.7 | Green Innovation

Lack of resources, environmental concerns, pollution, sustainable use of resources, and increasing customer awareness of environmentally friendly products encourage organizations to create GI and management [52]. GI is among the most severe types of environmental strategies. From an environmental perspective, Small and Medium-Sized Enterprises (SMEs) are among the most critical industries in developing environmental concerns. Recent articles see GI as the kind of creativity that companies employ to redesign their products and customer service. They also continue production processes by minimizing negative ecological impacts [53]. Companies applying a green entrepreneurship approach create value for customers and environmentally friendly products and services through innovation. Entrepreneurial companies, such as SMEs, are committed to accepting risks to be the first companies to provide new products, services, and operational technologies. In other words, they have a positive attitude to accomplish innovative strategies. Organizations that employ green methods in their activities can move forward in the market by asking a higher price for their green products and entering newer markets in terms of strategic management [54].

GI enables companies, banks, and governments to harmonize their decision-making in acquiring knowledge from preparing this direction.

On the other hand, it patronizes manufacturers to possess long-term contracts with their suppliers based on mutual trust [55]. Organizations may exchange information relevant to green technology, contribute knowledge and GI in better formulation of green technology programs, and boost innovation to progress green products and services of companies. Supply chain partners may set forth different ideas, information, and resources. In other words, when companies are positive toward producing green products, GI can progress in the supply chain. Innovation can be achieved by redesigning processes and developing research and development measures, reducing transaction and tax costs for buying and importing green equipment and machinery, and developing environmental monitoring systems to recognize and monitor pollution and ecological hazards [56].

To show the available gaps in the literature and novelties of the current research model, *Table 1* presents a more detailed classification of the literature.

Table1. Comparison of research background.

Author/Year	Variables					Research Results
	Supply Chain Integration	Resilience	Environmental Performance	Knowledge Combination	Innovation	
Ji et al. [42]	√	√	√	√		Supplier integration and KC are favorable for the active and RDs of SCR. Also, they moderate the relationship between environmental performance and GSI.
Du et al. [8]	√				√	Integration in supplier and customer interaction is seriously associated with innovation. When the internal level is higher, the relationship between innovation and customer integration will be decisive.
Zhang et al. [52]	√		√		√	Supplier integration promotes environmental innovation. On the other hand, environmental innovation reduces pollution.
Chiou et al. [32]			√		√	In addition to gaining a competitive advantage, companies experience supplier greening, new products, and process innovation.
Burki [9]			√		√	A supply chain becomes green when its stakeholders can work together on GSC goals. Such proportion requires transferring information and skills to achieve productivity.
Li et al. [33]	√	√	√			The successful combination of an active environmental master plan can enhance the organization's environmental performance and mediate green internal and supplier integration.
Lopes de Sousa Jabbour et al. [2]	√		√			External management is significant for organizations' response to environmental modernization. Customers play an essential role because success in this vast responsibility depends on the customer.
Zhang et al. [52]	√		√			Structural accumulation modulates supplier integrity and company proficiency. Specific possible factors (e.g., commitment, confidence, and dependency) affect the correlation between green supplier integrity and company performance. Social performance also is essential in this process.
Yu et al. [57]	√		√			Customer quality and supplier integration are beneficial for customer green purchasing and collaboration and the environment.
García-Machado et al. [57]	√		√		√	Innovation is a mediating variable between environmental performance and culture. Also, an ecological process plays a positive. Product innovation mediates environmental ethics and competitive advantage. Companies need to address innovation and environmental challenges.

Table1. Continued.

Author/Year	Variables					Research Results
	Supply Chain Integration	Resilience	Environmental Performance	Knowledge Combination	Innovation	
Song et al. [14]	√		√			The best method to manage a GSC is having green internal and external integration.
Aboelmaged [58]			√		√	Eco-innovation, environmental attitude, and supplier partnership have a beneficial impact on hotel performance. Also, the use of subjective metrics is vital in evaluating the hotel's performance.
Peng et al. [59]	√		√	√		High levels of internal and external knowledge accumulation can increase green knowledge integration. Thus, it effectively enhances GSC performance.
Pham [31]	√		√	√		Environmental knowledge is the basis for expanding green strategies. In addition, suppliers and customers affect green performance.
current study	√	√	√	√	√	

As shown in *Table 1*, this paper examines the determinants of supply chain environmental performance with the presence of reactive and preventive dimensions of SCR. The conceptual model of the research, which is extracted from the theoretical foundations of the investigated research, is presented in the form of *Fig. 1*. This figure was prepared using the models of Ji et al. [42] and Farbod and Hamidieh [60]. Also, the hypotheses of this research are proposed in a model presented in *Fig. 1*.

H1. Green supplier integration positively affects the reactive and PDs of SCR.

H2. The Proactive Dimension (PD) of SCR positively affects environmental performance.

H3. The RD of SCR affects environmental performance.

H4. The reactive and PDs of SCR mediate between environmental performance and Green supplier integration.

H5. The combination of knowledge modulates the effects of Green supplier integration on the reactive and PDs of SCR.

H6. GI mediates between environmental performance and Green supplier integration.

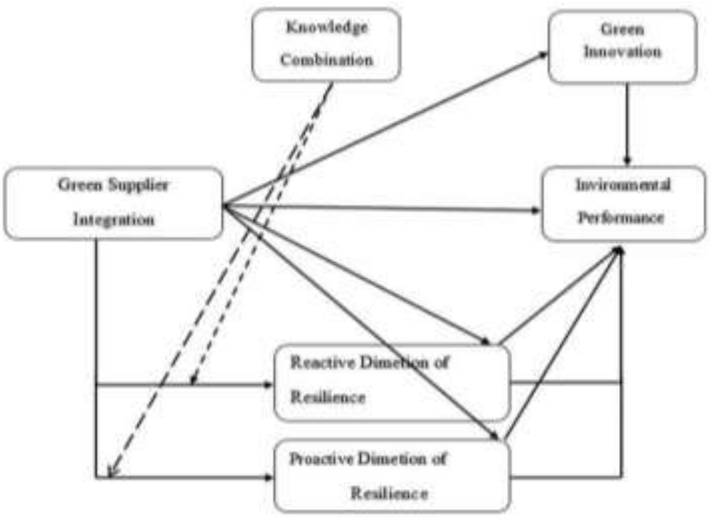

Fig. 1. Conceptual framework.

3 | Material and Methods

This quantitative study has a descriptive-correlational nature and practical purpose. The data of the research population are available to professionals in this field. A total of 184(184<200 sample) people were used through the non-probabilistic sampling method. The required data were collected using the standard questionnaire in *Table 2*. In the present study, to test the hypotheses by considering the mediating effect of GI and dimensions of resilience, including reactive and preventive dimensions, as well as the modulating variable of knowledge synthesis using the method of variance-based structural equations in SmartPls 3.3.3 software and the Artificial Neural Network (ANN) Radial Basis Function (RBF) in Spss26 software was used *Fig. 2* and *Fig. 5*.

There are two types of SEM techniques: covariance-based techniques such as LISREL, EQS, or AMOS, and variance-based SEM techniques like Partial Least Squares (PLS). Given the increasing importance of SEM techniques, choosing the appropriate technique between these two is essential for better fitting a theoretical model. Additionally, with the increasing complexity of a theoretical model, researchers have been seeking new SEM techniques to address this issue [61].

Hackl and Westlund [62] claimed that SEM techniques based on ANN might have superiority over traditional SEM techniques, as they can measure non-linear relationships using various activation functions and hidden layers of nodes. Therefore, this study extends previous research in several directions. Firstly, fitting a theoretical model based on PLS is performed. Secondly, the theoretical model is fitted using the SEM technique and then compared with the ANN-based technique. Since the above two approaches are the same, their results can be compared to select the best-fit model [63].

Hsu et al. [61] compared PLS, SEM, and ANN techniques in simulation studies and reported similar results between ANN and PLS [61].

Fig. 2 represents the research conceptual model after fitting. Besides, we scanned the validity and reliability before examining the hypotheses. Moreover, the questionnaire's validity and reliability were determined using Fornell and Larker divergence validity, Cronbach's alpha index, criterion validity, combined reliability, convergence validity, and average variance.

Table 2. Research variables.

Components	Measurement method
Environmental Performance	5 items [64], [65
GI	7 items [60]
RD of Resilience	4 items [15]
PD of Resilience	4 items [15]
KC	5 items [66]
Green Supplier Integration(GSI)	6 items [67], [68]

4 | Results

The research findings are expressed in two parts: 1) the fitness model with the variance-based structural equation approach, and 2) the RBF network approach. The fitting variance-based structural model is formed in the following three steps; measurement fitness of the model, structural model fitting, and general model fitting.

4.1 | Measurement Model Fitness

This stage specifies whether the perceived variables accurately measure the theoretical concepts. For this purpose, the construct model validity is examined using two convergence and divergence validity criteria.

Table 3 shows that the factor loads of variables' all dimensions are greater than 0.4, suggesting the good validity of the Confirmatory Factor Analysis (CFA) and the well-explained structures of all dimensions.

Table 3. Convergent validity.

Component	Original sample (O)	T statistics (|O/STDEV|)	Result
q10 ← KC	0.817	36.110	Accepted
q11 ← KC	0.795	29.736	Accepted
q12 ← RD of resilience	0.821	31.488	Accepted
q13 ← RD of resilience	0.835	47.456	Accepted
q14 ← RD of resilience	0.846	45.634	Accepted
q15 ← RD of resilience	0.850	52.778	Accepted
q16 ← PD of resilience	0.860	45.236	Accepted
q17 ← PD of resilience	0.823	35.310	Accepted
q18 ← PD of resilience	0.822	43.433	Accepted
q19 ← PD of resilience	0.881	54.786	Accepted
q2 ← GSI	0.841	42.965	Accepted
q20 ← Environmental performance	0.811	29.843	Accepted
q21 ← Environmental performance	0.823	36.022	Accepted
q22 ← Environmental performance	0.792	28.430	Accepted
q23 ← Environmental performance	0.519	5.768	Accepted
q24 ← Environmental performance	0.565	5.937	Accepted
q25 ← GI	0.782	23.929	Accepted
q26 ← GI	0.863	49.860	Accepted
q27 ← GI	0.777	23.339	Accepted
q28 ← GI	0.811	27.470	Accepted
q29 ← GI	0.776	30.029	Accepted
q3 ← GSI	0.768	24.070	Accepted
q30 ← GI	0.812	33.928	Accepted
q31 ← GI	0.765	23.551	Accepted
q4 ← GSI	0.784	24.232	Accepted
q5 ← GSI	0.745	17.477	Accepted
q6 ← GSI	0.783	28.043	Accepted
q7 ← KC	0.853	43.939	Accepted
q8 ← KC	0.840	43.937	Accepted
q9 ← KC	0.790	29.172	Accepted
q1 ← GSI	0.824	30.039	Accepted

Convergent validity criteria are extracted variance and Cronbach's alpha. The values obtained from *Tables 3* and 4 for these two indicators are greater than 0.5 and 0.7, respectively. On the other hand, the absolute value of the significant number obtained for all items is higher than 1.96, suggesting that the convergent validity of the research tool is within the acceptable range.

Table 4. Construct reliability and validity.

Component	Cronbach's Alpha	Combined Trust Ability	Mean-Variance Extracted
GSI	0.881	0.909	0.626
Environmental performance	0.756	0.834	0.510
GI	0.905	0.925	0.638
KC	0.877	0.911	0.671
PDs of SCR	0.868	0.910	0.717
RDs of SCR	0.859	0.904	0.702

Divergent validity is evaluated using the Fornell and Lanker criterion. This criterion is calculated by putting the root of the extracted variance's mean instead of 1 in the principal diameter of the correlation coefficient matrix. From *Table 5*, it is inferred that this value for each variable is greater than the correlation of one structure with others. Hence, the research tool has satisfactory divergent validity.

Table 5. Fornell-Larcker criterion in the correlation matrix.

Component	GSI	Environmental Performance	GI	Knowledge Combination	PD of SCR	RD of SCR
GSI	0.791					
Environmental performance	0.706	0.714				
GI	0.338	0.570	0.799			
KC	0.755	0.711	0.333	0.819		
PDs of SCR	0.715	0.634	0.345	0.769	0.847	
RDs of SCR	0.763	0.638	0.336	0.778	0.816	0.838

The desirability of the calculated composite reliability, factor loads, differential validity, and convergence validity proves the fit of the research measurement model.

4.1.1 | Structural model fitness

In the present section, the fitness of the structural model is investigated. The second step is to apply the model fitness index, path analysis, and coefficient of determination (R^2). *Fig.2* and *3* exhibit the research model's structural equation, path diagram, path coefficients, and significant numbers.

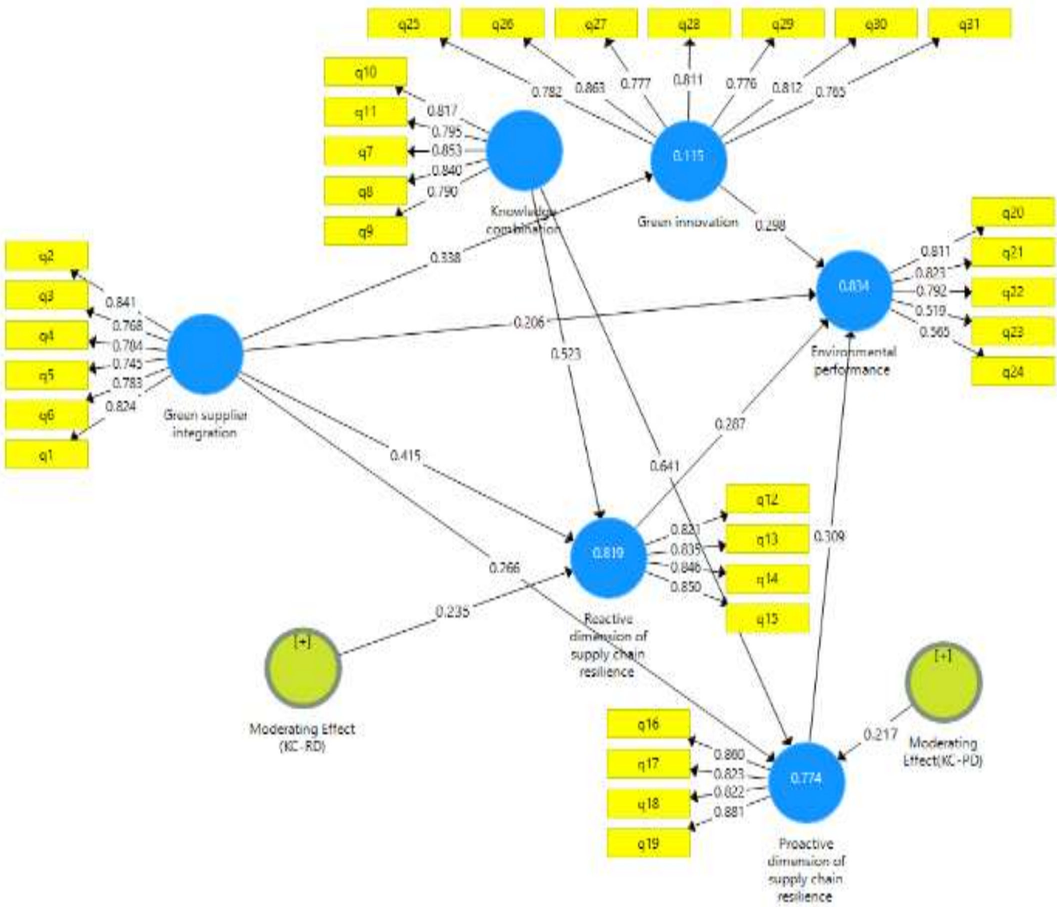

Fig. 2. The conceptual model fitted in standard estimation mode.

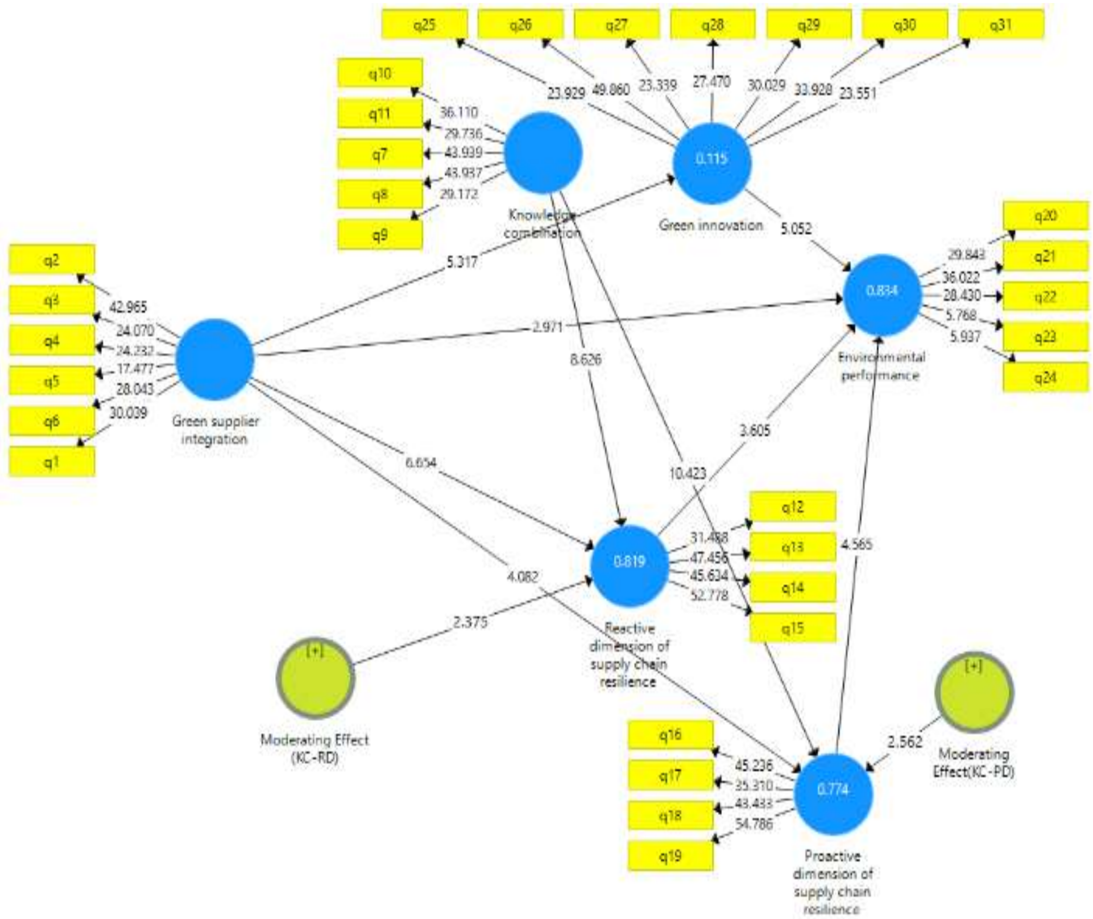

Fig. 3. The conceptual model fitted in the significance mode of parameters.

R^2 is the most important criterion to extract the association between the dependent parameter and one or more independent parameters. This coefficient, whose value is between 0 and 1, represents the percentage change of the dependent variable by independent variables. Aston-Geyser coefficient index (Q^2) is a criterion that shows the predictive efficiency of the fitted model. If this index has one of the three values of 0.02, 0.15, and 0.35 for the current fitted model, it indicates the model structure's weak, medium, or strong predictive power. *Table 6* indicates the Stone-Geiser coefficient and R^2 for GI, environmental performance, and reactive and PDs' resilience.

Table 6. R^2 and Q^2 of model constructs.

Construct	R^2	Q^2
Environmental performance	0.834	0.411
GI	0.115	0.070
PDs of SCR	0.774	0.548
RDs of SCR	0.819	0.567

According to *Table 6*, about 83% of the environmental variables are affected by GI, green supplier integrity, and reactive and PDs of resilience and KC. Also, the structural part of the model shows satisfactory fitness regarding the model's R^2 values and predictive power.

4.1.2 | Overall model fit

The fitting is obtained from the geometric mean of the expected average and R^2, which is called the model's Goodness of Fit (GOF). An acceptable model's GOF should be above 0.36. According to the model's GOF calculated by SmartPls software, the model has a good fit [69].

Table 7. CR-redundancy and CR-communality indexes.

Construct	Construct Cross validated Redundancy	Construct Cross validated Communality	R^2
GSI		0.474	
Environmental performance	0.411	0.288	0.834
GI	0.070	0.515	0.115
KC		0.500	
PDs of SCR	0.548	0.516	0.774
RDs of SCR	0.567	0.493	0.819

$$\text{GOF} = \sqrt{\text{AverageR}^2 \times \text{AveregeCommunality}.} \quad (1)$$

In *Eq. (1)*, Average R^2 is the model's average R^2, and Average Communality is the average of the validity index of the subscription or cross-validity applied to determine the morality-of-fit index.

$$\text{GOF} = \sqrt{0.464 \times 0.635} = 0.543. \quad (1)$$

In the overall fit of the structural model that is calculated using the GOF index, three values are considered for this index: 0.01 (poor fit), 0.25 (moderate fit), and 0.36 (good fit) [70]. Based on *Eq. (1)*, the GOF = 0.543 suggests a perfect fit of the overall model. In *Table 7*, the numbers in the CR-Red column show the validity or redundancy check indicator, indicating the standard of the structural model. Moreover, the CR-Com column numbers show the cross-validity or cross-validity check index [71].

4.1.3 | Examining the hypotheses

The research hypotheses test includes the mediator effects test (i.e., indirect effects), the direct effects test (i.e., the effect of independent variables on the dependent variable), and the real effects test (i.e., the effect of independent variables on the dependent variable in the presence of mediator variables).

Table 8. Testing hypotheses (Path coefficients).

Path Diagram with Mediating Variables	Original Sample (O)	T Statistics (|O/STDEV|)	P -Values
GSI → Environmental performance	0.206	2.971	0.002
Supplier integration → innovation	0.338	5.317	0.000
GSI → PDs of SCR	0.266	4.082	0.000
GSI → RDs of SCR	0.415	6.654	0.000
GI → Environmental performance	0.298	5.052	0.000
KC → PDs of SCR	0.641	10.423	0.000
KC → RDs of SCR	0.523	8.626	0.000
PDs of SCR → Environmental performance	0.309	4.565	0.000
RDs of SCR → Environmental performance	0.287	3.605	0.000

Notably, in case the significant numbers exceed 1.96, the path significance is confirmed between the two variables. Besides, the relationship itself is confirmed, as well. Hence, according to *Table 8*, the research's first, third, fourth, and sixth hypotheses are accepted.

Table 9 gives the test of mediator variables. Overall, it is inferred that the GI variable mediates between environmental performance and green supplier integrity with a T statistic of 3.208, which is higher than 1.96. The resilience dimension variable mediates between environmental performance and green supplier integrity with a T statistic of 2.950, which exceeds 1.96. Moreover, preventive resilience plays a mediating role between GSI and environmental performance with a T statistic of 3.202, which is greater than 1.96. Accordingly, the approved mediator variables can be considered complete mediators because of the significance of the direct paths *Table 8*.

Table 9. Effect of mediating variables.

Path Diagram with Mediating Variables	Original Sample (O)	T Statistics (|O/STDEV|)	P -Values
GSI → RDs of SCR → environmental performance	0.119	3.202	0.001
GSI → PDs of SCR → environmental performance	0.082	2.950	0.002
GSI → GI → environmental performance	0.101	3.208	0.001

Table 10 represents the test of modulator variables. As can be seen, the KC variable has a moderating role in the performance of the supplier integration and the resilience response dimension because the T statistics is 2.375, which is greater than 1.96. Also, the knowledge composition variable has a mediating role in the performance of GSI and the preventive dimension of resilience, as its T statistic (2.562) is greater than 1.96. Hence, it is inferred that the moderating role of the knowledge composition variable is accepted.

Table 10. The consequence of moderating variables.

Path Diagram with Mediating Variables	Original Sample (O)	T Statistics (|O/STDEV|)	P Values
Moderating effect (KC-RD)	0.235	2.375	0.000
Moderating effect (KC-PD)	0.217	2.562	0.000

Table 11 presents the efficacy of independent variables on the dependent variable in the presence of moderator and mediator variables. Since all T statistics are greater than 1.96, the path significance between the two variables is confirmed. Besides, the significance of the relationship itself is confirmed. Thus, according to *Table 10,* independent variables have an explicit effect on the dependent variable.

Table 11. The total consequence of independent variables on the dependent variable.

Path Diagram	Original Sample (O)	T Statistics (|O/STDEV|)	P Values
GSI → environmental performance	0.508	10.231	0.000
GSI → GI	0.338	5.317	0.000
GSI → PD of SCR	0.266	4.082	0.000
GSI → RD of SCR	0.415	6.654	0.000
GI → environmental performance	0.298	5.052	0.000
KC → environmental performance	0.348	7.581	0.000
KC → PD of SCR	0.641	10.423	0.000
KC → RD of SCR	0.523	8.626	0.000
PD of SCR → environmental performance	0.309	4.565	0.000
RD of SCR → environmental performance	0.287	3.605	0.000

Based on *Table 11* and *Fig. 4*, the independent variables affecting environmental performance are prioritized as follows: the GSI variable (total impact factor = 0.508), the combination of knowledge (total impact factor = 0.348), the reaction dimension of resilience (total effect factor = 0.309), the GI (total effect factor = 0.298), and the preventive dimension of resilience (total effect factor = 0.287).

Fig. 4. Prioritized order of the factors affecting economic performance considering the mediating and moderating role.

4.1.4 | Assessment of variance-based structural equation model

The primary basis of variance-based structural equations is creating explanatory models with sufficient predictive power. These equations generate some mechanisms to make predictions by maximizing the variance explained by endogenous constructs placed in a hypothetical path model. This feature is employed to distinguish these equations from machine learning tools prepared for predictive applications. When fitting the conceptual model of the research with SmartPLS software, the path coefficients significance is evaluated. Accordingly, the significance of the coefficients leads to the validation of the model and the rejection or acceptance of the hypotheses. ANOVA-based structural equations provide a "predictive-causal" technique [72]. The root means square error (RMSE) in SmartPLS software is used to assess the predictive power of variance-based structural equation models [73]. The prediction results of the fitted model of *Fig. 2* are implemented in *Table 12*:

Table 12. Evaluating the predictive power of the SEM-PLS model.

PLS Predictions (Descriptives)	Mean	Min	Max	RMSE
Environmental performance	3.087	1.784	4.335	0.547

4.2 | Fitting the Artificial Neural Network Model to the Radial Basis Function.

Fig. 5 presents an RBF feedforward network trained with the backpropagation technique. The network uses the feedforward backpropagation technique to learn. This architecture has an input layer of neurons, one or more hidden (middle) layers of neurons that compute and replicate data, and an output layer that predicts the output [74].

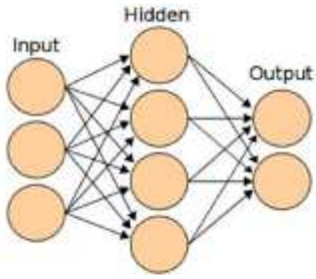

Fig. 5. RBF structure of the artificial neural network.

As can be seen in *Table 13*, the outcome neural network architecture consists of 5 input layers, 1 middle layer with 10 neurons, and 1 output layer. The activation function used in the middle layer is the Softmax function, and the identity function and the error function used in the output layer are the sums of the squares. The data imported to the model were normalized before the modeling. In this research, 72.8% of the data are as training samples and 27.2% as test samples.

Table 13. Summary of RBF neural network model.

Network Statistics			
Input layer	Covariates	1	GSI
		2	KC
		3	RD of resilience
		4	PD of resilience
		5	GI
	Number of units		5
	Rescaling method for covariates		normalized
Hidden layer	Number of units		101
	Activation function		Softmax
Output layer	Dependent variables	1	Environmental Performance
	Number of units		1
	Rescaling method for scale dependents		Normalized
	Activation function		Identity
	Error function		Sum of Squares

The sum of the error squares is 11.489 in the training sample and 5.151 in the test sample. Since the error obtained in the training sample is less than in the experimental sample, the model fit is acceptable. The RBF neural network model of the current research circuit with the structure of input, hidden, and final layers is presented in *Fig. 6*.

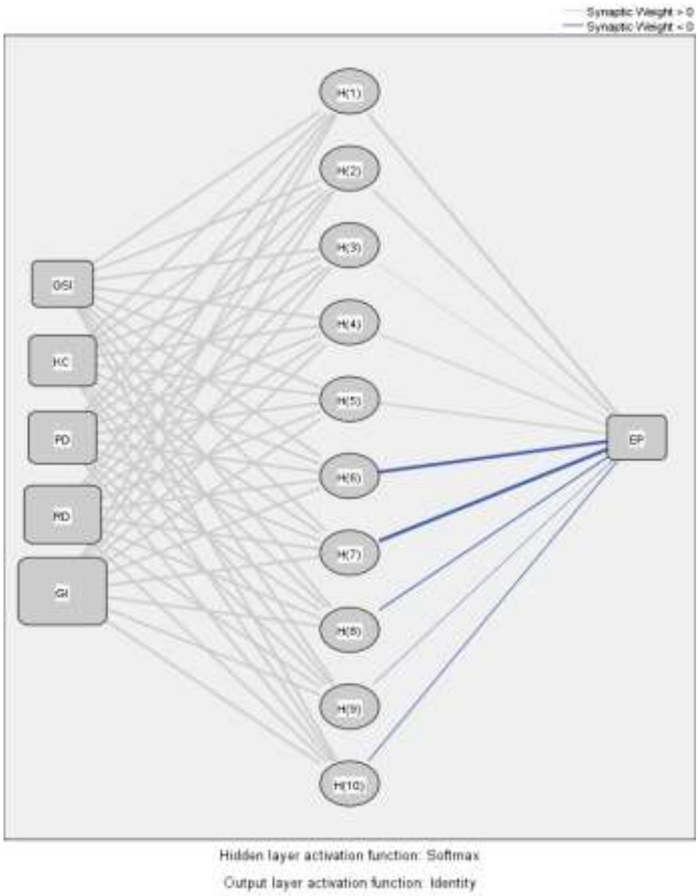

Fig. 6. The architecture of the RBF neural network model prepared in this research.

The impact of independent variables in the neural network structure model is shown in *Table 14* and *Fig. 7*. Overall, GI, preventive resilience, resilient reaction, combining knowledge, and integration of the green supplier are prioritized in the RBF model with impacts of 100%, 80.2%, 65.6%, 63.1%, and 53.3%, respectively.

Table 14. The effect of variables in the neural network model.

Variables	Importance	Normalized Importance
GSI	0.147	53.3%
KC	0.174	63.1%
PD of SCR	0.181	65.6%
RD of SCR	0.221	80.2%
GI	0.276	100.0%

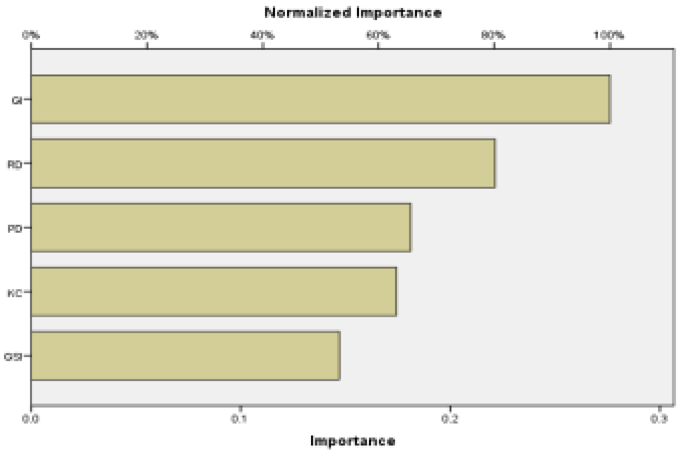

Fig. 7. The effect of variables in the neural network model.

The predictive criteria of the fitted model are shown in *Table 15*.

Table 15. Evaluate the predictive power of the RBF model.

RBF Predictions (Descriptive)	Mean	Min	Max	RMSE
Environmental performance	3.094	1.89	4.07	0.015

4.3 | Sensitivity Analysis

This research applied variance-based structural equations and ANNRBF to fit the conceptual model. The analysis of variance-based structural equations showed that the variables of GI, knowledge composition, green supplier integrity, RDs, and resilience prevention had a direct and productive effect on environmental performance. After fitting the research model with the variance-based structural equation approach and the RBF neural network, GI had the highest impact on environmental performance in both approaches. Both approaches could predict environmental performance. RMSE criterion was used to evaluate the fitted model with these two approaches. *Fig. 8* shows that RMSE is 0.015 for RBF and 0.547 for the variance-based structural equation. Hence, the neural network method can predict environmental performance with much less error and be used as an optimal model.

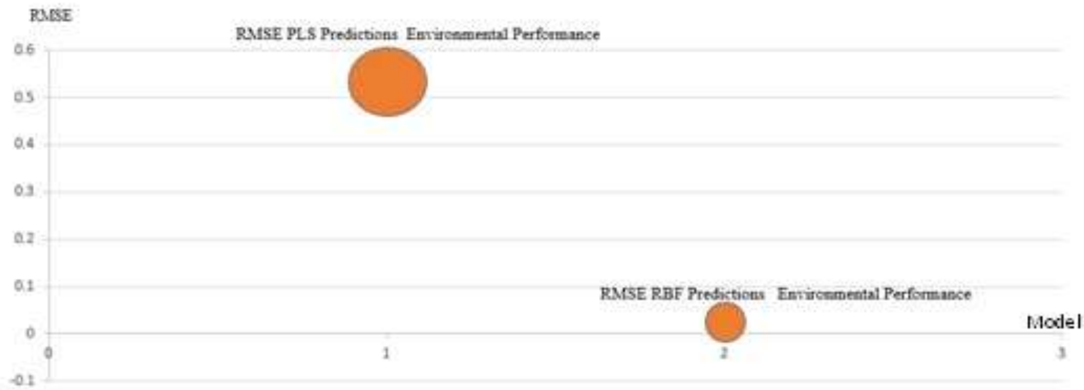

Fig. 8. Comparison of root mean square error in two approaches.

5 | Discussion and Conclusion

The present study investigates the influence of supply chain integration on the environment with the role of combining knowledge SCR and GI. The findings were presented with two approaches: variance-based structural equations and RBF network. The research instrument had acceptable convergent validity and a high level of reliability. Also, according to the six hypotheses proposed in this study, environmental variables, including GI, GSI, reactive/PDs of resilience, and KC, express a large share of the variance. Therefore, the GI variable mediates environmental performance and GSI. The RD of resilience plays a mediating role between supplier integration and environmental performance. Meanwhile, the PD of resilience mediates environmental performance and supplier integration. Also, the KC variable has a mediating role between GSI performance and the reactive resilience dimension. In addition, KC has a mediating role in the performance of GSI and the PD of resilience. Based on the study results, GSC management is effective from an environmental perspective. As a result, it is inferred that companies implementing GSC management meet environmental requirements. Moreover, by meeting these requirements, labor productivity improves through specialized training of employees. The research results with variance-based structural equations showed that the variables of GI, KC, GSI, and reactive and PDs of resilience have a direct and productive effect on environmental performance. Notably, after fitting the research model with the variance-based structural equation approach and the RBF network approach, both meet "GI" requirements. However, it increases coordination costs and, as a critical prerequisite in transforming a typical supply chain into a GSC, it has the highest impact on environmental performance. Furthermore, it is considered a source of competitive advantage to reduce harmful environmental effects. Therefore, both approaches can predict environmental performance.

The research conducted is based on the research results of Ji et al. [42] Du et al. [8], Zhang et al. [22], Chiou et al. [32], Burki [9], Song et al. [14].

Finally, future researchers are suggested to develop this research both from the perspective of research methods (e.g., using random forest or vector approach) and from the perspective of using variables appropriate to the model (e.g., supply chain sustainability, management of risk in the supply chain, and creating a competitive advantage). Alternatively, they can employ both perspectives to develop this study.

Data Availability Statements

The author confirms that all data generated or analyzed during this study are included in this published article.

Conflict of Interest

The author declares that they have no competing interests.

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