Developing the supply chain of tomorrow: a path to resilience and sustainability

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Abstract

Purpose – This article aims to develop reliable and valid factors/antecedents and their interrelationship for structuring the supply chains to become more resilient and sustainable. Resilience and sustainability are both expected components of a modern supply chain. Prima facie, these appear contradictory to each other; therefore, a resilient sustainable supply chain (RSSC) needs in-depth exploration to find the factors supporting and contradicting the resilience and sustainability.

Design/methodology/approach – This paper explores the Indian manufacturing sector, through an empirical study, to understand and develop the reliable and valid factors/antecedents for an RSSC. First, a conceptual model of RSSC is proposed based on the extant literature evidence, domain knowledge and expert opinion. Second, hypotheses were developed to validate the proposed model by using statistical analysis of exploratory factor analysis, confirmatory factor analysis and structural equation modelling.

Findings – The findings of the study suggest that supply chain visibility, flexibility, collaboration, control network design and digitalisation are the important factors/antecedents to build an RSSC. It was also found that digitalization control and flexibility have a full mediating effect on sustainability, whereas visibility collaboration and network design have a partial mediating effect on sustainability. Resilience has a direct effect on sustainability.

Originality/value – Based on the findings, the authors in this study proposed a more precise and contextual RSSC definition as compared to few definitions available in the extant literature.

Keywords Resilient sustainable supply chain, Structure equation modelling, Indian manufacturing sector

Paper type Research article

1. Introduction

Resilient sustainable supply chains (RSSC) are gaining traction as supply chains have become vulnerable to disruptions and environmental scrutiny. By improving the resiliency and sustainability of the supply chains simultaneously, organizations can ensure long-term success and competitiveness in a rapidly changing global marketplace. An RSSC aims at achieving a trade-off among economic viability, social responsibility and environmental sustainability (Negri *et al*., 2024; Chowdhury *et al*., 2012). RSSC considers the entire supply chain (SC), i.e. from raw materials to end-of-life disposal to reduce adverse impacts, optimize positive outcomes and enhance responsiveness (Patidar *et al*., 2023a). As per Chowdhury *et al*. (2012)

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"A Resilient Sustainable Supply Chain is the management of resources with a view to meeting stakeholders' expectations so as to achieve high resilience and subsequent sustainability of organizations supply chain".

The literature on supply chain management has focused on two key dimensions: supply chain resilience and sustainability (Negri *et al.*, 2021). However, these aspects have mostly been studied in isolation, with limited exploration of how they can be effectively integrated to build a resilient sustainable supply chain. Researchers and practitioners have examined supply chain resilience, which refers to the ability of a supply chain to withstand and recover from disruptions and unexpected events, such as natural disasters, geopolitical conflicts or supply chain disruptions (Negri *et al.*, 2021; Manurung *et al.*, 2023; Zhu and Wu, 2022). Resilience strategies involves redundancy, flexibility, and adaptive capability within the supply chain to ensure business continuity in odd times (Negri *et al.*, 2021). On the other hand, sustainability has been a dominant area of focus, emphasizing environmentally and socially responsible practices that focus on negative impact of SC on the environment and society (Negri *et al.*, 2021; Oubrahim and Sefiani, 2024). Sustainable supply chain initiatives aim to minimize resource consumption, reduce greenhouse gas emissions, promote ethical sourcing and ensure fair treatment of workers (Negri *et al.*, 2021). Some studies have attempted to combine resiliency and sustainability within the supply chain context, but these efforts have primarily centred on supply chain network design (López-Castro and Solano-Charris, 2021). Such research often focuses on optimizing the supply chain structure to achieve both resilience and sustainability objectives, without providing a framework that considers other critical factors and indicators (Negri *et al.*, 2021). The research gap emerges from the absence of a holistic framework that not only addresses the integration of resilience and sustainability but also provides a set of clear indicators and factors essential for building a resilient sustainable supply chain (Negri *et al.*, 2021; Warmbier *et al.*, 2022; Manurung *et al.*, 2023; Zhu and Wu, 2022). The SCs should be resilient and sustainable, which is clear to the organizations (what) but how to develop a resilient and sustainable supply chain is not clear (how). Therefore, it is important to know the common factors of resiliency and sustainability in a supply chain and how these factors integrate to support each other. There is a need to understand how resilience and sustainability can be amalgamated, leading to a more flexible, agile, robust and environmentally friendly supply chain (Yadav and Kumar, 2023; Singh and Modgil, 2025). The framework will provide insights and guidance to organisations and policy makers seeking to build a resilient sustainable supply chain.

Despite an increasing number of studies on resilient supply chains, limited empirical research explores how resilience mediates the relationship between antecedents (such as visibility, flexibility and collaboration) and sustainability in the Indian manufacturing context. Moreover, circularity and digitalization have been underexplored as contributors to sustainable outcomes in developing economies.

This calls for research that may identify factors that affect resilience and sustainability and assess their relationships, which leads to the emergence of the following research questions:

RQ1. Which factors make a supply chain resilient and sustainable?

RQ2. Does supply chain resilience affects sustainable supply chain performance?

RQ3. Does supply chain resilience plays a mediating role to improve sustainable supply chain performance?

To answer these research questions, the study employs exploratory factor analysis (EFA) and confirmatory factor analysis (CFA) for validating the measurement model, followed by structural equation modelling (SEM) to test the hypothesized relationships.

The study contributes theoretically by integrating resilience as a mediating construct across multiple antecedents of sustainability. From a practical standpoint, the findings offer actionable insights for practitioners to improve visibility, flexibility, and collaborative mechanisms within their supply chains to achieve sustainability. This study develops and empirically validates a framework that integrates resilience as a mediating construct in a supply chain. It extends prior research by examining both linear and circular models and linking theoretical underpinnings to practical applications in the Indian industrial sector.

The rest of the article is structured as follows: Section 2 presents the literature review and development of the conceptual framework. Section 3 discusses the research methodology and model validation. Section 4 presents the results. Section 5 discusses the findings, theoretical and managerial implications. Section 6 concludes the article, highlighting its limitations and future research directions.

2. Development of factors, research hypotheses and conceptual framework

In the extant literature, a paucity was evident for the resilient sustainable supply chain. Though the majority of the studies focus on network designing but understanding resilient sustainable supply chain in terms of theoretical and conceptual aspects is very little focused (Patidar *et al.*, 2023b; Michel-Villarreal, 2023). Table 1 shows the summary of key existing studies and comparison with the current study.

2.1 Identification of factors and sub-factors

Primarily, factors and sub-factors were identified from the literature. This provided a list of seven factors and their corresponding 38 sub-factors. Furthermore, two factors – supply chain resiliency (SCRes) and sustainable supply chain performance (SSCP) with their corresponding sub-factors (four for SCRes and eight for SSCP) were adopted from Brandon-Jones *et al.* (2014) and Bag *et al.* (2020), respectively. The scales for these two constructs were adopted without any change. These factors and sub-factors (Table 2) were identified in conjunction with the next section – development of hypotheses.

Table 1. Summary of key existing studies and comparison with current study

Author(s) and year	Focus area	Methodology	Key findings
Negri *et al.* (2021)	Resilience and Sustainability Integration	Systematic Literature Review	Authors suggested to analyse implementation relationship and impact. Also advised to develop performance measurement systems
Zavala-Alcívar *et al.* (2020)	Resilience management as a strategic capability and deal with the three dimensions of sustainability	Systematic Literature Review	A conceptual framework that integrates the fundamental elements for analyzing, measuring, and managing resilience to increase sustainability in the supply chain
Zhu and Wu (2022)	Integration of Supply Chain Flexibility and Sustainability	Survey with 21 companies based on 200 questionnaires	Supply chain flexibility enhances the performance of the supply chain under the mediating effect of sustainability
Sarkis (2020)	To provide research guidance for investigation sustainability in COVID-19 environment	Literature review, personal research experiences and practitioner interviews	Sustainability and Resilience are complementary and need more exploration
Our Study	To explore and define resilient sustainable supply chains in Indian manufacturing sector	Literature Review, Expert Opinion, Survey, Structure Equation Modelling	The key constructs that affects resilient sustainable supply chain and how practitioners can define and achieve them

Source(s): Authors' own creation

Table 2. Proposed factors and sub-factors

S.no	Sub-factors/Items	Code
SC Visibility		SCV
1	Information Sharing	SCV1
2	Data Analytics Capability	SCV2
3	Facility Protection Using Devices	SCV3
SC Flexibility		SCF
4	Lead time	SCF1
5	Strategic Stock	SCF2
6	Surplus Capacity	SCF3
7	Flexible Transportation and rerouting	SCF4
8	Geographical dispersion	SCF5
9	Quick Response/Agility	SCF6
10	Production Multi Uses and Postponement	SCF7
11	Supplier Contract Flexibility	SCF8
SC Collaboration		SCCol
12	Business Continuity Planning	SCCol1
13	Supply Continuity	SCCol2
14	Delivery Reliability	SCCol3
15	Research Planning (R&D)	SCCol4
16	Supplier Partnership	SCCol5
SC Control		SCCo
17	Technical Resource Restoration	SCCo1
18	Adaptive capability	SCCo2
19	Vulnerability	SCCo3
20	Anticipation	SCCo4
21	Preparedness	SCCo5
22	Risk Assessment	SCCo6
23	Risk Sharing	SCCo7
SC Circularity		SCC
24	Waste Reduction	SCC1
25	Sustainable Practices	SCC2
26	Costs	SCC3
27	In-Transit Material loss	SCC4
SC Network Design		SCND
28	Flow, node and cluster reliability	SCND1
29	Node accessibility	SCND2
30	Node Criticality	SCND3
31	Distribution Channel	SCND4
32	Multi-Sourcing	SCND5
SC Digitalisation		SCD
33	Interoperability	SCD1
34	Virtualisation	SCD2
35	Decentralisation	SCD3
36	Modularity	SCD4
37	Service Orientation	SCD5
38	Real time information	SCD6

Source(s): Authors' own creation

2.2 Development of hypotheses

The development of the research hypotheses is as follows:

2.2.1 SC visibility (SCV). Supply chain visibility refers to the ability to track and monitor products and materials as they pass various stages of the supply chain (Brau *et al.*, 2023; Zimmermann *et al.*, 2025). It is highly important as organisations demand to optimize their supply chains, reduce costs and improve customer satisfaction (Gunasekaran *et al.*, 2004;

Rainer *et al*., 2025). The key factors that create supply chain visibility are information sharing, data analytics capability and facility protection using devices.

The data acquired from the devices used for facility protection helps in achieving supply chain visibility (Al-Khatib, 2023). These include IoT devices and other devices such as security cameras, motion sensors and access control systems to monitor facilities and ensure that products and materials are secure. Protecting facilities from theft and other threats, organisations can minimize, reduce delays and enhance responsiveness to ensure that products are delivered on time and in good condition (Falagara Sigala *et al*., 2022). Another example of facility protection using devices is the use of video surveillance systems in warehouses and distribution centres to detect potential security threats and respond quickly to cope with potential disruptions (Raja Santhi and Muthuswamy, 2022).

H1a. The supply chain visibility directly impacts the supply chain resilience

H1b. The supply chain visibility directly impacts the sustainable supply chain performance.

2.2.2 SC flexibility (SCF). A flexible supply chain quickly responds to the changes in customer demands, shifts in market conditions, and disruptions in the SC (Benzidia and Makaoui, 2020; Singh and Modgil, 2025). A flexible SC can mitigate disruption impact and confirm business continuity (Azadegan *et al*., 2020; Singh and Modgil, 2025). Flexibility is a critical enabler of supply chains, allowing firms to adapt to disruptions effectively. It supports risk management while maintaining continuity in operations. Imparting flexibility helps organizations to respond quickly to disruptions, such as pandemics, and economic depressions (Raja Santhi and Muthuswamy, 2022). It also enables organizations to minimize the impact of their supply chain operations on the environment (Ivanov, 2021).

H2a. The supply chain flexibility directly impacts the supply chain resilience

H2b. The supply chain flexibility directly impacts the sustainable supply chain performance.

2.2.3 SC collaboration (SCCol). Supply chain collaboration is the partnership and coordination among different players in the supply chain, namely, suppliers, manufacturers, distributors and customers (Jain *et al*., 2009; Maheshwari *et al*., 2025). Supply chain collaboration facilitates information sharing, aligning of goals and combining efforts to achieve objectives to improve supply chain performance (Wong *et al*., 2020). Collaboration helps in cost reduction, customer satisfaction enhancement and ensuring a resilient sustainable supply chain. Moreover, it also facilitates for effective risk management and information sharing about potential risks such as natural disasters, pandemics or economic downturns (Laufs and Waseem, 2020). This leads organizations to work together and mitigate the impact of disruptions, thereby ensuring business continuity. Furthermore, collaboration between supply chain stakeholders facilitates the sharing of information about the resource utilisation, energy consumption, waste generation, and the social impact of operations, thereby promoting sustainability (Esmaeilian *et al*., 2020). SC collaboration supports better decision-making by allowing organizations to share information and align their goals (Wong *et al*., 2020; Seo *et al*., 2025). Through collaboration, organisations can make informed decisions about supply chain optimisation, cost reduction and customer satisfaction enhancement simultaneously.

H3a. The supply chain collaboration directly impacts the supply chain resilience

H3b. The supply chain collaboration directly impacts the sustainable supply chain performance.

2.2.4 SC control (SCCo). Effective supply chain control is required for increasing efficiency, reliability and performance of a supply chain (Francisco and Swanson, 2018; Wang and Zhang, 2025). It is vital for enabling effective responses to risks and disruptions. It ensures that operations remain aligned with sustainability goals under uncertain conditions. SC control helps organizations in operations monitoring and potential risk identification so that they can take preventive measures to mitigate the risk impacts (Aqlan and Lam, 2015; Ahuja and Kaur, 2025). Modern supply chains are looking for supply chain control towers that help organizations to monitor and manage resource utilisation, energy consumption and waste generation (Annosi *et al.*, 2021). This helps organizations in environmental footprint reduction and sustainable operations.

H4a. The supply chain control directly impacts the supply chain resilience

H4b. The supply chain control directly impacts the sustainable supply chain performance.

2.2.5 SC circularity (SCC). SC circularity is managing supply chain operations in a closed-loop system, where wastage of resources is reduced, and the value of materials is preserved and extended (Farooque *et al.*, 2019; Kreye, 2025). The supply chain circularity aims at creating a sustainable and regenerative system in contrast to the traditional linear model of take-make-dispose (Kuniawan *et al.*, 2022). In the context of RSSC, circularity helps in reducing waste, reusing waste (such as packaging material waste) and making it an alternate source of supply. By minimizing waste and maximizing the value of materials, organizations can reduce their environmental footprint, harness the benefit of reusing the material and improve its performance (Farooque *et al.*, 2019; Nunes, 2025). It helps organizations to be more resilient by reducing their dependence on finite resources and creating potential to absorb the risks of resource shortages or price fluctuations (Nygaard, 2023).

H5a. The supply chain circularity directly impacts the supply chain resilience

H5b. The supply chain circularity directly impacts the sustainable supply chain performance.

2.2.6 SC network design (SCND). SC network design determines the optimal structure and configuration of a supply chain by considering factors such as the location of suppliers and customers, transportation costs, production capacities, and inventory levels (Sazvar *et al.*, 2021; Ostovari *et al.*, 2025). Building an efficient, reliable and cost-effective supply chain is the aim of a supply chain network design (Lemmens *et al.*, 2016; Hussain *et al.*, 2025). Ensuring the responsive and efficient ability of the supply chains is the ultimate aim of an RSSC. For being responsive to changing demands, disruptions and other related risks in a timely manner, organisations need to integrate flexibility and adaptability in their supply chain network design (Modgil *et al.*, 2021). An effective network design also reduces environmental footprints by optimising transportation distances, production processes and reducing waste (Sazvar *et al.*, 2021).

H6a. The supply chain network design directly impacts the supply chain resilience

H6b. The supply chain network directly impacts the sustainable supply chain performance.

2.2.7 SC digitalisation (SCD). Imparting digital technologies and data analytics into the operations of a supply chain is its digitalization (Hallikas *et al.*, 2021; Karuppiah *et al.*, 2025). Generation of the data using IoT devices or sensors, data acquisition and data handling result in improved supply chain visibility, efficiency and resilience (Kurpjuweit *et al.*, 2021). Incorporating digital technologies like Blockchain, Artificial Intelligence (AI) and Augmented reality/Virtual Reality (AR/VR) increases efficiency and responsiveness of the supply chain (Attaran, 2020; Kostadimas, 2025). Organisation may enhance their absorption and reactive capabilities by developing their prediction potential using AI and visualising using AR/VR (Zamani *et al.*, 2022). In addition, the digital technologies may enhance the tracking and tracing potential of a supply chain. Blockchain technology has the potential to create environmental transparency, trust and authenticity (Kumar *et al.*, 2023). Smart contracts help in increasing the controlling power of the SC by reducing its variability (Zhu and Kouhizadeh, 2019; Kostadimas, 2025).

Although there is a different school of thought for sustainability and supply chain digitalisation, which suggests that increasing digitalisation adversely affects supply chain sustainability as it is directly proportional to the energy consumption (Patidar *et al*., 2023b; Caiado *et al*., 2022). For resilience, digitalisation appears to be a boon. It increases the prediction potential of the supply chain (Zamani *et al*., 2022). Parallelly, it also helps in predicting possible scenarios and their consequences through digital twins (Burgos and Ivanov, 2021).

H7a. The supply chain digitalisation directly impacts the supply chain resilience

H7b. The supply chain digitalisation directly impacts the sustainable supply chain performance.

2.2.8 Resilient sustainable supply chain (RSSC). Resilient sustainable supply chain has two crucial components, i.e. resilience and sustainability, although the dependence of these on each other is debated in the literature. Davis *et al*. (2021), Pires Ribeiro and Barbosa-Povoa (2018) and Rashid *et al*. (2025) argue the dependence of sustainability on resilience. At the same time, Jain *et al*. (2017), Ivanov (2018) and Mollashahi *et al*. (2025) argued the dependence of resilience on sustainability. Chowdhury *et al*. (2012) defined resilient sustainable supply chain as the resource management to meet stakeholders' expectations and to achieve high resilience and subsequent sustainability. Based on the following hypothesis, a model is developed to get a clearer view:

H8. The Supply Chain Resilience directly impacts the sustainable supply chain performance.

2.3 Proposition of the conceptual model

Considering the theoretical underpinning, literature survey and expert opinion and domain knowledge of the authors, a conceptual model of the RSSC is proposed for further validation. Figure 1 represents the proposed conceptual model.

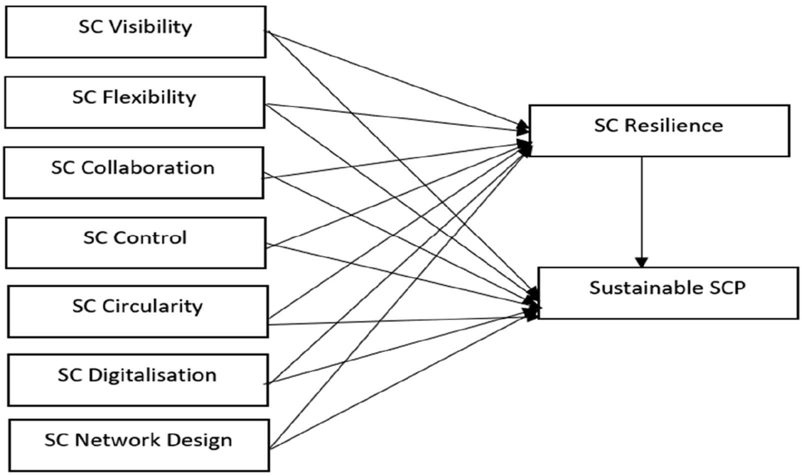

Figure 1. Proposed conceptual model, Source: Authors' own creation

The model consists of seven factors (antecedents) and one measurable variable and a mediating variable. The developed model considers resilient sustainable supply chain as dependent variable as per the definition provided by Chowdhury *et al*. (2012).

3. Research methodology and validation of the conceptual model

The proposed model is tested with the data from the Indian manufacturing industries by using the survey methodology. A pilot test with 109 respondents was conducted to ensure clarity and reliability. The final version was distributed through professional and industrial networks, including LinkedIn and industry associations. We employed convenience sampling. In total, 278 responses were received, of which 257 were retained after data cleaning. The respondent profile distribution is listed in Table 3.

Table 3. Respondents profile

Item(s)		N (257)
Total work experience	<5 Years	96
	5–10 Years	83
	>10 Years	78
Management Hierarchy	Top Level Management	73
	Mid-Level Management	87
	Lower-Level Management	97
Organisation sector	Food Processing	29
	Drugs and Pharmaceuticals	22
	Electronics	45
	Automobile	70
	Chemical	22
	Mineral, Cement and Gypsum	23
	Electrical	19
	Textile	21
	Agriculture	6
	Others	1
Age of the Organisation	less than 5 years	84
	5–10 years	86
	greater than 10 years	87
Type of Organisation	Micro	66
	Small	84
	Medium	48
	Large	59
Turnover	less than 5 Cr	66
	5 Cr- 50 Cr	84
	50 Cr- 250 Cr	48
	greater than 250 Cr	59
Business Model of the Organization	All	91
	Business to Business (B2B)	92
	Business to Consumer (B2C)	74
Supplier Base	Global	61
	Local (Within State)	84
	Pan India	112
Customer Base	Global	73
	Local (Within State)	88
	Pan India	96
Operations Risks	Yes	252
	No	3
Disruption Risks	Yes	225
	No	32

Source(s): Authors’ own creation

The survey was distributed to executives working in manufacturing industries in India. The sector faces challenges related to resource depletion, environmental degradation, climate change and global market pressures, making sustainability a necessity for its long-term viability and competitiveness.

3.1 Measurement methods

EFA is a measurement method that enables researchers to identify underlying factors influencing a set of observed variables. EFA as its name suggests, is an exploratory method, meaning that it is used to explore the data to identify the patterns, without having a specific theory about the underlying factors. Mostly, EFA is used to reduce a large set of items into a smaller set of factors that explain the variation in the data.

Confirmatory factor analysis (CFA) is a method widely used in psychometrics and social sciences to establish and validate the relationships among observed variables and latent factors. It serves to confirm theoretical statements among the variables. CFA produces a measurement model that outlines relationships. Validity is gauged using fitness indices.

SEM, or path analysis, is a comprehensive measuring technique used in behavioural research, social sciences and sciences that tests a complex model of relationships between variables. This includes testing the relations among observed variables, potential factors and other variables that might affect the relations. It allows for testing direct and indirect relationships among variables, as well as estimating models' fitness.

Mediation analysis is a measurement technique that tests the indirect relationship between the predictor variable and outcome variable through a third variable, called a mediating variable. It is often used to test the effectiveness of an intervention or treatment, to understand how it works, and to identify potential points of intervention. The mediations are classified as full mediation, partial mediation or no mediation.

4. Results

The survey method was applied to understand and explore the resilient sustainable supply chain for Indian manufacturing Industries. As depicted in the conceptual framework, supply chain resilience was considered as mediating variable as per definition given by Chowdhury *et al*. (2012). The measurement model assumes that indicators are reflective and unidimensional, with acceptable internal consistency (Cronbach's alpha >0.7). The mediation analysis follows Baron and Kenny's approach, assuming causal ordering between antecedents, mediator (resilience) and outcome (sustainability), with no significant omitted variables influencing these paths.

4.1 Exploratory factor analysis

The suitability of the data is checked before EFA can be conducted by using CITC (corrected items total correlation), Bartlett's test and Kaiser–Meyer–Olkin (KMO) test. KMO value of 0.922, p value of 0.000 for Barletts' test suggest suitability of the data to perform EFA as suggested by Hair *et al*. (1995). CAID (Cronbach alpha if Item Deleted) values for all factors were above the minimum suggested value of 0.7, so the data is also reliable. Principal Component Analysis (PCA) with Varimax rotation was used to extract the factors.

Nine factors were extracted, having loadings from 0.577 to 0.825 as shown in Table 4. Absence of cross-loading was observed in performing exploratory factor analysis at a suppression level of 0.5. To test the common method bias, Herman's single-factor test was administered. The test explains the variance explained by the data when considered as a single factor. The dataset being one factor must not explain variance more than 50% (Das, 2017). Here, the independent variables, the dependent variables and both the variables together were tested and found explaining 31.97%, 44.75% and 32.64% variance, respectively. All

Table 4. Measurement items, loading factors, Cronbach's alpha (alpha), composite reliability (CR), average variance extracted (AVE), maximum shared variance (MSV) and maximum reliability (MaxR(H))

Construct	Item code	Loading	Cronbach α	CR	AVE	MSV	MaxR (H)
SCV	SCV1	0.795	0.765	0.853	0.660	0.152	0.857
	SCV2	0.815					
	SCV3	0.731					
SCF	SCF1	0.736	0.927	0.927	0.614	0.499	0.929
	SCF2	0.670					
	SCF3	0.733					
	SCF4	0.719					
	SCF5	0.731					
	SCF6	0.742					
	SCF7	0.750					
	SCF8	0.656					
SCCol	SCCol1	0.647	0.850	0.850	0.534	0.393	0.862
	SCCol2	0.613					
	SCCol3	0.611					
	SCCol4	0.653					
	SCCol5	0.721					
SCCo	SCCo1	0.743	0.908	0.908	0.585	0.499	0.915
	SCCo2	0.792					
	SCCo3	0.796					
	SCCo4	0.577					
	SCCo5	0.607					
	SCCo6	0.580					
	SCCo7	0.677					
SCC	SCC1	0.736	0.828	0.828	0.547	0.248	0.833
	SCC2	0.716					
	SCC3	0.698					
	SCC4	0.826					
SCND	SCND1	0.792	0.869	0.916	0.687	0.092	0.930
	SCND2	0.807					
	SCND3	0.786					
	SCND4	0.727					
	SCND5	0.761					
SCD	SCD1	0.664	0.885	0.885	0.564	0.357	0.893
	SCD2	0.770					
	SCD3	0.653					
	SCD4	0.825					
	SCD5	0.733					
	SCD6	0.634					
SCRes	SCRes1	0.677	0.956	0.956	0.846	0.429	0.964
	SCRes2	0.706					
	SCRes3	0.738					
	SCRes4	0.725					
SSCP	SSCP1	0.707	0.905	0.904	0.547	0.375	0.921
	SSCP2	0.725					
	SSCP3	0.682					
	SSCP4	0.711					
	SSCP5	0.742					
	SSCP6	0.732					
	SSCP7	0.669					
	SSCP8	0.744					

Source(s): Authors' own creation

assumptions of EFA were met and hence CFA can be performed to confirm the relational structure.

4.2 Confirmatory factor analysis

Authors in this study performed CFA with seven variables as factors (antecedents) of RSSC and the two variables of SC resilience and SC sustainability performance as simple variables for the Indian manufacturing industries. The CFA findings represent RMSEA of 0.051 (suggested value < 0.05; and acceptable between 0.05 and 0.10), chi-square test divided by degree of freedom (1.659) <3.0 and NFI (0.813) > 0.8. CFI and GFI were 0.915 and 0.782, respectively, which are under the acceptable as the values closer to 1 are considered better model fit. Thus, it can be concluded that the data sample has allowable findings in terms of Goodness of Fit statistics. The CFA figure (measurement model) is shown in Figure 2.

To ensure the quality of the survey instrument, its reliability and validity need to be tested (Paul and Maiti, 2008). Reliability value is predicted by the Cronbach's alpha values. Nunnally (1978) argued that the desired or risk-free level of Cronbach's alpha is ≥ 0.7, but 0.6 is also acceptable in exploratory studies. All the constructs in this study have Cronbach's alpha values

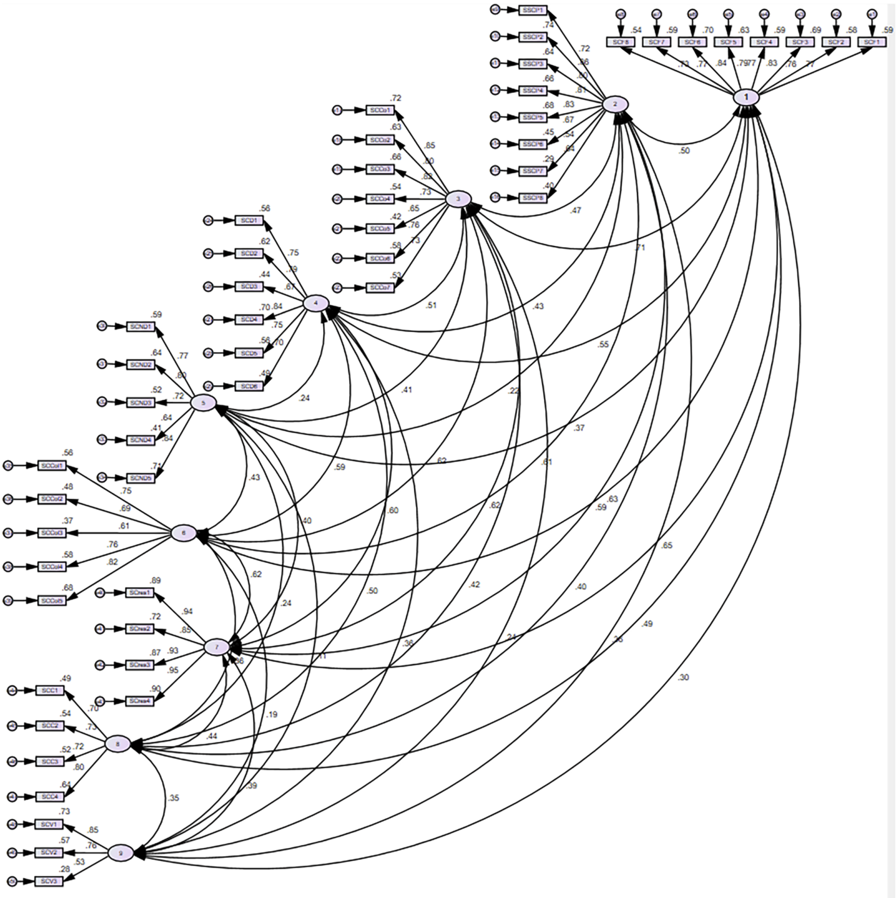

Figure 2. CFA path diagram (Measurement Model), Source: Authors' own creation

greater than 0.7, making the questionnaire and the study highly reliable. The validity of constructs was checked by determining convergent, discriminant, nomological and criterion validity. To obtain convergent validity, three conditions need to be met (Das, 2017): item loadings >0.3, CR > 0.6 and AVE >0.5. Referring Table 4, all the conditions required to obtain convergent validity were met. To obtain discriminant validity, the conditions to be met are (Das, 2017): the values of the correlations between the constructs must be less than 0.9, if the values of AVE are more than the values of maximum shared variance (MSV) for each construct then discriminant validity is established, and the heterotrait-monotrait ratio of correlations (HTMT) values < 0.9 (Henseler *et al.*, 2015; Hu and Bentler, 1999). The dataset used in the study met all the above conditions, thereby achieving discriminant validity. For nomological validity, Das (2017) argued that the correlations between all the constructs must be positive, as was found in this study. The study observes a significant criterion related to validity as eight of fourteen correlations were found significant. Multicollinearity was tested and the values of the variance inflation factor (VIF) were found to be less than 5; therefore multi-collinearity was not an issue (Chen, 2019). This refers to the acceptability of confirmatory factor analysis findings.

4.3 Structure equation modelling (SEM)

To examine the relationships between dependent and independent variables, structure equation modelling was used. Figure 3 shows the path diagram. The chi-square test value (1.681) < 3.0 and GFI was (0.779) < 0.95. In addition to the above, RMSEA (0.052) was greater than 0.05, which means the goodness of fit statistics unveil acceptable outcomes for the gathered data. Table 5 lists out the SEM model-path analysis results.

Table 5 lists all fifteen hypotheses represented in the conceptual model and their associations. Conducting path analysis revealed that ten hypotheses were fully supported, one was partially supported, and four hypotheses were not supported. The study revealed six

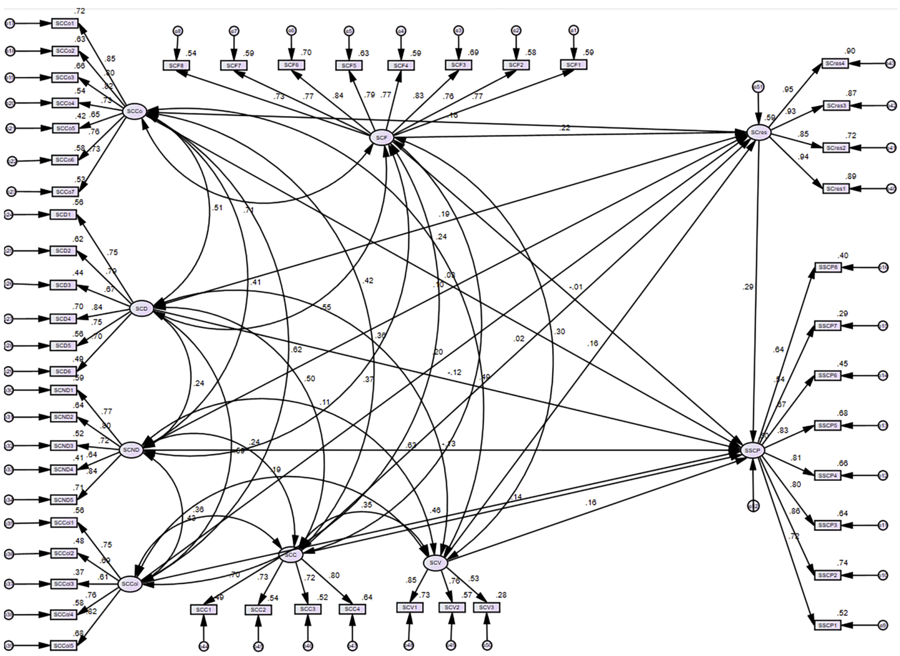

Figure 3. SEM path diagram, Source: Authors' own creation

Table 5. Outcomes of hypothesis testing

Hypothesis		Estimate (path coefficient)	*p* value	Supported (Yes/No/ Partial)	Comparative findings	Contrasting findings
H1a	SC visibility → SC Resilience	0.163	0.003*	Yes	Dubey *et al.* (2017)	
H2a	SC flexibility → SC Resilience	0.216	0.005*	Yes	Piprani *et al.* (2022)	
H3a	SC collaboration → SC Resilience	0.197	0.010*	Yes	Belhadi *et al.* (2021)	
H4a	SC Control → SC Resilience	0.165	0.025*	Yes	Gupta *et al.* (2022)	
H5a	SC Circularity → SC Resilience	0.022	0.716	No		Zhang *et al.* (2021)
H6a	SC Network Design → SC Resilience	0.097	0.070*	Yes	Aman and Seuring (2023)	
H7a	SC Digitalisation → SC Resilience	0.187	0.007*	Yes	Shi *et al.* (2023)	
H1b	SC Visibility → SC Sustainability Performance	0.156	0.019*	Yes	Dubey *et al.* (2019)	
H2b	SC Flexibility → SC Sustainability Performance	−0.007	0.940	No		Edwin Cheng *et al.* (2022)
H3b	SC Collaboration → SC Sustainability Performance	0.462	***	Yes	Nayal *et al.* (2022)	
H4b	SC Control → SC Sustainability Performance	0.027	0.755	No		Hamprecht *et al.* (2005)
H5b	SC Circularity → SC Sustainability Performance	0.138	0.057*	Yes	Le (2023)	
H6b	SC Network Design → SC Sustainability Performance	−0.127	0.046*	Partial	Joshi (2022)	
H7b	SC Digitalisation → SC Sustainability Performance	−0.117	0.156	No		Oubrahim *et al.* (2023)
H8	SC Resilience → SC Sustainability Performance	0.291	***	Yes	Shan *et al.*, (2023), Zhu and Wu (2022)	

Source(s): Authors' own creation

hypotheses support SCRes and four hypotheses (three fully and one partially) support SSCP. SCND (−0.127) directly affects SSCP but not positively, hence it was considered as partially supporting. The hypothesis shows that SCRes supports SSCP, which supports the findings in line with the Chowdhury *et al.* (2012).

Mediation analysis revealed that out of seven indirect effects, three hypotheses support a full mediating condition, three show a partial mediating condition, and one with no mediating condition. Table 6 lists the mediation amongst variables. Overall, it can be concluded that to SCV, SCCol and SCND affect RSSC and SSCP both, whereas SCF, SCCo and SCD affect SCRes and RSSC both. Possible reason for this may be SCF somewhat supports redundancy, which is against SSCP and SCD is also based on the energy generation and consumption, therefore it may affect SSCP adversely but in terms of net results it supports RSSC.

Table 6. Mediation effect of SCRes on SSCP

	SSCP	SCRes → SSCP	Result
SCV	0.156 (0.019) *	0.047 (0.008) *	Partial
SCF	−0.007 (0.940)	0.063 (0.021) *	Full
SCCol	0.462 (***) *	0.057 (0.006) *	Partial
SCCo	0.027 (0.755)	0.048 (0.048) *	Full
SCC	0.138 (0.057) *	0.007 (0.693)	No effect
SCND	−0.127 (0.046) *	0.028 (0.040) *	Partial
SCD	−0.117 (0.156)	0.054 (0.028) *	Full

Note(s): * Significant at $\alpha < 0.10$; parenthesis represents p values
Source(s): Authors' own creation

5. Discussion

Flexibility has a significant impact on sustainability (Edwin Cheng *et al.*, 2022) and resilience (Piprani *et al.*, 2022). However, this study reveals that the flexibility affects resilience but not sustainability. The possible reason may be Edwin Cheng *et al.* (2022) have considered sustainable supply chain flexibility considering green products, environmental practices and technology, and resource consumption. For example, redundancy enhances resilience but reduces sustainability. Similarly, demand fluctuations can be met by creating a buffer stock, which reduces sustainability by creating excess waste. However, supplier flexibility helps an organization (OEM) in achieving sustainability. The observed negative relationship between supply chain flexibility and sustainability may reflect inefficiencies caused by over-flexibility, such as frequent changes in production plans leading to waste or energy inefficiency, consistent with findings by Tao *et al.* (2025).

Next significant construct in the model is SC collaboration. Extant studies have discussed SCCo as a significant construct that affects resilience and sustainability (Belhadi *et al.*, 2021; Nayal *et al.*, 2022). This study also supports the literature. SCCo creates shared information, coordinated responses, resource pooling and risk sharing to improve resilience, and imparts shared goals, resource optimisation, knowledge sharing and stakeholder engagements to improve sustainability.

Digitalisation is the next significant construct in the model. Extant studies explored the impact of digitalisation on resilience and sustainability. This study asserts that SCD has a significant impact on resilience, which is in line with the findings of Shi *et al.* (2023), but does not have impact on sustainability, which is against the findings of Oubrahim *et al.* (2023). The negative or non-significant impact of digitalization on sustainability, though surprising, may be attributed to the technological maturity of the firms studied. As highlighted by Shahadat *et al.* (2023), firms in developing economies often face a digital divide where technology adoption does not translate immediately into environmental outcomes. The possible reason for the contradiction is the energy consumption.

SCCo can cater unexpected disruptions by judicious resource allocation and robust risk mitigation strategies. Control strengthens the SC ability to endure challenges and improve. Some researchers argue that SCCo does not affect sustainability performance directly, but does it by means of collaborative efforts and localised understanding. However, Gupta *et al.* (2022) and Hamprecht *et al.* (2005) suggested that control affects resilience and sustainable performance, respectively. Control indirectly fuels sustainability by providing financial stability, accurate risk assessments and long-term planning for sustainable initiatives.

SCV appeared to be the fifth most significant construct of this model. It also supports the findings of the studies by Dubey *et al.* (2017, 2019). SCV provides risk management and efficient responses to disruptions through information sharing. The information sharing also fosters collaboration and trust among supply chain partners. Supply chain visibility helps in tracing the origin of material, sourcing ethics and environment impact assessment.

SCND affects resilience fully and sustainability partially via SCRes, which is supported by the findings of Aman and Seuring (2023). The findings assert that SCND does affect SSCP but in a negative manner. Possible reasons may be larger the network, larger will be the operations, higher number of partners and possibly lower will be the sustainability. Joshi (2022) argued that SCND affects SSCP. Furthermore, impact of SCND on SSCP via SCRes is evident in risk-aware sustainable practices and financial stability.

Supply chain circularity (SCC) appears to be a non-significant construct. The findings of the study contradict the findings of Zhang *et al*. (2021) and support the findings of Le (2023). Possible reasons may be that authors in this study have considered circularity in terms of Reduce, Reuse and Recycle. The relatively low impact of SCC can be explained by infrastructural and regulatory bottlenecks in India. For instance, in the textile sector, closed-loop recycling practices remain fragmented due to a lack of formalized waste recovery systems (Charnley *et al*., 2024). In the Indian context, it is less popular to consider the reuse of material as an alternate source of supply. Circularity has a direct impact on sustainability. Overall, SCC does not affect SSCP via SCRes. Resiliency primarily deals with supply chain's ability to withstand and recover from disruptions. It does not address factors like diversified sourcing, contingency planning or response mechanism. SCC is crucial for the supply chain, but its impact on SCRes and SSCP may differ in scope and focus.

In the Indian manufacturing context, where supply chains often operate with limited digital infrastructure and fragmented logistics, the role of collaboration and visibility becomes even more critical. For example, industries such as automotive and pharmaceuticals rely heavily on multi-tier supplier networks, where disruptions at the lower tier can severely impact performance.

Based on the results and assessment, this article proposes to define an RSSC as *a process of managing resources to meet stakeholder expectations by creating supply chain visibility, flexibility collaboration and control through the use of supply chain network design and digitalization by means of people, process and technology.*

5.1 Theoretical implications

The work extends the body of knowledge on RSSC by providing its factors, sub-factors and co-relation among them. The validated model of the factors shows how resilience and sustainability can be imbibed in an SC simultaneously, directly or through mediating effects. The identified and validated seven factors and their corresponding 38 sub-factors or observed variables provide future researchers a ready reckoner or a launch pad to start their research.

5.2 Managerial implications

The results of this study offer several strategic insights for supply chain managers aiming to enhance both resilience and sustainability. First, firms should prioritize the development of resilience-building capabilities, including supplier collaboration, robust internal control systems and real-time visibility tools, which collectively enable organizations to better absorb and respond to disruptions. Integrating digital transformation initiatives with day-to-day operational practices is also critical; while such technologies may not yield immediate sustainability benefits, they lay the foundation for long-term value creation by improving responsiveness and efficiency. A practical illustration of this can be seen during the COVID-19 pandemic, when several Indian automotive manufacturers that had invested in digital visibility solutions and flexible supplier contracts were able to adapt rapidly to supply disruptions, demonstrating the real-world effectiveness of these practices.

5.3 Policy implications

The findings of this study hold relevance not only for industry practitioners but also for policymakers seeking to foster resilient and sustainable supply chains. Government intervention is particularly crucial in scaling up digital infrastructure and eliminating the systemic barriers that hinder the widespread adoption of circular supply chain practices. To this end, policymakers should consider implementing standardized sustainability metrics and promoting mechanisms for cross-industry data-sharing. In addition, targeted incentives – such as financial subsidies or tax benefits – could encourage firms, particularly in sectors like textiles, packaging and automotive, to adopt collaborative and circular approaches. Regulatory measures mandating product recovery, combined with fiscal incentives for remanufacturing, would further support these goals.

6. Conclusion, limitations and future scope

This study has developed and tested a conceptual model of resilient sustainable supply chains (RSSC) for the Indian manufacturing sector. The model was built from literature and expert opinions, and then validated using EFA, CFA and SEM. It includes key factors such as supply chain visibility, flexibility, collaboration, control, network design and digitalization. The results show that resilience is a central link in the model, strengthening the positive effects of many of these factors on sustainability. Digitalization and collaboration emerged as strong drivers of resilience, while flexibility showed a more mixed role in sustainability. Circularity had only a small effect, which is probably due to infrastructure and policy challenges in the region. On the theory side, this work adds to supply chain literature by showing how resilience can be integrated and empirically tested in a developing economy context. On the practical side, it gives managers clear ideas on how to use visibility, control and collaboration to make their supply chains resilient sustainable. It also points policymakers towards building better digital infrastructure and supportive regulations to promote circular practices. The study is limited to the Indian manufacturing sector, so results might be different in other settings. Future studies could apply the model in other industries or countries, follow changes over several years and explore more about digital tools and circular economy practices in different situations. Overall, the framework presented here offers useful insights for both academicians and practitioners, encouraging firms to focus on resilience capabilities and urging policymakers to create conditions that support a shift towards supply chains that are resilient sustainable.

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