Analysing the Challenges in Building Resilient Net Zero Carbon Supply Chains using Influential Network Relationship Mapping

Abstract: Implementing net zero carbon supply chain (NZCSC) practises has become critical for organisations across the globe to achieve carbon neutrality in the wake of increasing climate change and global warming. Hence it is important to identify the challenges in the implementation of resilient NZCSC to support the stakeholders. The key thirteen challenges in the implementation of resilient NZCSC were identified from an extensive literature review using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) method. and industrial experts' opinions. The challenges were investigated and ranked based on interrelations using procedures like Influential Network Relationship Mapping *i.e.,* Decision Making Trial and Evaluation Laboratory (DEMATEL) and Level Partitioning by Total Interpretive Structural Modelling (TISM) is utilised to understand the cause-effect relationship among the challenges and to further identify the key influential challenges. The alpha value after DEMATEL was found to be 0.11 and identified the lack of management willingness as the main barrier. Level partitioning showed that lack of carbon accounting is the most critical barrier, based on which a roadmap is developed to support the stakeholders. The results from the study can help managers of organisations to implement techniques to achieve an NZCSC. Combining DEMATEL and TISM is the main novelty of the study along with the roadmap. The key findings from the study provide important insights into achieving an NZCSC from both a strategic and policy-making point of view.
Keywords: Supply chain resilience; Challenges; Sustainable development goals; Net zero carbon supply chain; Carbon Emission.

1. Introduction

In recent years, it has become very evident how Greenhouse Gases (GHG) emissions have a widespread effect on human life and nature (Rogelj *et al.,* 2018). The surge in GHG is considered a cause of negative effects on vegetation and water security, infectious and non-infectious diseases, and other social disruptions (Mikhaylov *et al.,* 2020). However, the most prominent predicament is global warming. It is expected that mean global surface temperatures will rise between 3°C and 4°C by the year 2100 relative to the averages in the period 1986-2005. Researchers note that at the current pace, the rise in mean near-surface air temperatures would become 1.5 °C by the year 2052 (Rogelj *et al.,* 2018).

Globally, greenhouse gas emissions began to rise significantly with the onset of the 20th century due to the dramatic rise in fuel consumption by various industrial processes. These changes have already started adversely affecting different parts of the world. Annual carbon emissions have risen from less than 1000 million MT of carbon in 1900 to nearly 10,000 million MT of carbon in 2014 as per the US Environmental Protection Agency. The transportation sector, which essentially involves fossil fuels burned for road, rail, marine and air, constitutes about 14% of the total GHG emissions in the United States (Javed *et al.,* 2014). In India, the CO_2 emissions grew from 615 MT in 1990 to 1897 MT in 2013, which is around 5% of the global emission (Sanghi *et al.,* 2008). The power sector contributes the most to these statistics, around 50%, followed by transport and iron and steel (Garg *et al.,* 2017). Moreover, the emissions from supply chains far exceed those from other direct and indirect emissions (Notte *et al.,* 2018; Mcdowall *et al.,* 2018)

With growing concerns on this topic, many governments have put forward policies and goals to reach negative emissions by 2050. It will take considerable amounts of investment to keep the global warming temperature below 2°C by the mid-century (UNFCC, 2015). The United Kingdom was the first major economy to pass laws related to net zero carbon emissions, in 2019 and targeted the year 2050 to achieve this goal (Department of Business, Energy and Industrial strategies, UK Govt, 2019). In South Korea, a building concept called Zero Emission Buildings (ZEB) is an interesting case study. In such buildings, the requirements needed for the building to function such as water, energy, biomass and nutrients are met via processes aided by net zero energy consumption facilitated by locally produced renewable sources of energy (Schuetze *et al.,* 2015). Implementation of water-efficient systems coupled with rainwater harvesting, processing and reuse of wastewater for non-drinking purposes reduces the pressure on fresh water sources. The biomass produced from kitchen and sanitation is processed and recycled for local use, on-site. Optimal planning of these water-carbon-energy plants will help in achieving Sustainable Development Goals (SDG) as well (Mehrjerdi *et al.,* 2021). In India, the union budget for 2022 emphasizes transitioning towards a carbon-neutral economy and put forth proposals to target emissions in sectors such as energy and the issuing of sovereign green bonds to mobilise resources for green infrastructure (Chakraborty, 2022).

The United States Environmental Protection Agency reports that the supply chain of organisations often constitutes more than 90% of the organisation's GHG emissions. In India, companies are at risk of losing about $274 billion worth of exports as more and more multinational companies are demanding their supply partners adopt sustainable practices in their operations (Standard Chartered white paper, 2021). The primary challenge in building a sustainable supply chain is to build a model that achieves both the sustainability and profitability goals of an organisation (Gurzawska, 2020) which is further complicated by consumer demands for faster services which leads to unsustainable and inefficient supply chain practises. Moreover, sustainable business practice is a concept with a broad scope that can have targets such as zero plastics, zero wastage etc., on top of zero emissions, which makes it difficult for organisations to formulate an effective sustainability policy that meets multiple targets at once (Vulturius *et al.,* 2022). In addition, a supply chain consists of various nodes which are not necessarily controlled centrally and thus conflict due to lack of centrality as well as a concern in building a sustainable supply chain. Achieving the set target of carbon neutrality in several industries, followed by pressure from governments all over the world, the need to shift to net zero carbon supply chain practices has become critical.

In this context, there is a need to explore methods to improve supply chain sustainability and resilience to meet net zero emissions targets to reduce global emissions on a large scale as well as tackle disruptions. To do that, the challenges involved in the transitioning of a supply chain model to a sustainable and resilient one has to be identified, while addressing how to overcome these challenges. Thus, this study identifies two research questions in this regard.

RQ1: What are the important challenges in building a resilient net zero carbon supply chain?
RQ2: How the priority of the net zero challenges could be identified considering their interrelationships?

To address these research questions, the study defines the following research objectives:

- To identify the important challenges in building a resilient net zero carbon supply chain through extensive literature review and by utilising the knowledge of expert members.
- To analyse the interrelationship and prioritise the challenges for building a net zero carbon supply chain.
- To formulate a roadmap for building a net zero carbon supply chain (NZCSC).

The study aims to identify the main challenges standing before implementing a resilient net zero carbon supply chain followed by ranking them in order of criticality using Multi-Criteria Decision Making (MCDM) techniques. The paper identifies the main challenges after an extensive literature survey. Using an interrelation chart and data received from industrial experts, the study utilises a decision-making trial and evaluation laboratory (DEMATEL) method to rank the challenges followed by level partitioning to formulate a road plan to overcome the identified challenges. The DEMATEL technique establishes relationships between these challenges while elucidating the degree of influence of the study criteria (Sumrit *et al.,* 2012). The DEMATEL method can be interpreted as an extended procedure for deciding and analysing a structural model from which the interrelation between complex factors can be extracted. DEMATEL technique is more advantageous than the existing MCDM methods as it successfully evaluates the mutual influence, either as direct or indirect effects, among the various factors, providing insight into the causes and effects in a complex decision-making scenario (Song *et al.,* 2020).

Using level partitioning, the paper aims to formulate a road map to tackle the challenges based on their criticality as per DEMATEL, giving a clear-cut idea for the concerned authorities to focus on each barrier. Level partitioning separates similarly linked challenges after DEMATEL into 'levels' such that each barrier in the same level can be tackled partially using a specific solution. The lower the level, the higher the importance of the challenges and solving them helps tackle other related challenges. The roadmap formulated after level partitioning makes policy-making and implementation easier. The novelty of this paper is in utilising these MCDM methodologies to focus on a wider range of challenges in deploying resilient net zero carbon supply chain policies instead of literature focusing on niche industry cases Also the study focuses on the interrelation between the major challenges.

The study is structured as follows: Section 2 focuses on the literature survey followed for the study using the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) which is followed by Section 3, detailing the methodology followed and the data collection procedure. Section 4 deals with performing DEMATEL and level partitioning on the data as per our use case; while Section 5 makes up the results and discussions along with the proposed roadmap. Section 6 comprises the research implications with Section 7 presents future research directions and concludes the study.

2. Literature review

The paper conducts an extensive literature review using the PRISMA method. Papers published from 2016 to 2022 related to DEMATEL, TISM and existing NZCSC scenarios were collected from Scopus and ScienceDirect databases and objectively selected 63 papers and conducted meta-data analysis. Section 2 deals with the NZCSC practices, followed by the main challenges identified in implementing net zero carbon practices. The challenges are elaborated on as per a

00literature survey. The PRISMA method is used to classify the papers collected from the literature review as shown in Figure 1. The PRISMA method helps in organising relevant papers according to the needs of this study.

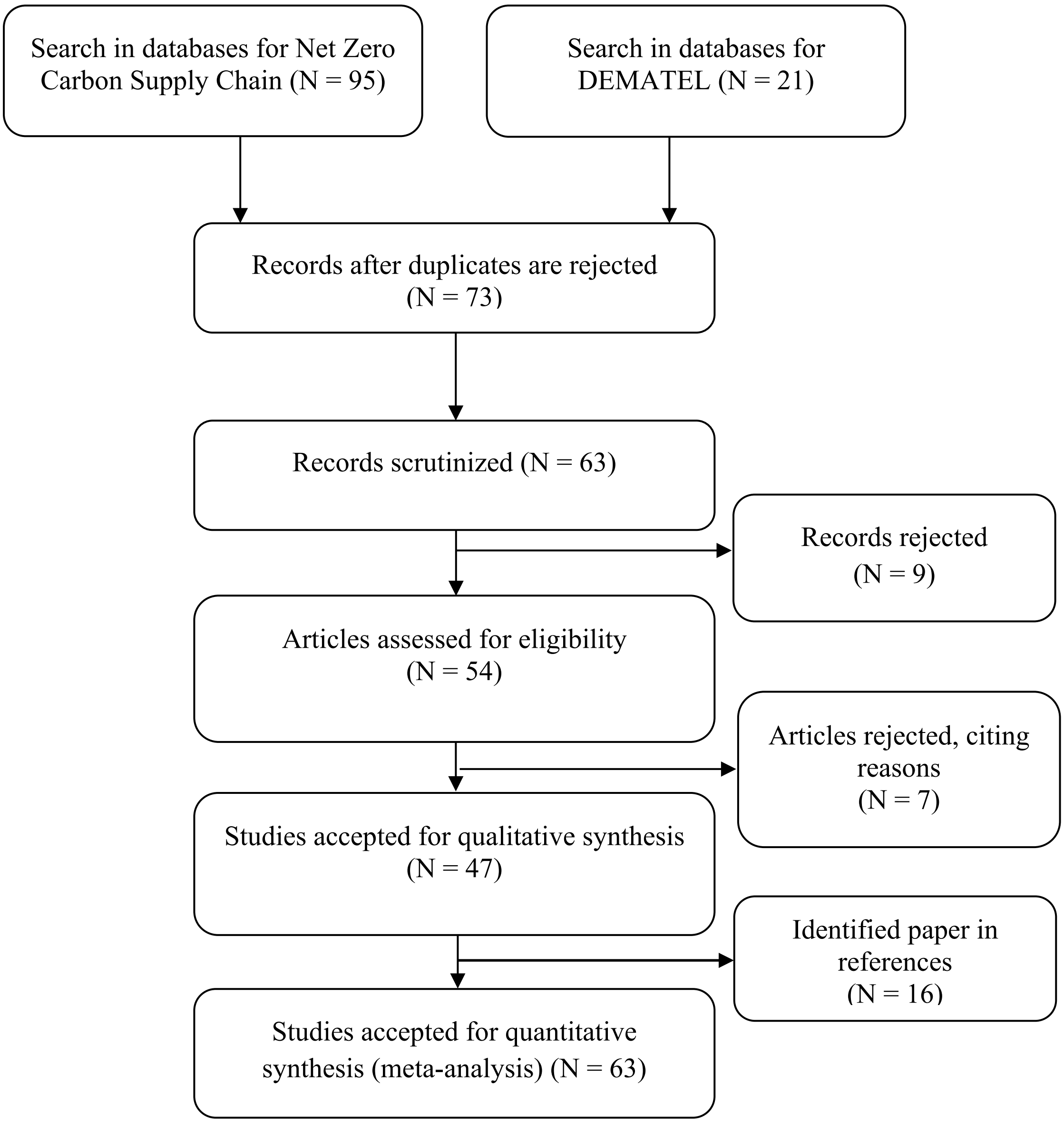

Figure 1. PRISMA Technique

2.1 Net zero carbon supply chain

With increasing concerns over global warming and the subsequent threats to nature owing to human practices, it is very important to keep a check on the active GHG emission across the world. Hence there is a need to lay down the foundations for low carbon transition in infrastructure connected to the individual nodes in a supply chain (Satola *et al.,* 2021). This needs to limit GHG emissions gave rise to the concept of emission control known as Net Zero Carbon Emissions (NZCE).

The term NZCE refers to removing the exact amount of carbon added to the atmosphere by any given activity. The goal of setting NZCE targets is to keep global temperatures within an acceptable level in alignment with sustainable development objectives (Fankhauser *et al.,* 2022). Net zero not being just a scientific concept, but rather a frame of reference for action against climate change and it requires operationalization in different fields. This concept is generalised to house all the collective actions necessary to achieve a net zero emission statistic of CO_2 and other GHG in the environment from operations related to the different nodes of the supply chain, which are major causes of global warming.

Even though there are efforts to shift from the traditional supply chain practices and move on to an NZCSC, the infrastructure shift is not as easy as envisioned by the policymakers. There are several challenges in achieving this shift in supply chain operations; ranging from policy making to financial constraints. It is important to address these issues before formulating a framework to achieve NZCSC (Marteau *et al.,* 2021). These challenges can be broadly classified into transparency, supplier engagement, execution and support. There is ample literature available on redesigning supply chain processes and operating in low-carbon production systems (Wimbadi *et al.,* 2020). Studies show that the electricity sector is easier to decarbonize and has had decent progress, with suggestions on improving carbon accounting to speed up the decarbonization process (Mastrandrea, 2020, Papadis *et al.,* 2020, Adun *et al.,* 2022, Gerbaulet *et al.,* 2019). Also, on market mechanisms based on emission caps, carbon tokens, taxation schemes etc. Emphasis should be laid upon removing the existing challenges in achieving this NZCSC. Countries have begun to work in this direction with Sweden being the forerunner in achieving close to zero emission by the end of 2045 (Karlsson *et al.,* 2020). As supply chain organizations are a major contributor to global carbon emissions and hence it is necessary to come up with measures to control emissions by adopting net zero principles. This study provides strength to stakeholders in implementing net zero strategies across the supply chain. Also improved collaboration between stakeholders in the supply chain helps in developing NZCSC. Table 1 shows a few contemporary papers on the research premise.

Table 1. Closely related articles

Authors	Description
Jagriti *et al.* (2022)	This paper discusses the drivers, challenges and practices through which a net zero economy can be achieved in a knowledge-based supply chain.
Luthra et al. (2022)	In this research work, the authors discussed how to overcome cross-sector collaboration.
Moktadir *et al.* (2020)	This paper identifies and evaluates critical success factors needed for the development of Circular Economy practices.
Tumpa *et al.* (2019)	This paper provides viewpoints and hurdles in adopting green supply chain management practices in the context of the Bangladesh textile industry.
Bocken *et al.* (2019)	This paper discusses the challenges and drivers of interconnections and how it obstructs or enables sustainable business model innovation.
Moktadir *et al.* (2018)	This study identifies the most crucial challenges to sustainable supply chain management practices in the Bangladesh leather processing industry and examines the causal relationships between them using the DEMATEL method.
Moktadir *et al.* (2018)	This study identifies and ranks the drivers of sustainable manufacturing practices in the leather industries of Bangladesh.
Linton *et al.* (2007)	This paper provides insight on trends in the sustainable supply chain that intersect with operations management, and the research possibilities and challenges it presents.

2.2 Circular network under investigation

The construction sector contributes the most share of GHG emissions globally, every year. In the construction sector, it is the cement industry which drives the emission data. Cement materials contribute to 8% of emissions annually throughout the world. This industry is driven by Carbon producing chemical reactions, mainly limestone breakdown (Andrew, 2018). Due to the abundance of limestone and CO_2, there is a need for proper removal and recapture of these emissions. With many countries being heavily invested in construction infrastructure, the emission data is speculated to rise (Bataille, 2020). With the help of this study, the cement industry can implement policies with an emphasis on tackling common challenges. By developing better policies about material estimation, flexible design of processes, and improved carbon accounting and storage, the industry can reduce emissions by a decent margin. Improving collaboration between construction companies and the introduction of green procurement procedures, coupled with circular economy models incorporating local businesses improves the recyclability of materials paving for reduced CO_2 emissions.

In the context of carbon emissions and circular economy, the paper pulp industry with a considerable amount of biomass combustion and related carbon emission is explored in this study. The Paper pulp sector requires proper net zero carbon policies and supply chain practises. In this industry, around 75% of emissions are biogenic sources which are not counted towards carbon emission data according to several European Union (EU) policies. With increasing amendments to carbon accounting policies, it is important to address these biogenic emission sources and contain them properly (van Sluisveld *et al.,* 2021). From sourcing and transporting raw wood to fuel combustion during pulp making, improving the processes can greatly help reduce emission data. Introducing improved technologies in the pulping mills, implementing policies on collaboration among several suppliers (pulp mills) to reduce fuel consumption, cost cutting (transportation and storage) and shifting alternate kiln/fuel types could help reduce the annual emission of CO_2. Using raw materials with shorter growth periods is another way to tackle the issues faced. This industry has significant potential toimplementing NZCSC and carbon accounting practices. Following the developed roadmap with emphasis on carbon accounting is suggested for NZCSC policies.

With many sugar companies diversifying production to electricity, many types of fuel, papers and different types of chemicals, the emission carbon accounting has to be revised. These by-products contribute to increased emissions of GHG from sugar mills, making it important to switch to a resilient NZCSC by them. This industry is already a pioneer in reusing and recycling which are a part of circular economy practices. But with this diversification of production, carbon analysis and accounting have become indispensable to determine the impact of GHG emissions on the surrounding environment. With the introduction of several energy systems to facilitate the production of several by-products, energy consumption has increased drastically. Studies have shown that an average sugar mill has carbon emissions of around 50 kg-CO_{2eq}/T of sugar produced (Yuttitham *et al.,* 2011). Sugar mills have direct emissions due to sugar processing and indirect emissions through equipment usage. Setting up strict government policies is necessary to control the environmental impact of GHG emissions by the sugar industry, diversification of production to produce fuel, and construction materials, improved carbon capture along with improved production methods are positive steps towards achieving sustainable development goals, but without proper carbon accounting and data sharing, it becomes difficult to keep the operation in check (Sethupathy *et al.,* 2021).

The three case industries mentioned, when connected in a circular economy setup, can further improve their carbon footprint and emission statistics with proper carbon accounting, improved policy-making and mathematical analysis of the challenges faced while shifting to an NZCSC.

Identifying the challenges and tackling them with resilience and SDGs as the main focus while relying on circular economy metrics, makes the study more useful for the three industries. With the support of an impartial mathematical model, the roadmap developed to tackle the challenges has a high degree of assurance of success. Moreover, it also focuses on consumer behaviour and knowledge allowing for these industries to achieve better efficiency in implementing resilient NZCSC policies. In this context, the case organisations found this study worthwhile and effective to pursue.

2.3 Challenges in net zero carbon supply chain

According to the recent 2022 Union Budget of India, the government has become proactive in formulating rules related to NZCSC and circular economy; however, the implementation of these rules might still take a while due to the large number of challenges it faces. The knowledge gap among suppliers and consumers concerning existing policies and alternate materials and processes is a major concern (Van Sluisveld *et al.,* 2021). Furthermore, the individual nodes in the supply chain may be operating on older data which causes increased emissions and uncertain analysis of lifetime CO_2 emissions (Robati *et al.,* 2019). This coupled with the lack of strong government action and policy regarding GHG emissions makes the target of an NZCSC harder to achieve.

It is observed how a lack of transparency across the supply chain regarding emission data due to financial/technical reasons causes emission control to fall short of targeted efficiency. Reduced exposure to the nodes also affects the efficiency of maintaining the emission data (Higgins *et al.,* 2020). Lack of clarity and immaturity of carbon accounting also amounts to the challenges faced while implementing the policies. Several studies have put forward reasons related to challenges faced in developing a resilient NZSC but a comparative analysis to identify the interrelation of these challenges has not been carried out, which is the main motivation of this study. Based on this, the study has identified 13 potential challenges in making a resilient NZSC. The challenges listed in Table 2 are identified after an extensive literature survey and discussions with industry experts

Table 2. Challenges identified along with source

Notation	Challenges identified	Explanation	Source
NZC1	Knowledge gap among suppliers	Lack of knowledge about green processes and low emission alternatives in the supply chain nodes. The individual supply chain nodes are still operating on old data about emissions from materials.	Van Sluisveld *et al.,* 2021; Pan *et al.,* 2019; Kemp *et al.,* 2021
NZC2	Non-availability of green suppliers	Organizations find it difficult to identify and confirm that the suppliers are adopting green practices in their operations.	Pye *et al.,* 2021, Huang *et al.,* 2021
NZC3	High initial investment and ROI	Organizations find it difficult to shift to these practices because of the high investment required. New technology is costly compared to existing processes.	Sachin and Rajesh 202; Tvinnereim *et al.,* 2018; Burke *et al.,* 2019; Bertheau *et al.,* 2022
NZC4	Lack of government policy	There is a need for improved government action in setting up proper regulations regarding GHG emissions. The lack of a decentralised decision-making system for proper review of the supply chain emission is important.	Ramandi and Bafrui 2020; Zhang and Yousaf 2019; Albuquerque *et al.,* 2020
NZC5	Conflicting procurement priorities	Green Public Procurement (GPP) and conflicting priorities due to lack of financial obligations. Untraditional procurement policies with agents doing more than needed cause a financial burden.	Spareevik *et al.,* 2018
NZC6	Lack of consumer awareness and willingness	Consumers are unaware of low carbon/carbon-neutral alternatives for the products they use and the service providers they employ. They are also less willing to pay for energy-efficient products/services which are 10% costlier compared to their counterparts.	Pan *et al.,* 2020; Kim *et al.,* 2018
NZC7	Lack of transparency and trust	Collecting emissions data from each node is often difficult due to technical and financial challenges. Reduced exposure and transparency when nodes provide relevant information.	Higgins *et al.,* 2020; Comello *et al.,* 2021; Zhongming *et al.,* 2021; Williams *et al.,* 2019.
NZC8	Lack of collaboration among suppliers	There is a gap in technology between different nodes of the supply chain	Davis *et al.,* 2018, Khan *et al.,* 2020

Notation	Challenges identified	Explanation	Source
		as well as no collaboration among potential suppliers with alternative materials with less emission.	Adomako *et al.,* 2020
NZC9	Unclear benefits	Companies find it difficult to commit to long-term deep decarbonization procedures in their supply chains without a clear-cut guarantee that they will pay off in the future. Without any incentives, it is hard for companies to put effort into decarbonization.	Papadis *et al.,* 2020; Energy transitions commission 2017
NZC10	Lack of management willingness	Managing authorities are not willing to shift to net zero carbon policies due to financial concerns and additional workload.	Pye *et al.,* 2021; Kemp *et al.,* 2021 Hafner *et al.,* 2021
NZC11	Lack of low carbon alternatives	Organisations are not adept with improved low-emissions alternatives for manufacturing processes. Also, the absence of a proper substitute in emission data is a challenge.	Pye *et al.,* 2021; Bonsu 2020; Garvey *et al.,* 2022
NZC12	Immaturity of carbon-accounting techniques	Questions regarding traditional carbon accounting practices. Need for better understanding of data concerned with carbon emissions.	Carlton *et al.,* 2021; Brander *et al.,* 2021; Schaltegger *et al.,* 2012
NZC13	Difficulty to sustain	Organisations tend to lack commitment toward maintaining their Sustainable Development Goals after the initial phase of adoption.	Tsvetkova et al., 2020; Drobyazko et al., 2021 Obrist et al., 2021

2.4 CE performance assessment method and indices

The paper also includes a brief overview of previous research on CE evaluation and pertinent measures. Parchomenko *et al.* (2019) examined the dependency of a wide variety of measurements, indicators, and methods with 24 components of CE, and found both potentially undeveloped and well-covered topics for CE evaluation without exploring the things that needed to be assessed. Further, Moraga *et al*. (2019) and Corona *et al.* (2019) have also conducted research and introduced a framework for introducing the CE outcome indicators and sub-indicators. To better analyse and convey CE effectiveness, Saidani *et al.* (2019) suggested a typology with 55 circularity metrics to support professionals. Kristensen and Mosgaard (2020) looked at 30 CE metrics utilising a common technique, even though they focused on metrics at the micro-level of technology. A literature analysis was carried out by Sassanelli *et* *al.* (2019), and CE performance evaluation methodologies were categorised using the concept of a positioning paradigm focused on a good's lifespan phases. Moreover, Sassanelli *et al.* (2019) emphasised the variables employed within the approaches, in addition to the layer of the TBL region that they investigate. The most recent and extensive work on the assessment method and indices of CE performance is presented by Vinate *et al.* (2021) from the findings of 130 publications. Also, in their research, a circular value chain architecture has been used to recognise and categorise 365 unique firm-level metrics, which have then been grouped into 23 distinct categories.

3. Methodology

3.1 Data collection

The necessary data was obtained through industry experts. Discussions were done during which the panel of experts finalised the thirteen challenges and gave numerical values for the interrelation of challenges based on Table 2. The five-member panel consisted of experts from several fields/industries. Table 3 shows the expert details, their area of expertise and years of experience. An empirical analysis is the basis of the data collection procedure. The challenges mentioned in Table 2 were gathered through a literature review. With the help of an empirical analysis using questionnaires about the identified challenges, the team surveyed 3 major industries, namely sugar, paper and cement. These industries were chosen after discussions with industry experts and due to their potential for a Circular Sharing Network. The questionnaire collected responses using a scale of 0 to 5 as shown in Table 4, which forms the base of the mathematical procedure in the study. The scale scores are used in generating a direct relations matrix, which illustrates pairwise comparisons of causal relationships. The panel of experts is made of managers, heads of operations, researchers etc. Previous research by Lin (2013) and Fu *et al.,* (2012) on similar methodologies had used data sets of similar sizes of 8 and 4-panel members respectively. The experts mentioned in Table 3, who gave insights into the data, act as a collective voice of the organization in question. As this is a case-specific study, a panel of 5 members was deemed as the optimum sample size for practicality due to the limited expertise available. This panel is structured to provide valuable knowledge relevant to the case organisations in the study.

Table 3. Expert details

Organization	Designation	Experience	Expertise
Paper industry	Manger – Pulp division	12 years	Pulp processing
Cement industry	Plant in-charge	13 years	Cement production
Sugar Industry	Head Operations	21 Years	Sugar processing
Environment Expert	Academic and Research	12 Years	Sustainable Supply chain planning
Supply chain Expert	Manager- Transport	11 Years	Transportation logistics

3.2 DEMATEL method

The challenges/challenges related to making a resilient NZCSC have a causal dependency between them which should be analysed in depth for overcoming them. Causal dependency is defined as the cause-and-effect relationship among two criteria. Decision Making Trial and Evaluation Laboratory (DEMATEL), Total Interpretive Structural Modelling (TISM) and Structural Equation Modelling (SEM) are some of the common methodologies used to study causal dependencies among criteria. This study utilises DEMATEL which helps visualise the interrelationships between the challenges, helping in decision making (Sivakumar *et al.,* 2018). It also helps in converting the structural framework interrelationship between causes and effects. DEMATEL has clear advantages over other MCDM methodologies like Analytical Hierarchy Process (AHP), Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) etc. It helps in confirming the interdependence among challenges identified along with aiding in the development of a map, depicting the relative relationships within chosen challenges. The method is also used for investigating and solving complicated and intertwined problems. Along with DEMATEL, the study uses level partitioning to separate the challenges based on criticality. Level partitioning is performed after DEMATEL to optimise the decision-making and come up with a stronger and clearer roadmap to tackle the challenges. This procedure is a part of the TISM methodology. Utilising DEMATEL and Level partitioning together is one of the novelties of this study. The outlines of both procedures are discussed in the proceeding sections as summarized in Figure 2. The steps followed in the DEMATEL procedure are as follows:

Step 1: A panel of industry experts are asked to indicate the effect(interrelationship) of factor (i) on every other factor (j), denoted by a_{ij}. Table 4 shows the scale used by experts while rating the interrelationship of factors. For each expert a non-negative matrix $X^k = [x_{ij}^k]$ is created.

Using Equation 1, the judgements from 5 experts are aggregated into one average/cumulative matrix.

$$C = [a_{ij}] = \frac{1}{n}\sum_{i=1}^{n} x_{ij}^{k} \qquad (1)$$

Table 4. Used scale for data collection

Numeral	Description
-	No influence
1	Very Low influence
2	Low influence
3	Medium influence
4	High influence
5	Very High influence

Step 2: The cumulative matrix is normalized using Equations (2) and (3). The resulting matrix has values ranging from 0-1

$$N_m = C/u \qquad (2)$$

$$u = max\ 1 \leq i \leq n\{\sum_{j=1}^{n} aij\} \qquad (3)$$

Step 3: From the normalized matrix, the total relation matrix is achieved using Equation (4) where I denote the identity matrix. Matrix T_{RM} denotes the total relationship between each pair of factors considered.

$$T_{RM} = N_m (I - N_m)^{-1} \qquad (4)$$

Step 4: Using Equations (5) and (6), row and column sums are computed separately to obtain matrices. Matrices represent the factors' driving power and dependency, respectively.

$$R = \left[\sum_{j=1}^{n} m_{ij}\right]_{n\times 1} = (r_1, r_2, \ldots, r_i, \ldots, r_n) \qquad (5)$$

$$D = \left[\sum_{i=1}^{n} m_{ij}\right]'_{1\times n} = (d_1, d_2, \ldots, d_i, \ldots, d_n) \qquad (6)$$

$$M = m_{ij} i, j = 1,2,3, .. n$$

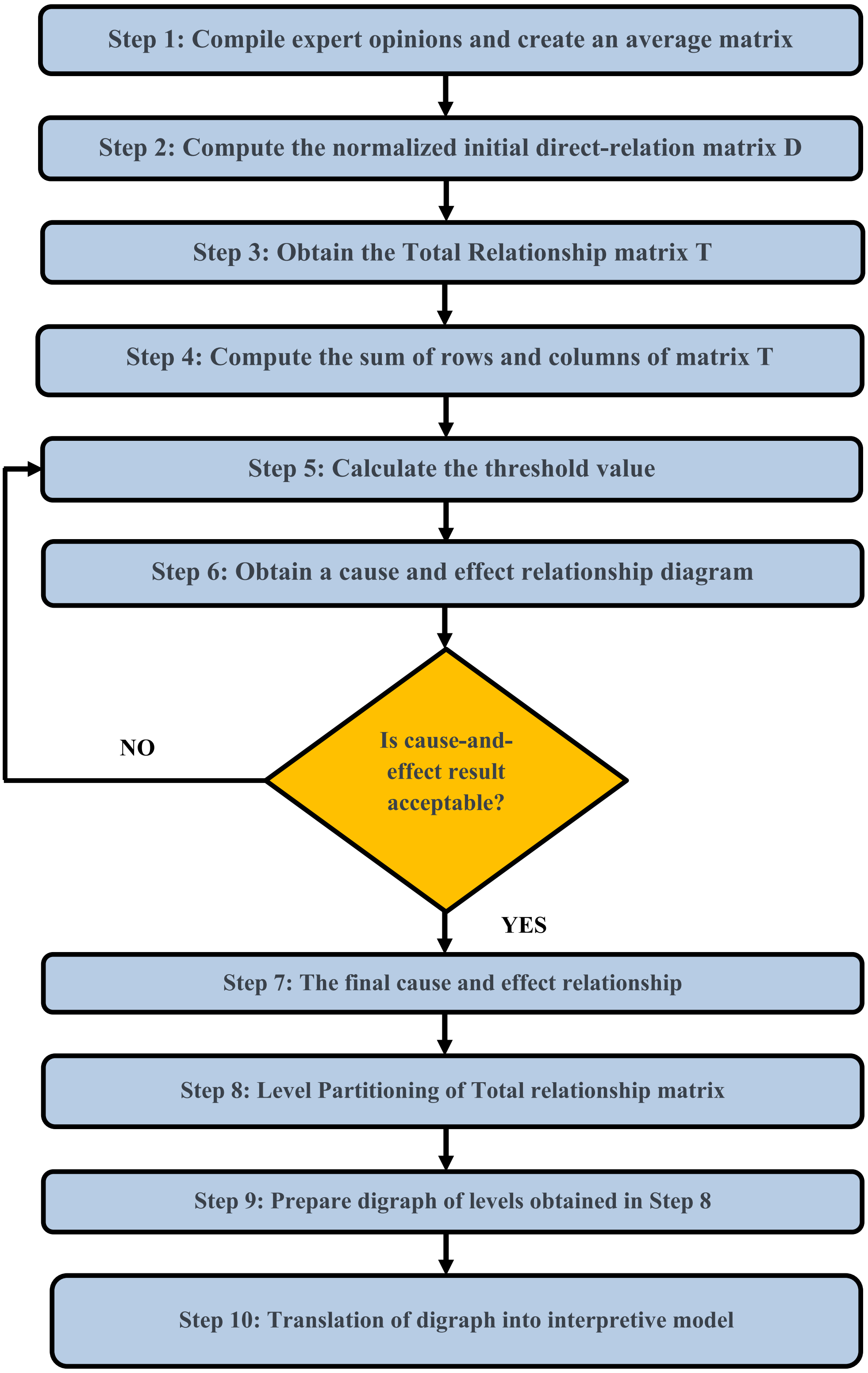

Figure 2. Research methodology flow chart

Step 5: Computation of threshold value

The threshold value (α) for DEMATEL is calculated using Equation 7.

$$\alpha = \frac{\sum_{j=1}^{n}\sum_{i=1}^{n} dij}{n^2} \qquad (7)$$

Step 6: The cause-and-effect diagram is computed using D and R by plotting the set of $\{ri + si, ri - si\}, \forall\, i \in n$. The graph is constructed where ($r_i + s_i$) is the horizontal axis and (r_i - s_i) is the vertical axis. The digraph clearly defines the interrelationship between the challenges and is a valuable decision-making aid.

4. Data collection and analysis

4.1 DEMATEL on net zero carbon supply chain

The data for performing DEMATEL is collected from a panel of industry experts. Table 5 shows the collected data from one expert with the rest mentioned in Tables A1-4 in the Appendix section, with respective scales to perform the DEMATEL procedure and level partitioning later on.

Step 1: Collection of data from experts.

The collected data, Table 5 and Tables A2-5, is used to make the average matrix using Equation 1.

Table 5. Data from Expert 1

	NZC1	NZC2	NZC3	NZC4	NZC5	NZC6	NZC7	NZC8	NZC9	NZC10	NZC11	NZC12	NZC13
NZC1	-	-	-	-	3	-	2	2	3	-	-	-	1
NZC2	-	-	-	-	-	-	-	-	-	4	-	-	1
NZC3	-	-	-	-	2	-	-	-	3	2	-	-	2
NZC4	-	-	2	-	-	-	2	-	-	2	3	-	1
NZC5	-	-	-	-	-	-	4	-	-	-	-	-	2
NZC6	-	-	-	-	-	-	-	-	-	2	-	-	3
NZC7	1	-	-	-	3	-	-	3	-	1	-	-	3
NZC8	2	1	2	-	-	-	3	-	-	-	-	-	3
NZC9	-	-	-	3	3	3	-	1	-	3	-	-	2
NZC10	-	-	-	-	-	-	3	3	-	-	-	-	2
NZC11	-	2	-	3	1	-	-	-	-	2	-	-	3
NZC12	3	-	-	2	-	-	-	-	-	-	-	-	2

	NZC1	NZC2	NZC3	NZC4	NZC5	NZC6	NZC7	NZC8	NZC9	NZC10	NZC11	NZC12	NZC13
NZC13	-	-	-	-	-	-	-	-	-	3	-	-	-

An average matrix B, is made from the individual matrices (expert's input). This is presented in Table 6

Table 6. Average matrix B

	NZC1	NAC2	NZC3	NZC4	NZC5	NZC6	NZC7	NZC8	NZC9	NZC10	NZC11	NZC12	NZC13	Sum
NZC1	-	-	-	-	3	-	2.6	2.4	2.4	-	-	-	2	12.4
NZC2	-	-	-	-	-	-	-	-	-	2.8	-	-	2.6	5.4
NZC3	-	-	-	-	3	-	-	-	1.4	3.4	-	-0.4	3.4	11.6
NZC4	-	-	3.4	-	-	-	-0.4	-	-	3.6	2.8	-	3.2	13.4
NZC5	-	-	-	-	-	-	3.6	-	-	-	-	-	2.8	6.4
NZC6	-	-	-0.4	-0.4	-0.4	-	-	-	-	2	-	-	2.6	5.8
NZC7	2.4	-	-	-	3	-	-	3.8	-	2	-	-	2.4	13.6
NZC8	3.4	2.4	-0.4	-	-	-	3.6	-	-	-0.4	-	-	3.6	13.8
NZC9	-	-	-	4	2.8	3	-	2.6	-	3.2	-	-	2	17.6
NZC10	2.8	-	-	-	-	-	3.6	3.8	-	-	-	-	3	13.2
NZC11	-	-0.4	-	3.2	3.4	-	-	-	-	2.2	-	-	1.8	11
NZC12	2.8	-	-	2.8	-	-	-	-	-0.4	-0.4	-0.4	-	1.8	8.6
NZC13	-	-	-	-	-	-	-	-	-	3.8	-	-	-	3.8

Step 2: Normalising the average matrix

A normal matrix, N, is made from the average matrix B by dividing the matrix by the maximum value of the sum of columns in matrix B. Table 7 shows matrix N.

Table 7: Normalization matrix N

	NZC1	NZC2	NZC3	NZC4	NZC5	NZC6	NZC7	NZC8	NZC9	NZC10	NZC11	NZC12	NZC13
NZC1	-	-	-	-	0.1704	-	0.1477	0.1363	0.1363	-	-	-	0.1136
NZC2	-	-	-	-	-	-	-	-	-	0.159	-	-	0.1477
NZC3	-	-	-	-	0.1704	-	-	-	0.0795	0.1931	-	0.0227	0.2045
NZC4	-	-	0.1931	-	-	-	0.0227	-	-	0.2045	0.159	-	0.1818
NZC5	-	-	-	-	-	-	0.2045	-	-	-	-	-	0.159
NZC6	-	-	0.0227	0.0227	0.0227	-	-	-	-	0.1136	-	-	0.1477
NZC7	0.1363	-	-	-	0.1704	-	-	0.2159	-	0.1136	-	-	0.1363
NZC8	0.1931	0.1363	0.0227	-	-	-	0.2045	-	-	0.0227	-	-	0.2045
NZC9	-	-	-	0.2272	0.159	0.1704	-	0.1477	-	0.1818	-	-	0.1136

	NZC1	NZC2	NZC3	NZC4	NZC5	NZC6	NZC7	NZC8	NZC9	NZC10	NZC11	NZC12	NZC13
NZC10	0.159	-	-	-	-	-	0.2045	0.2159	-	-	-	-	0.1704
NZC11	-	0.0227	-	0.1818	0.1931	-	-	-	-	0.125	-	-	0.1022
NZC12	0.159	-	-	0.159	-	-	-	-	0.0227	0.0227	0.0227	-	0.1022
NZC13	-	-	-	-	-	-	-	-	-	0.2159	-	-	-

Step 3: Calculating Total Relation Matrix

The total relation matrix *T*, is made from the normalised matrix N using Eq. 4. The software MATLAB is used to compute the total relation matrix. Table 8 presents the total relation matrix, *T*.

Step 4: Finding the Sum of columns (Sc) and rows (Sr)

Using the equations, the sum of rows and columns is found. Sc and Sr are computed from the Total Relation Matrix, T. Sc and Sr values are shown alongside the matrix T in Table 8.

Table 8: Total relation matrix

	NZC1	NZC2	NZC3	NZC4	NZC5	NZC6	NZC7	NZC8	NZC9	NZC10	NZC11	NZC12	NZC13	Sc
NZC1	0.1221	0.0380	0.0140	0.0367	0.2731	0.0263	0.3125	0.2782	0.1541	0.1622	0.0058	0.0003	0.3352	1.7584
NZC2	0.0595	0.0100	0.0021	0.0020	0.0245	0.0014	0.0742	0.0732	0.0083	0.2217	0.0003	0.0000	0.2247	0.7018
NZC3	0.1026	0.0182	0.0085	0.0264	0.2324	0.0161	0.1571	0.1324	0.0947	0.3266	0.0047	0.0229	0.3824	1.5249
NZC4	0.1149	0.0233	0.2038	0.0382	0.1213	0.0054	0.1752	0.1432	0.0320	0.3938	0.1652	0.0046	0.4083	1.8291
NZC5	0.0669	0.0118	0.0024	0.0022	0.0581	0.0016	0.2625	0.0866	0.0093	0.0902	0.0004	0.0001	0.2487	0.8407
NZC6	0.0518	0.0088	0.0292	0.0257	0.0507	0.0016	0.0700	0.0640	0.0094	0.1874	0.0041	0.0007	0.2299	0.7334
NZC7	0.2746	0.0490	0.0101	0.0091	0.2626	0.0065	0.2183	0.3592	0.0382	0.2461	0.0015	0.0002	0.3708	1.8462
NZC8	0.3041	0.1589	0.0287	0.0105	0.1236	0.0075	0.3491	0.1658	0.0437	0.1969	0.0017	0.0007	0.4113	1.8025
NZC9	0.1548	0.0429	0.0581	0.2443	0.2492	0.1748	0.2252	0.3085	0.0257	0.4044	0.0389	0.0013	0.4290	2.3573
NZC10	0.3117	0.0523	0.0109	0.0104	0.1285	0.0074	0.3885	0.3835	0.0434	0.1613	0.0017	0.0002	0.4032	1.9029
NZC11	0.0810	0.0371	0.0392	0.1907	0.2458	0.0024	0.1413	0.1008	0.0142	0.2648	0.0303	0.0009	0.2888	1.4375
NZC12	0.2160	0.0139	0.0373	0.1812	0.0797	0.0094	0.1032	0.0935	0.0551	0.1556	0.0515	0.0008	0.2547	1.2521
NZC13	0.0673	0.0113	0.0023	0.0022	0.0278	0.0016	0.0839	0.0828	0.0094	0.2507	0.0004	0.0001	0.0870	0.6267
Sr	1.9272	0.4756	0.4466	0.7797	1.8774	0.2620	2.5609	2.2718	0.5374	3.0618	0.3064	0.0328	4.0740	

Step 5: Calculating threshold value, alpha

While calculating alpha value, n =169 as it's a 13×13 matrix of values in our use case. The alpha value is found to be 0.11013. The T matrix is adjusted to fit the alpha values. Table 9 shows the adjusted values.

Table 9 Adjusted Total Relation Matrix

	NZC1	NZC2	NZC3	NZC4	NZC5	NZC6	NZC7	NZC8	NZC9	NZC10	NZC11	NZC12	NZC13
NZC1	-				0.2731		0.3125	0.2782	0.1541	0.1622			0.3352
NZC2		-								0.2217			0.2247
NZC3			-		0.2324		0.1571	0.1324		0.3266			0.3824
NZC4	0.1149		0.2038	-	0.1213		0.1752	0.1432		0.3938	0.1652		0.4083
NZC5					-		0.2625			0.0902			0.2487
NZC6						-				0.1874			0.2299
NZC7	0.2746				0.2626		-	0.3592		0.2461			0.3708
NZC8	0.3041	0.1589			0.1236		0.3491	-		0.1969			0.4113
NZC9	0.1548			0.2443	0.2492	0.1748	0.2252	0.3085	-	0.4044			0.4290
NZC10	0.3117				0.1285		0.3885	0.3835		-			0.4032
NZC11				0.1907	0.2458		0.1413			0.2648	-		0.2888
NZC12	0.2160			0.1812						0.1556		-	0.2547
NZC13										0.2507			-

Step 6: Construction of directed causal graph

Using Sr+ Sc and Sr-Sc values as the x and y axes respectively, the causal plot for the DEMATEL procedure is made. Table 8 shows the significant relation matrix S, made after implementing the threshold value, which is also used while constructing the directed causal graph. This plot helps understand the interrelation among the identified challenges to implementing net zero carbon policies in supply chains. The plot also helps to study the critical barrier among the listed 13 challenges. Figure 3 shows the digraph and Table 10 shows the final results as per the DEMATEL procedure.

Table 10. Causal Matrix

Causal matrix	Sc	Sr	Sr-Sc	Sr+Sc	Cause/Effect	Ranking
Knowledge gap among suppliers	1.76	1.93	0.17	3.69	Cause	5
Non-availability of green suppliers	0.70	0.48	-0.23	1.18	Effect	11
High initial investment and ROI	1.52	0.45	1.5	1.97	Cause	9
Lack of government policy	1.83	0.78	-1.05	2.61	Effect	8
Conflicting procurement priorities	0.84	1.88	1.04	2.72	Cause	7
Lack of consumer awareness and willingness	0.73	0.26	-0.47	1.00	Effect	13
Lack of transparency and trust	1.85	2.56	0.71	4.41	Cause	3
Lack of collaboration among suppliers	1.80	2.27	0.47	4.07	Cause	4

Causal matrix	Sc	Sr	Sr-Sc	Sr+Sc	Cause/Effect	Ranking
Unclear benefits	2.36	0.54	-1.82	2.89	Effect	6
Lack of management willingness	1.90	3.06	1.16	4.96	Cause	1
Lack of low carbon alternatives	1.44	0.31	-1.13	1.74	Effect	10
Immaturity of carbon-accounting techniques	1.25	0.03	-1.22	1.28	Effect	12
Difficulty to sustain	0.63	4.07	3.45	4.70	Cause	2

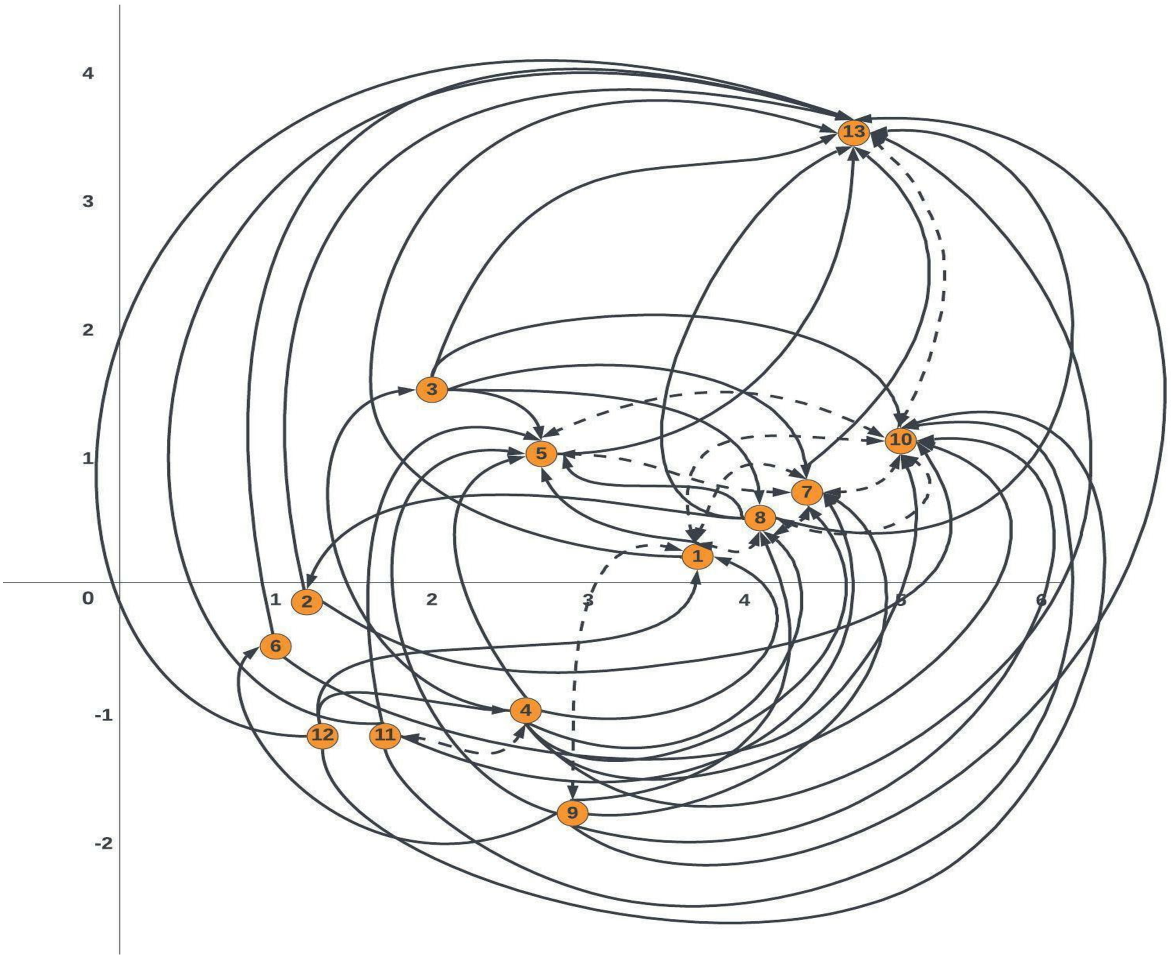

Figure 3. Network relation map

4.2 Level partitioning on net zero carbon supply chain

Level partitioning is a part of the TISM MCDM methodology used to separate the factors based on their criticality in the model. In this method, a matrix is developed based on the interrelation of challenges (Yadav *et al.,* 2020). An influencing (reachability) set and influenced by (antecedent) set is created. The reachability set consists of variables influencing itself and others while the antecedent set consists of variables being influenced by a variable. An intersection set is created from this matrix (Vimal *et al.,* 2022). When the intersection set and reachability set of a variable is the same, it is awarded the top-most level as per the ISM hierarchy. This level does not influence any other variable above it. The top-level variable is then removed from the matrix and is repeated till every variable is assigned to a particular level. Level partitioning helps to create the final model of the study.

The initial matrix is created based on Table 9 the adjusted total relation matrix. Table 11 shows the top most level L1 allotted for NZC10 and NZC13 as per the procedure.

Table 11. Level partitioning matrix with L1

	Influencing	Influenced by	Intersection set	Levels
NZC1	NZC5,NZC7,NZC8,NZC9,NZC10,NZC13,NZC1	NZC4,NZC7,NZC8,NZC9,NZ10,NZC12.NZC1	NZC7,NZC8,NZC9,NZC10,NZC1	
NZC2	NZC10,NZC13,NZC2	NZC8, NZC2	NZC2	
NZC3	NZC5, NZC7, NZC8, NZC10, NZC13, NZC3	NZC4, NZC3	NZC3	
NZC4	NZC1, NZC3, NZC5, NZC7, NZC8, NZC10, NZC11, NZC13, NZC4	NZC9, NZC11, NZC12, NZC4	NZC11, NZC4	
NZC5	NZC7, NZC10, NZC13, NZC5	NZC1, NZC3, NZC4, NZC7, NZC8, NZC9, NZC10, NZC11, NZC5	NZC7, NZC10, NZC5	
NZC6	NZC10, NZC13, NZC6	NZC9, NZC6	NZC6	
NZC7	NZC1, NZC5, NZC8, NZC10, NZC13, NZC7	NZC1, NZC3, NZC4, NZC5, NZC8, NZC9, NZC10, NZC11, NZC7	NZC1, NZC5, NZC8, NZC10, NZC7	
NZC8	NZC1, NZC2, NZC5, NZC7, NZC10, NZC13, NZC8	NZC1, NZC3, NZC4, NZC7, NZC9, NZC10, NZC8	NZC1, NZC7, NZC10, NZC8	
NZC9	NZC1, NZC5, NZC6, NZC7, NZC8, NZC10, NZC13, NZC9	NZC1, NZC9	NZC1, NZC9	
NZC10	NZC1, NZC5, NZC7, NZC8, NZC13, NZC10	NZC1, NZC2, NZC3, NZC4, NZC5, NZC6, NZC7, NZC8, NZC9, NZC11, NZC12, NZC13, NZC10	NZC1, NZC5, NZC7, NZC8, NZC13, NZC10	1
NZC11	NZC4, NZC5, NZC7, NZC10, NZC13, NZC11	NZC4, NZC11	NZC4, NZC11	
NZC12	NZC1, NZC4, NZC10, NZC13, NZC12	NZC12	NZC12	
NZC13	NZC10, NZC13	NZC1, NZC2, NZC3, NZC4, NZC5, NZC6, NZC7, NZC8, NZC9, NZC10, NZC11, NZC12, NZC13	NZC10, NZC13	1

The partitioning iteration is performed until every barrier is allotted into levels. In the second iteration, NZC2, NZC5 and NZC7 are allotted to L2 as shown in Table A5. L3 consists of NZC1, NZC6 and NZC8 challenges. Table 12 shows this iteration of the level partitioning procedure.

In the next iteration, L4 is allotted. The challenges NZC3 and NZC9 belong to this level as shown in Table A7, L4 iteration, as mentioned in Table A8, is made of barrier NZC4.

The final iteration in level partitioning is performed to allocate NZC12 as the lowermost level as shown in Table 12. Iterations 2-5, represented by Tables A5-A8 are mentioned in the Appendix section.

Table 12. Final iteration

	Influencing	Influenced by	Intersection set	Levels
NZC1	NZC5,NZC7,NZC8,NZC9,NZC10,NZC13,NZC1	NZC4,NZC7,NZC8,NZC9,10,NZC12.NZC1	NZC7,NZC8,NZC9,NZC10,NZC1	3
NZC2	NZC10,NZC13,NZC2	NZC8,NZC2	NZC2	2
NZC3	NZC5,NZC7,NZC8,NZC10,NZC13,NZC3	NZC4,NZC3	NZC3	4
NZC4	NZC1,NZC3,NZC5,NZC7,NZC8,NZC10,NZC11,NZC13,NZC4	NZC9,NZC11,NZC12,NZC4	NZC11,NZC4	5
NZC5	NZC7,NZC10,NZC13,NZC5	NZC1,NZC3,NZC4,NZC7,NZC8,NZC9,NZC10,NZC11,NZC5	NZC7,NZC10,NZC5	2
NZC6	NZC10,NZC13,NZC6	NZC9,NZC6	NZC6	3
NZC7	NZC1,NZC5,NZC8,NZC10,NZC13,NZC7	NZC1,NZC3,NZC4,NZC5,NZC8,NZC9,NZC10,NZC11,NZC7	NZC1,NZC5,NZC8,NZC10,NZC7	2
NZC8	NZC1,NZC2,NZC5,NZC7,NZC10,NZC13,NZC8	NZC1,NZC3,NZC4,NZC7,NZC9,NZC10,NZC8	NZC1,NZC7,NZC10,NZC8	3
NZC9	NZC1,NZC5,NZC6,NZC7,NZC8,NZC10,NZC13,NZC9	NZC1,NZC9	NZC1,NZC9	4
NZC10	NZC1,NZC5,NZC7,NZC8,NZC13,NZC10	NZC1,NZC2,NZC3,NZC4,NZC5,NZC6,NZC7,NZC8,NZC9,NZC11,NZC12,NZC13,NZC10	NZC1,NZC5,NZC7,NZC8,NZC13,NZC10	1
NZC11	NZC4,NZC5,NZC7,NZC10,NZC13,NZC11	NZC4,NZC11	NZC4,NZC11	3
NZC12	NZC1,NZC4,NZC10,NZC13,NZC12	NZC12	NZC12	6
NZC13	NZC10,NZC13	NZC1,NZC2,NZC3,NZC4,NZC5,NZC6,NZC7,NZC8,NZC9,NZC10,NZC11,NZC12,NZC13	NZC10,NZC13	1

Using the six iterations of level partitioning, a chart is made to understand the interrelation of these thirteen challenges and their criticality regarding the data received from the industry experts. Table 12 is used to make the chart shown in Figure 4.

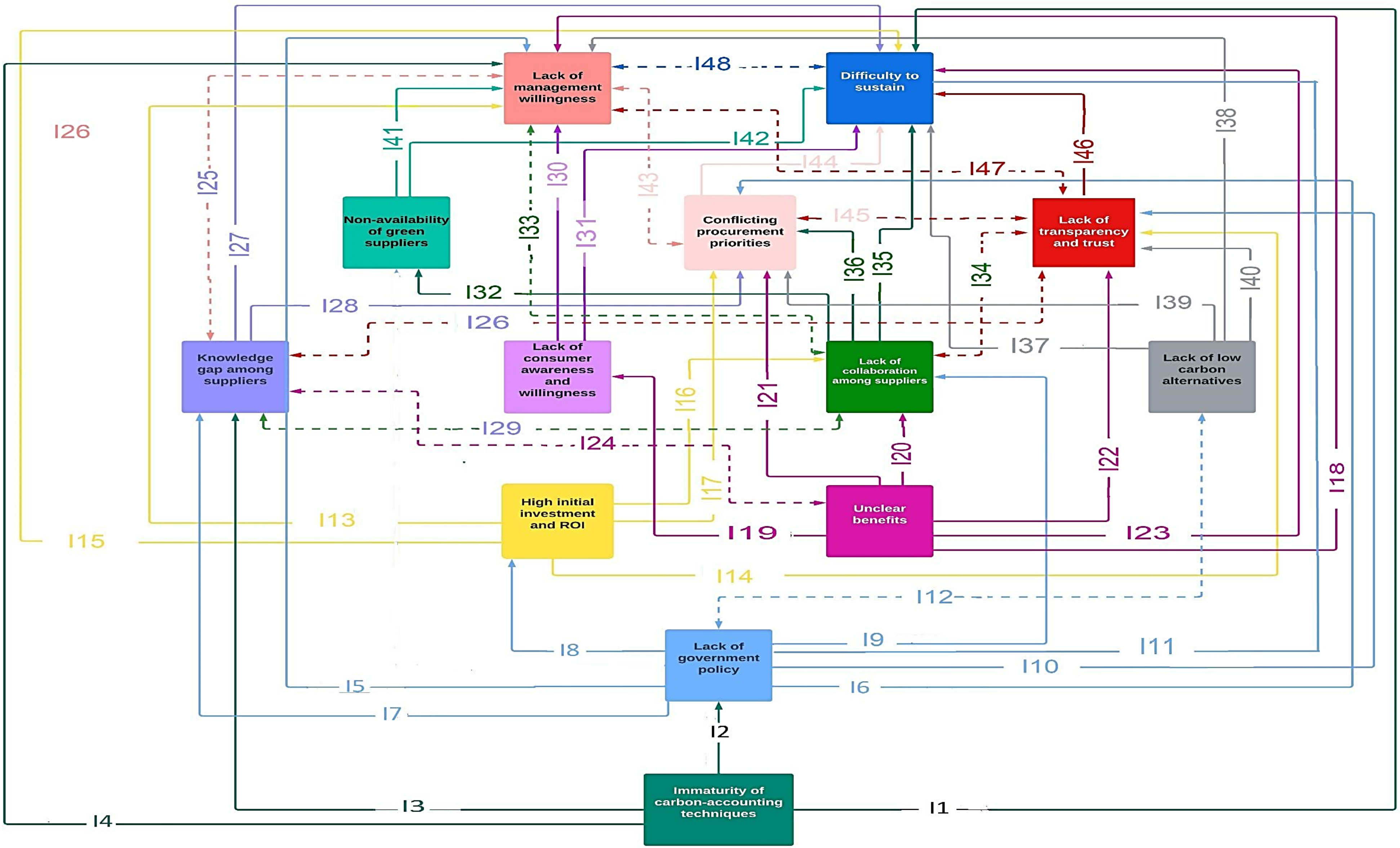

Figure 4. Level partitioning chart

Table 13. An explanation for the interrelation between barriers

Criteria	Description
I1	Immaturity of carbon accounting leads to the lack of support for the different nodes in the supply chain
I2	Immature carbon accounting techniques are responsible for the lack of proper policies
I3	Lack of proper carbon accounting affects the knowledge gap among suppliers
I4	Immature accounting leads to a decrease in motivation for implementing net zero policies
I5	Lack of government policies leads to the lack of management willingness in deploying a new model
I6	Conflicts in procurement policies are bound to appear if there is no proper policy to guide.
I7	The knowledge gap among suppliers is created due to the lack of strong government guidelines regarding net zero policies.
I8	Without strong policies, a decrease in interest from shareholders to invest is bound to happen.
I9	The absence/lack of government policies hinders collaboration among suppliers.
I10	Reduced transparency and trust issues among the nodes in supply chain are created due to the lack of government policies.
I11	Without proper guidelines, it is difficult to sustain any model. This issue is created due to a lack of government policies.
I12	If policies do not distinguish between usable materials, it becomes difficult to identify alternative material sources for production.
I13	High investment and Return on Investment (RoI) affect management willingness.
I14	Trust issues are created when the investment value is very high, causing shareholders to resort to underhanded tactics for profit.
I15	With very high investments and RoI concerns, it becomes difficult to sustain the model/process.
I16	High initial investment hinders collaboration between suppliers as they focus on personal gain than improving the carbon footprint.
I17	Conflicts in procurement strategies are bound to arise due to high initial investment and shareholders trying to reduce their spend.
I18	Management willingness is reduced due to the lack of clarity on benefits received from shifting to NZCS.
I19	Unclear benefits hinder customer willingness to shift to cleaner products to reduce carbon footprint
I20	Collaboration among suppliers is reduced due to the lack of clarity on the benefits they will receive from following clean policies.
I21	Conflicts in procurement policies happen due to unclear benefits.
I22	Lack of transparency and trust is seen among shareholders due to them not knowing the benefits of NZCS.
I23	Unclear benefits hinder the sustainability of a new NZCS model.
I24	A knowledge gap among suppliers is prominent due to unclear benefit policies.
I25	A knowledge gap among suppliers causes the lack of management's willingness to shift to an NZCS.
I26	Lack of transparency and trust is created due to the knowledge gap in suppliers.
I27	A knowledge gap hinders the ability to maintain the new NZCS model.
I28	Conflicting procurement priorities are bound to happen due to the knowledge gap among suppliers.
I29	Knowledge gaps create a lack of collaboration among suppliers.

Criteria	Description
I30	Lack of consumer awareness creates a lack of willingness to shift to the NZCS model in the upper management.
I31	Lack of awareness makes sustaining the new model difficult. Without every node improving, it becomes difficult to maintain.
I32	Lack of collaboration creates the non-availability of green resource suppliers.
I33	The management is unwilling to shift to the NZCSC model due to a lack of collaboration between the shareholders/suppliers
I34	Lack of collaboration creates trust issues between suppliers.
I35	Without collaboration, it is difficult to maintain a new model
I36	Conflicts in procurement priorities are created due to the lack of collaboration between suppliers.
I37	The lack of low-carbon alternatives makes it difficult to sustain the NZCSC model.
I38	Management is unwilling to shift to a new model due to a lack of alternative resources.
I39	The lack of alternatives affects procurement policies.
I40	Trust issues and low transparency is created due to low amounts of alternative resources. Shareholders try to produce low-quality substitutes.
I41	Non-availability of green suppliers affects the management's willingness to shift to the new NZCSC model
I42	Low availability makes it hard to sustain the new model.
I43	Conflicting procurement policies reduce management's willingness to shift to the new model.
I44	The model becomes difficult to sustain due to procurement policy issues
I45	Lack of transparency and conflicting policies go hand in hand in sustaining the new model.
I46	Lack of trust and transparency among shareholders make it difficult to sustain the NZCSC model.
I47	Reduced management willingness is seen as a result of reduced trust and transparency.
I48	Lack of management willingness and difficulty to sustain the new model go hand in hand.

5. Results and discussion

With increasing pressure on industries to shift to greener operational standards, it has become imperative for them to implement resilient NZCSC practises in close relation to circular economy metrics to achieve proper standards of operation. The shift to this new supply chain practice is a great transformation from traditional operating principles. So, there is a need to identify the challenges in facilitating this shift. In this context, the main aim of this study is to identify and understand the interrelation of challenges in implementing an NZCSC in current supply chain scenarios across industries. The necessary data for the pairwise comparison is obtained from industry experts and then compared using the DEMATEL method to analyse the interrelationships.

The results of DEMATEL as presented in Table 10 show the prominence and net/cause-effect of the challenges identified. This study identified 'Lack of management willingness' (NZC10) as the most critical barrier to developing a resilient net zero supply chain based on its high Sr + Sc value of 4.96. A study by Zhang et al.(2021)presents similar results on how top management should make it a priority to shift to NZCSC. Also, this barrier is among the cause group as the Sr-Sc value is (1.16) positive with all of the other challenges influencing it. The barrier with the second most importance is Difficulty to sustain (NZC13) with Sr + Sc value of 4.7 and Sr - Sc value of 3.45 which, being positive, puts it in the cause group. Just like C10, this barrier is influenced by all of the other 12 challenges, making NZC10 and NZC12 the two most critical challenges as per the DEMATEL procedure. Lack of transparency and trust (NZC7) with an Sr+Sc value of 4.41 and Sr-Sc value of 0.71 comes up as the third critical barrier after performing DEMATEL. Talus and Ason(2022) present similar findings on the importance of transparency. NZC7 is a part of the cause group owing to the positive Sr - Sc value. It influences a few challenges, namely, Knowledge gap among suppliers (NZC1), Conflicting procurement priorities (NZC5), Lack of collaboration among suppliers (NZC8), NZC10 and NZC13 while being influenced by High initial investment and ROI (NZC3), Lack of government policy (NZC4), Unclear benefits (NZC9), Lack of low carbon alternatives (NZC11) and NZC10.

Lack of collaboration among suppliers (NZC8) is the next barrier while moving down the order of criticality. It has a Sr + Sc value of 4.07 and a Sr-Sc value of 0.47 putting it in the cause group. It is influenced by NZC1, NZC3, NZ C4, NZC7, NZC9 and NZC10 while influencing NZC1, NZC2, NZC5, NZC7, NZC10 and NZC13. Knowledge gap among suppliers (NZC1), belonging to the cause group with Sr - Sc of 0.17 and Sr + Sc of 3.69 is the next one in order of criticality (Gong *et al.,* 2018). The barrier is influenced by NZC4, NZC7, NZC8, NZC9, NZC10 and NZC12 while influencing NZC5, NZC7, NZC8, NZC9, NZC10 and NZC13. Unclear benefits (NZC9) are the first barrier in the effect group owing to its negative Sr-Sc value (-1.82). Its Sr + Sc value is 2.89. This barrier is influencing quite a few other challenges, NZC1, NZC5, NZC6, NZC7, NZC8, NZC10 and NZC13.

Figure 3 shows the interrelation between all 13 challenges. Conflicting procurement priorities (NZC5) is the next barrier in the cause group. It has a Sr - Sc value of 1.04 and Sr + Sc value of 2.72. NZC5 is the seventh critical from the list of 13 challenges, influencing NZC7, NZC10 and NZC13 while being influenced by NZC1, NZC3, NZC4, NZC7, NZC8, NZC9, NZC10 and NZC11. The next barrier in the effect group is 'Lack of government policy (NZC4)'. It is influenced by NZC9, NZC11 and NZC12 while being influenced by NZC1, NZC3, NZC5, NZC7, NZC8, NZC10, NZC11 and NZC13. A Sr + Sc value of 2.61 makes it the eighth critical barrier while a Sr - Sc value of -1.05 puts it in the effect group of challenges. Government policies are necessary to encourage top management in companies to shift to NZCS. These policies further alleviate the lack of clarity on benefits as a major challenge in sustaining the new model (Chang *et al.,* 2021).

As per DEMATEL, High initial investment and ROI (NZC3) is the ninth barrier based on SR + SC values. A 1.97 in Sr + Sc and 1.5 in R-C make it a cause barrier. Based on the calculations, it is influenced by NZC4 alone while it influences NZC5, NZC7, NZC8, NZC10 and NZC13. With an R-C value of -1.16 and Sr + Sc value of 1.74, 'Lack of low carbon alternatives (NZC11)' is tenth in the list of criticalities while belonging to the effect group. NZC11 influences NZC4, NZC5, NZC7, NZC10 and NZC13 while being influenced by NZC4 alone. Influenced by NZC8 and influencing NZC10 and NZC13, the twelfth critical barrier, the non-availability of green suppliers (NZC2) has a Sr - Sc value of -0.23, making it one of the effective challenges. It has a Sr + Sc value of 1.18 which gives it the low criticality of twelfth among 13 challenges. Lack of consumer awareness and willingness (NZC6) is the least critical barrier according to the DEMATEL procedure with a Sr + Sc value of 1. It is a net effect barrier due to a Sr - Sc value of -0.47. The barrier influences NZC10 and NZC13 and is in turn influenced by just NZC9 alone.

The challenges, after performing a level partitioning procedure, are separated into six levels. The topmost level consists of Difficult to sustain (NZC13) and Lack of management willingness (NZC10). These challenges at the top level indicate that they are the least influential on other challenges, but they are influenced the most by other challenges (Figure 4). Table 13 explains the interrelationship between the barriers after level partitioning. The lack of enthusiasm in the administrative section of companies to switch to NZCSC is one still holding back the implementation of net zero carbon policies across industries (Ohene *et al.,* 2022). This combined with the difficulty in sustaining a newly deployed model shows how challenges NZC13 and NZC10 are not the most pivotal challenges but they are influenced by quite a few other challenges. NZC13 is influenced by every other 12 challenges identified in the model, implying that finding solutions for the other challenges would help solve the challenges posed by barrier NZC13. In level 1 challenges, Lack of management willingness comes next (NZC10). NZC10 is influenced by, just like the other level 1 barrier, every other 12 challenges. Firm action by the management is necessary for tackling the barriers faced in developing an

NZCS in companies (Jia *et al.,* 2019). The justification for this is how management willingness can be swayed by finding solutions for the other influencing challenges. Improving return on investment, clarifying the benefits of implementing net zero carbon policies and improving collaboration among different nodes of the supply chain can improve the trust of managerial authorities (Zhang *et al.,* 2022).

Non-availability of green suppliers (NZC2), Conflicting procurement priorities (NZC4) and Lack of transparency and trust (NZC7) make the level 2 challenges as per level partitioning. These challenges highlight the lack of trust and difference in opinion between the supply chain nodes (Babcock *et al.,* 2022). The scepticism of stakeholders is a major issue in sustaining a new supply chain model. Level 2 also shows the relation between procurement priorities, transparency and availability of alternatives. NZC7 and NZC4 are influenced by a range of other challenges, making them a priority barrier in level 2. NZC2 is mainly influenced by 'Lack of collaboration among suppliers (NZC8)'. Improving collaboration between several suppliers makes it easier to find more green suppliers among the supply chain nodes. This is the justification for NZC8 to NZC2 influence. Knowledge gap among suppliers (NZC1), Lack of consumer awareness and willingness (NZC6), Lack of collaboration among suppliers (NZC8) and Lack of low carbon alternatives (NZC11) make the level 3 challenges. The stakeholders do not understand the extent of damage unchecked carbon emissions do, in the long term, making it a key constraint in switching to NZCS (Burchardt *et al.,* 2021). These makeup challenges are more influential in setting up net zero carbon policies compared to level 2 and level 1 challenges. Resolving these in turn resolves the challenges in previous levels. Level 3 challenges are related to 'lack of knowledge and understanding between both suppliers and consumers'. These challenges are influenced by High initial investment and ROI (NZC3) and Unclear benefits (NZC4) which make the level 4 challenges. The justification for this influence is how customer willingness and lack of collaboration stem from unclear benefits and ROI for the customers and suppliers alike (Burchardt *et al.,* 2021). This could be improved with better government policies, making sure that all the shareholders in the project are adequately compensated. Lack of government policy (NZC4) makes the level 5 barrier which is directly influenced by the Immaturity of carbon-accounting techniques (NZC12). Improved accounting is necessary to classify emission data across localities, helping to focus on the proper implementation of NZCS policies (Kennedy *et al.,* 2011). The immaturity in carbon accounting is responsible for the lack of proper policies which leads to a lack of support for the different nodes in the supply chain, leading to a loss of motivation in implementing the net zero carbon policies. Level 6 is the most influential barrier. Finding solutions for this barrier is of utmost importance to achieve proper results. A clear definition of the scope of carbon emissions is the first step in understanding carbon emissions and reducing the carbon footprint on any scale (Kennedy *et al.,* 2011). Based on the understanding, a roadmap is proposed to tackle the challenges faced in building a resilient NZCSC.

Similar research on the topic of net zero carbon has been done in recent years. A study on understanding the socio-economic environmental challenges focusing on knowledge-based net zero carbon supply chains done by Singh *et al.* (2022) depicts how the primary stakeholders should have active roles in implementing net zero practices. The development of strong policies with government aid is also an important factor in achieving success as reported by the study. The current paper shows similar results, with lack of management willingness being the most critical barrier as per DEMATEL. Findings from studies were done by Tumpa *et al.,* (2019) and Mokhtadir *et al.,* (2018) further strengthen the results of the current paper. These papers show how green procurement, financial constraints and lack of policies are significant challenges in improving the emissions from supply chains. Further, the implementation of circular economy practices can give directions to the global market, aiding in the switch to sustainable and clean supply chains. Identifying the critical success factors and the challenges faced helps in the easier implementation of the policies (Mokhtadir *et al.,* 2020). This study fills the gaps in research related to the challenges in implementing net zero carbon policies across supply chains and adds to the literature related to net zero carbon supply chains.

5.1 Development of Roadmap

Regarding the results of level partitioning, the study formulates a roadmap for achieving a resilient NZCSC. According to level partitioning, the challenges in the lowermost level are the most critical ones in terms of influence. Correcting that challenge helps tackle the other higher-level challenges. Closely following the results of level partitioning, the study developed a road map (Refer to Figure 5) to help in implementing the NZCSC practises. It follows a bottom-up problem-solving approach with emphasis on solving challenges mentioned in lower levels which partially solves the upper-level challenges. This roadmap is developed with major emphasis on tackling the challenges listed in Table 1 and the results obtained after the level partitioning procedure. It is a generalised problem-solving approach for eradicating the underlying challenges in implementing an NZCSC within the three industrial scenarios discussed in this study. Using this supporting framework, industry experts can further improve the efficacy of the framework with more in-depth studies on the individual solutions for the challenges.

As per the results of level partitioning, improving carbon accounting and policy-making to sustain the model comes first in the processing pipeline. Strong policies help in creating a well-planned model which can be sustained for years without much revision. It is evident that developing new policies and improving carbon accounting are two of the most critical challenges as per DEMATEL and level partitioning. The Indian government has planned new policies according to the latest Union Budget. Even though policies are being developed, enforcement still lags. These policies should focus on regulating the investment by companies and also make allowance (financial aid) for smaller industries to embark on the shift to net zero carbon practices. When new policies are set up, the benefits scheme acts as an incentive for customers to be updated with alternate products with low emission rates and suppliers to deal with environment-friendly, green sources. The governmental aid can help small-scale industries to shift to alternate sources and implement green procurement methods. Training to industry personnel about developing sustainable policies at the industry level should be provided which will aid in improving management enthusiasm and effective implementation of a resilient NZCSC model.

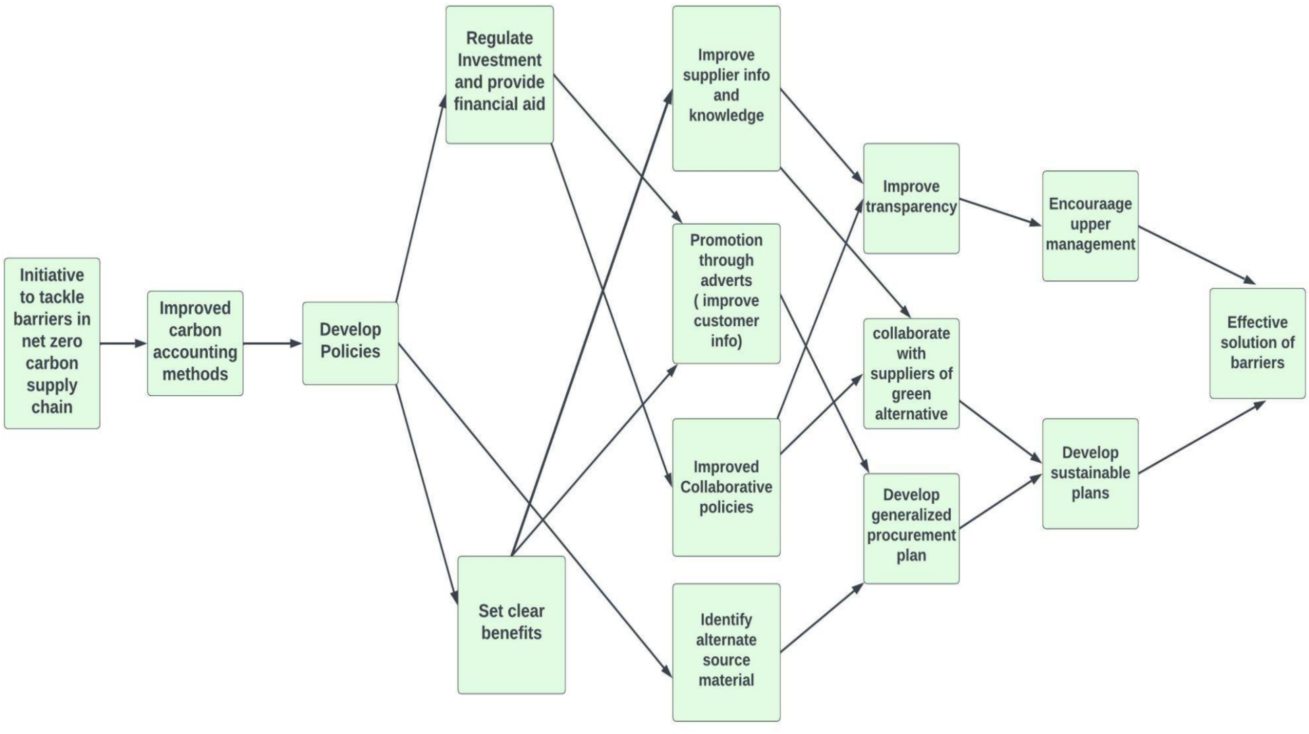

Figure 5. Roadmap for tackling the challenges identified in this study

6. Implications

6.1 Theoretical implications

The concept of sustainable supply chains and its development has become a major talking point in recent times. The current research seeks to identify the interrelation of challenges faced in the implementation of NZCSC across various industries. The research findings are geared towards overcoming the challenges and building resilient NZCSCs in various sectors to combat global emissions.

The research identifies the important challenges in building a resilient NZCSC and simultaneously aims to find their interrelationship. Then they are prioritised accordingly to establish the key factors in building an NZCSC. The challenges identified and their interrelationships can serve as a base for future studies on the development of a sustainable supply chain. The various challenges have been weighed using DEMATEL using inputs from industry experts.

DEMATEL is a very useful tool that helps to establish the interrelationship between the various challenges chosen. The interrelationship is established based on the influence of one challenge over the other. The findings in the study indicate that the critical challenges towards building a resilient NZCSC are the immaturity of carbon accounting techniques and lack of government policy. Simultaneously, lack of management willingness and the difficulty to sustain was relatively not as critical a challenge towards the same. Using the level partitioning procedure from TISM, an MCDM technique, a roadmap has been developed which can be incorporated into the development of NZCSCs. This study demonstrates the scope of DEMATEL and TISM in future studies for the development of sustainable supply chains.

The methodology followed in this study can be used to identify challenges and to push for further advancement of net zero carbon goals in other sectors such as manufacturing, energy production, infrastructure development, etc. Furthermore, this study contributes to the existing literature on supply chain management and sustainable operations by compiling the findings from various studies on the development of sustainable supply chains in a variety of industries. The incorporation of numerical analysis techniques, DEMATEL and TISM, can be seen as a novelty in this study.

6.2 Managerial implications

The primary objective is to overcome the challenges in building an NZCSC. To accomplish the same, the practitioners and policymakers involved in the development and implementation of supply chains have to take a multitude of factors into account. Past studies attempt to define the concept of sustainable supply chain management (Carter *et al.,* 2008) and to converge the interdisciplinary factors involved in the development of a sustainable supply chain (Linton *et al.,* 2007) for the personnel involved. However, the current study provides insights that can enable the personnel involved in supply chain planning and execution to understand how the challenges investigated can impact the emissions in a supply chain. Understanding the interrelationship of the various challenges explored and their order of importance will help the practitioners involved in supply chain development build a roadmap towards a resilient NZCSC.

The solutions brought forward in this study attempt to assist practitioners involved in supply chain development to build a sustainable and resilient NZCSC network. The main benefits of implementing the proposed solutions are:

- **Climate Impact**: By addressing the challenges discussed in the study, organisations can reduce their emissions and can bring positive climate impact. This in turn can help organisations meet the environmental, social, and governance criteria and meet their sustainability goals.
- **Efficiency**: By implementing an NZCSC, organisations will automatically reduce the consumption of energy and water thereby generating less waste. This in turn will reduce miscellaneous spending. Moreover, this would also emphasize extracting maximum output from minimal input.
- **Appeal**: With consumers growing more and more environmentally conscious and demanding responsibly sourced goods, adopting an NZCSC can be very effective in appealing to the climate-conscious buyer.
- **Transparency**: To build an NZCSC, details regarding how operations are carried out at each node of the supply chain need to be known. This can help promote information sharing across various nodes of the supply chain and in turn, can make the supply chain more streamlined

For the benefit of the supply chain practitioners, a roadmap has been created from the outcomes of this study. The application of this roadmap can be an effective tool for the personnel involved in supply chain development to move in the right direction towards building a resilient NZCSC and to efficiently allocate resources for the same.

6.3 Social implications

The implementation of an NZCSC has a range of positive effects on human lifestyles. Prior studies by Pagell *et al.* (2009) and Seuring *et al.* (2008) discuss the importance of social factors as an important element and emphasise its consideration in developing sustainable supply chains along with environmental and economic factors. As such, the findings derived from the study can be applied to building a responsible supply chain that benefits society in a variety of ways. Some of the aforementioned benefits include:

- **Employment and skill building**: The shift of supply chain operations from a traditional model to a net-zero carbon model requires a shift in operational thinking, reconsidering various nodes within the supply chain and personnel skilled in the execution of sustainable supply chain practices. A change of such magnitude will create a need for relevant personnel with competent skills in the NZCSC building.
- **Environmental cleanliness**: By implementing an NZCSC, the amount of GHG emissions would fall significantly. Additionally, this would also lead to a reduction of waste generated. This would help in the improvement of air, water and land quality. By extension, this implies better health, clean food and clean water.
- **Ethical Labour:** Transparency of processes is a key element in building an NZCSC. Thus, it enables the monitoring of supply chain practices and helps expose the discrepancies in labour practices which can then be addressed properly to ensure socially responsible sourcing within the supply chain.

7. Conclusion

This research defines and analyses 13 barriers to implementing resilient NZCSC after a thorough literature review and discussions with supply chain field experts. Several studies commenting on the importance of NZCSC exist. This study aims to provide supporting material to stakeholders in implementing the necessary actions in achieving the target of net zero carbon, using a comprehensive study with an emphasis on mathematical results. Based on the data received from a panel of experts, an interrelation chart of the barriers is made. Identifying the lack of management willingness as the most critical and lack of consumer awareness as the least critical barriers were one of the major outcomes of the study. Identifying the interrelation among these would help the policy makers in shifting to NZCSC from the traditional supply chain. Hence the study evaluates these barriers using DEMATEL and Level Partitioning that provides a structural hierarchy based on the barriers influencing each other concerning the three chosen case industries, sugar, paper pulp and construction. Level partitioning aids in finalising the roadmap, which was another major outcome of the study. The roadmap follows a bottoms-up solution procedure, developed to tackle the identified challenges based on their criticality as per DEMATEL and acts as a comprehensive guide for policy makers to focus their implementation of NZCSC policies. These actions can help accelerate the move towards meeting the various SDGs and thereby multiply the climate and sustainability impact of an institution positively. The implications mentioned in the study sheds light on prior studies conducted in this field and how the current paper tries to improve the literature on developing sustainable and resilient NZCSCs. With a shift in managerial approach to net zero carbon policies, more opportunities for social and ecological improvement are possible.

Although the study explores decisional factors which influence the development of a resilient NZCSC, the paper inevitably has limitations. The DEMATEL method may be a highly optimised decision-making procedure, but the data it works on is limited in the context of this study (only five experts). With a much more diverse panel, the methodology could be further optimised. Also, the solution roadmap proposed is limited to a broad case of challenges. Those policy suggestions can be further streamlined to suit the needs of specific industries. Hence, future studies should aim to incorporate a larger and more diverse expert panel across the world. This will provide a much clearer understanding of the challenges faced by NZCSC. Emphasis could also be made on incorporating other MCDM methodologies along with DEMATEL and level partitioning to increase the accuracy of the results.

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Appendix

Table A1. Data from Expert 2

	NZC1	NZC2	NZC3	NZC4	NZC5	NZC6	NZC7	NZC8	NZC9	NZC10	NZC11	NZC12	NZC13
NZC1	-	-	-	-	3	-	2	3	3	-	-	-	2
NZC2	-	-	-	-	-	-	-	-	-	3	-	-	2
NZC3	-	-	-	-	3	-	-	-	2	2	-	2	2
NZC4	-	-	2	-	-	-	-	-	-	3	2	-	2
NZC5	-	-	-	-	-	-	4	-	-	-	-	-	2
NZC6	-	-	-	-	-	-	-	-	-	1	-	-	3
NZC7	2	-	-	-	3	-	-	3	-	2	-	-	2
NZC8	1	2	-	-	-	-	2	-	-	2	-	-	2
NZC9	-	-	-	3	2	3	-	2	-	4	-	-	1
NZC10	2	-	-	-	-	-	2	3	-	-	-	-	3
NZC11	-	-	-	3	2	-	-	-	-	2	-	-	2
NZC12	2	-	-	2	-	-	-	-	-	-	-	-	3
NZC13	-	-	-	-	-	-	-	-	-	3	-	-	-

Table A2. Data from Expert 3

	NZC1	NZC2	NZC3	NZC4	NZC5	NZC6	NZC7	NZC8	NZC9	NZC10	NZC11	NZC12	NZC13
NZC1	-	-	-	-	3	-	3	3	3	-	-	-	3
NZC2	-	-	-	-	-	-	-	-	-	3	-	-	3
NZC3	-	-	-	-	3	-	-	-	1	5	-	-	5
NZC4	-	-	5	-	-	-	-	-	-	5	3	-	5
NZC5	-	-	-	-	-	-	3	-	-	-	-	-	3
NZC6	-	-	-	-	-	-	-	-	-	3	-	-	3
NZC7	3	-	-	-	3	-	-	5	-	3	-	-	3
NZC8	5	3	-	-	-	-	5	-	-	-	-	-	5
NZC9	-	-	-	5	3	3	-	3	-	5	-	-	3
NZC10	3	-	-	-	-	-	5	5	-	-	-	-	3
NZC11	-	-	-	3	5	-	-	-	-	3	-	-	1
NZC12	3	-	-	3	-	-	-	-	-	-	-	-	1
NZC13	-	-	-	-	-	-	-	-	-	5	-	-	-

Table A3. Data from Expert 4

	NZC1	NZC2	NZC3	NZC4	NZC5	NZC6	NZC7	NZC8	NZC9	NZC10	NZC11	NZC12	NZC13
NZC1	-	-	-	-	4	-	4	2	-	-	-	-	2
NZC2	-	-	-	-	-	-	-	-	-	2	-	-	4
NZC3	-	-	-	-	4	-	-	-	-	4	-	-	4
NZC4	-	-	4	-	-	-	-	-	-	4	4	-	4
NZC5	-	-	-	-	-	-	4	-	-	-	-	-	4
NZC6	-	-	2	2	2	-	-	-	-	2	-	-	2
NZC7	4	-	-	-	4	-	-	4	-	2	-	-	2

	NZC1	NZC2	NZC3	NZC4	NZC5	NZC6	NZC7	NZC8	NZC9	NZC10	NZC11	NZC12	NZC13
NZC1	-	-	-	-	4	-	4	2	-	-	-	-	2
NZC8	5	4	-	-	-	-	4	-	-	-	-	-	4
NZC9	-	-	-	5	4	4	-	4	-	-	-	-	2
NZC10	4	-	-	-	-	-	4	4	-	-	-	-	4
NZC11	-	-	-	4	5	-	-	-	-	2	-	-	2
NZC12	4	-	-	4	-	-	-	-	2	2	2	-	2
NZC13	-	-	-	-	-	-	-	-	-	4	-	-	-

Table A4. Data from Expert 5

	NZC1	NZC2	NZC3	NZC4	NZC5	NZC6	NZC7	NZC8	NZC9	NZC10	NZC11	NZC12	NZC13
NZC1	-	-	-	-	2	-	2	2	3	-	-	-	2
NZC2	-	-	-	-	-	-	-	-	-	2	-	-	3
NZC3	-	-	-	-	3	-	-	-	1	4	-	-	4
NZC4	-	-	4	-	-	-	-	-	-	4	2	-	4
NZC5	-	-	-	-	-	-	3	-	-	-	-	-	3
NZC6	-	-	-	-	-	-	-	-	-	2	-	-	2
NZC7	2	-	-	-	2	-	-	4	-	2	-	-	2
NZC8	4	2	-	-	-	-	4	-	-	-	-	-	4
NZC9	-	-	-	4	2	2	-	3	-	4	-	-	2
NZC10	3	-	-	-	-	-	4	4	-	-	-	-	3
NZC11	-	-	-	3	4	-	-	-	-	2	-	-	1
NZC12	2	-	-	3	-	-	-	-	-	-	-	-	1
NZC13	-	-	-	-	-	-	-	-	-	4	-	-	-

Table A5. L2 iteration

	Influencing	Influenced by	Intersection set	Levels
NZC1	NZC5, NZC7, NZC8, NZC9, NZC1	NZC4, NZC7, NZC8, NZC9, NZC12. NZC1	NZC7, NZC8, NZC9, NZC1	
NZC2	NZC2	NZC8, NZC2	NZC2	2
NZC3	NZC5, NZC7, NZC8, NZC3	NZC4, NZC3	NZC3	
NZC4	NZC1, NZC3, NZC5, NZC7, NZC8, NZC11, NZC4	NZC9, NZC11, NZC12, NZC4	NZC11, NZC4	
NZC5	NZC7, NZC5	NZC1, NZC3, NZC4, NZC7, NZC8, NZC9, NZC11, NZC5	NZC7, NZC5	2
NZC6	NZC6	NZC9, NZC6	NZC6	
NZC7	NZC1, NZC5, NZC8, NZC7	NZC1, NZC3, NZC4, NZC5, NZC8, NZC9, NZC11, NZC7	NZC1, NZC5, NZC8, NZC7	2
NZC8	NZC1, NZC2, NZC5, NZC7, NZC8	NZC1, NZC3, NZC4, NZC7, NZC9,, NZC8	NZC1, NZC7, NZC8	

	Influencing	Influenced by	Intersection set	Levels
NZC9	NZC1, NZC5, NZC6, NZC7, NZC8, NZC9	NZC1, NZC9	NZC1, NZC9	
NZC10	NZC1, NZC5, NZC7, NZC8, NZC13, NZC10	NZC1, NZC2, NZC3, NZC4, NZC5, NZC6, NZC7, NZC8, NZC9, NZC11, NZC12, NZC13, NZC10	NZC1, NZC5, NZC7, NZC8, NZC13, NZC10	1
NZC11	NZC4, NZC5, NZC7, NZC11	NZC4, NZC11	NZC4, NZC11	
NZC12	NZC1, NZC4, NZC12	NZC12	NZC12	
NZC13	NZC10, NZC13	NZC1, NZC2, NZC3, NZC4, NZC5, NZC6, NZC7, NZC8, NZC9, NZC10, NZC11, NZC12, NZC13	NZC10, NZC13	1

Table A6. L3 iteration

	Influencing	Influenced by	Intersection set	Levels
NZC1	NZNZC8, NZNZC9, NZNZC1	NZNZC4, NZNZC8, NZNZC9, NZNZC12. NZNZC1	NZNZC8, NZNZC9, NZNZC1	3
NZC2	NZC2	NZC8,NZC2	NZC2	2
NZC3	NZC8,NZC3	NZC4,NZC3	NZC3	
NZC4	NZC1,NZC3,NZC8,NZC11,NZC4	NZC9,NZC11,NZC12,NZC4	NZC11,NZC4	
NZC5	NZC7,NZC5	NZC1,NZC3,NZC4,NZC7,NZC8, NZC9,NZC11,NZC5	NZC7,NZC5	2
NZC6	NZC6	NZC9,NZC6	NZC6	3
NZC7	NZC1,NZC5,NZC8,NZC7	NZC1,NZC3,NZC4,NZC5,NZC8, NZC9,NZC11,NZC7	NZC1,NZC5,NZC8,NZC7	2
NZC8	NZC1,NZC8	NZC1,NZC3,NZC4,NZC9,NZC8	NZC1,NZC8	3
NZC9	NZC1,NZC6,NZC8,NZC9	NZC1,NZC9	NZC1,NZC9	
NZC10	NZC1,NZC5,NZC7,NZC8,NZC13,NZC10	NZC1,NZC2,NZC3,NZC4,NZC5, NZC6,NZC7,NZC8,NZC9,NZC11,NZC12,NZC13,NZC10	NZC1,NZC5,NZC7,NZC8,NZC13,NZC10	1
NZC11	NZC4,NZC11	NZC4,NZC11	NZC4,NZC11	3
NZC12	NZC1,NZC4,NZC12	NZC12	NZC12	
NZC13	NZC10,NZC13	NZC1,NZC2,NZC3,NZC4,NZC5,NZC6, NZC7,NZC8,NZC9,NZC10,NZC11,NZC12,NZC13	NZC10,NZC13	1

Table A7. L4 iteration

	Influencing	Influenced by	Intersection set	Levels
NZC1	NZC8,NZC9,NZC1	NZC4,NZC8,NZC9,NZC12.NZC1	NZC8,NZC9,NZC1	3
NZC2	NZC2	NZC8,NZC2	NZC2	2
NZC3	NZC3	NZC4,NZC3	NZC3	4
NZC4	NZC3,NZC4	NZC9,NZC12,NZC4	NZC4	

	Influencing	Influenced by	Intersection set	Levels
NZC5	NZC7,NZC5	NZC1,NZC3,NZC4,NZC7,NZC8, NZC9,NZC11,NZC5	NZC7,NZC5	2
NZC6	NZC6	NZC9,NZC6	NZC6	3
NZC7	NZC1,NZC5,NZC8, NZC7	NZC1,NZC3,NZC4,NZC5,NZC8, NZC9,NZC11,NZC7	NZC1,NZC5,NZC8,NZC7	2
NZC8	NZC1,NZC8	NZC1,NZC3,NZC4,NZC9,NZC8	NZC1,NZC8	3
NZC9	NZC9	NZC9	NZC9	4
NZC10	NZC1,NZC5,NZC7, NZC8,NZC13,NZC10	NZC1,NZC2,NZC3,NZC4,NZC5, NZC6,NZC7,NZC8,NZC9,NZC11, NZC12,NZC13,NZC10	NZC1,NZC5,NZC7,NZC8,NZC13,NZC10	1
NZC11	NZC4,NZC11	NZC4,NZC11	NZC4,NZC11	3
NZC12	NZC4,NZC12	NZC12,	NZC12	
NZC13	NZC10,NZC13	NZC1,NZC2,NZC3,NZC4,NZC5, NZC6,NZC7,NZC8,NZC9,NZC10, NZC11,NZC12,NZC13	NZC10,NZC13	1

Table A8. L5 iteration

	Influencing	Influenced by	Intersection set	Levels
NZC1	NZC8,NZC9,NZC1	NZC4,NZC8,NZC9,NZC12 .NZC1	NZC8,NZC9,NZC1	3
NZC2	NZC2	NZC8,NZC2	NZC2	2
NZC3	NZC3	NZC4,NZC3	NZC3	4
NZC4	NZC4	NZC12,NZC4	NZC4	5
NZC5	NZC7,NZC5	NZC1,NZC3,NZC4,NZC7, NZC8,NZC9,NZC11,NZC5	NZC7,NZC5	2
NZC6	NZC6	NZC9,NZC6	NZC6	3
NZC7	NZC1,NZC5,NZC8, NZC7	NZC1,NZC3,NZC4,NZC5, NZC8,NZC9,NZC11,NZC7	NZC1,NZC5,NZC8,NZC7	2
NZC8	NZC1,NZC8	NZC1,NZC3,NZC4,NZC9, NZC8	NZC1,NZC8	3
NZC9	NZC9	NZC9	NZC9	4
NZC10	NZC1,NZC5,NZC7, NZC8,NZC13,NZC10	NZC1,NZC2,NZC3,NZC4, NZC5,NZC6,NZC7,NZC8, NZC9,NZC11,NZC12,NZC13,NZC10	NZC1,NZC5,NZC7,NZC8, NZC13,NZC10	1
NZC11	NZC4,NZC11	NZC4,NZC11	NZC4,NZC11	3
NZC12	NZC4,NZC12	NZC12	NZC12	
NZC13	NZC10,NZC13	NZC1,NZC2,NZC3,NZC4, NZC5,NZC6,NZC7,NZC8, NZC9,NZC10,NZC11,NZC12,NZC13	NZC10,NZC13	1