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Barrier analysis for carbon regulatory environmental policies implementation in manufacturing supply chains to achieve zero carbon

Devika Kannan[a,*], Rahul Solanki[b], Arshia Kaul[c], P.C. Jha[b]

[a] Center for Sustainable Supply Chain, Department of Technology and Innovation, University of Southern Denmark, Odense M - 5230, Denmark
[b] Department of Operational Research, Univeristy of Delhi, Delhi, India
[c] ASMSOC, NMIMS University, Mumbai, India

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ABSTRACT

Many pressing challenges that perennially affect countries today are those related to environmental sustainability. As major entities, business organizations play a primal role in boosting the economy, stakeholders are increasingly under pressure to achieve net zero emissions. However, in emerging economies, these entities are scarcely inclined towards implementation of newer environmental policies as they're oblivious to perils of excessive carbon emissions and its consequences. Therefore, it is essential to look for sustainability measures to secure a system that reduces the carbon footprint and ultimately reaches a zero-carbon future. This research proposes a method to identify and assess the barriers of carbon regulatory policies (CRPs) so that advancements in carbon emission reduction practices can be pursued; we present a specific focus on developing nations. An integrated multi-criteria decision-making approach is proposed to achieve environmental sustainability. Initially, the Best Worst Method is used to determine the relative importance of the barriers in the implementation of regulatory policies. Subsequently, we utilize Decision Making Trial and Evaluation Laboratory to establish interrelationships among the barriers of carbon policies. To elucidate the application of the proposed novel framework, a case considering multiple manufacturing firms with multiple stakeholders in India is examined.

1. Introduction

In recent years, supply chains have prominently emphasized on ecological sustainability to achieve United Nations' Sustainable Development Goals (SDGs) (Govindan, 2022; Sachs et al., 2021; United Nations, 2016) . The rise in industrial activities and their impacts on a sustainable future have gained the interest of policy experts and ecological activists who advocate for more stringent regulations to curb carbon emissions (Ilyas et al., 2020). It is important to note that industrial growth leads to perils such as excessive waste generation, financial distress and unsafe work environment (Mani et al., 2018). Governments across the globe are finally beginning to respond to these concerns for advancement of sustainable development agenda. Therefore, organizations have started to integrate ecological sustainability goals with strategic, tactical, and operational levels of supply chains (Gupta et al., 2021). A few studies have highlighted the importance of ecological sustainability through emerging economies perspective (Álvarez Jaramillo et al., 2019). Sustainable development augments the need of zero-carbon future, motivating industries to adopt newer environmental policies. Such novel practices need further enhancement because they incorporate economic, ecological, and social sustainability aspects, which broadens sustainability principles through SCs. Currently, many national governments have sought different carbon environmental policies to enhance ecological sustainability and ensure sustainable development in their attempt to move towards a zero-carbon society (see Table 1).

The idea of sustainable development is based on building innovative strategies that can efficiently withstand various impediments within manufacturing processes of SC. A major concern that hampers environmental sustainability over the years are the Carbon Emissions (CEs) produced through various activities of the businesses. Zhang et al. (2021) identifies China as most carbon emitting nation in the world with 9.3 GT of total CO_2 emissions. Following closely behind China is USA at second place with 4.8 GT and India on the 3rd position with 2.2 GT, which accounts for 6.8% of global emissions. In 2015, 196 countries agreed to ensure that their development will strive towards sustainability and reduce global warming to well below 2 °C which, in ideal situations, should be 1.5 °C above the industrial levels. To meet these

* Corresponding author.
E-mail address: deka@iti.sdu.dk (D. Kannan).

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Table 1
Current carbon regulatory environmental policies around the world.

Carbon Environmental Policy	Description
Carbon Tax	A penalty is imposed on business entities or industries that produce CO_2 emissions through their operations; a fixed price is set by the respective governments.
Carbon Cap	A fixed number of annual permits allows business entities to emit certain amount of CO_2 emissions; hence, the limited amount of permits becomes the 'Cap' on emissions. If a business entity produces higher emissions than its defined CAP, a fine is imposed.
Carbon Cap and Trade	Fixed number of allowances (credits), equal to the desired cap on total emissions, are distributed or sold to business entities. A firm operating under this policy has flexibility to buy or sell credits if they fall short of credits or generate excess.
Carbon Offset	A measure to curtail CO_2 emissions or equivalent greenhouse gases emissions through imposing a penalty for emissions beyond strict capacity. Although business entities cannot trade carbon credits, they can maintain an allowance by investing in projects such as solar or wind farms, planting trees, or preserving forests.

goals, global carbon emissions levels must be reduced by 45% by 2030 from the levels estimated in 2010 with the goal of eventually reaching net-zero emission levels by 2050 (Wu et al., 2022). A massive rise in greenhouse gas emissions occurred in 2020; the global scenario averaged mole fractions of CO_2 which exceeded 410 parts per million. One consequence of the COVID-19 pandemic was a reduction of human activities, which resulted in CO_2 emissions falling. Emerging economies demonstrated a massive decline of 10% in their emissions, and a 4% reduction in emissions was observed in developed countries in 2019. However, this reduction is only temporary, since emissions once again accelerated when the world began to demonstrate a recovery from the pandemic. With an alarming production of carbon emissions and their negative impact on the environment, businesses need to ensure that they align their activities so their carbon emission levels are considerably reduced. Their contribution to the economy cannot merely be in terms of economic contributions; instead, it must consider all activities that lead to overall long-term sustainability (Xu et al., 2022). Immense global pressure on all nations makes it imperative to contribute towards environmental sustainability and adopt environmental policies in tandem with global standards. Business organizations are important stakeholders who also need to follow suit (Kusi-Sarpong et al., 2019).

From the Indian perspective, government is closely monitoring the implementation of ecological measures at various sectors and, more importantly, seeking to mitigate climate degradation and carbon emissions issues. Consecutively, the prime minister of India has announced few measures to curb emissions in the energy sector, that is, 20% ethanol blending in petrol by 2025. The benefits of the blending will help in saving of USD $ 4 billion foreign exchange in imports, lower carbon emissions, increase in enhancing security, improvement in air quality, promotion of farmers' incomes, creation of employment and better opportunities for investment. Manufacturing industries are considered to be one of the major contributors to CEs, where supply chains are subjected to various policies (An et al., 2021). Globally, efforts are being made to curb CEs across the manufacturing sector; emerging economies in the past have introduced some strategies to reduce emissions (Xu et al., 2019). As per Christina Figueres, "*In order to be a decarbonized economy by the year 2050 the carbon emissions curve must bend by 2030*" (Ghosh, 2019). Further, it is essential to understand that the major contributor to economic growth in developing countries comes from Small and Medium Enterprises (SMEs), companies that are considered the backbone for any developing nation. In India, SMEs contribute 45% of the manufacturing output, which accounts to an 8% contribution to the Indian GDP (Bagale et al., 2021). In order to achieve sustainability among SMEs of the manufacturing sector, effective implementation of policies is required at various stages, starting with the procurement of raw materials, product designing, production, transportation, collection, and disposal. These organizational operations are known to be not environmentally friendly; indeed, many of these activities pose a threat to the environment (Rahman et al., 2020). The growing environmental hazards of manufacturing need to be controlled since governmental policies are not aligned with global stringent policies. Therefore, manufacturing firms have come under great pressure from various dimensions globally to reduce carbon footprints (Xu et al., 2022).

Equipping SCs with effective understanding of ecological sustainability, many studies illustrate CE reduction measures by developing optimization models that incorporate a variety of carbon policies (Saxena et al., 2018). Moreover, it is interesting to note that barriers pertaining to manufacturing SCs, such as low carbon design, lack of in-house reverse logistics, or improper waste disposal, are different from those of other SCs. From the perspective of emerging economies, lack of sustainable organizational improvements across manufacturing sectors is due to unaccountability and non-regularization of business entities, which leads to higher CEs and waste generation; therefore, fewer investments and gains through government schemes are attained. To improve ecological sustainability and to curtail emissions through manufacturing SCs, carbon regulatory policy mechanisms need to be introduced. To the best of our knowledge, no study has explored or developed a multi-criteria decision-making model that determines barriers for the implementation of CRPs for manufacturing SCs. In light of the ongoing discussion, this research highlights the following research objectives:

1. What are the possible barriers for carbon regulatory policies implementation in manufacturing SCs?
2. What is the relative importance of these identified barriers for different types of manufacturing firms?
3. What interrelationships exist among the barriers involved in implementation of carbon regulatory policies and how should the most influential barriers be identified?

In order to answer the aforementioned questions, we propose a novel multi-criteria decision-making model for analyzing barriers to introduce and adopt CRPs within an industrial setting. The research renders itself useful to managers of the business organizations by guiding them to improve business performance through ecological sustainability. The research framework developed is validated with a real-life case study incorporating six Indian goods manufacturing firms. These case firms have been considered as they are major contributors of CEs in entire manufacturing sector. The rest of the paper is organized as follows. Section 2 gives the detailed literature in the field of implementation of CRPs in SC for sustainable development. Proposed research methodology is presented in section 3. The industrial application and results of the proposed methodology is presented in section 4. Section 5 provides detailed discussion. Finally, implications and conclusions are explored in sections 6 and 7, respectively.

2. Literature review

The constant need for ecological sustainability around the globe makes it imperative for business organizations to reduce carbon emissions at different levels of supply chain. The following sub-sections aid in elaborating environmental sustainability of manufacturing SC through implementation of carbon regulatory environmental policies. Section 2.1 presents the need of CRPs for ecological sustainability, Section 2.2 highlights the importance of zero carbon and sustainable development goals for SC, Section 2.3 discusses CRPs' implementation barriers in detail, and Section 2.4 builds on novelty and explores the motivation for present research.

2.1. Carbon regulatory policies for environmental sustainability in supply chain

Ecological sustainability has gained immense attention from researchers and industrial experts in recent years. Emission regulation is an important feature of environment sustainability, and it helps to mitigate excessive carbon emissions (Y. An et al., 2021). Various governments across the globe have adopted diverse regulatory policies due to their significant role in green development (Zhang, G. et al., 2021). As a pre-requisite to restrict firms' emissions, carbon regulations were introduced in the 1970s in the United States under the Clean Air Act (Calel, 2013). However, it was only after the implementation of 'Kyoto Protocol' in 2005 that significant focus on carbon emissions in SCs gained importance (Du et al., 2017). The four different carbon regulatory mechanisms in use are carbon offset, carbon tax, carbon cap, and carbon cap-trade (Waltho et al., 2019; Zhou et al., 2021). Nevertheless, researchers are eager to analyze the macro level perspective of CRPs' impact and feasibility (Cheng et al., 2016; Zhang et al., 2019). Lately, there has been a growth in the number of studies incorporating and integrating CRPs into operational, manufacturing, coordination, and inventory decisions of SCs (Halat and Hafezalkotob, 2019). A few studies analyze how regulatory policies are better than imposing penalties on the SCs in a bid to be more sustainable (Gandhi et al., 2018; Sim and Kim, 2021). Furthermore, a few studies address sustainable SC sourcing and network design incorporating CRPs (Saberi, 2018). Adoption of such sustainability practices in SCs requires extensive support from top management, strategic development, and external decision-making bodies. In the literature, researchers have investigated different ways of mitigating carbon emissions throughout the SCs (Zhang et al., 2020). One of the ways to reduce emissions is by incorporating emissions minimizing technology (Balcombe et al., 2018). Inventory issues under carbon policies in multi-echelon SCs are also thoroughly investigated (Manupati et al., 2019). Further, this study establishes the role of collaboration among different SC partners which is an important parameter for reducing excessive carbon emissions. However, manufacturing firms are still vulnerable due to presence of multiple constraints while executing and implementing such regulatory policies, resulting in reduced economic and ecological performance of the entire SC. Therefore, this section investigates the extant literature that focuses on the different policies for environmentally sustainable development of the SCs.

The above-mentioned CRPs are embodied in SCs at various levels. Carbon tax is one of the most widely implemented policies to lower carbon emissions levels. It is relatively easy to be implemented because it can be merged in the existing tax system. This policy offers price stability, but uncertainties regarding emission levels persist (Zhang, H. et al., 2021). The main challenge with the carbon tax policy is in pricing the carbon; decision-makers always tend to keep the prices high to reduce emissions, but it should also be low enough that it doesn't hamper economic development. A solution that emerged is the carbon cap policy. Carbon cap is inducted as a measure of reducing emissions through SCs, where a certain limit of CEs is allotted to a firm. He et al. (2019) presented a carbon cap model that restricts emissions due to transportation; this model sets a bar on per unit carbon emissions produced due to transportation. A third option, the most practiced carbon regulatory policy, is the cap-and-trade policy, where carbon credits can be bought and sold under strict regulations. Xu et al. (2019) examined coordination and decision mechanisms for sustainable SC under cap-and-trade policy. The least explored carbon regulatory policy is carbon offset, which places a cap on the SC emissions and penalizes any additional emissions. Unlike the cap-and-trade policy, it does not allow a firm to sell or buy carbon credits. Given the extant literature on carbon policies, to the best of our knowledge there is limited research which has concentrated on the implementation of carbon policies in developing nations. Moreover, we observed that no such study has concentrated on the implementation of policies in manufacturing sector SMEs of developing nations.

2.2. Zero-carbon future for supply chain

Mitigating carbon emissions through manufacturing has become a significant hurdle for policymakers worldwide. Due to expansive use of natural resources in emerging economies, this concern becomes more compelling. Consequently, few studies have sought to adopt different strategies and policies to achieve carbon neutrality targets (Qin et al., 2021). There are political and ideological constraints which further emphasize the need for entrepreneurial actors to modify the preferences for emission reduction legislation. Chien et al. (2021) exemplified how long-term temperature targets must be achieved by focusing on net-zero emissions. This can be attained by implementing changes in the key carbon emitter sectors which include human activities, consumption of energy, and utilization of land (Rogelj et al., 2015; Bailey et al., 2021; Wimbadi and Djalante, 2020). From the net-zero emissions perspective, eco-efficient products manufactured through eco-innovations contribute to the reduction of carbon emissions to a large extent (Zhuang et al., 2021). Furthermore, Rehman Khan and Yu (2021) examined 415 manufacturing industries and found that an efficient environmental management system can uplift the sustainability and increase competitiveness in the business environment, leading to sustainable development of an enterprise. Emerging economies like South Korea and India have presented their net-zero carbon targets for 2050, but a large section of manufacturing, transportation, and energy sectors are still dependent on natural resources and traditional fuels (Wu et al., 2022). Therefore, the goal of a successful transition from carbon dependency to carbon neutrality remains uncertain.

2.3. Barriers of carbon regulatory policies implementation

The idea of adopting regulatory policies to minimize ecological impacts in developing countries is still in its initial stage. This section concentrates on understanding the existing barriers for CRP implementation in the manufacturing sector. Firms are motivated to develop strategies for reducing carbon emissions into their supply chains due to rigorous governmental pressures for environmental sustainability. Research on CRPs usually focus on the aspects of improving transportation emissions, operation emissions, inventory emissions, recycling, disposal, handling, network design, or a trade-off among various policies (Yu and Cruz, 2019). Barriers to CRPs implementation in manufacturing SCs of developing nations differ from those of developed nations in several ways. These barriers include lack of environmental data generation, lack of resources (in terms of time, technical expertise, ecological experience), and organizational structure differences. To tackle such problems, an identification of appropriate barriers and their evaluation and implementation is necessary. Due to paucity of literature on the CRPs' implementation barriers, literature on green supply chains, sustainable supply chains, carbon emission reductions, carbon management in SCs, and sustainable manufacturing are pertinent topics (Acquaye et al., 2018; Solanki et al., 2020).

For the successful implementation of CRPs, various impediments must be overcome. Decision-makers' involvement has high driving power towards sustainability as it develops the ecological consciousness in the organization. Lack of involvement never encourages an organization to adopt regulatory policies (Li et al., 2021). Furthermore, lack of training among the employees for regulatory policies prevents decision-makers from implementing them (García-Quevedo et al., 2020). Government and other authorities have a vital role to play in the adoption of regulatory policies. With no reward system and special benefits in place, practitioners lack the motivations to concentrate on the implementation of such regulations (Xu et al., 2022) . Delays in legal framework, certification difficulties, and unorganized tax structures may further demotivate firms. New regulations always come with a few hindrances and fear of success is one of them. Further, the fear of financial losses affects the brand image and a firm's competitiveness (Krishnan et al., 2020). Broadly, ecological issues in production processes are of high importance because of the excessive increase in carbon emissions levels in recent years. Production emissions are a matter of concern for industrial managers who seek to create a balance in sustainable business environment. The uncertainty of carbon market prices affects transportation and emissions costs, thus affecting entire SC cost that makes the adoption of regulatory policies even more complex (Rezaei et al., 2022). The key component of potential growth for any firm is trust among different departments or collaborating firms; insufficient communication hinders the process of sharing of information regarding data and resources. One of the measures to continuous depletion of natural resources is the use of reverse logistics in SCs. In an Indian scenario, consumers sell off their wastes to individual collectors that further goes to informal recycling process. This is because of the lack of in-house reverse logistics for manufacturing firms, creating additional environmental hazards on the firms and resulting in adoption of regulatory policies that are much more trivial (Khan et al., 2021). All these barriers, as explained in the literature for CRPs adoption, result in economic, institutional, technical, and ecological impediments. It can be observed that although there are many who have discussed sustainable SC, no studies have discussed the barriers for CRPs implementation. Further, no studies have quantitatively analyzed CRPs impediments. Hence, this study presents a clear path forward for research, and we seek to bridge this gap by quantitatively analyzing the barriers for implementation.

2.4. Research gaps and highlights

Extensive research findings accentuate that the manufacturing sector has been experiencing severe ecological issues due to exploitation of natural resources which leads to global warming. Owing to the increasing environmental degradation, various developed nations have established carbon emissions reduction targets for a zero-carbon future. The literature reviewed demonstrates that an integration of carbon regulatory policies and strategies in SCs is a progressing field of study among researchers and industry practitioners, and constructive results are often yielded (Yu and Cruz, 2019; Hu et al., 2020). In the context of emerging economies there has been a limited focus on carbon regulatory policies issues throughout the manufacturing SCs (Saxena et al., 2018). Therefore, this area remains unexplored with the absence of initiatives to analyze impediments, unawareness among the decision-makers, and a lack of original studies and industrial projects.

The present research attempts to fill this research gap by investigating barriers for CRPs implementation with an application in a manufacturing sector. Several papers have focused on sustainable supply chain management (Panigrahi et al., 2019), but to the best of our knowledge, no study has explored barriers to CRPs implementation, thus creating a knowledge gap. It is interesting to note that the knowledge gained through sustainable SC could be used and extended to develop a low carbon SC to a certain extent, but the need of exhaustive work on barrier assessment specific to manufacturing SC is necessary. The lack of empirical studies on barriers of CRPs in manufacturing SCs has led to the development of a novel mathematical model presented in subsequent sections of this research. This model could assist firms in curbing excessive emissions and attaining sustainability goals. The literature reveals three important points: (a) carbon regulatory policies are one of the most accepted, recognized, and influential tools to curb emissions through SCs, (b) the majority of studies are focused on developing optimization models from the perspective of developed nations; the context of emerging economies has not been investigated despite contributing to global carbon emissions to a large extent, and (c) there are not enough studies that examine the implementation barriers of regulatory policies for manufacturing SCs and their complex interrelationships. Hence, to understand the nature of carbon regulatory policies implementation impediments, this study is novel and needs to be carried out. The novelty of the present study and its contribution to the existing literature can be seen in the following ways:

1. It identifies barriers associated with the implementation of carbon regulatory policies in manufacturing SCs.
2. It determines the relative importance of identified barriers for carbon regulatory policies implementation.
3. It analyzes the interrelationships among the barriers involved in implementation of carbon regulatory policies and identifies the most influencing barriers.

3. Research methodology

This study embraces a quantitative approach for identifying and analyzing CRPs implementation barriers in manufacturing SCs. A four-phase methodology of the research is manifested in Fig. 1.

The framework developed for this study has been modelled to be adopted as it pertains to the different needs and requirements of the company. In the first phase, barriers relevant to implementation of CRPs are identified through an exhaustive literature review and extensive interaction with the decision-makers. In the second phase, identified barriers are categorized on the basis of their nature and functionality. Thereafter, an integrated Multi-Criteria Decision Making (MCDM) model incorporating Best Worst Method (BWM) and Decision Making Trial and Evaluation Laboratory (DEMATEL) is utilized to evaluate the identified barriers (Bhatia and Srivastava, 2018). In this context, the third phase deduces the relative importance of the main category barriers and the sub-category barriers with the help of BWM method. The last phase determines the interrelationship among the critical barriers with high relative importance using DEMATEL (Govindan, 2022; Govindan et al., 2021, 2022). There are numerous multi criteria techniques available in the literature, but selection of the technique is highly dependent on complexity, nature, and outcome of the problem. The present research considers an integrated BWM- DEMATEL approach for analyzing barriers, as these two methods are mutually complementary, and can execute the defined research objectives effectively. The analysis through this study will assist the manufacturing firms to direct their funds in the direction through which most impediments for implementation of CRPs can be eliminated.

The research framework developed for this study is illustrated as follows:

3.1. Selection of barriers

An important step towards developing a proposed framework is the identification of suitable barriers, which results in complete and best choice. The present literature highlights various studies identifying sustainability barriers for SCs, but a selection of the barriers for the purpose of implementation of carbon policies for manufacturing SCs is a tedious process. Therefore, primary research was conducted pertaining to literature on low carbon SCs, carbon emissions in SCs, barriers for manufacturing SCs, barriers for environmental policies, carbon footprint reduction in SMEs, and sustainability to identify most suitable barriers (given the concentration on SMEs research). Teamwork and mutual understanding among the various industry practitioners, policy makers, authors and stakeholders is one of the key factors to determine a comprehensive list of barriers, which can be considered for the analysis process (Kusi-Sarpong et al., 2019). Additionally, the exhaustive list of barriers can be classified into different groups based on their commonalities to reduce complexity (Trivedi et al., 2021). Accordingly, an initial list of barriers is first prepared from a thorough literature survey (Appendix Table A).

3.2. Relative importance of barriers using Best-Worst Method

Best-Worst Method (BWM) is a quantitative approach developed to

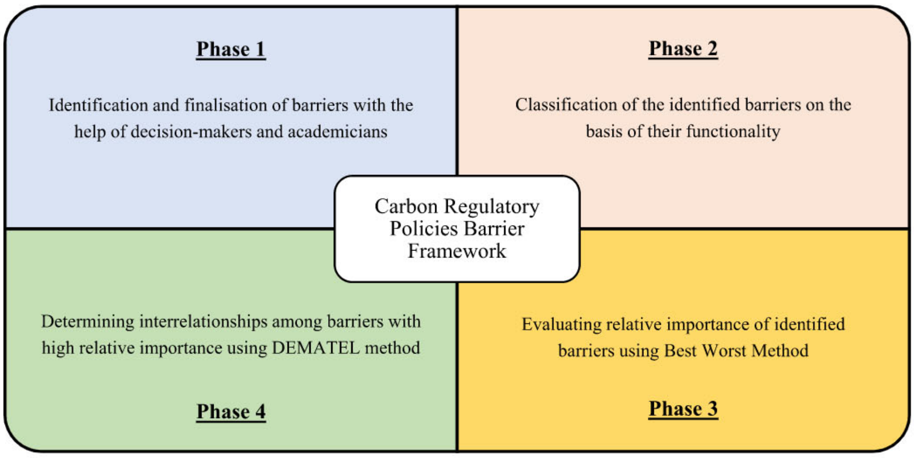

Fig. 1. Barrier analysis framework.

obtain a trade-off that keeps conflicting criteria in mind. This method is based on concept of pair-wise comparisons, which differentiate the given set of criteria to the best and worst factors and aid in determining the relative importance for each listed criterion. This feature of BWM helps in ranking the factors under consideration (Rezaei et al., 2016). Further, due to utilizing only two vectors, this technique reduces computational time and complexity. As a result, this approach has been widely incorporated in different business environments to find solutions of various research problems, especially in barrier analysis of supply chains, such as supplier selection, evaluation of sustainability, collaboration of different stakeholders, strategic and tactical planning (Govindan et al., 2022; Kannan, 2021) . Some of the advantages of BWM over other MCDM techniques are as follows: (a) it requires input of a fewer number of decision-makers for the purpose of weight calculations and determination of ranking, and (b) the consistency of results generated is greater. However, like all MCDM techniques, it has a few limitations, that the results obtained are based on the judgments of the decision-makers considered for the study.

Implementation of BWM method involves four steps, described briefly as follows:

Step 1 Selection of best and worst barriers from the list of main and sub-category barriers:

This step identifies most desirable (best) main and sub-category barrier and the least desirable (worst) main and sub-category barrier.

Step 2 Determination of the preference of the best barrier over all other barriers:

The preference of the best barrier over others is determined on a 9-point scale where values range from 1 to 9 (refer to Appendix Table B). A score '1' means 'equally important' and a score '9' means 'extremely more important' of the best identified barrier over all other barriers (or sub-category barriers). Given that there may be multiple decision-makers in a case, we take opinions from each decision-maker. This results in Best-to-Others (B–O) barrier (vector) of dth decision-maker as follows:

$$Z_b^d = \left(Z_{b1}^d, Z_{b2}^d, Z_{b3}^d, \ldots, Z_{bI}^d\right) \quad \text{(i)}$$

where Z_{bi}^d is the preference of the barrier B over other $\{i=1,2, \ldots,I\}$ barriers $Z_{bb}^d = 1$.

Step 3 Determination of the preference of the worst barrier over all the other barriers:

The preference of the other barriers to the worst is determined on a 9-point scale where values range from 1 to 9. This results in Worst-to-Others (O–W) barrier (vector), represented as follows:

$$Z_w^d = \left(Z_{w1}^d, Z_{w2}^d, Z_{w3}^d, \ldots, Z_{wi}^d\right)^T \quad \text{(ii)}$$

where $Z_{iw}^d = 1$ is the preference of the barrier j over worst barrier W: $Z_{ww}^d = 1$

Step 4 Evaluation of the optimal weights of all the barriers for each Decision-Maker (DM):

In this step we evaluate the optimal weights.

$(x_1^{d*}, x_2^{d*}, x_3^{d*}, \ldots, x_i^{d*})$ of the barriers such that they will satisfy the following criteria:

$$\frac{x_b^{d*}}{x_w^{d*}} = Z_{bi}^d \ \& \ \frac{x_i^{d*}}{x_w^{d*}} = Z_{iw}^d \quad \text{(iii)}$$

This requires a minimization of maximum absolute difference, that is, in order to get close to the ideal solution, the following condition must be satisfied:

$$minmax_i\left\{\left|x_b^d - z_{bi}^d x_i^d\right|, \left|x_i^d - z_{iw}^d x_i^d\right|\right\} \quad \text{(iv)}$$

Therefore, the optimal weights $(x_1^{d*}, x_2^{d*}, x_3^{d*}, \ldots, x_i^{d*})$ are obtained as a solution by the formulation of the following Linear programming problem (LPP):

$(\mathrm{P1}) Min\ \xi^d$

Subject to:

$$\left(\left|x_b^d - z_{bi}^d x_i^d\right|\right) \leq \xi^d \ \forall\ i = 1, 2, \ldots, I$$

$$\left(\left|x_i^d - z_{iw}^d x_i^d\right|\right) \leq \xi^d \ \forall\ i = 1, 2, \ldots, I$$

$$\sum_I x_i^d = 1 x_i^d \geq 0 \quad \forall\ i = 1, 2, \ldots, I$$

The model (P1) is solved for every DM and optimal weights of all the barriers are obtained as $(x_1^{d*}, x_2^{d*}, x_3^{d*}, \ldots, x_i^{d*})$ and the optimal value ξ^d. Here ξ^d is an indicator of consistency of comparison systems. The closer the value is to zero value, the higher is the consistency, that is, the comparisons are more reliable.

3.3. Interrelationships of barriers using DEMATEL method

Decision-Making Trial and Evaluation Laboratory (DEMATEL) was designed at "Science and Human Affairs Program of the Battelle

Memorial Institute of Geneva" by Fontela and Gabus in the year 1973 (Tzeng et al., 2007). This method identifies the prominent inter-influences in a complex system, thus simplifying intricate problems based on DMs' judgments. DEMATEL is based on the concept of direct graphs, which divides the given set of criteria into two subsets: Cause and Effect groups; these direct graphs are called 'Diagraphs'. They provide a structural representation of the model that defines the relationships among the criteria under consideration. DEMATEL has been widely used in various supply chain problems, for example, risk management, evaluation of SCs considering sustainability, supplier selection and barrier analysis (). This extensive use is mainly due to its advantage that the criteria under consideration may not be independent and mutually exclusive. This property is not a feature of other multi criteria techniques (such as Analytical Hierarchal Process), where criteria need to be independent.

In this study, the critical barriers are identified with the help of decision-makers on the basis of their relative importance values, after successful implementation of BWM. Further, experts provide their judgments regarding the degree of influence that each critical barrier *i* has on each barrier *j*. The scale ranges from 0 (no influence), 1 (low influence), 2 (medium influence), 3 (high influence) and 4 (high influence), and it is represented as follows:

$$Q = [Q_{ij}]_{n\times n} \quad \text{(v)}$$

where Q_{ij} represents the degree by which barrier *i* affects barrier *j* and $n \times n$ is the dimension of the matrix *Q*. Thereafter, a normalized matrix p is evaluated to identify the strength of interrelationships among the critical barriers, utilizing the following equation,

$$P = \frac{Q}{s} \quad \text{(vi)}$$

$$where,\ s = \max\left(\max_{1\le i\le n}\sum_{j=1}^{n} p_{ij}, \max_{1\le j\le n}\sum_{j=1}^{n} p_{ij}\right)$$

Further, a total relation matrix T^* is developed, highlighting the degree of the total influence that a barrier *i* exerts on barrier *j* (t^*_{ij}). Row and column sum through the matrix T* are obtained afterwards. Finally, Influence Relationship Map (IRM) is constructed with the help of row and column sums. ($R_i + C_i$) determines the degree of importance that a barrier *i* has on the overall system and the difference of R_i and C_i, (R_i - C_i) determines net cause and effect that a barrier *i* has on the overall system. When (R_i - C_i) has a positive value, only then does it have an effect on other barriers (cause group); if the (R_i - C_i) has a negative value, then the barrier can be influenced by other barriers (effect group). Using the dataset of ($R_i + C_i$) and (R_i-C_i) IRM is constructed, by plotting ($R_i + C_i$) on the horizontal axis and (R_i-C_i) on the vertical axis. Formulas utilized to calculate T^*, R_i and C_i are given as follows:

$$T^* = [r_i]_{n\times 1} = \lim_{m\to\infty}\left(P + P^2 + P^3 \ldots + P^\infty\right) = P(I-P)^{-1} \quad \text{(vii)}$$

$$r = [r_i]_{n\times 1} = \left[\sum_j t^*_{ij}\right]_{n\times 1} \quad \text{(ix)}$$

$$c = [c_{ij}]_{1\times n} = \left[\sum_j t^*_{ij}\right]_{1\times n} \quad \text{(x)}$$

4. Industrial application and results

This section presents a multi-stakeholder case study of a medium-scale manufacturing sector in India to elucidate the application of the proposed methodology. Additionally, to have an in-depth understanding of barriers, a multiple case study approach is utilized. The case study research method has the ability to encapsulate conceptual developments, taking into account the contextual data and determining the specific problem. There are many studies which use this approach because of its advantage (Guldmann and Huulgaard, 2020). A total of six manufacturing firms were considered for this purpose, and an expert from each firm forms a decision-making body for the evaluation of CRPs' implementation barriers. The name of the companies has not been disclosed due to reasons of confidentiality. Case firm 1 is an electronic component manufacturer, case firm 2 is an automobile component manufacturer, case firm 3 is a plastic products manufacturer, case firm 4 is an automobile plastic components manufacturer, case 5 is an electric component manufacturer, and case firm 6 is a plastics manufacturer. All six firms are medium scale manufacturers and have been in operations for more than seven years. Selection of these firms was based on the common organizational goals, viz. achieving ecological sustainability by reduction of carbon emissions in their respective processes. The representatives have agreed to be part of the panel with an aim to ensure that they are able to implement carbon regulatory policies for improved SC.

The decision-making body comprises various field experts from the manufacturing sector. The average work experience of the DMs is more than seven years, and each holds a key managerial position throughout the industry. Table 2 highlights the details of the decision-making body for the present research. The initial list of 36 barriers identified through literature review (shown in Appendix Table A) is presented to decision-making body and their responses were taken in the form of '*yes*' and '*no*'. We determined that eleven barriers were found not suitable for the study and they were rejected. Due to the absence of relevant studies in the literature, the decision-making body proposed six new barriers after thorough detailed discussion. The list of proposed barriers through consensus among decision-making body is presented in Appendix Table C. This section thus follows a four-phase methodology presented in detail for the multi-stakeholder manufacturing sector of India.

4.1. Identification and classification of the barriers

After brainstorming sessions, managers from all selected firms participated in refining the barriers. The responses were obtained after the brief provided about the objective of the study; we utilized physical interviews, e-mails, and Skype meetings. These barriers were then screened according to the case considered for the study. From the list of 36 barriers, 11 identified barriers were dropped and 6 were incorporated post discussions with the DMs. Through in-depth interaction with the decision-making body, the extensive list of barriers was categorized into various groups depending on commonality of their functions. Five main categories were identified: economic, social, environmental, technical,

Table 2
Profile of the respondents in decision-making body.

Decision-maker	Designation	Years of Experience	Role in the industry
1	Operations and Productions Manager	6 years	Operations management for electronics component manufacturing firm
2	Corporate Social Responsibility Manager	9 years	Strategies development for CSR of automobile component manufacturing firm
3	R&D Manager	6 years	New product development for plastic products manufacturing firm
4	Planning and Strategy manager	9 years	Sustainability strategies development for ecological development, for automobile component manufacturing firm
5	Finance Manager	7 years	Forecasting and monitoring flow management for electrical component manufacturing firm
6	Market Development Manager	7 years	Marketing management for a plastic manufacturing firm

and organizational. Within these five categories, 31 sub-category barriers are identified. Therefore, the final list of barriers obtained through rigorous analysis is shown in Table 3.

4.2. Application of BWM to identify relative importance of barriers

After the categorization of barriers, the managers were asked to submit their responses, that is, to identify the main best and main worst barriers. Table 4 illustrates the best and worst barriers, which are the most and least desirable barriers for the purpose of implementation of carbon policies for manufacturing SCs of developing nations. The best and worst main category barriers were identified using pairwise comparisons as mentioned in section 3 (Rezaei et al., 2016). All experts in the decision-making body submitted their response for the results in 'best to others' (B–O) barrier. Thereafter, other barriers were also rated with respect to the main worst barrier (refer section 3) by all managers. Economic barrier was rated as the best barrier by managers of the case firm 1, 2, and 3, respectively. In contrast, the Organizational barrier was rated the best by managers of case firm 4 and 5, and lastly, the manager of case firm 6 rated Environmental barrier as the best barrier. The Worst barrier rated by all managers of the case firms was found to be Technical barrier.

To elaborate on further how the evaluations of BWM are carried out for barriers of CRPs we present the calculations of one firm (firm 6) in Table 5a and Table 5b. Similar calculations have been done for the other firms. The pairwise comparisons of main category barriers for the case firm 6 are given. Here, Environmental (ENV) barrier is moderately more important than the Economic (ECN) barrier and hence gets the score '2' in the corresponding cell by the manager of the case firm 6. Similarly, while comparing the Social (SOC) with ENV, ENV and Technical (TEC), and ENV and Organizational (ORG), scores of '5', '6' and '3' are given by the manager. As can be observed, comparing ENV with ENV a rating of '1' is obtained, which means they are equally important. Table 5b describes the rating of the other barriers with respect to the worst barrier on similar lines.

The manager from the case firm 6 rated the sub-category barriers using the similar 9-point scale. Table D, E, F, G and H (see Appendix) describe the comparison scores of the sub-category barriers for DM of firm 6. Similar calculations are done for the other sub-category barriers for other firms. After unique pairwise comparisons of every main category barrier and sub-category barrier by all the managers were identified, BWM linear model is utilized to calculate weights of each of the barriers.

To determine the relative importance of all the barriers, 'local weights' of main barriers and sub-category barriers were calculated with the help of equations as discussed in section 3.2 (using BWM). These local weights are obtained for all the case firms, rated by all the decision-makers considered for the study. The global weights of each sub-category barrier are calculated as product of weight of main category barrier and corresponding local weights. The sub-category barrier with the maximum 'global weight' was ranked '1' in the relative importance list, barrier with the second maximum value in the 'global weight' was ranked '2' and so forth. These barriers were ranked with the descending value of the global weights until all the barriers obtained some rank. Table 6 summarizes the main barrier and sub-category weights for the case firm 6.

Similarly, each industrial manager rated main and sub-category barriers for all case firms. These weights were averaged to obtain aggregated scores. The aggregated scores of all case firms are summarized in Table 7, where 'Lack of Initial Funding' obtained first rank, rank 2 is "Hidden costs' and the last rank, that is, '31' is obtained by 'Lack in Forecasting'.

4.3. Application of DEMATEL for interrelationships among barriers

Due to various constraints such as limited availability of resources

Table 3
Identified list of barriers.

Main Category Barriers	Sub-Category Barriers	Description	References
Economic (ECN)	High Operational Costs (ECN1)	Higher operating cost due to use of environmental friendly material for production, requires changes in the existing strategies and technology. This leads to financial burden on the firm, hampering the CRPs implementation.	Rahman et al. (2020)
	Lack of Initial Funding (ECN2)	Initiation of CRPs implementation causes high cost for recruiting new workforce, carrying out pilot research, and setting up new strategies.	Zhu & Geng (2013)
	Irrational Current Taxes (ECN3)	Different central and state government taxes in developing nations. Due to high taxation system, implementation of CRPs becomes more difficult for SMEs.	Experts' opinions
	Uncertain Carbon Market Price (ECN4)	Due to uncertainty of carbon price in the manufacturing sector, the firm's ability to obtain potential financial gains through banks and lenders becomes difficult.	Experts' opinions
	Uncertainty related to economic issues (ECN5)	Economic gains through CRPs have not yet been assessed in developing nations but it leads to financial benefits. However, continuous demand for profits from stakeholders constitutes a high economic uncertain environment.	Rahman et al. (2020)
	Hidden costs (ECN6)	Financial cost might differ significantly from the estimated cost during the implementation. The implementation of new policies sometimes leads to interruptions which results in disruption costs.	Cagno et al. (2017)
Social (SOC)	Low Education (SOC1)	Lack of understanding and awareness about carbon emission and its impact on the supply chain activities among suppliers, employees and DMs, and benefits of adoption of CRPs in SC.	Mangla et al. (2016)
	Irregular behavioral issues (SOC2)	Lack of industrial managers and decision-makers to	Gillingham, & Sweeney (2012)

(continued on next page)

Table 3 (*continued*)

Main Category Barriers	Sub-Category Barriers	Description	References
		have vision for carbon emission reductions that leads to systematic biases in the decision-making.	
	Unemployment (SOC3)	Employees of the firms fear in implementing new regulatory policies, as it will cost them to lose flexibility, increase the workload on few employees, and, in worst cases, loss of job.	Experts' opinion
	Tax burdens on consumers (SOC4)	Levying additional tax on the manufacturers results in increased cost of the product.	Experts' opinion
	Political resistance (SOC5)	Lack of regulations at the regional level in developing nations, restricting them from financial support and law enforcement. The firm may be weakened and/or diminished.	Experts' opinion
	Lack of Social Demand (SOC6)	Customer requirements of products from less carbon emitting firms are not clear; this uncertainty makes firms unwilling to adopt such regulatory policies.	Tumpa et al. (2019)
	Lack of Stakeholders Pressure (SOC7)	Lack of pressure from the decisions-makers to implement CRPs highlights its importance and urgent need in the manufacturing sector due to absence of literature work.	Gupta (2018)
Environmental (ENV)	Low Carbon Design (ENV1)	Lack of supply chain design for the reduction of environmental impact from manufacturing.	Bai et al. (2017)
	Excessive Production Emissions (ENV2)	Use of older machinery and technologies for the production generates excessive carbon emissions.	Experts' opinion
	Lack of in-house reverse logistics (ENV3)	Recycling, remanufacturing, and reusing facilities are integral parts of sustainable manufacturing. Lack of such practices would lead to higher emissions, resulting in higher taxes on the firm and thus making implementation of CRPs difficult.	Rahman et al. (2020)
	Lack of alternative energy source (ENV4)	Lack of alternative renewable source of energy, as non-renewable source of energy emits large amount of carbon, for example coal.	Karuppiah et al. (2020)
	Unaccountability of production waste (ENV5)	Lack of procedures and processes to reduce the over consumption of resources, leading to excessive waste generation.	Mao et al. (2017)
Technical (TEC)	Certification Difficulty (TEC1)	Lack of environmental certification that helps the manufacturing firms to be sustainable according to international standards and practice environment friendly activities.	Rahman et al. (2020)
	Lack in Forecasting (TEC2)	Inadequacy of production planning due to uncertainty in the availability of resources.	Govindan et al. (2020); Experts' opinion
	Lack of Information Sharing (TEC3)	Unwillingness of the SC partners to share information about technological or new changes implementation with a fear of product being affected.	Burritt et al. (2011)
	Inadequate Infrastructure (TEC4)	Lack of efficient storage and transportation in the SC, along with poor telecommunication infrastructure.	Silvestre (2015)
	Growing informal sector (TEC5)	Presence of large number of informal manufacturing firms in the developing nations makes the implementation of CRPs a challenging task.	Kumar & Dixit (2018)
	Lack of skilled labor (TEC6)	Unskilled workforce hampers the implementation of CRPs difficult in manufacturing firms.	Experts' opinion
Organizational (ORG)	Lack of Legal Framework (ORG1)	Lack of legal support from the regulatory bodies and government hinders the implementation of CRPs in developing nations.	Rahman et al. (2020); Experts' opinion
	Lack of Research and Development (ORG2)	Lack of R&D facilities for carbon management hinders the implementation of CRPs.	Mao et al. (2017)
	Fear to shift to new system (ORG3)	Fear of switching to a new working environment due to conventional thinking that new regulatory policies are risky and less comfortable to operate in.	Mudgal et al. (2010)
	Lack of Experts (ORG4)	Lack of presence of industrial experts on	Zhu & Geng, Y., 2013

(continued on next page)

Table 3 (*continued*)

Main Category Barriers	Sub-Category Barriers	Description	References
		CRPs management, who can aid and tackle problems that arise during the implementation stage.	
	Lack of support from the authorities and the government (ORG5)	Support from the government is one of the most important driving forces in implementing new regulations. Absence of such support hinders the CRPs implementation.	Murillo-Luna et al. (2011)
	Unaccountability of Supply Chain Actors (ORG6)	Lack of transparency in the network involved among the various actors of SC, which is complex to understand for manufacturing SMEs due to absence of communication and organizational experts.	Experts' opinion
	Lack of Tools to Measure (ORG7)	Lack of knowledge and attempts to measure the total carbon emissions from the lifecycle of the product.	Li et al. (2021)

and limited time to achieve major outcomes, manufacturing firms cannot focus their attention on all barriers. To tackle this problem an interrelationship hierarchy is created to determine which critical barriers should be prioritized. Further, if DMs focus on these critical barriers, it would create a ripple effect, enhancing overall performance of supply chains and thus making CRPs implementation process much easier. After detailed discussion with the decision-making body for the case considered, the top twelve barriers were selected, known as '*critical barriers*'. These barriers were selected as they are the most critical barriers for implementation of carbon regulatory policies in manufacturing supply chains. DEMATEL is used to identify the interrelationships among the identified barriers. For this purpose, inputs were again taken from managers considered for the study on a five-point scale, that is, 0 to 4, where '0' corresponds to "No Influence", '1' corresponds to "Low Influence", '2' corresponds to "Moderate Influence", '3' corresponds to "High Influence" and '4' corresponds to "Very High Influence", which describes the influence of one barrier on the others (refer to details in Section 3). Based on the methodology described for DEMATEL in section 3.3 'Aggregated Direct Relation Matrix' is evaluated and is shown in Table I (Appendix) and normalized direct relation matrix through Table J (Appendix). Further, a 'Total Relation Matrix' is generated and is shown in Table 8.

Finally, the sum of all the rows and columns of 'Total Relation Matrix' is calculated and they are denoted as "R_is" and "C_is" shown in Table 9. The degree of importance from the listed barriers is inferred from the (R_i+ C_i) values; the three most important barriers are Hidden costs (ECN6), Uncertain Carbon Market Price (ECN4), and Lack of Social Demand (SOC6).

On the basis of the values of (R_i-C_i), barriers can be categorized into cause group and effect groups. Here the cause group consists of five barriers as follows: Lack of Initial Funding (ECN2), Lack of Research and Development (ORG2), Irrational Current Taxes (ECN3), Unaccountability of Supply Chain Actors (ORG6), and Lack of Support from the Authorities and the Government (ORG5). In contrast, the effect group

Table 4
Best and worst identified barriers by group decision-making body.

Main Category Barriers	Sub-Category Barriers	Best by Managers	Worst by Managers
Economic (ECN)		1,2,3	
	Higher Production Costs (ECN1)		3,4,5
	Lack of Initial Funding (ECN2)	1,2,3,4	
	Irrational current Taxes ((ECN3)		6
	Uncertain Carbon market Price (ECN4)	5	
	Uncertainty related to economic issues (ECN5)		1,2
	Hidden costs (ECN6)	6	
Social (SOC)			
	Low Education (SOC1)		
	Irregular behavioral issues (SOC2)		1,2,3,6
	Unemployment (SOC3)	6	
	Tax burdens on consumers (SOC4)		
	Political resistance (SOC5)		4,5
	Lack of Social Demand (SOC6)	4,5	
	Lack of Stakeholders Pressure on adoption of policies (SOC7)	1,2,3	
Environmental (ENV)		6	
	Low carbon Design (ENV1)		
	Excessive Production Emissions (ENV2)		1,2,3,4,5,6
	Lack of in-house Reverse logistics (ENV3)		
	Lack of alternative energy source (ENV4)	1,2,3,5	
	Unaccountability of production waste (ENV5)	4,6	
Technical (TEC)			1,2,3,4,5,6
	Certification Difficulty (TEC1)		
	Lack in Forecasting (TEC2)		1,2,3,4
	Lack of Information Sharing (TEC3)		5,6
	Inadequate Infrastructure (TEC4)	1,2,3,4,5	
	Growing informal sector (TEC5)	6	
	Lack of skilled labor (TEC6)		
Organizational (ORG)		4,5	
	Lack of Legal Framework (ORG1)		1,3,4
	Lack of Research and Development (ORG2)	4,5,6	
	Fear to shift to new system (ORG3)		
	Lack of Experts (ORG4)		5,6
	Lack of support from the authorities and the government (ORG5)	1,2,3	
	Unaccountability of Supply Chain Actors (ORG6)		
	Lack of Tools to Measure (ORG7)		2

consists of the remaining seven barriers: Unaccountability of Production Waste (ENV5), Lack of Social Demand (SOC6), Hidden costs (ECN6), Lack of in-house reverse logistics (ENV3), Fear to shift to new system (ORG3), Uncertain Carbon Market Price (ECN4), and Lack of alternative energy source (ENV4). The cause and effect groups are shown in Fig. 2.

Finally an InterRelationship Map (IRM) is constructed after calculating the threshold value and taking all values greater than the threshold value from the Total Relation Matrix (Table 8). For the barreir

Table 5a
Best-To-Others Pairwise comparisons for firm 6.

Best-to-Others	Economic	Social	Environmental	Technical	Organizational
Environmental	2	5	1	6	3

Table 5b
Others-to-Worst Pairwise comparisons for firm 6.

Others-to-Worst	Technical
Economic	5
Social	2
Environmental	6
Technical	1
Organizational	3

Table 6
Weights of main and sub-category barriers for case firm 6.

Main barriers	Local weights of main barriers	Sub-category barriers	Local weights of sub-category barriers	Global weights	Ranking
Economic (ECN)	0.2459	ECN1	0.0828	0.0204	16
		ECN2	0.1241	0.0305	10
		ECN3	0.0438	0.0108	21
		ECN4	0.2483	0.0611	5
		ECN5	0.0993	0.0244	13
		ECN6	0.4017	0.0988	2
Social (SOC)	0.0984	SOC1	0.0741	0.0073	26
		SOC2	0.0328	0.0032	31
		SOC3	0.3699	0.0364	9
		SOC4	0.0890	0.0088	23
		SOC5	0.0635	0.0063	28
		SOC6	0.2224	0.0219	14
		SOC7	0.1483	0.0146	18
Environmental (ENV)	0.4303	ENV1	0.1148	0.0494	7
		ENV2	0.0598	0.0257	11
		ENV3	0.1914	0.0824	3
		ENV4	0.1675	0.0721	4
		ENV5	0.4665	0.2008	1
Technical (TEC)	0.0615	TEC1	0.1409	0.0087	24
		TEC2	0.1057	0.0065	27
		TEC3	0.0542	0.0033	30
		TEC4	0.2114	0.0130	19
		TEC5	0.3469	0.0213	15
		TEC6	0.1409	0.0087	25
Organizational (ORG)	0.1639	ORG1	0.0645	0.0106	22
		ORG2	0.3598	0.0590	6
		ORG3	0.1506	0.0247	12
		ORG4	0.0335	0.0055	29
		ORG5	0.2259	0.0370	8
		ORG6	0.0904	0.0148	17
		ORG7	0.0753	0.0123	20

ECN3, the cell corresponding to ENV5, ECN6, and ORG3 has values greater than 0.102 (threshold value, computed on the same lines as Trivedi et al., 2021). Therefore, there is a direct relationship between these barriers as seen in the diagraph. Similarly, all the relationships among the barriers are constructed as shown in Fig. 3.

5. Discussion

The integration of carbon emissions issues in SCs is imperative today as it has a high negative impact on the environment. Due to various internal and external factors, Indian manufacturing firms face numerous challenges for implementation of regulatory policies. Lack of carbon policies and environmental awareness initiatives are some of the reasons manufacturing firms are less ecologically conscious (Maas et al., 2018). Implementation of carbon policies is one of the powerful tools to curb emissions and make manufacturing firms ecologically more viable (Sherafati et al., 2020). To implement new policies, its barriers are evaluated for the purpose of reduction and removal of various impediments, so that there is a smooth transition to sustainable development. Therefore, this study presents an illustrative framework by which firms can select and evaluate the barriers for implementation of carbon regulatory environmental policies in manufacturing SCs in order to attain net zero emissions. A total of thirty-one comprehensive barriers were finalized on the basis of extant literature and were then grouped into five main categories. From the list of 31 barriers, six were classified as economic, seven as social, five as environmental, six as technical, and seven as organizational barriers. These main category and sub-category barriers were evaluated by implementing BWM to calculate their weights and to identify their relative importance. DEMATEL is then used to assess interrelationships among critical barriers for CRPs.

Table 7
Aggregated weights of main and sub-category barriers for all firms.

Main barriers	Local weights of main barriers	Sub-category barrier's	Local weights of sub-category barriers	Global weights	Ranking
Economic (ECN)	0.361	ECN1	0.0651	0.0235	16
		ECN2	0.3310	0.1194	1
		ECN3	0.0844	0.0304	10
		ECN4	0.2146	0.0774	3
		ECN5	0.0817	0.0295	14
		ECN6	0.2232	0.0805	2
Social (SOC)	0.114	SOC1	0.0740	0.0084	25
		SOC2	0.0423	0.0048	29
		SOC3	0.2008	0.0229	17
		SOC4	0.0946	0.0108	24
		SOC5	0.0641	0.0073	27
		SOC6	0.2655	0.0303	12
		SOC7	0.2589	0.0296	13
Environmental (ENV)	0.191	ENV1	0.1458	0.0278	15
		ENV2	0.0627	0.0120	22
		ENV3	0.1620	0.0309	9
		ENV4	0.3565	0.0679	6
		ENV5	0.2730	0.0520	7
Technical (TEC)	0.053	TEC1	0.1188	0.0063	28
		TEC2	0.0681	0.0036	31
		TEC3	0.0822	0.0044	30
		TEC4	0.3601	0.0192	20
		TEC5	0.2169	0.0116	23
		TEC6	0.1540	0.0082	26
Organizational (ORG)	0.281	ORG1	0.0563	0.0158	21
		ORG2	0.2635	0.0741	4
		ORG3	0.1595	0.0449	8
		ORG4	0.0759	0.0214	19
		ORG5	0.2607	0.0733	5
		ORG6	0.1078	0.0303	11
		ORG7	0.0762	0.0214	18

The BWM outcomes are summarized in Table 7. The results give area of focus by giving strategic insights for decision-makers and others on economic, social, environmental, technical, and organizational barriers. These results are graphically represented with the help of radar chart as shown in Fig. 4. The radar chart helps managers for better understanding of results, making it ideal to display the importance of the

Table 8
Total relation matrix.

CB[a]	ENV5	ECN2	ORG2	SOC6	ECN6	ECN3	ENV3	ORG6	ORG3	ORG5	ECN4	ENV4
ENV5	0.0501	0.0171	0.0274	0.0462	0.1658	0.0288	0.0390	0.0718	0.1465	0.0185	0.1094	0.0399
ECN2	0.1020	0.0495	0.1155	0.1783	0.2684	0.1248	0.1466	0.0947	0.1400	0.0415	0.1225	0.1086
ORG2	0.2377	0.1213	0.0389	0.0853	0.2261	0.0538	0.0779	0.0963	0.1227	0.1396	0.2008	0.1157
SOC6	0.0818	0.0791	0.0679	0.0553	0.2023	0.1140	0.1686	0.0455	0.0932	0.0663	0.1439	0.0642
ECN6	0.1568	0.0441	0.0281	0.1112	0.1104	0.0786	0.1366	0.1850	0.0981	0.0592	0.1403	0.1733
ECN3	0.1312	0.1351	0.0724	0.0510	0.1556	0.0343	0.0432	0.0403	0.1259	0.0228	0.0878	0.0417
ENV3	0.1678	0.0584	0.0175	0.0480	0.1824	0.0308	0.0464	0.0424	0.0514	0.0531	0.1295	0.1238
ORG6	0.1149	0.1107	0.0353	0.2055	0.2217	0.0835	0.1406	0.0470	0.0942	0.0295	0.0737	0.1316
ORG3	0.1893	0.0428	0.1766	0.1164	0.1667	0.0700	0.0476	0.0444	0.0616	0.0739	0.0780	0.0493
ORG5	0.2124	0.1939	0.0898	0.1630	0.1510	0.0998	0.1566	0.0516	0.1627	0.0347	0.2404	0.1822
ECN4	0.0746	0.0363	0.0322	0.1570	0.1294	0.1093	0.1600	0.0661	0.1179	0.0254	0.0579	0.1193
ENV4	0.1392	0.0098	0.0092	0.0605	0.1173	0.0180	0.0276	0.0268	0.0326	0.0102	0.0696	0.0250

[a] CB: critical barriers.

Table 9
Result analysis using DEMATEL method.

Critical Barriers	R_i	C_i	$R_i + C_i$	R_i-C_i
Unaccountability of Production Waste (ENV5)	0.7605	1.6577	**2.4183**	−0.8972
Lack of Initial Funding (ECN2)	1.7380	0.5748	**2.3128**	1.1632
Lack of Research and Development (ORG2)	1.5159	0.7108	**2.2267**	0.8050
Lack of Social Demand (SOC6)	1.1821	1.2776	**2.4597**	−0.0955
Hidden costs (ECN6)	1.3217	2.0972	**3.4188**	−0.7755
Irrational Current Taxes ((ECN3)	0.9414	0.8457	**1.7871**	0.0956
Lack of in-house reverse logistics (ENV3)	0.9515	1.1907	**2.1422**	−0.2392
Unaccountability of Supply Chain Actors (ORG6)	1.2881	0.8119	**2.1000**	0.4763
Fear to shift to new system (ORG3)	1.1166	1.2467	**2.3634**	−0.1301
Lack of support from the authorities and the government (ORG5)	1.4924	0.8981	**2.3905**	0.5943
Uncertain Carbon Market Price (ECN4)	1.0853	1.4537	**2.5390**	−0.3684
Lack of alternative energy source (ENV4)	0.5459	1.1745	**1.7204**	−0.6287

criteria under consideration. Here it aids in visualization of the weights for all barriers and their respective ranks, where ranks are depicted on the edges of the circle and weights along the x-axis. Barriers with least importance (with the minimum weight) are plotted towards the center of the circle and one with the most importance is plotted along the outer ring of the circle.

The first observation from Table 7 is that Economic category has obtained the highest weight among all the main category barriers, which is then followed by organizational and environmental categories. This finding explains that manufacturing firms primarily consider sustainability from the environmental perspective to control carbon emissions which are essentially dependent on the economic stability of the firm. It is noteworthy that environmental criteria take a step back when it comes to carbon emissions reductions in manufacturing SCs, and the most important category comes out to be economic. These results are strictly case specific and might have been influenced by managers who were actively engaged in the economic elevation of their firms. Further, it also shows that there is lack of implementation of the CRPs, which must be worked upon.

The main observation from the Table 7 and Fig. 4 is the top twelve sub-category barriers as per the weights obtained are Lack of Initial Funding (ECN2), > Hidden costs (ECN6), > Uncertain Carbon Market Price (ECO4), > Lack of Research and Development (ORG2), > Lack of support from the authorities and the government (ORG5), > Lack of alternative energy source (ENV4), > Unaccountability of Production Waste (ENV5), > Fear to shift to new system (ORG3), > Lack of in-house reverse logistics (ENV3), > Irrational Current Taxes (ECN3), > Unaccountability of Supply Chain Actors (ORG6) and > Lack of Social Demand (SOC6). Further, it's seen that ECN2 obtained the highest weight of 0.1193. Conversely, the least weight is obtained by the barrier Lack in forecasting (TEC2) of 0.0036. Additionally, ECN6 is ranked second with the weight of 0.0805 and ECN4 is ranked third with the weight of 0.0774 in order of their priority. Ranks fourth, fifth and sixth are obtained by ORG2, ORG5, and ENV4 with their corresponding weights 0.0741, 0.0733, and 0.0679 respectively. It is evident that the most critical and important barrier that is to be taken care of in implementation of carbon regulatory policies is ECN2. Managers may argue that there should be enough funding present for the SMEs to support and function in the new policy environment. Hidden costs, ranked second, is another concern to be taken care of by the managers. The need is to streamline the selection of unsustainable suppliers and irregular operation planning problems

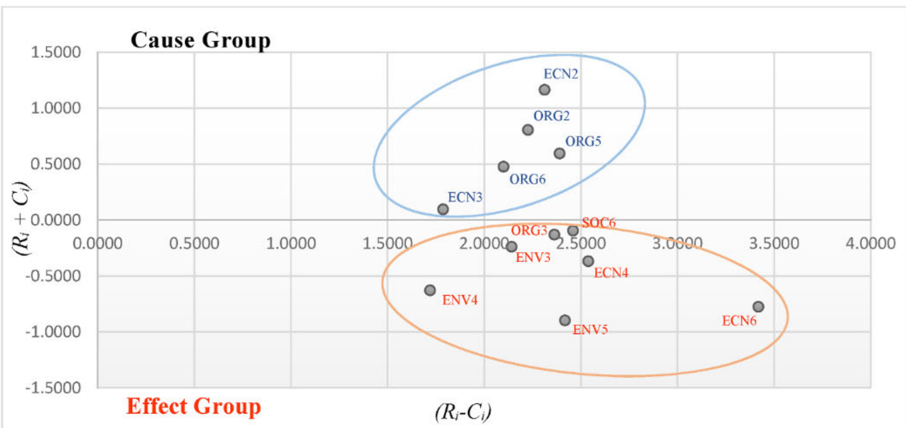

Fig. 2. Graphical representation of barriers into Cause and Effect Groups.

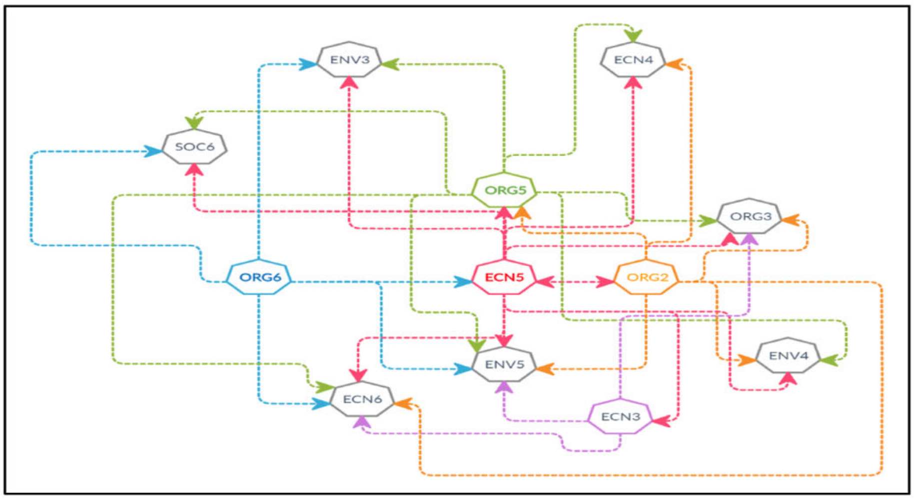

Fig. 3. Relationship diagraph of critical barriers.

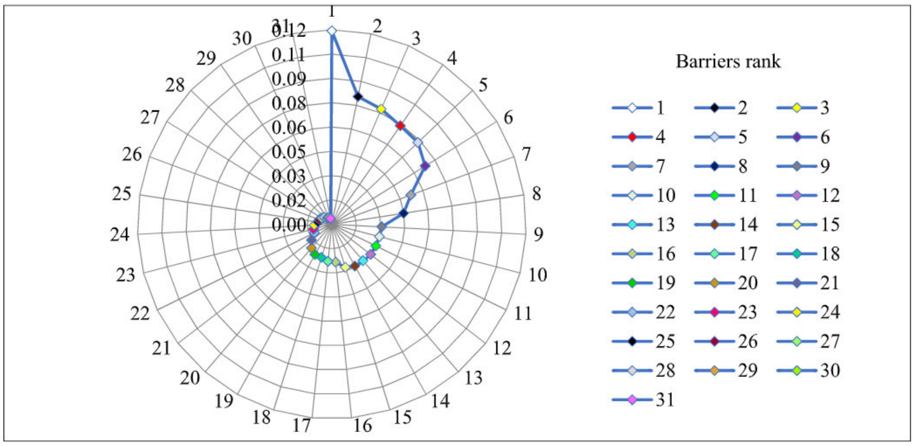

Fig. 4. Graphical illustration of BWM results.

would result in additional emissions for the manufacturing SCs. In turn, this increase in emissions would hamper the implementation of carbon regulatory policies. Therefore, to have bare minimum effect from this barrier, sustainable supplier selection practices along with adequate operation planning should be practiced by manufacturing sector. Further, uncertain carbon market price, ranked third, is a prominent barrier. The carbon must be priced appropriately; overpriced carbon would lead to a loss in production that could result in unemployment and decreased wages of the workforce. On the other hand, underpriced carbon would lead to an ineffectiveness of the policy introduction; manufacturers would violate the regulatory norms (Li et al., 2021). The fourth scored rank, Lack of Research and Development, is an integral barrier, because before the introduction of any new regulatory policies its merits and demerits must be evaluated for the purpose of better implementation and for avoiding similar mistakes as done in the past. From the interpretation of these results, it is apparent that the major barriers for the implementation of carbon regulatory policies in manufacturing SCs are inclined towards economic and organizational categories.

The irregular behavioral issues, Lack of Information sharing and Lack in Forecasting, are viewed to be least important sub-category barriers, as they neither add up to any economic value nor organizational value, aiding in the implementation of carbon regulatory policies. The introduction of the new policies is not reliant on such barriers; social and technological categories do not address the issues of emissions reduction majorly, nor do they create any hindrance in this setting, which helps explain the reason for attaining the lowest overall relative importance. Another point that can be noted from the result is that ECN2, ECN6, and ECN4 among other barriers for manufacturing SCs require the most managerial attention. For example, financial barriers can delay the entire process of regulatory policies implementation; absence of initial funding would not let business entities prepare and function in the new environment and thus disrupt the entire system. Among the top twelve sub-category barriers, four of six are economical, four of seven are organizational, three of five are environmental, and one is social. Hence, it is evident from the study that most critical barriers that impede successful implementation of carbon policies arise from Economical and Organizational perspectives.

The lack of resources and time among SMEs of emerging economies restricts them to concentrate only on a limited number of barriers. From the elaborate list, interrelationships and prominence among critical barriers are determined (see Tables 8 and 9). The main observation from Table 9 is that it helps in categorizing the barriers into Cause and Effect groups. The positive values of R_i-C_i in the Table 9 are highlighted and represent most influential barriers. The negative values of R_i-C_i represent the barriers which get influenced from other barriers. These values are plotted on the horizontal (R_i+ C_i prominence values) and vertical axis ($R_i - C_i$ relationship values) for every barrier as shown in Fig. 3, and are also the values on the basis of which diagraphs are constructed. The positive R_i - C_i values fall under Cause group and have a total of five barriers out of top twelve. The negative values of R_i-C_i fall under Effect group and have a total of seven barriers.

The diagraphs are graphical representation of the cause-and-effect relationships among the barriers. These diagraphs are also called interrelationship maps (IRM) as it presents the influences among the various barriers considered for the study. As shown in Fig. 3, the relation between the barriers is delineated with the help of arrows. The relation between two barriers is represented by a single arrow, where its tail identifies the barrier which endeavors influence on other barriers. The head of the arrow is pointed towards the barrier that receives the net influence. The main observation from Fig. 3 is that it gives a pictorial representation of the interrelationships among critical barriers, that is, influence of the top five most influencing barriers on all critical barriers. This is beneficial for the policy makers and industrial experts in order to execute the process of CRPs adoption and implementation, to attain zero-carbon future. Therefore, primary focus of manufacturing firms should be on the Economic and Organizational barriers in order to successfully implement carbon regulatory policies.

6. Implications for theory and practice

This research supplements the sustainable SC literature by examining the impediments of carbon regulatory policy implications in the manufacturing sector. Further contributing to the extant literature, where focus has been only on adopting green and sustainable practices to achieve sustainability dimension in SCs. The study proposes CRP implementation as an important measure of environmental sustainability for manufacturing SCs. The conceptualization of framework for evaluation of the barriers strengthens the effective and efficient administration of CRPs in SMEs of developing nations. This section outlines theoretical, managerial, and policy implications drawn through detailed case illustrations. At last, Section 6.3 highlights few limitations of the research.

6.1. *Theoretical implications*

This research has major theoretical contributions for the manufacturing sector. The utilization of multiple stakeholders ensures all aspects of sustainability are covered through their diverse knowledge in their respective fields, thus leading towards a zero-carbon future. Since each decision-maker has equal importance, this study follows a proactive and policy driven approach. Due to major contributions of manufacturing sectors to environmental degradation, it's always a focal point for new policy discussions. From emerging economy perspective, this sector is in dire need of strategies and policies adoption in order to curb excessive carbon emissions. As a majority of the firms in developing nations are unregulated, the complexity to adopt newer policies becomes even more difficult and thus hinders the process of controlling ecological sustainability. The present study identifies 31 barriers to CRPs implementation in the context of manufacturing industries of emerging economies. Barrier analysis plays a vital role for the implementation of carbon regulatory policies not only for curbing the carbon emissions in the manufacturing SCs but also for enhancing overall sustainability. Therefore, selection of barriers should be critically assessed for effective and meaningful evaluation. Accordingly, this work serves as a key contribution to the existing body of literature with its applicability to other nations and industries. In order to be more innovative, barrier analysis identifies twelve critical barriers as major hindrances for adoption and implementation of CRPs. Further, interrelationships of these critical barriers provide a validation and clarity to enhance the ecological sustainability. Therefore, the findings of this study strengthen CRPs literature and supports the strategic formulation and implementation to manufacturing SCs for a net zero-carbon society.

6.2. *Managerial and policymaking implications*

The current work has several policy implications. A central focus is the objective to increase awareness among policymakers of the impediments related to adoption and implementation of carbon regulatory policies in manufacturing SCs. This will also help managers to obliterate the issues and barriers that create a hindrance to improving sustainability of the firm. Not only will it aid in identifying the most crucial barriers but also will facilitate in strategic coordination in an unorthodox and effective manner. Therefore, the findings of this study will be a benchmark to other developing countries such as Indonesia, Brazil, etc. for preparation and practicing beforehand the adoption of such regulatory policies.

Moreover, integrated BWM and DEMATEL based mathematical models can be utilized as analytical tools for managers by ranking the barriers on the basis of their relative importance, by further determining the interrelationships among them, and by recognizing the effect of one barrier on the others and on the overall system. Implications highlighted through this study are as follows:

1. Policymakers and regulatory bodies of emerging economies can benefit through adopting such framework for different manufacturing industries to understand existing hindrances. Managers can adopt carbon regulatory environmental policies by targeting barriers with high relative importance (*critical barriers*) as an initial step towards implementation, as focusing on all the barriers isn't economically feasible for all manufacturing firms.
2. The study shows that lack of initial funds is the most crucial impediment among all the barriers. Overcoming this hindrance would lead to significant outcomes; external governmental pressure and support from various policies would help improve sustainability among manufacturing firms. As a result, firms might be made more competitive at the regional level and bring accreditation to global environments. Therefore, governments, along with major private funding bodies, should provide better economic support for smooth adoption of such regulatory policies.
3. The interrelationships among the top twelve barriers are governed by the following barriers: Lack of initial funds, Lack of support from the government, and Lack of research and development. If the firm manages to eradicate these three barriers, they will be able to eliminate critical barriers. Therefore, Indian manufacturing firms would be able to attain emission reductions among manufacturing SCs, with long term sustainability. Policymakers should develop strategies such as mandatory technological awareness and assistance to SMEs by large enterprises.
4. The net zero-carbon targets would lead to a cleaner production which results in a cleaner environment. The urgent need is to adopt environmental regulatory policies for sustainable supply chains for all manufacturing operations. Thus, it is important for both urban and rural authorities to be aware of such innovative regulations, and policymaking bodies can initiate campaigns for such awareness.

Although governments may be aware of such environmental regulations, substantial efforts for adopting and implementing needs augmentation. Countries such as South Korea, Kazakhstan, and China have already started taking such steps towards adopting carbon regulatory policies. In the same way, high carbon emitting nations such as India, Indonesia, Iran, Brazil, etc. need extensive efforts to make it a reality.

6.3. *Limitations*

While this research has provided numerous contributions, there are a few limitations as well. First, the collection of barriers is through limited publications that have confronted carbon regulatory policies issues from the Indian context. Existence of very few articles on CRPs from emerging economies perspective brings about limited support to identified barriers. Second, this study considers inputs from only a few industrial experts through Indian manufacturing sectors; therefore, these experts' opinions may be subjective and could vary among different sets of decision-making body. Further, validity of results through different statistical tools to remove bias with the help of more data set is another limitation of the study.

7. Conclusion

Sustainable production is an integral practice that requires global attention. It is essential to build environmental, economic, and social strategies related to products, services, and processes. Due to increased pressure on decision-makers though government and global agencies on carbon emission related issues, change in manufacturing sector is inevitable. The organizations today need to ensure that besides considering economic benefits they also need to perform their activities in an environmentally responsible manner. From the supply chain perspectives, the organizations need to ensure that they are able to concentrate on reduction of carbon emissions to a greater extent.

It was found out that the tremendous growth in the Indian manufacturing sector over the years is now compelling SMEs to move towards ecological sustainability. In order to attain this, manufacturing firms now seek various ways to control negative impacts on the environment. Implementation of carbon regulatory policies is one of the powerful tools to curb emissions in SCs. The main purpose of the carbon regulatory policies is not only to restrict the manufacturers from emitting excessive emissions but also to provide opportunities to yield financial gains. In this context, this study introduced a novel and comprehensive framework to identify, select, evaluate, and assess the barriers for the implementation of carbon regulatory policies within Indian manufacturing sector. The integrated BWM-DEMATEL MCDM technique is applied to aid in evaluating subjectivity in real-life decisions.

There exist several studies that have addressed the sustainability issues in developing nations manufacturing sector. But these studies were focused on broader ranges of sustainability, rather than emphasizing on carbon regulatory policies as a measure of environmental sustainability. A few studies have incorporated carbon emissions interventions into their SC framework and have emphasized only some specific parts of SCs. There is no comprehensive study for multi-criteria decision-making evaluation of barriers for carbon regulatory policy implementation. As a remedy to this situation, a review of the existing sustainability studies was conducted for identification of relevant barriers. Furthermore, there has been no effective amalgamation of BWM and DEMATEL techniques for the barrier evaluation. The results of the study clearly reflect the effective categorization of the barriers based on their commonality. The linear programming BWM model is then applied to assess the relative importance order of the identified barriers that can help the managers in overcoming such difficulties. On the other hand, DEMATEL identifies the interrelationships among the critical barriers that can help in further refinement of the barriers, saving essential resources of SMEs.

A total of 31 barriers were finalized from a comprehensive list on the basis of reviewed literature and assistance of multiple managers from the manufacturing sector SMEs under consideration. From the list of main barriers, Economical and Organizational barriers were the most crucial. From the list of sub-category barriers, Lack of Initial Funding was the most critical, followed by Hidden costs, Uncertain Carbon Market Price, Lack of Research and Development, Lack of support from the authorities and the government. It was evident from the study that Lack in information sharing and Lack in forecasting were the lowest ranked barriers. Additionally, it was found that Lack of Initial Funding, Lack of Research and Development, and Lack of Support from the authorities and the government were three most influential barriers. The resolution of those barriers results in elimination of top twelve barriers.

Carbon regulatory environmental policies adoption and implementation is still in early stage. Most of the studies in this field involve developing optimization models to curtail emissions through manufacturing processes. In the future, detailed studies could be performed pertaining to threats and measures to overcome such inhibitors thus making implementation process effortless. Additionally, it is important to identify the driving factors and understand relationships among such metrics for better policy absorption in developing countries. This research is from a single nation's perspective, so future case studies might involve other emerging economies. In this way, a comparative analysis can be drawn. In conclusion, adoption of environmental regulatory policies for any nation can aid in achieving sustainable development goals leading to a zero-carbon future.

CRediT authorship contribution statement

Devika Kannan: Conceptualization, Methodology, Supervision, Writing – original draft, Writing – review & editing, Funding acquisition **Rahul Solanki:** Methodology, Formal analysis, Writing – original draft. **Arshia Kaul:** Methodology, Formal analysis, Visualization **P.C. Jha:** Supervision, Resources, Visualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

APPENDIX

Table A
Initial comprehensive list of barriers through literature review

S.No.	Barrier	S.No.	Barrier
1	Higher Production Costs	19	Lack in Forecasting
2	Lack of Initial Funding	20	Lack of Information Sharing
3	Market and Competitors*	21	Inadequate Infrastructure
4	Uncertainty about buyers*	22	Growing informal sector
5	Political resistance	23	Lack of tools to measure
6	Low carbon Design	24	Lack of skilled labor
7	Lack of Involvement of Media and Public*	25	Lack of Technical Experts
8	Lack of in-house reverse logistics	26	Lack of support from the authorities and the government
9	Lack of alternative energy source	27	Insufficient extensions*
10	Unaccountability of production waste	28	Lack of Social Demand
11	Lack of Legal Framework	29	Vested Interest of Business Sector*
12	Lack of Research and Development	30	Funds for training*
13	Fear to shift to new system	31	Strong Industrial focus on Current Linear business Models*
14	Low Education	32	Lack of Stakeholders Pressure on adoption of policies
15	Irregular behavioral issues	33	Inadequate Management Capacity*

(continued on next page)

Table A (*continued*)

S.No.	Barrier	S.No.	Barrier
16	Limited number of Environmental NGO's*	34	Hidden costs
17	High Costs of hazardous waste disposal*	35	Lack of Responsibility*
18	Certification Difficulty	36	Uncertain Carbon Market Price

Source: Rahman et al. (2020); Zhu and Geng (2013); Cagno et al. (2017); Mangla et al. (2016); Gillingham and Sweeney (2012); Tumpa et al. (2019); Gupta (2018); Bai et al. (2017); Karuppiah et al. (2020); Mao et al. (2017); Burritt et al. (2011); Silvestre (2015); Kumar and Dixit (2018); Zhu and Geng (2013); Li et al., 2021; Murillo-Luna et al. (2011).

Table B
BWM ranking scale

Importance	Equally important	Equal to moderately more important	Moderately more important	Moderately to strongly more important	Strongly more important	Strongly to very strongly more important	Very strongly more important	Very strongly to extremely more important	Extremely more important
Rating value	1	2	3	4	5	6	7	8	9

Table C
Barriers dropped and incorporated according to the case considered

Barriers dropped from the main list	Barriers added to the main list
Market and Competitors*	Irrational Current Taxes**
Uncertainty about buyers*	Uncertain Carbon Market Price**
Lack of Involvement of Media and Public*	Unemployment**
Limited number of Environmental NGO's*	Tax burdens on consumers**
High Costs of hazardous waste disposal*	Excessive Production Emissions**
Inadequate Management Capacity*	Unaccountability of SC actors**
Insufficient extensions*	
Vested Interest of Business Sector*	
Funds for training*	
Strong Industrial focus on Current Linear business Models*	
Lack of Responsibility*	

*Barriers dropped by the experts.
**Barriers incorporated for the study by the experts.

Table D
Pairwise comparisons for economic sub-category barriers for firm 6

Best-to-Others	ECN1	ECN2	ECN3	ECN4	ECN5	ECN6
ECN6	6	4	7	2	5	1

Others-to-Worst	Worst barrier: ECN3
ECN1	2
ECN2	5
ECN3	1
ECN4	6
ECN5	3
ECN6	7

Table E
Pairwise comparisons for social sub-category barrier for firm 6

Best-to-Others	SOC1	SOC2	SOC3	SOC4	SOC5	SOC6	SOC7
SOC3	6	9	1	5	7	2	3

Others-to-Worst	SOC2
SOC1	3
SOC2	1
SOC3	9
SOC4	5
SOC5	2
SOC6	7
SOC7	6

Table F
Pairwise comparisons for environmental sub-category barrier for firm 6

Best-to-Others	ENV1	ENV2	ENV3	ENV4	ENV5
ENV5	5	6	3	3	1

Others-to-Worst	ENV2
ENV1	3
ENV2	1
ENV3	5
ENV4	1
ENV5	7

Table G
Pairwise comparisons for technical sub-category barrier for firm 6

Best-to-Others	TEC1	TEC2	TEC3	TEC4	TEC5	TEC6
TEC5	3	4	5	2	1	3

Others-to-Worst	TEC3
TEC1	2
TEC2	2
TEC3	1
TEC4	5
TEC5	5
TEC6	4

Table H
Pairwise comparisons for organizational sub-category barrier for firm 6

Best-to-Others	ORG1	ORG2	ORG3	ORG4	ORG5	ORG6	ORG7
ORG2	7	1	3	8	2	5	6

Others-to-Worst	ORG4
ORG1	3
ORG2	8
ORG3	7
ORG4	1
ORG5	7
ORG6	4
ORG7	5

Table I
Aggregated direct relation matrix

CB*	ENV5	ECN2	ORG2	SOC6	ECN6	ECN3	ENV3	ORG6	ORG3	ORG5	ECN4	ENV4	Sum
ENV5	0	0	0	0	3	0	0	1	3	0	2	0	9
ECN2	0	0	2	3	4	2	2	1	2	0	1	1	18
ORG2	4	2	0	0	3	0	0	1	1	3	3	1	18
SOC6	0	1	1	0	3	2	3	0	1	1	2	0	14
ECN6	2	0	0	1	0	1	2	4	1	1	2	3	17
ECN3	2	3	1	0	2	0	0	0	2	0	1	0	11
ENV3	3	1	0	0	3	0	0	0	0	1	2	2	12
ORG6	1	2	0	4	3	1	2	0	1	0	0	2	16
ORG3	3	0	4	2	2	1	0	0	0	1	0	0	13
ORG5	3	4	1	2	0	1	2	0	2	0	4	3	22
ECN4	0	0	0	3	1	2	3	1	2	0	0	2	14
ENV4	3	0	0	1	2	0	0	0	0	0	1	0	7
Sum	21	13	9	16	26	10	14	8	15	7	18	14	171

Table J
Illustration of normalized direct relation matrix

CB*	ENV5	ECN2	ORG2	SOC6	ECN6	ECN3	ENV3	ORG6	ORG3	ORG5	ECN4	ENV4
ENV5	0.0000	0.0000	0.0000	0.0000	0.1154	0.0000	0.0000	0.0385	0.1154	0.0000	0.0769	0.0000
ECN2	0.0000	0.0000	0.0769	0.1154	0.1538	0.0769	0.0769	0.0385	0.0769	0.0000	0.0385	0.0385
ORG2	0.1538	0.0769	0.0000	0.0000	0.1154	0.0000	0.0000	0.0385	0.0385	0.1154	0.1154	0.0385
SOC6	0.0000	0.0385	0.0385	0.0000	0.1154	0.0769	0.1154	0.0000	0.0385	0.0385	0.0769	0.0000
ECN6	0.0769	0.0000	0.0000	0.0385	0.0000	0.0385	0.0769	0.1538	0.0385	0.0385	0.0769	0.1154
ECN3	0.0769	0.1154	0.0385	0.0000	0.0769	0.0000	0.0000	0.0000	0.0769	0.0000	0.0385	0.0000
ENV3	0.1154	0.0385	0.0000	0.0000	0.1154	0.0000	0.0000	0.0000	0.0000	0.0385	0.0769	0.0769
ORG6	0.0385	0.0769	0.0000	0.1538	0.1154	0.0385	0.0769	0.0000	0.0385	0.0000	0.0000	0.0769
ORG3	0.1154	0.0000	0.1538	0.0769	0.0769	0.0385	0.0000	0.0000	0.0000	0.0385	0.0000	0.0000
ORG5	0.1154	0.1538	0.0385	0.0769	0.0000	0.0385	0.0769	0.0000	0.0769	0.0000	0.1538	0.1154
ECN4	0.0000	0.0000	0.0000	0.1154	0.0385	0.0769	0.1154	0.0385	0.0769	0.0000	0.0000	0.0769
ENV4	0.1154	0.0000	0.0000	0.0385	0.0769	0.0000	0.0000	0.0000	0.0000	0.0000	0.0385	0.0000

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