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Circular Economy Reinforcement to Diminish GHG Emissions: A grey DEMATEL Approach

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Abstract: GHG emissions cause climate change and environmental degradation. The proposed research examines the role of CE in reducing GHG emissions to achieve sustainable goals and an evergreen future by recirculating materials and products. The present work identified thirteen essential CE strategies from a literature review and expert perspective to reduce GHG emissions in India's rubber industry. To provide a comprehensive explanation of the problem, the identified CE strategies were ranked by importance and categorised using the grey DEMATEL (G-DEMATEL) approach. The study offers managers and policymakers a work plan to reduce the carbon footprint.

Keywords: Greenhouse gas (GHG) emissions; Carbon footprint; Circular Economy strategies; grey DEMATEL (G-DEMATEL); Green Asia strategy; rubber industrial sector.

1. Introduction

Climate change is a major concern these days and it is predicted that it could create calamities in the near future. Rendering to a report by IPCC (2006)[1] on climate alteration, the current global average surface temperature has been mounted by 0.4 to 0.8ºC by increasing GHG concentration in the atmosphere. The primary cause behind climate change is greenhouse gases (GHG) emissions in the atmosphere. The GHG effect is principally caused by the emissions of CO_2, NO_2, CH_4, water vapor (natural process), and fluorinated gases (synthetic).

According to the Circularity gap report by Haigh et al. (2021)[2], by the end of this century, continual GHG emission could lead to a 3.2ºC rise in temperature. The concentration of various GHG gases like CO_2, CH_4, and NO_2 has been risen by 29 percent, 150 percent, and 15 percent, respectively, in the atmosphere. Precipitation has grown more spatially variable, increasing the severity and frequency of extreme occurrences. Additionally, the sea level has increased at an average annual rate of 1–2 mm over this time period[3]. Continuous increases in the concentration of GHGs in the atmosphere are anticipated to result in climate change, which would alter ecosystems dramatically, threatening livelihoods, economic activity, living conditions, and human health[4,5]. Materials management, which encompasses the production, consumption, and disposal of materials, goods, and infrastructure, is responsible for a sizable portion of global GHG emissions - which could be projected up to two-thirds of total GHG emissions[6]. Presented work aspires on the notion that increasing the efficiency of material flows and extending materials and products' useful life and value could decrease the GHG emissions hazards, thus portrays circular economy paradigm as a resolution towards green Asia strategies.

Circular economy (CE) seeks to reduce resource input, waste, emissions, and energy leakages by limiting energy and material loops. Through the concept of "take-make-reuse", CE is capable of overcoming the fundamental premise of the linear model, which considers the material loop as "take-make-waste"[7]. Enduring design, reuse, repair, maintenance, refurbishing, remanufacturing, and recycling all contribute to establishing CE principles[8]. Climate change and material consumption are inextricably intertwined, and following a CE, concepts could effectively reduce global carbon footprints, which might restrain the climatic alterations. According to the Circularity gap report by Schmidt et al. (2020)[9], 62% of global GHG emissions (apart from those from land use and forestry) are emitted during the extraction, processing, and production of goods to meet society's requirements; only 38% are emitted during the supply and use of products and services. According to Sitra (2018)[10], if the CE becomes a reality, industrial emissions will decline by 56% in 2050. However, if the demand for raw material decreases globally, it could decline worldwide GHG emissions.

1.1. Motivation of the study

The innumerable human activities (such as energy supply, manufacturing, transportation, commercial and residential buildings, and waste) release excessive GHG into the environment. In addition, agricultural and forest management operations on land would boost GHG emissions significantly. The majority of global GHG emissions are attributable to the electricity and heat sector that accounts for 25 percent, followed by the agriculture, forestry sector including all types of land uses - 24 percent, manufacturing sector - 21 percent, transportation sector - 14 percent, and buildings - 6 percent[11]. However, in the Indian context, the energy sector accounts for 52.5 percent of GHG emissions, followed by the industrial sector – 21.7 percent, agricultural sector, forestry, and other land uses - 17.6 percent, other energy – 5.3 percent and waste sector - 3 percent[12] and it is showcased in Fig.1.

CO_2 is the major contributor to the GHG emissions contributing to 76 percent of the total GHG emissions, followed by CH_4 – 16 percent, NO_2 - 6 percent, and other miscellaneous gaseous – 2 percent[13]. In 2019, India emitted 2,597.40 million tonnes (Mt) of CO_2 equivalent ($MtCO_2e$), accounting for 7.09 percent of world CO_2 emissions in 2019[13]. Fig. 2 displays the increasing tendency of CO_2 emissions in Indian from 2008 to 2019.

Fig. 2 establishes that the CO_2 emissions in India are persistent and increasing every year. The linear reference line originates that the emission jump in 2014 from 2013 is maximum compared to other years' emissions.

Furthermore, the waste sector significantly contributes to GHG emissions by emitting CO_2 and CH_4 gaseous. During the 1990s, the waste sector outspread approximately 90 million tonnes of CH_4 to global CH_4 emissions. The majority of methane waste sector emissions come from solid waste handling. According to Kolsepatil et al. (2019)[14], based on a rigorous disaggregated analysis of India's GHG emissions from 2005 to 2013, the waste sector emitted around 4% of India's total GHG emissions, that had come from municipal solid waste disposal and decay, as well as the treatment and discharge of urban domestic and industrial wastewater. Municipal solid waste, home wastewater, and industrial wastewater are the waste Sector's primary sources of GHG emissions. CH_4 is created and released into the atmosphere as a by-product of the anaerobic decomposition of solid waste and the treatment or disposal of home and industrial wastewater anaerobically. Besides this, a minor portion of N_2O emissions occurs due to home wastewater's protein concentration.

Witnessing the emissions hazards and their unrestrained nature, the present research aims to attain a sustainable future by reducing the influences of GHG emissions through the application of CE philosophies. To pursue the research objective, the present work spotted the causes for carbon emissions by confining the research domain to the Indian rubber manufacturing sectors. The analysis revealed that the emissions caused during various processes like raw material extraction, manufacturing and production, transportation, and packaging of rubber products significantly impact GHG emissions. Besides this, the industrial waste leakage during rubber and allied material processing and wastages of the used products accounts for a significant portion of GHG emissions. Correspondingly, the present work establish that the strategies associated with the linear business model pursued by the industrial sector are the primary reason behind these undesirable emissions. To this foundation, the presented research proposed the CE notion (opposite to linear business model) to tackle adverse environmental conditions by identifying CE correlated strategies. Further, to obtain the expressive results that could create clarity among the managers and the policymakers towards the adoption of CE notion towards reduction in negative environmental emissions, presented work proposed the preference order of the CE strategies that were based on the attained importance score by using the grey theory based DEMATEL (Decision making trial and evaluation laboratory), from now onwards will be referred as G-DEMATEL approach.

The G-DEMATEL is a multi-criteria decision-making (MCDM) approach that had also assisted in defining the contextual relationship between the proposed CE strategies, and correspondingly the strategies were divided into the cause-and-effect group based on their influential power.

Remaining paper follows the sequence: the ***second section*** elaborates the literature survey and identification of CE strategies; the ***third section*** discusses the solution methodology; the ***fourth section*** elucidates the numerical illustration of the applied MCDM; the ***fifth section*** includes the result and discussion; the ***sixth section*** discusses the conclusion of the study and managerial implications; and last ***seventh section*** elaborates the future research directions.

2. Literature survey

According to the Circularity gap report by Haigh et al. (2021)[2], transitioning to a CE could reduce GHG emissions by 39% and alleviate demand for virgin resources by 28%. The report estimated that 22.8 billion tonnes of carbon emissions could be avoided by the use of CE, hence could prevent the climatic breakdown. However, just 8.6 percent of the world economy can be classified as circular, down 0.5 percent from the previous two years' figures. India generated twice as many GHGs as the rest of the world on a per capita basis. Between 1990 and 2014, the GDP of India climbed 357 percent, but GHG emissions increased 180 percent[15].

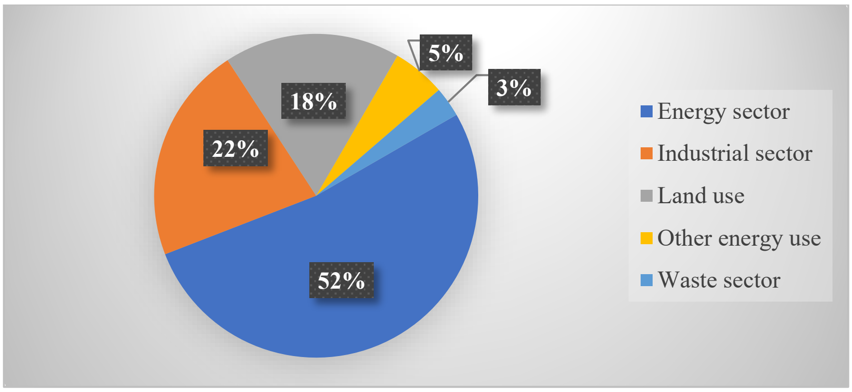

Fig. 1: Major contributing sectors towards GHG emissions in the Indian context

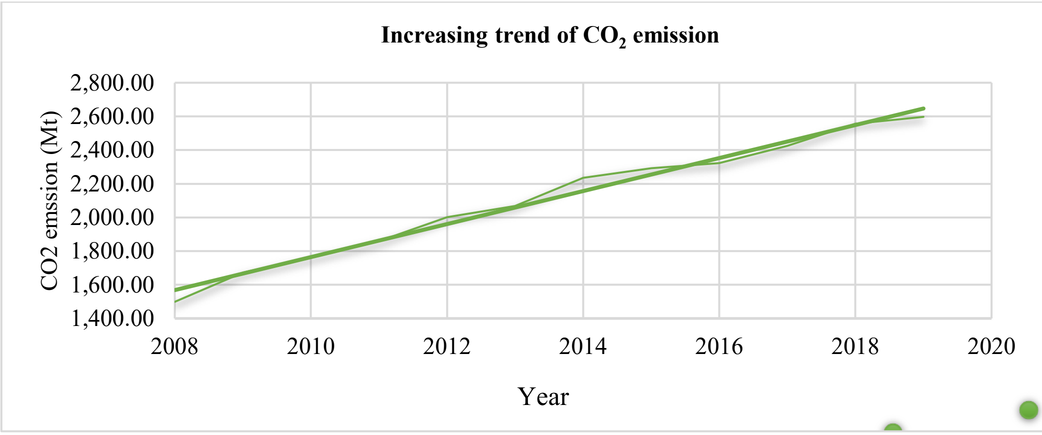

Fig. 2: Increasing trend of CO_2 emissions in India

To address environmental concerns while also delivering socio-economic benefits, the approach towards material consumption and disposal should be transformed. The world's requirement for virgin materials such as minerals, fossil fuels, metals, and biomass negatively influence the environment, ranging from GHG emissions to deforestation, which could be reduced by reusing and recycling end-of-life (EOL) products.

Many scholars have contributed to identifying the major causes of GHG emissions and suggested their ratification. Magazzino et al. (2021)[16)] investigate the causal relationship between per capita MSW generation, urbanization, earnings level, and waste sector GHG emissions in Denmark. The study's findings indicate that a transition from traditional linear economic models to circular ones is crucial for declining GHG emissions. Another study from Mohamed Abdul Ghani et al. (2017)[17)] emphasized the importance of systematically understanding and using CE principles for GHG emissions reduction across the US construction supply chain businesses. Chang (2014)[18)] suggested an approach for identifying the highest-emitting sectors and optimizing their production structures through multi-objective programming to reduce GHG emissions.

A requirement that CE theories emphasize on the need for collaboration and integration across the organizations. Contributing to this theme, Dong et al. (2014)[19)] demonstrated that both industrial synergy and urban collaborations offer a unique approach for carbon emission reduction through the use of a hybrid life cycle assessment model.

The products and materials emit GHG at many stages of their life cycle, including manufacturing, usage, and disposal; the CE activities could tackle that. According to research published by EMF (2019)[20)], CE methods have the potential to eliminate nearly half of residual emissions from the manufacture of commodities by focusing on just five critical sectors (plastics, steel, cement, aluminium, and food), resulting in a 9.3 billion tonne CO_2e reduction in 2050. In addition to this, a report published by Deloitte (2016)[21)] revealed that implementation of CE philosophies could lead to a 13 percent to 66 percent reduction in GHG emissions by highlighting four significant sectors: automobiles, food, construction, and electronic and electrical equipment.

The CE is about optimizing resource use, maintaining long-term sustainability, and creating profit. The CE follows the 3Rs principle of reducing, recycling, and reusing the material cycle. This 3R principle aims to close the material loops and aids in declining GHG emissions. To this rationale, Liu et al. (2018)[22)] analyzed growing GHG emissions from the Chinese plastic recycling industries and propose CE-based approaches for reducing them. Hashimoto et al. (2010)[23)] had investigated a case of cement manufacturing in Japan which has cut GHG emissions by nearly 15 percent (41,300 tonnes per year) through the reuse of industrial and municipal wastes and the associated saving of 272,000 tonnes of virgin materials.

To recognize the standing of CE philosophies for shrinking the over-limit GHG emissions, the proposed study identified various CE strategies capable of handling the significant causes of these harmful emissions. An extensive literature survey analysis and valuable propositions from the experts' panel were carried out to identify the crucial CE strategies. The literature analysis encompasses published scholarly work, published reports and monographs, and newspaper articles. The trailing sub-section explores the identified CE strategies.

2.1 Identification of CE strategies to mitigate the GHG emissions

The CE's primary idea is to transform linear supply networks into closed-loop systems. The supply chain is designed in such a way that it preserves resources and generates zero waste. This involves managing the design of products and services in an effective manner. The industrial revolution has revealed the depletion of finite natural resources as a consequence of the linear manufacturing process, which is also a significant cause for landfilling and emissions caused by incinerations[24]. As an alternative to the current economic model, CE offers a model for maximum resource efficiency that enables its minimum extraction and maximum usage. Presented work identified fifteen CE strategies that are capable of handling the carbon emissions and negative environmental aspects, and are elaborated below:

S1. Recirculation of products and materials

The CE principles aim to circulate the materials and products in the value chain for as long as possible. CE activities like recycling, remanufacturing, reusing, and repairing enable the use of components and material directly to a new product fabrication. This reduces the direct manufacturing of the recovered component or material and saves several manufacturing processes. It would result in lessening the emissions associated with manufacturing processes[16,25].

S2. Emissions trading

Emissions trading is a market-based strategy for pollution control that provides economic incentives for pollutant reduction. The overall objective of an emissions trading scheme is to keep the cost of attaining a defined emissions target as low as possible. The government provides allowances for restricting the emissions levels. The central concept behind emission trading is to assign a monetary value to carbon emissions and create new investment opportunities to build a fund for green technology development[26,27].

S3. Declining waste incineration

Incinerating waste has a very adverse effect on the environment by emitting CH_4 gas and expanding GHG emissions. Additionally, rubber waste incineration emits toxic gases like carbon monoxide, cyanide, sulphur dioxide, butadiene, and styrene. CE creates a low waste economy in which zero waste and emission leakage is the aim. Reducing the wastages and utilizing the produced one for some practical purposes would decline their incineration[28–30].

S4. Waste landfilling prevention

Waste burying over open lands and dumping sites utilize a large amount of area. The open waste creates an enormous amount of pollution and leaks various toxic gases on decomposition that add up in GHG emissions. Additionally, the spent area for burying the waste could be used for beneficial purposes; e.g., if the stated area could be utilized for farming and plantation, it could stabilize the existing and forthcoming vulnerable GHG emissions. The CE principle’s purpose of using the end-of-life product and material that diminish the waste discharge hence would lessen the burying of wastes on the land and contribute to decreasing the GHG emissions[30,31].

S5. Focus on green energy

As discussed in the introduction section,the energy sector is at the top in producing GHG emissions. An alternative for current energy production and consumption is essential, based on renewable energy sources. Government policies and policymakers are currently focusing on this theme and providing subsidies for the same. CE emphases on green energy usage to reduce the emissions associated with non-renewable sources of energy[32–35].

S6. Efficient transportation

Pollutants that emerge from the transportation of products cause a significant portion of GHG emissions. CE philosophies direct efficient and reduced transportation through which harmful emissions could be diminished. Various transportation modes would be eliminated when the used products are circulated, e.g., less raw material extraction demand would result in reduced transportation. Similarly, CE focuses on green energy usage in the transportation modes, maintaining the shortest path and efficient transportation[36–39].

S7. Drop-in raw material extraction

CE purposes to recirculate the products and materials that support decreasing the usage of raw materials. The decreasing usages of raw material would decrease their extraction and hence their related energy consumption. The reduction in raw material extraction would decrease the associated GHG emissions and preserve the precious raw material for tomorrow's use[40–42].

S8. Sharing economy

Sharing economy is a concept of CE in which ownership of the resources is not shared with anyone; however, resources can be used by anybody. A peer-to-peer (P2P) based activity of acquiring, providing, or sharing access to goods and services is defined as the sharing economy. The sharing economy has a good influence on the environment since it reduces the overall number of resources required and helps to minimize pollutants, emissions, and carbon footprints[25,43,44)].

S9. Eco-design product development

To reclaim the used components and products, CE directs to modify the existing product with additional added value corresponding to a greener environment. Eco-design product development seeks to maximize product sustainability across the whole life cycle, employing a comprehensive methodology that looks at environmental impact at every stage. It focuses on ecological and economic necessity while integrating environmental factors into the product creation process[45–48)].

S10. Reductions in industrial scrap

During the entire supply chain activities, various kind of scrap wastes outflow. Many of these scraps are utilized within the industries, however a major of which is disposed of as waste, creating negative impressions on the environment. CE creates a supply chain in which waste material and scrap from one industry are used by other industries, e.g., scrab rubber waste from automobile industries could be used in forming the playground surfaces. This would result in declining the environmental impact as well as offering monetary benefits to the industries[19,49,50)].

S11. Avoiding wastewater leakage

The rubber industrial sector uses several chemicals to obtain the rubber products from the raw material and repercussion in toxic and polluted wastewater leakage. The wastewater leakages get mixed with the running water in upstream and are extremely dangerous for the environment and living organisms. Reusing EOL products would save the manufacturing process that includes toxic chemicals, resulting in avoiding wastewater leakages. Moreover, domestic wastewater is also a significant concern and can also be handled by applying CE philosophies[15,51,52)].

S12. Reforming tax system

Raising taxes on non-renewable resource use and eliminating VAT on recycled goods would reduce avoidable GHG emissions. Leveraging low tax liability for the organizations, workers, and customers towards using environmentally friendly products and material would also assist in the present theme[26,53,54)].

S13. Digitalized logistics system

The supply chain in this recent era is very dynamic and complicated. It includes a complex manufacturing process, multiple organization involvement, and global competition, changing the scenario day by day. The Internet has increased customer awareness about the product and has emerged, requiring supply chain management performance. Material information and platform sharing solutions, together with better ways to use side-streams and by-products, are governed by logistics digitalization. Digitalization tracks the waste streams, discarded products, the kind of material used in the product, and recycling and remanufacturing of an end product that supports decreasing waste and related emissions[53,55,56)].

Fig. 3 displays all the identified CE strategies jointly. After the identification of the CE strategies, the next phase discusses the solution methodology used in the present research work.

Fig. 3: Identified CE strategies to mitigate GHG emissions

3. Solution methodology

Present research's objective is to decline the entire supply chain GHG emissions of India's rubber manufacturing/processing industries. For that purpose, the industries dealing in manufacturing automobile rubber related components such as brake shoes, tires, tubes, brake paddles, and belts were taken into consideration. Due to many industries working in this field across the country, the present study focused on those in Punjab, particularly in Amritsar, Ludhiana, Patiala, and Jalandhar. In general, it is observed that the region or country has little influence on the working culture of enterprises. Thus, narrowing the focus to a single location does not affect the generalizability of the results for other industries located throughout the country.

Numerous case studies and interactions with industry representatives were conducted to understand the issue and their working environment better. Besides this, a proposal including eighteen CE strategies (identified from the literature survey) had been put forward, and after consecutive brainstorming sessions, thirteen of them have been finalized. These thirteen foremost CE strategies were identified to be most dominant for reducing the GHG emissions caused by rubber products and its processing industries. But, finding a way to explain the importance of all the strategies at once is a tedious process, and a simplified model to show the importance score for all the strategies should be presented to managers and policymakers that could help them to realize the CE paradigm outcomes and assist them in lowering environmental carbon footprint. To pursue the same, present research uses the grey DEMATEL (G-DEMATEL) method to propose the order-wise ranking of the strategies through their derived importance scores. Additionally, the strategies were classified in the cause-and-effect group to help understand their influential power.

G-DEMATEL approach is a combination of grey system theory and the DEMATEL method. Grey system theory can help solve problems of uncertain and incomplete information in the case of discrete data [57,58]. The significant advantage of this theory is to deal with limited data under uncertainty, and it is best suitable for small samples also[59]. This is the theory that can be easily combined with different decision-making processes to advance the accuracy of the judgments[60]. Combining DEMATEL with the grey sets would result in obtaining more robust results. In the G-DEMATEL approach, data is collected in linguistic terms, which are then converted into grey numbers. Grey numbers consist of intervals of numbers; one is lower bound, and the other is the upper bound. This means that a linguistic value has been transformed to a range of numbers (grey number) instead of a crisp set that expresses the value as either zero or 1[61,62]. This course assists in incorporating the uncertainty in the problem, which then results in attaining sturdy results.

To obtain data for the G-DEMATEL approach, a questionnaire-based survey had been prepared, which was be filled by the field experts. The survey comprised questions relevant to the CE strategies, and the responses are recorded in linguistic terms. Each question signifies the influence of one strategy over the rest. The engaged linguistic terms are: NO (no influence), VL (very low influence), L (low influence), M (medium influence), H (high influence), and VH (very high influence). The experts were chosen based on their job responsibilities, working field, assigned projects, and research profile. In total, six experts group teams participated in filling the survey. Among the six teams' groups, three belong to the experts from the different rubber components manufacturing industries for the automobile sector, one belongs to managers working in supply chain consultancy, and two belong to the academicians researching the relevant field. Each expert team group contained five to eight experts and had intense knowledge of the relevant field. The obtained data from the expert's survey was then recorded and analyzed through the G-DEMATEL approach to finding the powerful strategies. The following sub-section elaborates the MCDM tool methodology.

3.1 G-DEMATEL approach

The DEMATEL methodology was developed by Battelle Memorial Institute in Geneva. It assists in formulating and analyze the interdependence among various factors through causal relationships[63,64]. It is one of the best methodologies for analyzing cause-and-effect relationships in complex structural models[65], unlike other MCDM techniques like AHP and TOPSIS. DEMATEL primarily depends on the theory of digraph, which assists in dividing the complexities of the system and thus analyzing the cause and effect of factors associated with a complex system[66]. A significant limitation of crisp set-based DEMATEL is to deal with uncertain situations and in cases where there is conflict among experts due to lack of information[67]. To include the uncertainty for the present problem, the grey set theory had been linked with the crisp set DEMATEL approach.

Several authors have successfully applied a combination of grey set theory and DEMATEL methodology in various fields like service quality expectation[60], exploring core competencies of IC design service company[68], green supplier development[69], business process management critical success factors[70], FMEA assessment[71], modeling enablers of supply chain risk mitigation[72], analyzing barriers for automotive parts remanufacture[73], analysis of barriers of environmentally friendly products[74].

Steps to G-DEMATEL has been illustrated below:

Step 1: Formulating the initial relation matrix

Consider n as the total number of factors and k as the respondents. Similarly, consider u as an assessor evaluating the direct impact of factor x on factor y. The responses from the experts' teams had recorded in linguistic terms. The linguistic terms were then converted in grey numbers using Table 1.

Table 1: Linguistic scale and their corresponding grey numbers

Linguistic scale	NO	VL	L	M	H	VH
Lower bound grey number	0	0	1	2	3	4
Upper bound grey number	0	1	2	3	4	5

Step 2: Calculating initial grey relation matrix

It is essential to adjust and change the value of the integer or impact scale according to the aspects that apply to various grey values, with upper bounds ($\overline{\otimes}$) and lower bounds ($\underline{\otimes}$)

$$\otimes N_{xy}^{r} = (\underline{\otimes} N_{xy}^{r}, \overline{\otimes} N_{xy}^{r}) \quad (1)$$

Where, $1 \le r \le k, 1 \le x \le n, 1 \le y \le n$

$$\textit{Lower limit value} = \underline{\otimes} N_{xy}^{r} \quad (2)$$

$$\textit{Upper limit value} = \overline{\otimes} N_{xy}^{r} \quad (3)$$

Step 3: Computing the average grey relationship matrix

Consider P as the grey relation matrix average $[\otimes N_{xy}]$ formulated from $\otimes N_{xy}^{k}$ grey relation matrix; r = 1-k,

$$\otimes \widehat{N}_{xy} = \left(\frac{\sum_k \underline{\otimes} N_{xy}^{r}}{k} \frac{\sum_k \overline{\otimes} N_{xy}^{r}}{k} \right) \quad (4)$$

Step 4: Determining the crisp -relation matrix (Q) (modified CFCS method)

The crisp relationship matrix (Q) is computed through the average grey relation matrix. The grey numbers are converted to crisp numbers by the modified-CFCS (converting fuzzy data into crisp scores) method [73] involving a three-step procedure:

(i) Lower and upper normalized values

$$\underline{\otimes} N_{xy}^{*} = (\underline{\otimes} \widehat{N}_{xy} - {}^{min}{}_{y} \underline{\otimes} \widehat{N}_{xy}) / \Delta_{min}^{max} \quad (5)$$

Where $\underline{\otimes} N_{xy}^{*}$ symbolizes the normalized lower limit value of the grey number $\underline{\otimes} \widehat{N}_{xy}$

$$\overline{\otimes}N^*_{xy} = (\overline{\otimes}\hat{N}_{xy} - {}^{min}_{y}\overline{\otimes}\hat{N}_{xy})/\Delta^{max}_{min} \quad (6)$$

Where $\overline{\otimes}N^*_{xy}$ symbolizes the normalized lower limit value of the grey number $\overline{\otimes}\hat{N}_{xy}$

$$\Delta^{max}_{min} = ({}^{max}_{y}\overline{\otimes}\hat{N}_{xy} - {}^{min}_{y}\underline{\otimes}\hat{N}_{xy}) \quad (7)$$

(ii) Calculate the total normalized crisp value

$$Q_{xy} = \frac{\underline{\otimes}N^*_{xy}(1-\underline{\otimes}N^*_{xy})+(\overline{\otimes}N^*_{xy}\times\overline{\otimes}N^*_{xy})}{(1-\underline{\otimes}N^*_{xy}+\overline{\otimes}N^*_{xy})} \quad (8)$$

(iii) Compute the final crisp values

$$Q^*_{xy} = \left(min\,\underline{\otimes}\hat{N}_{xy} + \left(Q_{xy}\times\Delta^{max}_{min}\right)\right) \quad (9)$$

Where, $Q = [Q^*_{xy}]$

Step 5: Computing the normalized direct crisp relation matrix (L)
The normalized direct crisp relation matrix L is obtained by multiplying M with matrix Q
Where M denotes the normalization factor,

$$M = \frac{1}{\max_{1\le x\le n}\sum_{y=1}^{n}Q^*_{xy}} \quad (10)$$

$$L = Q \times M \quad (11)$$

Where elements in L would be in between 0 and 1

Step 6: Computing total relationship matrix (Y)

$$Y = L + L^2 + L^3 + \cdots L^r,$$
$$Y = L(1 + L + L^2 + \cdots L^{r-1}),$$
$$Y = L(1 + L + L^2 + \cdots L^{K-1})(1-L)(1-L)^{-1}$$
$$Y = L(I-L)^{-1} \quad (12)$$

Where I is the identity matrix

Step 7: Obtaining the influenced factors.

Let the matrix Y contains Y_{xy}elements. The vectors v, w represents the row and column elements in the total relational matrix Y,

The vector v is defined as = $n \times 1$
The vector w is defined as = $1 \times n$ (13)

$$Y = \begin{bmatrix} y_{11} & y_{12} & \cdots & y_{1n} \\ y_{21} & \cdots & \cdots & y_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ y_{m1} & y_{m2} & \cdots & y_{mn} \end{bmatrix} \quad (14)$$

$$Y = [y_{xy}], \quad i,j \in (1,2,3,\ldots,n)$$

$$v = (v_i)_{n\times1} = \left[\sum_{j=1}^{n} y_{ij}\right]_{n\times1} \quad (15)$$

$$w = (w_i)_{1\times n} = \left[\sum_{i=1}^{n} y_{ij}\right]_{1\times n} \quad (16)$$

(v + w) and (v - w) values infer the significance of the factors and classify them in the cause-and-effect group. (v + w) values indicate the importance of the factor, representing its effect power. (v - w) values indicate the casual-effect relationship between the factors. The negative (v - w) value suggests that the factor falls to the effect group and the positive value suggests that the factor falls under the cause group. Positive (v - w) value represents the factors that have high cause effect on others; negative (v - w) represents the factors that have been highly affected by others [75].

Step-8: Validating the results and framing the digraph

Matrix Y allows for data on how one criterion impacts another, and it takes into account the influence of the upper and lower threshold values by computing the mean value of the deviations. Significant associations are defined as having scores that are above the threshold. The links between these two components are shown in the digraph. The mean value of the digraph is computed using the below formula;

$$Mean = \left((Upper\ value - Lower\ value) \times 0.5\right) \quad (17)$$

Finally, the digraph is formulated with respect to

$$\left((v_i + w_j), (v_i - w_j)\right)\forall i = j \quad (18)$$

The trailing section elaborates the numerical illustration of the considered problem.

4. Numerical illustration

To obtain the importance scores of the CE strategies, data was collected from the experts in linguistic terms through the questionnaire-based survey. In the present problem, there are thirteen CE strategies and six experts panel groups. Hence six 13x13 matrices in linguistic terms had been obtained after the survey. All of the obtained data had been recorded in matrices form, and all the individual matrices in linguistic terms had been converted to an initial grey relationship matrix. Table 1 was used to convert the linguistic terms to grey numbers. As a result, a total of six initial grey relationship matrices had obtained.

The average grey relationship matrix was computed by averaging the elemental cell value of all the six initial grey relationship matrices, using Eq 4, and is shown in Table 2.

Table 2: Average grey relationship matrix

CE Str.	S1		S2		S3		S4		S5		S6		S7		S8		S9		S10		S11		S12		S13	
S1	0.00	0.00	0.17	0.33	3.50	4.50	3.33	4.33	1.33	2.33	0.50	1.50	3.50	4.50	0.17	0.33	1.50	2.50	3.50	4.50	3.33	4.33	0.17	0.33	1.33	2.33
S2	0.17	0.33	0.00	0.00	3.33	4.33	3.50	4.50	3.33	4.33	0.50	1.50	0.50	1.50	3.33	4.33	3.50	4.50	1.50	2.50	3.50	4.50	1.33	2.33	1.33	2.33
S3	3.50	4.50	3.33	4.33	0.00	0.00	3.33	4.33	1.50	2.50	1.50	2.50	1.33	2.33	0.50	1.50	1.50	2.50	3.50	4.50	3.33	4.33	0.17	0.33	3.33	4.33
S4	3.33	4.33	1.33	2.33	3.33	4.33	0.00	0.00	0.50	1.50	0.50	1.50	3.50	4.50	1.33	2.33	1.33	2.33	3.33	4.33	3.33	4.33	0.50	1.50	3.33	4.33
S5	1.50	2.50	3.50	4.50	0.50	1.50	0.50	1.50	0.00	0.00	3.33	4.33	0.50	1.50	1.50	2.50	1.50	2.50	3.33	4.33	1.33	2.33	3.50	4.50	3.33	4.33
S6	0.50	1.50	0.00	0.17	1.33	2.33	1.33	2.33	3.50	4.50	0.00	0.00	1.33	2.33	3.33	4.33	1.33	2.33	1.33	2.33	1.33	2.33	3.33	4.33	3.50	4.50
S7	3.50	4.50	1.33	2.33	3.50	4.50	3.33	4.33	1.33	2.33	0.50	1.50	0.00	0.00	3.50	4.50	3.50	4.50	3.33	4.33	1.33	2.33	0.50	1.50	1.50	2.50
S8	3.33	4.33	0.50	1.50	3.50	4.50	3.50	4.50	3.33	4.33	1.50	2.50	3.50	4.50	0.00	0.00	3.50	4.50	3.33	4.33	3.33	4.33	1.50	2.50	3.33	4.33
S9	3.50	4.50	3.33	4.33	3.33	4.33	3.33	4.33	3.50	4.50	1.33	2.33	3.33	4.33	1.50	2.50	0.00	0.00	1.33	2.33	1.33	2.33	0.50	1.50	1.50	2.50
S10	0.50	1.50	3.33	4.33	3.33	4.33	3.50	4.50	1.33	2.33	1.33	2.33	3.33	4.33	1.33	2.33	3.33	4.33	0.00	0.00	3.50	4.50	1.33	2.33	0.50	1.50
S11	0.50	1.50	3.33	4.33	0.50	1.50	3.33	4.33	1.50	2.50	0.17	0.33	0.50	1.50	1.33	2.33	3.33	4.33	1.33	2.33	0.00	0.00	3.33	4.33	1.50	2.50
S12	1.50	2.50	3.50	4.50	3.33	4.33	3.33	4.33	3.33	4.33	1.33	2.33	0.50	1.50	1.33	2.33	3.33	4.33	3.33	4.33	1.33	2.33	0.00	0.00	1.50	2.50
S13	3.33	4.33	1.33	2.33	1.33	2.33	0.50	1.50	3.33	4.33	3.33	4.33	1.33	2.33	3.33	4.33	3.33	4.33	3.50	4.50	1.33	2.33	1.50	2.50	0.00	0.00

The next step was to obtain the crisp-relation matrix (Q) and was attained using the modified CFCS method as mentioned from Eq 5 to 9. The computed crisp-relation matrix (Q) is shown in Table 3.

Next, the normalized direct crisp relation matrix (L) was computed using the relation mentioned in Eq

10 and 11. After that total relationship matrix (Y) was obtained using Eq 12 and is shown in Table 4. Table 4 also includes the vectors v and w. (v + w) and (v - w) values of the identified CE strategies are obtained in Table-5. Based on the values obtained from this table, the CE strategies are classified into the cause-and-effect group. (v + w) values indicate the standing of a CE strategy over others, representing its importance score, and the CE strategies were ranked based on their obtained score (Table 5). CE strategies obtained (v + w) has pictorially depicted in Fig. 4.

Additionally, (v-w) values indicated the casual-effect relationship between the CE strategies. The negative (v-w) value suggests that strategy would fall to the effect group, and the positive value suggests that it would come under the cause group. Fig. 4 reveals the importance score of the CE strategies based on which their rankings had been determined. The figure establishes that CE strategy S3 had attained the highest importance score and stood on the first position, on the contrary CE strategy S7 had attained the least importance score and stood at last place in the tally. On the basis of (v - w) values, CE strategies had been classified in the cause-and-effect group which can be visualized through Fig. 5.

Table 3: The crisp-relation matrix (Q)

	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13
S1	0.00	0.18	4.32	4.12	1.76	0.78	4.32	0.18	1.95	4.32	4.12	0.18	1.76
S2	0.18	0.00	4.12	4.32	4.12	0.78	0.77	4.12	4.32	1.95	4.32	1.76	1.76
S3	4.32	4.12	0.00	4.12	1.95	1.97	1.76	0.77	1.95	4.32	4.12	0.18	4.12
S4	4.12	1.76	4.12	0.00	0.77	0.78	4.32	1.76	1.76	4.12	4.12	0.77	4.12
S5	1.95	4.32	0.77	0.77	0.00	4.15	0.77	1.95	1.95	4.12	1.76	4.32	4.12
S6	0.77	0.01	1.76	1.76	4.32	0.00	1.76	4.12	1.76	1.76	1.76	4.12	4.32
S7	4.32	1.76	4.32	4.12	1.76	0.78	0.00	4.32	4.32	4.12	1.76	0.77	1.95
S8	4.12	0.77	4.32	4.32	4.12	1.97	4.32	0.00	4.32	4.12	4.12	1.95	4.12
S9	4.32	4.12	4.12	4.12	4.32	1.77	4.12	1.95	0.00	1.76	1.76	0.77	1.95
S10	0.77	4.12	4.12	4.32	1.76	1.77	4.12	1.76	4.12	0.00	4.32	1.76	0.77
S11	0.77	4.12	0.77	4.12	1.95	0.18	0.77	1.76	4.12	1.76	0.00	4.12	1.95
S12	1.95	4.32	4.12	4.12	4.12	1.77	0.77	1.76	4.12	4.12	1.76	0.00	1.95
S13	4.12	1.76	1.76	0.77	4.12	4.15	1.76	4.12	4.12	4.32	1.76	1.95	0.00

Table 4: Total relationship matrix (Y)

	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	w
S1	0.13	0.17	0.26	0.28	0.18	0.11	0.00	0.00	0.21	0.27	0.27	0.11	0.19	***2.18***
S2	0.16	0.20	0.28	0.31	0.27	0.14	0.00	0.00	0.29	0.25	0.29	0.17	0.21	***2.58***
S3	0.27	0.30	0.21	0.32	0.24	0.17	0.00	0.00	0.26	0.32	0.31	0.14	0.28	***2.81***
S4	0.24	0.22	0.28	0.20	0.18	0.13	0.00	0.00	0.23	0.29	0.28	0.13	0.25	***2.43***
S5	0.19	0.29	0.21	0.23	0.19	0.22	0.00	0.00	0.25	0.30	0.23	0.24	0.27	***2.62***
S6	0.15	0.16	0.19	0.21	0.25	0.10	0.00	0.00	0.20	0.22	0.19	0.21	0.24	***2.13***
S7	0.28	0.24	0.31	0.33	0.22	0.14	0.00	0.00	0.30	0.32	0.26	0.14	0.23	***2.77***
S8	0.32	0.27	0.36	0.38	0.34	0.21	0.00	0.00	0.36	0.38	0.36	0.22	0.33	***3.53***
S9	0.26	0.29	0.29	0.31	0.28	0.16	0.00	0.00	0.19	0.26	0.25	0.15	0.22	***2.66***
S10	0.17	0.29	0.29	0.31	0.22	0.15	0.00	0.00	0.29	0.20	0.30	0.17	0.19	***2.58***

S11	0.16	0.27	0.19	0.28	0.21	0.11	0.00	0.00	0.27	0.22	0.17	0.21	0.19	***2.27***
S12	0.23	0.32	0.32	0.34	0.30	0.18	0.00	0.00	0.32	0.33	0.27	0.14	0.24	***3.00***
S13	0.25	0.23	0.24	0.23	0.28	0.22	0.00	0.00	0.29	0.31	0.24	0.18	0.17	***2.63***
v	***2.81***	***3.25***	***3.45***	***3.72***	***3.17***	***2.04***	***0.00***	***0.00***	***3.45***	***3.67***	***3.43***	***2.19***	***3.02***	

Table 5: (v + w) and (v – w) values and CE strategies classification in cause-and-effect group

CE strategies	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13
v	2.18	2.58	2.81	2.43	2.62	2.13	2.77	3.53	2.66	2.58	2.27	3	2.63
w	2.81	3.25	3.45	3.72	3.17	2.04	0	0	3.45	3.67	3.43	2.19	3.02
v + w	4.98	5.84	6.26	6.15	5.79	4.17	2.77	3.53	6.11	6.25	5.7	5.18	5.65
v - w	-0.63	-0.67	-0.63	-1.29	-0.55	0.09	2.77	3.53	-0.79	-1.09	-1.15	0.81	-0.39
Cause/Effect	Effect	Effect	Effect	Effect	Effect	Cause	Cause	Cause	Effect	Effect	Effect	Cause	Effect
Ranking	10	5	1	3	6	11	13	12	4	2	7	9	8

Fig. 5 reveals that the CE strategies having positive (v - w) values, i.e., above the 0 values, are in the cause group. Here S6, S7, S8, and S12 came into the cause group, indicating strong influence over other CE strategies. On the other side, if the (v-w) value is negative, the strategy would be placed in the effect group. Here the rest of the strategies came in this group, indicating that they have been influenced by the cause group strategies.

5. Results and discussion

According to the attained importance score of the CE strategies based on (v + w) values in Table 5 and Fig. 4, CE strategies prioritized ranking was obtained. According to the importance score, CE strategy S3 "Declining waste incineration" had attained the highest priority over the rest and gained a 6.26 value. Burning of waste rubber materials such as a tube, tires cause immense GHG emissions, and the obtained CE strategy S3 could assist in declining this waste incineration, indicating the precision of the obtained result towards reducing the emissions. The second most important strategy obtained is S10 "Reduction in industrial scrap" – 6.25, followed by S4 "Waste landfilling prevention" – 6.15 and S9 "Eco-design product development" – 6.11.

Obtained values of all the top four strategies suggest that they a tough struggle with minor differences in the rating value indicating deliberation of all four strategies on the priority basis. The output of study infers that it is necessary to reduce the scrap flow from the industries and utilize them in a healthy manner by following the CE philosophies and avoiding landfilling and incineration of these scraps and other kinds of waste. A refined design of the product based on the eco-design principle could create a safer environment. Rest all CE strategies follows the order: S2 > S5 > S11 > S13 > S12 > S1 > S6 > S8 > S7

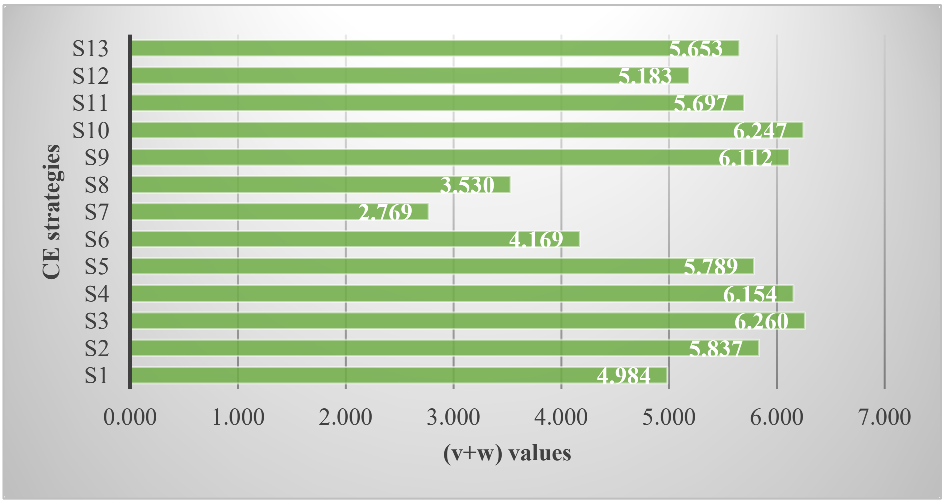

Fig. 4: CE strategies importance score

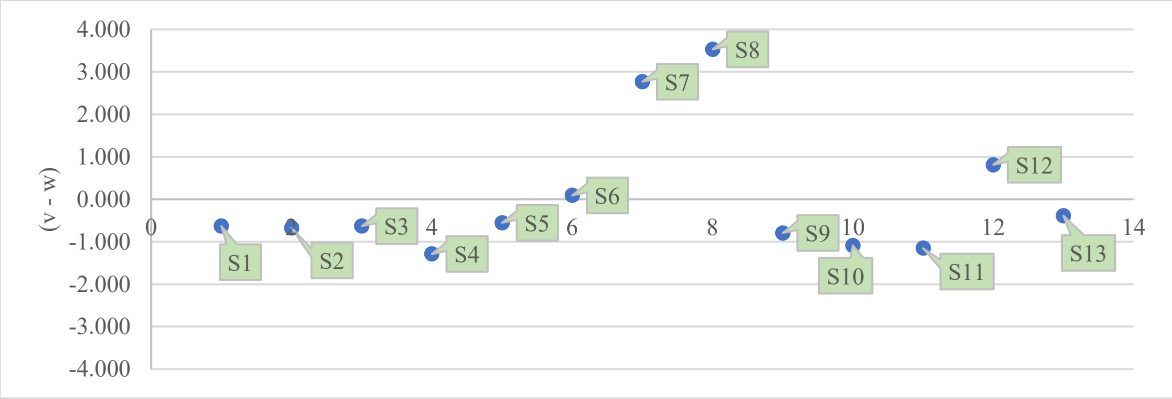

Fig. 5: Diagraph representation of CE strategies representing their causal relationship

However, it is to be noticed that all CE strategies are interlinked, and the advancement of one would benefit others. However, the performed analysis aimed to obtain the strategies' ranking, and all the strategies had obtained different values. This sequential manner suggests the important ranking of each CE strategy to overcome the unrestrained GHG emissions. The attained (v – w) values classified the CE strategies in the cause-and-effect group. Strategies S6 "Efficient transportation", S7 "Drop in raw material extraction", S8 "Sharing economy", and S12 "Reforming tax system" were fall under the cause group, indicating the influence of these strategies over the rest. In a similar fashion, strategies S1 "Recirculation of product and material", S2 "Emission trading", S3 "Declining waste incineration", S4 "Waste landfilling prevention", S5 "Focus on green energy", S9 "Eco-design product development", S10 "Reduction in industrial scrap", S11 "Avoiding wastewater leakage", and S13 "Digitalized logistics system were fall in effect group, indicating these strategies are influenced by the cause group strategies. The cause group strategies have more driving power and drive the effect group strategies. It suggests that cause group strategies infer the effective approaches for reducing GHG emissions and needs more focus when pondering the implementation of CE philosophy.

6. Conclusion and managerial implications

The management of materials, comprising the manufacturing, consumption, and disposal of materials, goods, and infrastructure, accounts for a significant portion of worldwide GHG emissions. The reduction of waste generation and improvement in its treatment for reusing is an urgent need of the society to reduce the GHG emissions and keeping a healthier environment. Present work proposes CE philosophy for reducing GHG emissions by treating waste as a resource. Improving circulation and increasing material management efficiency can take various forms, such as lengthening product lifetimes, dropping material losses, recirculating the products and materials and products, and replacing GHG intensive components with lower emission ones.

The present study analysis was confined to the rubber industrial sector in India's northern part, specifically in Punjab. However, the findings of the work are so particular that they could be generalized for the industrial rubber sector situated in other parts of the country. To meet the research objective, thirteen essential CE strategies were identified, and the G-DEMATEL approach was applied for their analysis which is an extension of the DEMATEL approach used to decrease or avoid vagueness and increase the judgment's preciseness. The importance score of the CE strategies and their categorization into cause-and-effect was done through G-DEMATEL. The study concludes that the cause group strategies (S6, S7, S8, and S12) have a superior degree of interaction and influence over other effect group strategies. It undertakes that the improvement of cause group strategies would promote the effect group strategies and create pathways for promoting the CE notion that would, in return, keep the environment healthy and reduce the carbon footprint.

Interpreting the attained prioritized ranking of the CE strategies, S3 "Declining waste incineration" was the most crucial strategy. Rubber waste incineration emits several toxic gases like carbon monoxide, cyanide, sulphur dioxide, butadiene, and methane, which boost the carbon footprints and create hazards for humanity. Their incineration could be declined by reusing and the rubber waste for the same or different purpose as governed by CE viewpoints. The other CE strategies in the preference order, S10 "Reduction in industrial scrap", S4 "Waste landfilling prevention" and S9 "Eco-design product development" had a very minute difference in importance score with the topmost strategy, indicating their effective influence towards reducing the GHG emissions. The generation of industrial rubber scrap is upsetting because fashioning the rubber process involves various finishing operations, which eventually head to produce these scrabs in the entire production process. However, efficient processes and innovative mould design could assist in reducing the rubber scrab. Further, the generated scrap could be utilized in other products using advanced techniques.

6.1 Managerial implications

Although the managers of the industrial sector and policymakers are exceedingly conscious and pressurized for reducing GHG emissions to achieve environmental sustainability, they are unable to implement the specified sustainability measures due to a lack of implementation techniques. Present research offers an empirical overview of the CE strategies that could reduce the environmental carbon footprint. The work highlights the categorization of CE strategies into causes and effects groups and establishes their importance score based on which the rankings were attained. The findings of the present work could enable managers and policymakers to understand the significant factors behind the GHG emissions from the industrial rubber sector and provides an impression to control these emissions by following the proposed CE strategies. To suggest a streamlined understanding, present work offers the prioritization of CE strategies that could assist the managers in sequentially implementing them. Additionally, the strategies fell under cause group express their influential nature over the other, and the leaders could also implement them significantly.

7. Future scope

This study solely focuses on proposing a framework based on the Indian context by selecting rubber manufacturing industries in the northern part of the country. However, the findings could be generalized for the rest of the country, but to overgeneralize the findings globally, data could be fetched from the industries situated in other countries and leaves a future research direction. Moreover, the rubber product user must also be included in future research to understand their mindset and prepare a framework based on the findings. Additionally, only the rubber industrial sector had been focused on in the present research, which could further be amplified by including other industrial sectors such as leather and plastic. In addition to this, the findings of the present work could also be validated by applying other MCDM tools like intuitionistic fuzzy DEMATEL, hesitant fuzzy DEMATEL, and interval values intuitionistic fuzzy DEMATEL.

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