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Sustainability Analysis in an Automobile Industry Using ISM and Micmac Analysis

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Abstract

In the automotive industry, sustainable manufacturing involves integrating the triple bottom line of economic, environmental, and social aspects into manufacturing operations. However, the automotive industry faces challenges in prioritizing sustainability due to its interdependence and complexity, where effective decision-making requires identifying influential factors and understanding their relationship. To address the challenge, a hybrid method combining Interpretive Structural Modeling (ISM) and MICMAC analysis is utilized. ISM establishes connections between specific criteria, enabling a comprehensive understanding of their interdependencies. MICMAC analysis then helps the prioritization process by classifying factors according to their driving and dependency power. This approach helps stakeholders identify the most crucial factors and develop action plans to reduce or eliminate obstacles hindering the adoption of sustainable manufacturing practices. This study addresses the sustainability issues in the automotive sector in Kerala, India. Furthermore, the study suggests the potential expansion by conducting a large-scale survey to include additional criteria, thereby enhancing the understanding of sustainable practices in the automotive sector. The results indicate the proposed ISM-MICMAC model outperforms existing methods in several areas, including accuracy of prioritization (92.5% vs. 70% for AHP), resource efficiency (85% vs. 60% for Carbon Footprint Analysis), emission reduction (30% vs. 20% for LCA), and stakeholder engagement (85% vs. 80% for LCA).

Keywords

sustainability, Interpretive structural modeling, Structural Self Interaction Matrix, Cronbach Alpha, Statistical Package for Social Science.

Introduction

Globally, the automobile sector is a key driver of innovation, economic growth, and technical improvement. However, the industry's traditional practices have often been questioned due to their impact on society, environment, and resource consumption (Pathak et al., 2021). In response to the urgent need to address social injustice and slow down environmental degradation, a paradigm shift towards sustainable manufacturing practices has occurred. This shift reflects a transition from conventional production methods to strategies that prioritize sustainability, environmental care, and social responsibility (Masoumi et al., 2019; Taiebat M et al., 2018). The Sustainable Development Goals present new obstacles for researchers and practitioners in the field of industrial management. The United Nations established the SDG as an agenda to address sustainable environmental concerns for the future of humanity. The term "sustainable manufacturing" or "sustainable production" refers to the integration of the sustainability idea into manufacturing sector. One way to characterize sustainable manufacturing is as a paradigmatic collection of technologies or systems. Today, the businesses increasingly have a deeper understanding of corporate environmental, social, and economic sustainability at both local and global levels (Böckin & Tillman, 2019; Ghobakhloo, 2020).

Finding a balance between the environmental, social, and economic facets is the aim of sustainable manufacturing, in order to satisfy stakeholder demands and gain a competitive edge. The use of energy and materials, the environment impact, social justice and community development, economic performance, labour force, and goods are the six primary facets of sustainable production. Identifying ways to reduce waste and create value while considering all sustainability

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aspects is important to improve the performance of sustainable manufacturing (Ray & Khaba, 2020; Raut et al., 2018; Jamwal et al., 2021). Economic practices that satisfy existing needs without jeopardizing the ability of future generations to meet their own needs constitute its general definition of it. A sustainable supply chain incorporates social and environmental aspects, alongside financial metrics for profit and loss. According to this definition, sustainability refers to reducing a company's adverse effects on people, environment, and society while preserving or increasing value for stakeholders, customers, and other parties involved. Achieving sustainable development requires organizations must redesign processes and adopt new technologies, even if it requires significant changes to existing supply chain management business models. A variety of analytical techniques are utilized to evaluate sustainability in the automotive sector. An example of one such strategy is the Interpretive Structural Modelling (ISM) method, which offers a systematic way to comprehend intricate linkages between sustainability issues. Through the identification of important systemic drivers, obstacles, and relationships, ISM supports stakeholders to make well-informed decisions (Castro & Silv Parreiras (2021); Krishnan et al., 2021; Bagherian et al., 2024).

Furthermore, recognizing the viewpoints and objectives of the parties involved in the automotive industry, manufacturers, consumers, regulators, and communities, requires comprehensive stakeholder analysis. Companies that involve stakeholders improve transparency, accountability, and stakeholder satisfaction by incorporating their input into sustainability initiatives. In addition, a decision-making framework that incorporates a variety of sustainability criteria, including social, environmental, and economic considerations, is known as Multi-Criteria Decision Analysis (MCDA). When choosing sustainable methods in the automotive sector, stakeholders select them by weighing conflicting objectives, trade-offs, and uncertainties using MCDA (Chen et al., 2021; Gupta et al., 2019). Moreover, System Dynamics Modelling (SDM) offers a comprehensive method for comprehending the dynamic behavior of sustainability programs in the automotive sector. To forecast the long-term effects of market dynamics, technology advancements, and governmental interventions on sustainable outcomes, SDM models include feedback loops, time delays, and nonlinear interactions. Sustainability is often considered a valuable, innovative, and difficult-to-replicate resource or capability that contributes to competitive advantage from a resource-based perspective. An organization's distinct value-chain opportunities and risks should be prioritized by a strong business strategy before developing a sustainable plan to gain a competitive edge (Rebs et al., 2019; Pelissari et al., 2022). An optimized solution and related underlying models are required for sustainable manufacturing, taking into account the difficulties inherent in the aforementioned emphasis areas. Hence, this research emphasizes modeling to provides an overview of the present developments and emerging difficulties in attaining sustainability in industrial processes. The main objective of this study are:

- To analyze the interdependencies and driving power of sustainability elements within the automobile sector, by integrating of ISM and MICMAC, thereby providing insightful information for decision-making.
- To classify sustainability elements according to their driving and dependent powers using MICMAC, utilizing to develop a deeper understanding of sustainability elements.

The paper has been structured as follows: Section 2 provides the literature survey, Section 3 describes the proposed methodology, and Section 4 examines the data analysis of the proposed model. Section 5 examines the results and discussion of the comparative analysis. Finally, section 6 concludes the paper.

Literature Survey

Ali et al. (2018) introduced interpretive structural modeling (ISM) to identify the green supply chain management enablers (GSCMEs) for the Indian automobile industry. This paper aimed to determine the driving and dependent power of these enablers through the application of Matriced' Impacts Croisés Multiplication Appliquée à un Classement (MICMAC) analysis. The primary data were collected from 45 car companies in the Pune-Nashik region using a survey approach. It is recommended that continual improvement and supplier collaboration be the two main tactics for improving GSCM performance. However, the management team lacks knowledge and training about GSCM, which makes implementation difficult.

Yadav & Sahay (2017) conducted the automotive sector in India, comprising around 500 large companies and 1000 small, legally established businesses that provide car services to their clientele. India was reaping several benefits from its management of the car industry as its primary sector, including cost, labour advantages, technology advancements, and other perks. Kerala Automobiles Limited served as India's hub for the manufacturing of electric autorickshaws. India was the world's second-largest market for two-wheelers and third-largest market for three-wheelers, with the fastest-growing vehicle market in 2004 based on Global

Vehicle Statistics. By utilizing economically viable production techniques to modify sustainable product designs. Sustainable car manufacturing aims to reduce its negative effects on the environment and continuously produce improvements that promote a more environmentally friendly world.

Fauzdar et al. (2022) examined the different Industry 4.0 components that affected India's car sector. It was determined that ten factors were significant. The generated replies were utilized to gauge their mutual influence. For this, an investigation using structural equation modeling (SEM) was conducted. Subsequently, MICMAC, a cross-impact matrix multiplication, was utilized to illustrate the interdependence of the variables, consequently scrutinizing the degree of correlation among Industry 4.0 components concerning their power-dependent and driving aspects. It was anticipated that the company was going to find it much easier to improve performance and competitiveness if these elements of obstacles were effectively mitigated. However, the major weakness of this research is the bias in the expert opinions.

Bux et al. (2020) developed a novel framework for analyzing obstacles by combining the Delphi method (DM), ISM, and MICMAC. This study examined challenges to CSR adoption in a developing country, namely, in Pakistan's manufacturing industry. To attain this purpose, researchers conducted literature surveys and collected expert comments, and then an integrated approach ISM-MICMAC model, was used in this study. Initially, corporate social responsibility (CSR) hurdles were found from previous studies and filtered using the DM. Expert data and ISM and MICMAC results show that "lack of resources", "lack of regulations and standards", and "lack of policy incentives" were the primary barriers to CSR implementation in Pakistan's manufacturing industry. The least significant barriers to CSR adoption were "lack of concern for reputation" and "customers lack interest in CSR". The low adoption of CSR in developing nations, due to barriers such as a lack of resources, rules, and governmental incentives, limits the potential for sustainable development and positive social effects within the manufacturing industry.

Azadnia et al. (2021) established the Total Interpretive Structural Modelling (TISM) and MICMAC approach to identify and analyze hurdles to the successful implementation of reverse logistics (RL) activities for electric vehicle lithium-ion batteries (EV-LIBs). Significantly, the report identifies market and societal, as well as policy and regulatory, factors as the most influential impediments to EV-LIB RL deployment. Prioritizing the most common barriers to RL operations for EVs-LIBs helped industrial decision-makers and policymakers. However, threshold selection in the TISM-MICMAC technique affects the barrier prioritization.

Stoycheva et al. (2018) developed a quantitative framework for sustainable manufacturing and demonstrated its application to the automotive sector. Multi-criteria decision analysis (MCDA) was used to integrate the values of industry executives and decision-makers with the performance criteria of various vehicle manufacturing materials. The study emphasized that future users utilize different score information and weighting frameworks, which led to contradicting results. It highlighted the significance of combining other analytical techniques, such as life-cycle assessment (LCA), with MCDA for more holistic, sustainable decision-making. The application of MCDA in decision-making processes promoted completeness, transparency, and adaptability, hence simplifying communication and decision-making. Nevertheless, the study admits its limitations, such as the need for complementary analyses like LCA and the risk of inconsistent findings when using various weighting structures in MCDA.

Ghadge et al. (2022) investigated the correlation between Industry 4.0 and GSCM in the automobile sector through empirical research. The developed hypotheses were tested using 243 replies from professionals in the automotive supply chain throughout Europe, including the UK. This study combined ISM and SEM techniques in an integrated, two-stage procedure to produce a variety of findings. The first step in enhancing GSC performance was to develop a multi-level structural relationship between the main Industry 4.0 technologies and GSC practices using the ISM technique. Compared to other Industry 4.0 technologies, the ten-level hierarchical structure showed that the most important elements impacting GSC practices were IoT and CPS. A driving and dependency power matrix was later developed with the assistance of MICMAC analysis. However, the moderating factors such as company size, expertise, and past performance were not considered.

Khaba & Bhar (2018) conducted a literature review, gathering expert opinions, classifying the barriers using MICMAC, and applying a questionnaire-based survey to validate the ISM model with structural equation modeling (SEM), ISM was used to develop a proper hierarchy and contextual relationship of key barriers to lean implementation in the Indian coal mining industry. The mining industry's biggest obstacles to implementing lean were determined to be a lack of commitment from senior management, financial limitations, and a lack of coordination between divisions.

Kumar et al. (2020) investigated the interaction between sustainable lean manufacturing (SLM) with the Indian automobile industry, delving into CSFs discovered from existing literature and expert input. The goal was to map the interrelationships between these CSFs using ISM, emphasizing top management's significance and identifying driving and dependent factors. The objective of the research was to demonstrate the superiority of sustainable manufacturing techniques in delivering economic, social, and environmental advantages by analyzing data from small, medium, and large-scale vehicle industries. The proposed approach to increase business profitability while promoting environmental development was in line with global sustainability goals. However, the study focus on the Indian auto industry limits the generalization of findings to other industries.

Jasiulewicz-Kaczmarek et al. (2021) analyzed the maintenance factors influencing the implementation of sustainable manufacturing challenges using an integrated approach, and the specific operational context of an enterprise was taken into consideration when ranking the factors. Initially, ten maintenance activity factors were identified from the perspective of sustainable manufacturing. To classify these factors according to their influence and dependence values, the MICMAC was then used in the second stage. The fuzzy analytic hierarchy process (F-AHP) was used to calculate the relative weights of the maintenance factors after the criteria for their evaluation were established in the third stage. In the final step, the fuzzy technique for order preference by similarity to the ideal solution (F-TOPIS) was applied with the results of the MICMAC and F-AHP analyzed as inputs to produce aggregate scores and choose the essential maintenance factors that affect sustainable manufacturing processes. Furthermore, subjectivity and interpretation bias were introduced by using several approaches, including MICMAC, F-AHP, and F-TOPIS, which affect the reliability and uniformity of the results.

From the assessment in Ali et al. (2018) the management team lacks knowledge and training about GSCM, which makes implementation difficult, in Yadav & Sahay (2017) there is a potential trade-off between economic viability and sustainability, in Fauzdar et al. (2022) one potential weakness of this research is the bias in the expert opinions, in Bux et al. (2020) low adoption of CSR in developing nations, due to barriers such as lack of resources, rules, and governmental incentives, in Azadnia et al. (2021) the threshold selection for the TISM-MICMAC technique affects the prioritization of barrier categories, in Stoycheva et al. (2018) there is a need for complementary analyses and the risk of inconsistent findings, in Ghadge et al. (2022) lacks moderating factors like business size, expertise, and past results, in Khaba & Bhar (2018), in Kumar et al. (2020) narrow focus on the Indian auto industry restricts the generalization of findings, and in Jasiulewicz-Kaczmarek et al. (2021) interpretation bias were introduced by using several approaches, including MICMAC, F-AHP, and F-TOPIS, which affect the reliability and uniformity of the results. Therefore, an innovative strategy is required to address these challenges, enhance sustainability, handle complexity, and successfully prioritize tasks in sustainability analysis in the automotive industry.

Methodology

Sustainability has emerged as a key issue for automotive manufacturers due to rising concerns about climate change and environmental degradation. Automobile companies are under increasing pressure from investors, governments, and customers to adapt their business practices, organizational cultures, and product offerings. This has major implications for the sector, which must intensify its sustainability initiatives even if it has already made progress. The sustainability of the automotive industry is affected by numerous factors. To achieve sustainability, it is essential to prioritize these factors based on their relative importance and interconnections.. Managers should prioritize sustainability criteria according to their relative driving power. Sustainability aspects are extremely interrelated, and their independence should be investigated before prioritizing them. It is also required to determine whether each element is dependent, independent, autonomous, or a linking factor. Hence, the combination of ISM and MICMAC addresses the problem by providing a comprehensive framework for analyzing the interdependencies and driving power of sustainability factors. Initially, relevant data are gathered from literature and journals to identify these critical factors. To verify their reliability, the Cronbach Alpha method is utilized, which includes gathering replies via a questionnaire given to managerial-level individuals in the business. During this process, elements with higher consistency and internal dependability are shortlisted, while those with lower reliability are excluded. With the nominated components together, Interpretive Structural Modeling (ISM) is used to generate a hierarchical representation of their interdependencies. This analytical strategy efficiently simplified complex linkages, providing useful insights into each factor's relative independence in impacting sustainability results. Following ISM, the factors are plotted based on their driving and dependent power, allowing them to be classified into several categories according to their nature. This categorization improved comprehension of how these aspects worked as driving forces or relied on other elements to attain sustainability objectives. Following that, the MICMAC (Cross-Impact Matrix Multiplication Applied to Classification) technique is used to classify factors according to their driving and dependence power. This classification clarifies the nature and significance of each factor in achieving sustainability goals in the automobile sector. By methodically following these methodological procedures, the study successfully finds, analyzes, and categorizes the essential elements influencing sustainability in the automotive sector, giving significant insights for informed decision-making and policy creation.

Figure 1 illustrates the overall flow diagram of the proposed model. Initially, gathering information from journals and books to pinpoint important sustainability aspects. The reliability of the factors is then evaluated through questionnaire distribution and analysis using the Cronbach's Alpha method. Following that, reducing the number of elements by increasing internal reliability and consistency. Interpreting structural modeling to show the hierarchical interdependencies between the variables. Plotting variables according to their driving and dependent powers helps to classify them efficiently. Finally, the model provides a clear understanding of the implications of sustainability for policy making and decision-making. The technical aspects of the proposed sustainability analysis using ISM and MICMAC analysis are discussed in the upcoming sections.

Survey Reliability and Internal Consistency

Following the selection of the basic criterion, a survey is distributed to experts to collect the necessary data. Surveys are widely used to gather information in various contexts. The reliability of the responses is to be verified. Assessing a survey's reliability ensures that the results are accurate and consistent and that the criteria are selected accurately. By determining the Cronbach's Alpha Brown of each item in the responses, the dependability of the responses is verified. A measure of internal consistency and dependability that indicates how closely a group of things is related is called Cronbach's Alpha. It is employed to characterize a factor's dependability. A higher score implies increased reliability. The Cronbach Alpha coefficient, which ranges from 0 to 1. When an item's Cronbach's alpha value is closer to 1, it suggests high internal consistency, meaning the items measure the same underlying construct accurately. Conversely, a value closer to 0 displays low internal consistency, meaning the items do not consistently measure the same contruct.

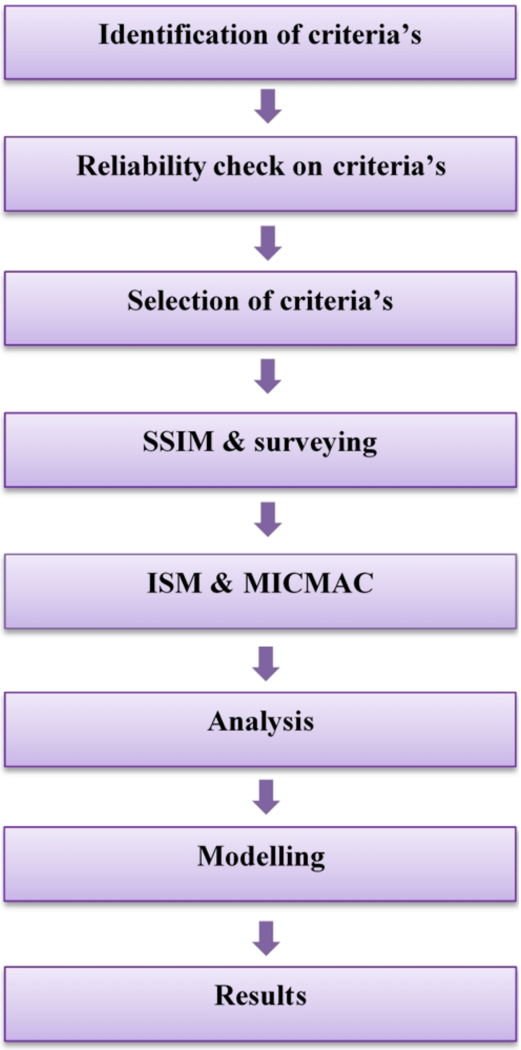


Fig. 1. Overall flow diagram of the proposed model

The formula for Cronbach's alpha is expressed in the following equation (1) (Jasiulewicz-Kaczmarek et al., 2021)

$$\alpha = \frac{k}{k-1}\left(1 - \frac{\sum_{i=1}^{k}\sigma_i^2}{\sigma_x^2}\right) \tag{1}$$

where the total number of items is k, α is referred to as the Cronbach Alpha value, σ_i^2 is the variance of each item, and σ_x^2 is the variance of the total of all items.

Steps in ISM

When working with complicated systems that involve multiple interacting components, ISM is utilized. It provides a structured approach to understanding the relationship among these elements and their collective impact on the system. ISM is a methodology for developing and analyzing structural models of complex problems or systems, often supported by computer tools. These structural models employ well-defined patterns combining words and pictures to represent the structure of a system, a complex problem, or an area of research. It's a way for a modeling group to impose structure on the intricate relationships between different pieces. The following are the different steps that go into ISM modeling:

- Identify Factors: Relevant factors or elements that influence the system (e.g., sustainability factors) are identified through expert consultations, literature reviews, or brainstorming sessions.
- Establish Relationships: Define the contextual relationships between the identified factors. Determine whether one factor influences or depends on another (e.g., if factor A influences factor B).
- Develop Structural Self-Interaction Matrix (SSIM): Create an SSIM that captures pairwise relationships between factors. This matrix shows how each factor influences or is influenced by others, using symbols like "V" (A influences B), "A" (B influences A), "X" (both influence each other), or "O" (no relationship).
- Construct Reachability Matrix: Convert the SSIM into a binary reachability matrix by replacing the symbols with 1s (indicating influence) and 0s (no influence). This matrix is also checked for transitivity, meaning indirect relationships between factors are included (if A Influences B, and B Influences C, then A Influences C).
- Partition Levels: Using the reachability matrix, factors are partitioned into different levels based on their influence (reachability) and dependency (antecedent) sets. This process organizes the factors hierarchically, starting with the most independent drivers at the bottom.
- Build the ISM Model: Based on the levels and relationships, a directed graph (digraph) is constructed, visually representing how factors are interlinked. The model helps stakeholders easily see how factors influence each other and which are the most critical drivers.
- Review and Refine: The final ISM model is reviewed to check for any inconsistencies or errors. Adjustments are made to ensure the model is conceptually accurate and useful for decision-making.

Figure 2 shows the flow diagram for preparing ISM. The ISM modeling process begins with identifying elements through surveys or group techniques, followed by establishing contextual relationships. SSIM captures pairwise relationships, checks for consistency. From SSIM, a reachability matrix is derived and partitioned into hierarchical levels. A directed graph is drawn, simplifying it by removing transitive links. This graph is converted into an ISM model, replacing nodes with relationship statements. A comprehensive review ensures conceptual alignment, enhances the model's reliability, and supports informed decision-making.

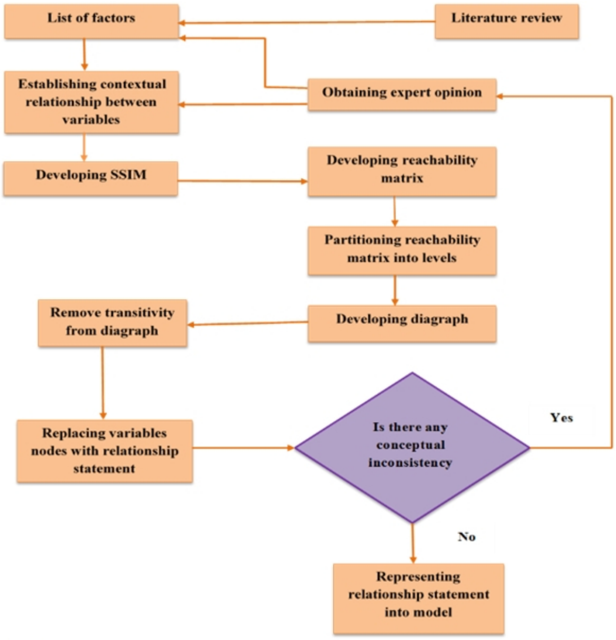


Fig. 2. Flow diagram for preparing ISM

Expert-Based Structural Self-Interaction Matrix (SSIM) Construction in ISM

The ISM technique requires obtaining opinions from subject-matter experts who possess a deep understanding of the issue under analysis. These experts are selected based on specific criteria, including their professional experience in the automotive industry, their academic qualifications in sustainability or industrial management, and involvement in sustainability related decision-making roles. A minimum threshold of 10 years of relevant industry experience or active participation in sustainability related projects is used to ensure the experts' familiarity with the complex interdependencies of sustainability factors.To gather expert viewpoints, structured methods like the Delphi technique, nominal group approaches, or brainstorming sessions are used. Experts are asked to establish connections between identified sustainability factors, classifying them into one of four categories: "leads to" or "influences", indicating how one factor affects another. The relationships between the factors are assessed based on the experts' contextual knowledge, using the following directional symbols. For each pair of factors (i and j), experts assign directional symbols to denote the relationship between them. Four symbols are commonly used:

- V (Vertical): Indicates that factor i influences factor j.
- A (Antecedent): Indicates that factor i is influenced by factor j.
- X (Bi-directional): Indicates that factors i and j influence each other.
- O (No Relation): Indicates that there is no discernible relationship between factors i and j.

The selection of these symbols is based on the expert consensus regarding the direction and type of influence between the factors. Using the assigned directional symbols, the SSIM is constructed. It is essentially a matrix where each cell represents the relationship between two factors based on the assigned symbols. For example, if factor i influences factor j (denoted by V), the corresponding cell in the matrix reflects this relationship. The constructed SSIM is then discussed among the group of experts to ensure consensus and validity. Experts provide feedback or suggest modifications based on their domain knowledge and understanding of the problem. Through this iterative process, the SSIM is refined and finalized.

Reachability Matrix Formation in ISM Process

The next step in the ISM approach is to develop the initial reachability matrix from SSIM. Create an initial reachability matrix based on the SSIM. This matrix represents the direct relationships between elements. Each symbol (V, A, X, O) in the SSIM is substituted with 1s or 0s in the initial reachability matrix according to the following rules:

If the symbol in the (i,j) entry of the SSIM is V, then the corresponding entry in the reachability matrix becomes 1, indicating a direct connection from element i to element j. The entry at (j,i) becomes 0, indicating no direct connection from j to i.

- If the symbol in the (i,j) entry of the SSIM is A, then the entry in the reachability matrix becomes 0, indicating no direct connection from i to j. The entry at (j,i) becomes 1, indicating a direct connection from j to i.
- If the symbol in the (i,j) entry of the SSIM is X, then the entry in the reachability matrix becomes 1, indicating a bidirectional connection between i and j. The entry at (j,i) also becomes 1.
- If the symbol in the (i,j) entry of the SSIM is O, then both entries in the reachability matrix become 0, indicating no direct connection between i and j, nor between j and i.

After substituting the symbols according to the rules, the reachability matrix has gaps in connectivity. To incorporate transitivity and fill these gaps, any 1* entries in the matrix are included. This means that if there is a path from element i to element j and from element j to element k, then a path from element i to element k is assumed. This process ensures that the reachability matrix accurately reflects both direct and transitive relationships between elements. After incorporating transitivity, the final reachability matrix is obtained, representing the complete set of relationships between elements, including both direct and transitive connections.

Identification of Hierarchical Levels in ISM

From the final reachability matrix, for each factor, the reachability set and antecedent set are derived. The reachability set consists of the factors themselves and the other factors that it impact, whereas the antecedent set consists of the factor itself and the other factor that impacts it. The levels of the various factors are found by examining the intersection of these sets for each factor. In the ISM hierarchy, factors that have the same reachability and intersection sets are considered to be at the top. The significance of these top-level factors lies in the fact that these variables represnets components that are immune to influence from factors higher up the hierarchy. After identifying a top-level component, it is eliminated from further consideration, and the process is repeated to identify factors at a lower level. This iterative procedure is carried out until the level of every factor is established. Building the ISM model is made more structured by these hierarchical stages.

Construction and Refinement of the Digraph

The initial step in constructing a digraph that illustrates the relationships among elements is to develop a reachability matrix, which captures both direct and indirect connections between nodes. This matrix serves as a starting point for constructing a preliminary digraph, in which items are represented by nodes and their interactions by edges. Both direct and indirect connections between items are captured through the transitive links in the preliminary digraph. The preliminary digraph is refined by eliminating indirect links to focus only on direct relationships. The final digraph, which is the result of this refinement, provides a clear visual representation of the elements and their interaction. The final digraph is organized in a hierarchical structure, placing the top-level factors at the highest tier, with subsequent factors arranged in descending order beneath them. This hierarchical arrangement ensures clarity in understanding the relationships among elements, with each factor's position in the digraph reflecting its relative importance or precedence within the system.

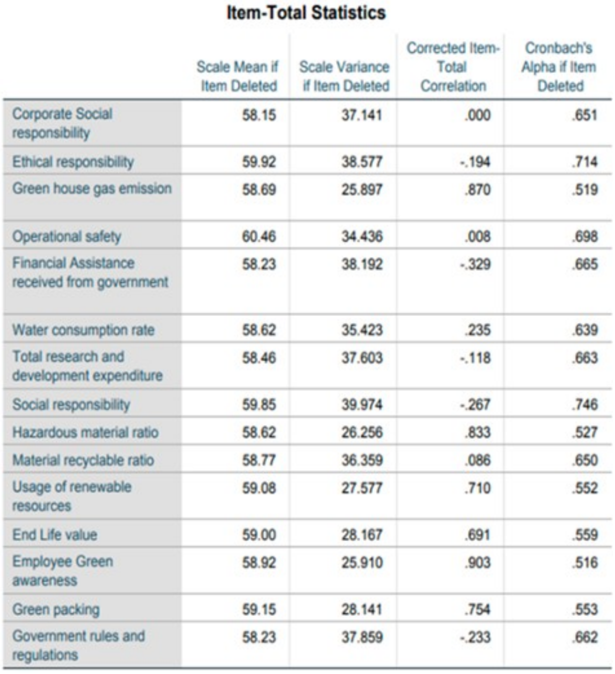
Overall, the proposed technique offers a systematic approach to analyze the interdependence of sustainability aspects in the automobile industry, allowing stakeholders to make informed decisions and develop effective sustainability legislation.

Data Analysis

The several ISM processes are extensively detailed in this section. To create the final model, its is essential to analyze and formulate the data gathered from personnel at the managerial level.

Assessment of Survey Reliability Using Cronbach's Alpha

Based on the Cronbach's alpha value, the 15 factors were subjected to a reliability check. IBM SPSS was used for this. The analysis of the data revealed an alpha value of 0.648, indicating that the survey's reliability was compromised by the inclusion of all 15 parameters. Certain elements were removed to ensure the survey's reliability. The SPSS tool was also used to determine which factors need to be deleted. The outcome is displayed in Fig. 3.



Item-Total Statistics

	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Cronbach's Alpha if Item Deleted
Corporate Social responsibility	58.15	37.141	.000	.651
Ethical responsibility	59.92	38.577	-.194	.714
Green house gas emission	58.69	25.897	.870	.519
Operational safety	60.46	34.436	.008	.698
Financial Assistance received from government	58.23	38.192	-.329	.665
Water consumption rate	58.62	35.423	.235	.639
Total research and development expenditure	58.46	37.603	-.118	.663
Social responsibility	59.85	39.974	-.267	.746
Hazardous material ratio	58.62	26.256	.833	.527
Material recyclable ratio	58.77	36.359	.086	.650
Usage of renewable resources	59.08	27.577	.710	.552
End Life value	59.00	28.167	.691	.559
Employee Green awareness	58.92	25.910	.903	.516
Green packing	59.15	28.141	.754	.553
Government rules and regulations	58.23	37.859	-.233	.662

Fig. 3. Cronbach alpha values before the factor is deleted

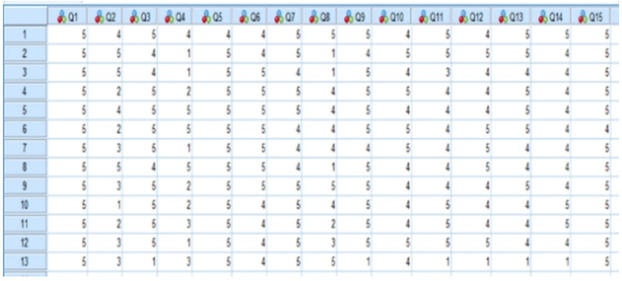
It was discovered that removing elements like operational safety, social duty, and ethical responsibility increased the Cronbach alpha value. Reducing these three variables improved the survey's reliability. After three variables were eliminated, the Cronbach alpha value was 0.858, indicating the reliability of the twelve factors. The removal of certain factors from the survey, which led to an increase in Cronbach's alpha from 0.648 to 0.858, highlights the critical role of internal consistency in enhancing the reliability of measurement instruments. This adjustment improves the internal coherence of the remaining items, leading to more reliable results by reducing noise and aligning better with the core constructs. However, it also poses potential challenges for construct validity, as important dimensions are omitted, affecting the comprehensiveness of the survey. This trade-off necessitates a careful balance between increasing reliability and maintaining a thorough measure of the intended constructs. Additionally, data interpretation shifts due to the revised factors, and practical considerations such as survey design and stakeholder communication must address the reasons for factor removal and its impact on findings. Overall, while refining the survey improves reliability, it is crucial to reassess construct validity to ensure that the revised instrument accurately reflects the intended constructs for more valid and insightful research outcomes.

The final ISM model was created using these 12 elements. The 12 factors selected in this step are shown in Table 1 below.

Table 1
Selected 12 factors

No	Criteria
1	Usage of Renewable Resources
2	Corporate Social Responsibility
3	Hazardous Material Ratio
4	End Life Value
5	Employee Green Awareness
6	Total Research and Development Expenditure
7	Financial Assistance Received from the Government
8	Green Packing
9	Greenhouse Gas Emissions
10	Water Consumption Rate
11	Government Rules and Regulations
12	Material Recyclable Ratio

The item analysis results, which show the Cronbach's Alpha coefficients for each item when removed from the scale one at a time, are illustrated in Fig. 4 by the SPSS program. This analysis is crucial for assessing the internal consistency and reliability of the survey instrument. Therefore, if the inclusion of all 15 parameters reduces the survey's reliability, it indicates that certain items are redundant or negatively affecting the consistency of responses. Adjustments such as item removal are necessary to enhance the survey's reliability and validity.



	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12	Q13	Q14	Q15
1	5	4	5	4	4	4	5	5	5	4	5	4	5	5	5
2	5	5	4	1	5	4	5	1	4	5	5	5	5	4	5
3	5	5	4	1	5	5	4	1	5	4	3	4	4	4	5
4	5	2	5	2	5	5	5	4	5	5	4	4	5	4	5
5	5	4	5	5	5	5	5	4	5	4	4	4	5	4	5
6	5	2	5	5	5	5	4	4	5	5	4	5	5	4	4
7	5	3	5	1	5	5	4	4	4	5	4	5	4	4	5
8	5	5	4	5	5	5	4	1	5	4	4	5	4	4	5
9	5	3	5	2	5	5	5	5	5	4	4	4	5	4	5
10	5	1	5	2	5	4	5	4	5	4	5	4	4	5	5
11	5	2	5	3	5	4	5	2	5	4	5	4	4	5	5
12	5	3	5	1	5	4	5	3	5	5	5	5	4	4	5
13	5	3	1	3	5	4	5	5	1	4	1	1	1	1	5

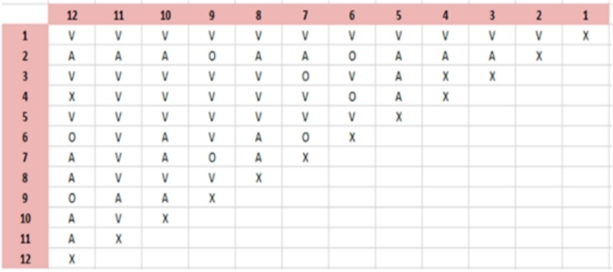
Fig. 4. IBM SPSS Data

Structural Self-Interaction Matrix (SSIM) Construction

Contextual relationships of the "leads to" category are selected, demonstrating that one aspect influences another and contributes to sustainability. The question lies in whether a relationship exists at all between any two enablers (i and j) and in which direction it should be allocated, given the contextual relationship for each enabler. To indicate the direction of the relationship between the enablers (i and j), four symbols are used:

- V for the relationship from factor i to factor j means i influences j, but the reverse is not true
- A for the relationship from factor j to factor i means j influences i, but the reverse is not true
- X for the relationship between i and j in both directions
- for no relation between i and j.

Figure 5 shows the structural self-interaction matrix. It depicts the connections between various components of a system, including how these components interact with one another over time. Generally, every component of the system is represented as a node in the matrix, and the matrix's cells show how these components interact with one another. The SSIM is then converted into a reachability matrix (RM) and its transitivity is examined in the following phase.



	12	11	10	9	8	7	6	5	4	3	2	1
1	V	V	V	V	V	V	V	V	V	V	V	X
2	A	A	A	O	A	A	O	A	A	A	X	
3	V	V	V	V	V	O	V	A	X	X		
4	X	V	V	V	V	V	O	A	X			
5	V	V	V	V	V	V	V	X				
6	O	V	A	V	A	O	X					
7	A	V	A	O	A	X						
8	A	V	V	V	X							
9	O	A	A	X								
10	A	V	X									
11	A	X										
12	X											

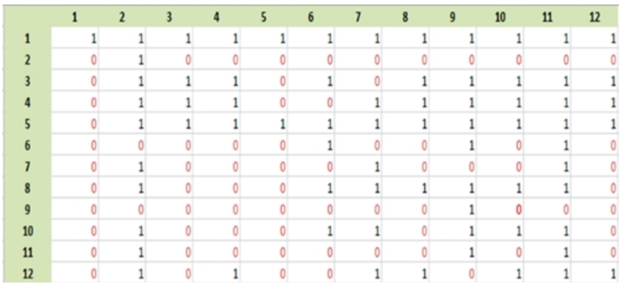
Fig. 5. Structural Self Interaction Matrix

Derivation of the Initial and Final Reachability Matrices

The SSIM is converted into a binary matrix by replacing V, A, X, and O with 1 and 0, respectively, in a process known as the initial reachability matrix. The following are the guidelines for replacing 1's and 0's:

- If the interaction between entity i and entity j in the SSIM is "V", then there is a one-way connection from i to j in the reachability matrix, marked as 1, while the connection from j to i is marked as 0.
- If the interaction between entity i and entity j in the SSIM is "A", then there is no connection from i to j in the reachability matrix, which is marked as 0, but there is a one-way connection from j to i, marked as 1.
- If the interaction between entity i and entity j in the SSIM is "X", then there are bi-directional connections between i and j in the reachability matrix, marked as 1 for both entries.
- If the interaction between entity i and entity j in the SSIM is "O", then there is no connection between i and j in the reachability matrix, marked as 0 for both entries.

The matrix thus obtained is called the initial reachability matrix (Fig. 6).

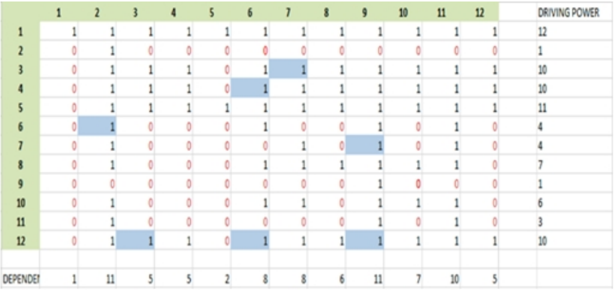


	1	2	3	4	5	6	7	8	9	10	11	12
1	1	1	1	1	1	1	1	1	1	1	1	1
2	0	1	0	0	0	0	0	0	0	0	0	0
3	0	1	1	1	0	1	0	1	1	1	1	1
4	0	1	1	1	0	0	1	1	1	1	1	1
5	0	1	1	1	1	1	1	1	1	1	1	1
6	0	0	0	0	0	1	0	0	1	0	1	0
7	0	1	0	0	0	0	1	0	0	0	1	0
8	0	1	0	0	0	1	1	1	1	1	1	0
9	0	0	0	0	0	0	0	0	1	0	0	0
10	0	1	0	0	0	1	1	0	1	1	1	0
11	0	1	0	0	0	0	0	0	1	0	1	0
12	0	1	0	1	0	0	1	1	0	1	1	1

Fig. 6. Initial Reachability Matrix

The final reachability matrix in ISM is derived from the fundamental premise of transitivity. It states that one assumes that element A is related to C if element

B is related to C and element A is related to B. The final reachability matrix fails to include any direct or indirect linkages between element I and element J if element (i, j) is zero. Since entry (i, j) is zero when there is no direct relationship between elements i and j, the original reachability matrix contains this feature. By increasing the original reachability matrix (with diagonal entries set to 1) to consecutive powers until no more entries are obtained, indirect relationships are identified. The final reachability matrix in Fig. 7 is the matrix that is obtained after all transitive relations have been identified. The total number of factors (including itself) that a factor impacts, or the sum of the interactions in the rows, essentially represents that factor its driving power. On the other hand, the total number of risks (including itself) by which a risk is impacted, or the sum of the interactions in the columns, is its dependence power. Afterwards, this has been employed to carry out the MICMAC analysis.



	1	2	3	4	5	6	7	8	9	10	11	12		DRIVING POWER
1	1	1	1	1	1	1	1	1	1	1	1	1		12
2	0	1	0	0	0	0	0	0	0	0	0	0		1
3	0	1	1	1	0	1	1	1	1	1	1	1		10
4	0	1	1	1	0	1	1	1	1	1	1	1		10
5	0	1	1	1	1	1	1	1	1	1	1	1		11
6	0	1	0	0	0	1	0	0	1	0	1	0		4
7	0	1	0	0	0	0	1	0	1	0	1	0		4
8	0	1	0	0	0	1	1	1	1	1	1	0		7
9	0	0	0	0	0	0	0	0	1	0	0	0		1
10	0	1	0	0	0	1	1	0	1	1	1	0		6
11	0	1	0	0	0	0	0	0	1	0	1	0		3
12	0	1	1	1	0	1	1	1	1	1	1	1		10
DEPENDE	1	11	5	5	2	8	8	6	11	7	10	5		

Fig. 7. Final Reachability Matrix

Partitioning of Levels

The final Reachability Matrix is used to derive the antecedent sets and reachability sets for each factor. The antecedent set consists of the factor and the other factor that affects it, whereas the reachability set consists of the factor and the other factor that it impacts. After that, levels of each factor are found, and the intersection of these sets is derived for every factor.

In the ISM hierarchy, the factors at the top are those for which the intersection sets and reachability are the same. The variables that do not elevate other factors above their position in the hierarchy are considered top-level factors. Upon identification of the top-level factor, it is eliminated from the analysis. To determine the elements at the following level, the identical procedure is then carried out again. This process is continued until the level of each factor is found, as in Table 11. These levels help in building the digraph and the ISM model.

Table 2
Level partitioning

Criteria	Reachability Set	Antecedent Set	Intersection Set	Levels
1	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12	1	1	
2	2	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12	2	
3	2, 3, 4, 6, 7, 8, 9, 10, 11, 12	1, 3, 4, 5, 12	3, 4, 12	
4	2, 3, 4, 6, 7, 8, 9, 10, 11, 12	1, 3, 4, 5, 12	3, 4, 12	
5	2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12	1, 5	5	
6	2, 6, 9, 11	1, 3, 4, 5, 6, 8, 10, 12	6	
7	2, 7, 9, 11	1, 3, 4, 5, 7, 8, 10, 12	7	
8	2, 6, 7, 8, 9, 10, 11	1, 3, 4, 5, 8, 12	8	
9	9	1, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12	9	
10	2, 6, 7, 9, 10, 11	1, 3, 4, 5, 8, 10, 12	10	
11	2, 9, 11	1, 3, 4, 5, 6, 7, 8, 10, 11, 12	11	
12	2, 3, 4, 6, 7, 8, 9, 10, 11, 12	1, 3, 4, 5, 12	3, 4, 12	

Table 3
Iteration 1

Criteria	Reachability Set	Antecedent Set	Intersection Set	Levels
1	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12	1	1	
2	2	1, 2, 3, 4, 5, 6, 7, 8, 10, 11, 12	2	I
3	2, 3, 4, 6, 7, 8, 9, 10, 11, 12	1, 3, 4, 5, 12	3, 4, 12	

Table continued on the next page

Table continued from the previous page

Criteria	Reachability Set	Antecedent Set	Intersection Set	Levels
4	2, 3, 4, 6, 7, 8, 9, 10, 11, 12	1, 3, 4, 5, 12	3, 4, 12	
5	2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12	1, 5	5	
6	2, 6, 9, 11	1, 3, 4, 5, 6, 8, 10, 12	6	
7	2, 7, 9, 11	1, 3, 4, 5, 7, 8, 10, 12	7	
8	2, 6, 7, 8, 9, 10, 11	1, 3, 4, 5, 8, 12	8	
9	9	1, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12	9	I
10	2, 6, 7, 9, 10, 11	1, 3, 4, 5, 8, 10, 12	10	
11	2, 9, 11	1, 3, 4, 5, 6, 7, 8, 10, 11, 12	11	
12	2, 3, 4, 6, 7, 8, 9, 10, 11, 12	1, 3, 4, 5, 12	3, 4, 12	

Table 4
Iteration 2

Criteria	Reachability Set	Antecedent Set	Intersection Set	Levels
1	1, 3, 4, 5, 6, 7, 8, 10, 11, 12	1	1	
3	3, 4, 6, 7, 8, 10, 11, 12	1, 3, 4, 5, 12	3, 4, 12	
4	3, 4, 6, 7, 8, 10, 11, 12	1, 3, 4, 5, 12	3, 4, 12	
5	3, 4, 5, 6, 7, 8, 10, 11, 12	1, 5	5	
6	6, 11	1, 3, 4, 5, 6, 8, 10, 12	6	
7	7, 11	1, 3, 4, 5, 7, 8, 10, 12	7	
8	6, 7, 8, 10, 11	1, 3, 4, 5, 8, 12	8	
10	6, 7, 10, 11	1, 3, 4, 5, 8, 10, 12	10	
11	11	1, 3, 4, 5, 6, 7, 8, 10, 11, 12	11	II
12	3, 4, 6, 7, 8, 10, 11, 12	1, 3, 4, 5, 12	3, 4, 12	

Table 5
Iteration 3

Criteria	Reachability Set	Antecedent Set	Intersection Set	Levels
1	1, 3, 4, 5, 6, 7, 8, 10, 12	1	1	
3	3, 4, 6, 7, 8, 10, 12	1, 3, 4, 5, 12	3, 4, 12	
4	3, 4, 6, 7, 8, 10, 12	1, 3, 4, 5, 12	3, 4, 12	
5	3, 4, 5, 6, 7, 8, 10, 12	1, 5	5	
6	6	1, 3, 4, 5, 6, 8, 10, 12	6	III
7	7	1, 3, 4, 5, 7, 8, 10, 12	7	III
8	6, 7, 8, 10	1, 3, 4, 5, 8, 12	8	
10	6, 7, 10	1, 3, 4, 5, 8, 10, 12	10	
12	3, 4, 6, 7, 8, 10, 12	1, 3, 4, 5, 12	3, 4, 12	

Table 6
Iteration 4

Criteria	Reachability Set	Antecedent Set	Intersection Set	Levels
1	1, 3, 4, 5, 8, 10, 12	1	1	
3	3, 4, 8, 10, 12	1, 3, 4, 5, 12	3, 4, 12	
4	3, 4, 8, 10, 12	1, 3, 4, 5, 12	3, 4, 12	
5	3, 4, 5, 8, 10, 12	1, 5	5	
8	8, 10	1, 3, 4, 5, 8, 12	8	
10	10	1, 3, 4, 5, 8, 10, 12	10	IV
12	3, 4, 8, 10, 12	1, 3, 4, 5, 12	3, 4, 12	

Table 7
Iteration 5

Criteria	Reachability Set	Antecedent Set	Intersection Set	Levels
1	1, 3, 4, 5, 8, 12	1	1	
3	3, 4, 8, 12	1, 3, 4, 5, 12	3, 4, 12	
4	3, 4, 8, 12	1, 3, 4, 5, 12	3, 4, 12	
5	3, 4, 5, 8, 12	1, 5	5	
8	8	1, 3, 4, 5, 8, 12	8	V
12	3, 4, 8, 12	1, 3, 4, 5, 12	3, 4, 12	

Table 8
Iteration 6

Criteria	Reachability Set	Antecedent Set	Intersection Set	Levels
1	1, 3, 4, 5, 12	1	1	
3	3, 4, 12	1, 3, 4, 5, 12	3, 4, 12	VI
4	3, 4, 12	1, 3, 4, 5, 12	3, 4, 12	VI
5	3, 4, 5, 12	1, 5	5	
12	3, 4, 12	1, 3, 4, 5, 12	3, 4, 12	VI

Table 9
Iteration 7

Criteria	Reachability Set	Antecedent Set	Intersection Set	Levels
1	1, 5	1	1	
5	5	1, 5	5	VII

Table 10
Iteration 8

Criteria	Reachability Set	Antecedent Set	Intersection Set	Levels
1	1	1	1	

Table 11
Level assigned

Criteria	Reachability Set	Antecedent Set	Intersection Set	Levels
1	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12	1	1	VIII
2	2	1, 2, 3, 4, 5, 6, 7, 8, 10, 11, 12	2	I
3	2, 3, 4, 6, 7, 8, 9, 10, 11, 12	1, 3, 4, 5, 12	3, 4, 12	VI
4	2, 3, 4, 6, 7, 8, 9, 10, 11, 12	1, 3, 4, 5, 12	3, 4, 12	VI
5	2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12	1, 5	5	VII
6	2, 6, 9, 11	1, 3, 4, 5, 6, 8, 10, 12	6	III
7	2, 7, 9, 11	1, 3, 4, 5, 7, 8, 10, 12	7	III
8	2, 6, 7, 8, 9, 10, 11	1, 3, 4, 5, 8, 12	8	V
9	9	1, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12	9	I
10	2, 6, 7, 9, 10, 11	1, 3, 4, 5, 8, 10, 12	10	IV
11	2, 9, 11	1, 3, 4, 5, 6, 7, 8, 10, 11, 12	11	II
12	2, 3, 4, 6, 7, 8, 9, 10, 11, 12	1, 3, 4, 5, 12	3, 4, 12	VI

Results and Discussions

In the previous section, the analysis provided insights into the hierarchical levels and interdependencies of factors within the automotive industry's sustainability framework. To visualize these relationships effectively, a digraph is constructed, representing the intricate interrelations among factors. To construct a digraph showing the interdependence of the factors, open-source software called GEPHI is used, which helps in solving transitivities in the ISM model.

Diagraph

The graph representing the examined data was created using GEPHI, an open-source program. It showed 79 potential interactions and various transitive linkages that were possibly concealed while creating the ISM model to make it more intelligible. Fig. 8 shows the obtained diagram.

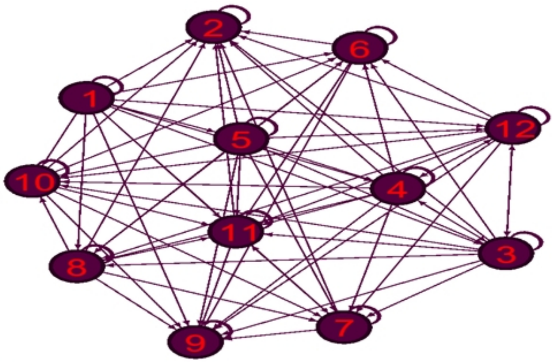


Fig. 8. Diagraph obtained using GEPHI software

The resulting diagraph, shown in Fig. 8, provides a visual depiction of the connections and interconnections between the data-examined points. GEPHI's features make it possible to visualize intricate networks, which helps to identify important nodes, clusters, and trends in the data. Decision-making and analytical processes are helped by this graphical depiction, which makes it easier to comprehend the interdependencies and dynamics present in the system.

ISM Model Construction and Error Analysis

A directed graph is created, and the transitive relationships are eliminated based on the associations provided in the final reachability matrix and the level that has been defined for each variable. Statements are used in place of variable nodes in the resulting diagram to transform it into an ISM. As a result, the ISM provides an excellent overview of the components and the interactions between them. The created ISM-based model of the variables influencing sustainability is examined to search for conceptual errors and make the required corrections. An ISM model of the elements influencing sustainability is presented in Fig. 9.

Figure 9 shows the obtained ISM model. On examining the ISM model, one finds that components that initialy drive other factors occupy the bottom layers of the model. The use of renewable resources, employee environmental consciousness, the ratio of recyclable materials to end-of-life value, and the ratio of hazardous materials are among the factors with strong driving ability. The independent driving variables tend to be linked to the dependent elements above by factors such as water consumption rate and green packaging. Level 1 of the model reveals that some aspects, such as corporate social responsibility, government regulations, and greenhouse gas emissions, are dependent on and heavily impacted by the driving forces. Their high reliance on the driving factors indicates that their decisions are likely to be negatively impacted by a change in the driving factors.

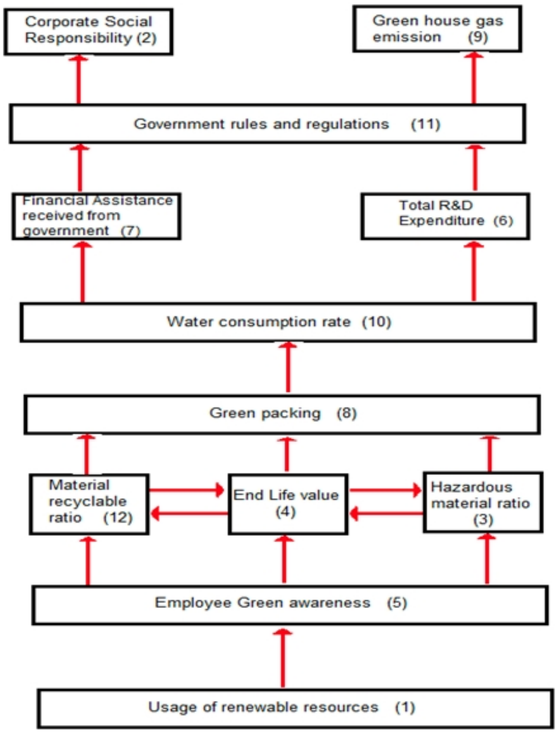


Fig. 9. The ISM Model obtained

MICMAC Analysis

The abbreviation MICMAC stands for Cross-Impact Matrix Multiplication Applied to Classification. Analyzing the driving power and dependency power of factors is the goal of MICMAC analysis. Matrix multiplication forms the foundation of the MICMAC concept. The purpose of this is to determine the primary drivers of the system across different categories. The factors have been divided into four groups: autonomous factors, linkage factors, dependent factors, and independent factors. These groups are based on the factors that driving and dependency power.

1. Autonomous factors: These factors have weak drive power and weak dependence power. These elements are largely isolated within the system, exhibiting very few strong connections.

2. Linkage factors: Both strong dependency and powerful driving powers are possessed by these elements. These factors are unstable because actions affecting one also impact and potentially harm the others.
3. Dependent factors: These factors have weak drive power but strong dependence power.
4. Independent factors: These factors have strong driving power but weak dependence power. A factor with a very strong driving power, called the "key factor", falls into the category of independent or linkage factors.

Analysis of Factor Clusters from MICMAC Analysis

Figure 10 shows that no factor is in the autonomous cluster, indicating that no element deserves to be viewed as being isolated from the system as a whole. As a result, management has to pay attention to every sustainable factor. The next cluster contains independent elements with strong driving strength but limited reliance, such as the use of renewable resources, employee knowledge of environmental issues, the material recycling ratio, end-of-life value, and the percentage of hazardous materials. The integration of sustainability in the automobile sector is significantly influenced by these aspects. The fourth class of determinants includes assistance from the government, laws and regulations, overall spending on research and development, and corporate social responsibility. These elements are the most independent and are at the top of the hierarchy. It stands for the elements that the automobile industry's successful integration of sustainability has brought about. Its high reliance suggests that for sustainable initiatives to be implemented effectively, all other aspects must coincide. However, it is significant because the company has now made it mandatory to measure the success of environmental sustainability.

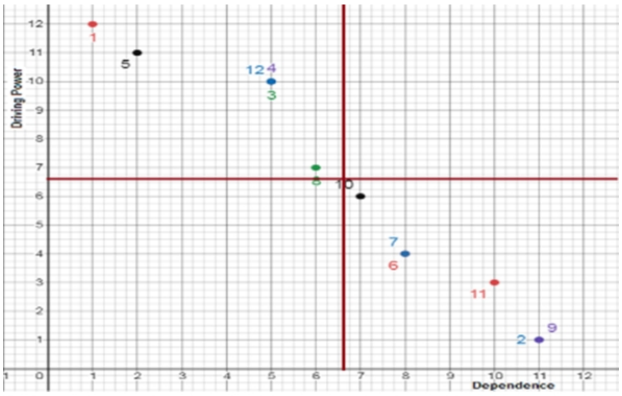


Fig. 10. MICMAC analysis

Comparative analysis of the proposed method

This section highlights the proposed method's performance by comparing it to the outcomes of existing approaches and showing their results based on various metrics such as accuracy of prioritization, resource efficiency, stakeholder engagement, emission reduction rate, water consumption reduction rate, waste generation, and effectiveness in decision-making.

Figure 11 compares the accuracy of the proposed model's prioritization with that of various existing approaches. Among the currently used techniques, Multi-Criteria Decision Analysis (MCDA) (Pagone E et al., 2020) shows a 60% prioritization accuracy, followed by Life Cycle Assessment (LCA) (Peppas A et al., 2021) at 92.5% and Analytic Hierarchy Process (AHP) (Ali SS et al., 2018) at 70%. However, the proposed strategy outperforms them all with a 92.5% accuracy rate. The proposed approach successfully prioritizes sustainability elements and provides a thorough understanding of interdependencies by using MICMAC analysis to classify factors based on their driving and dependency power and ISM to create links between criteria.

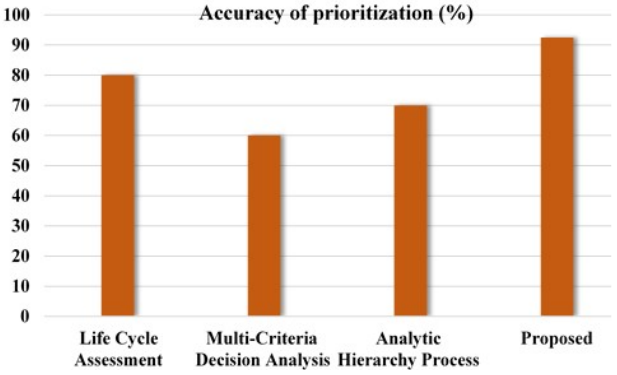


Fig. 11. Comparison of accuracy of prioritization

A comparison of resource efficiency (%) of various existing approaches to evaluating sustainability in the automobile sector is shown in Fig. 12. Carbon Footprint Analysis (Khan et al., 2020) scores the lowest at 60%, followed by Material Flow Analysis (Gebler et al., 2020) at 65%, Life Cycle Assessment (Peppas et al., 2021) at 75%, and the proposed method leads with 85% resource efficiency. This shows that while all approaches seek to address sustainability, the proposed strategy makes the best use of available resources, making it more effective in controlling the financial, environmental, and social elements of industrial processes.

Figure 13 illustrates the comparison of the emission reduction rate of the proposed model with existing models. The existing models, such as MCDA (Haase et al., 2022) and LCA (Peppas et al., 2021), achieve an

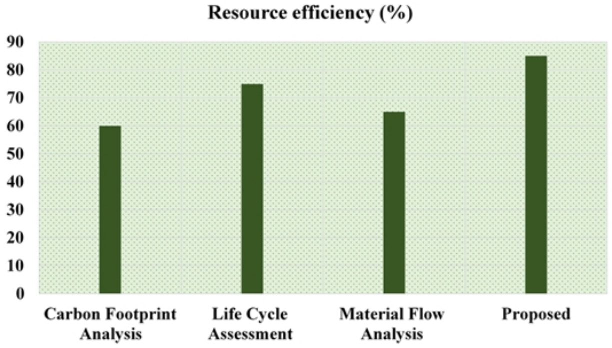


Fig. 12. Comparison of resource efficiency

emission reduction rate of 27% and 20%, respectively. The proposed hybrid method gives the better result than the previous methods because of their integrated approach that combines ISM and MICMAC analysis, allowing for a better understanding of interdependence and driving forces within the sustainability framework. By combining these strategies, it successfully identifies and prioritizes influential elements, resulting in a 30% reduction in emission rate.

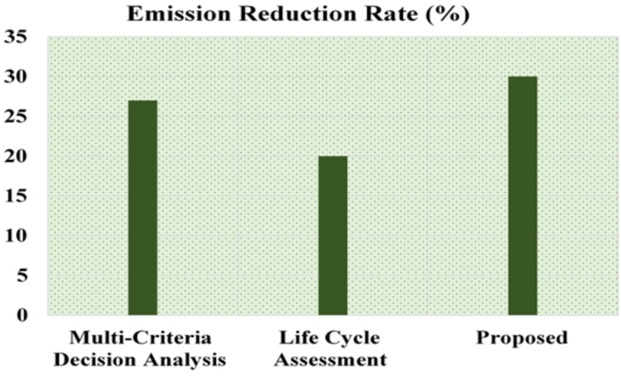


Fig. 13. Comparison of emission reduction rate

Figure 14 compares various sustainability analysis methods in the automobile industry based on their effectiveness in decision-making and stakeholder engagement. Life Cycle Assessment (Peppas et al., 2021) method achieves 80% stakeholder engagement and 75% effectiveness in decision-making, and the Multi-Criteria Decision Analysis (Pagone et al., 2020) method scores 75% stakeholder engagement and 85% effectiveness in decision-making. Compared with the existing method, the proposed method beats both, with 85% stakeholder engagement and 90% effectiveness in decision-making. Its combined usage of ISM and MICMAC, which effectively maps out interdependencies and driving forces among sustainability criteria, gives decision-makers a structured framework to properly prioritize activities and accounts for its excellence. Through the integration of these techniques, the proposed approach provides a greater understanding of the dynamics of sustainability factors, enabling stakeholders to make well-informed decisions that promote commercial and environmental goals in the automotive sector.

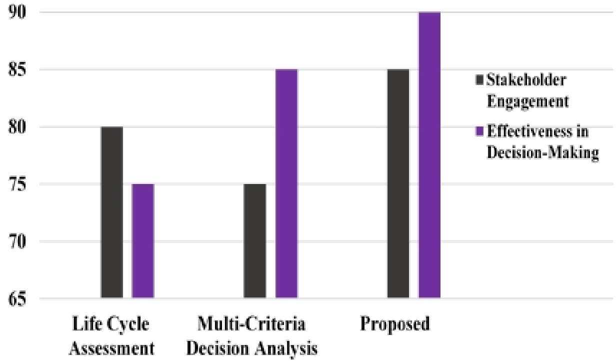


Fig. 14. Comparison of stakeholder engagement and effectiveness in decision-making

The comparison of the proposed model's water consumption reduction rate with that of existing models is shown in Fig. 15. The existing models, which include the Multi-Criteria Decision Analysis (Pagone et al., 2020) approach and the Life Cycle Assessment (Peppas et al., 2021), attain a water consumption reduction rate of 15.8% and 18.3%, respectively. The proposed approach achieves a higher reduction in water consumption rate of 25.8% when compared to existing models. The structured approach provided by ISM aids in comprehensively understanding the interdependencies between various criteria, allowing for informed decision-making that considers water conservation measures at every stage of the manufacturing process.

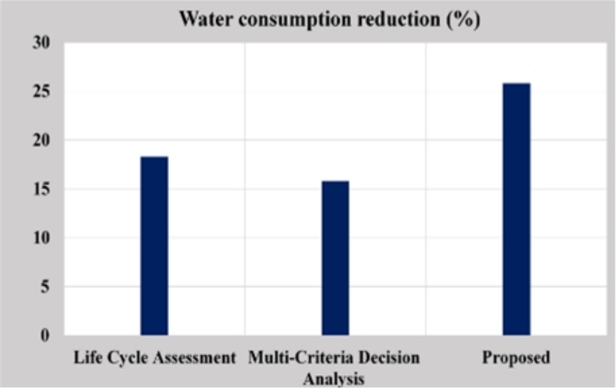


Fig. 15. Comparison of reduction in water consumption rate

Figure 16 depicts the comparison of the waste generation of the proposed model with existing models. The existing models achieve a waste generation value of

12.6% and 10.4%, respectively. Compared with existing models, the proposed model achieves a low waste generation value of 8.2%. The proposed method is lower water consumption rate and waste generation percentage indicate its efficacy in minimizing resource usage and environmental impact throughout the automotive manufacturing process.

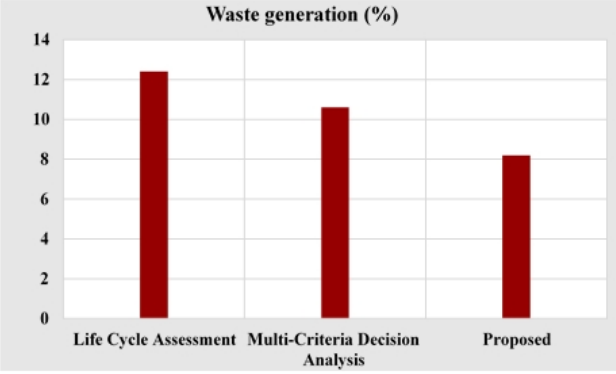


Fig. 16. Comparison of waste generation of the proposed model

Figure 17 depicts the comparison of the proposed method's composite reliability with Other Methods such as GSCMES (Ali et al., 2018), Delphi method (Bux et al., 2020), MCDA (Stoycheva et al., 2018), and GSCM (Ghadge et al., 2022). The composite reliability of the suggested method obtains the value of 0.93, where GSCMES, Delphi method, MCDA, and GSCM achieve 0.82, 0.79, 0.84, and 0.91, respectively. The proposed method achieves higher composite reliability by incorporating a range of additional reliability measures, such as test-retest, inter-rater, and internal consistency checks, whereas other methods may focus primarily on composite reliability alone, potentially limiting their overall reliability.

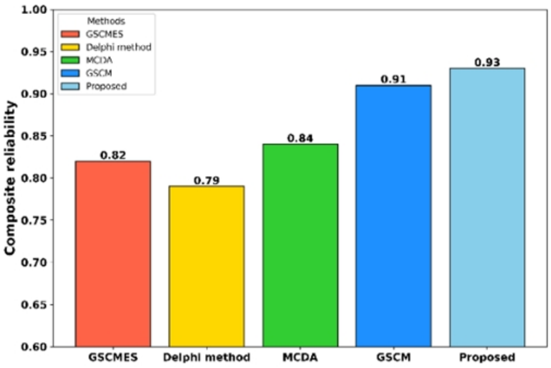


Fig. 17. Comparison of proposed composite reliability with other methods

Figure 18 depicts the comparison of the proposed method with other methods such as GSCMES (Ali et al., 2018), Delphi method (Bux et al., 2020), MCDA (Stoycheva et al., 2018), and GSCM (Ghadge et al., 2022). The AVE of the suggested method obtains the value of 0.87, where GSCMES, Delphi method, MCDA, and GSCM achieve 0.62, 0.57, 0.69, and 0.72, respectively. The proposed method achieves a higher AVE by employing robust factor analysis techniques and ensuring that a significant proportion of the variance in the observed variables is captured by the latent constructs, whereas other methods like the Delphi method have lower AVE due to less effective factor analysis or less comprehensive constructs, resulting in lower variance explanation.

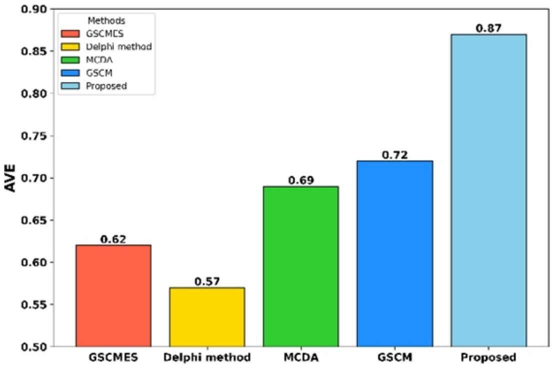


Fig. 18. Comparison of proposed methods, Average Variance Extracted (AVE) with other methods

Figure 19 depicts the comparison of the proposed method's loadings with other methods such as GSCMES (Ali et al., 2018), Delphi method (Bux et al., 2020), MCDA (Stoycheva et al., 2018), and GSCM (Ghadge et al., 2022). The loadings of the suggested method obtain the value of 0.91, where GSCMES, Delphi method, MCDA, and GSCM achieve 0.72, 0.70, 0.79, and 0.84, respectively. The proposed method achieves a higher factor loading by utilizing more precise and rigorous measurement techniques and data validation processes, ensuring that the factors are strongly represented and well-defined about the sustainability constructs. In contrast, existing Delphi methods have lower loadings due to less stringent validation or less accurate factor definitions, resulting in weaker representation of the constructs.

Overall, the study provides decision-makers in the automotive industry with a comprehensive understanding of the factors influencing sustainability and offers a roadmap for prioritizing actions to enhance environmental, economic, and social performance. By aligning decisions with the most influential factors, firms accelerate progress toward sustainability goals, benefiting both their bottom line and society as a whole.

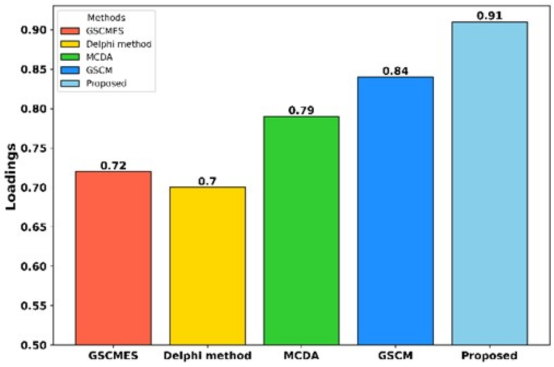


Fig. 19. Comparison of proposed methods Loadings with other methods

Conclusion

In conclusion, the integrated approach of ISM and MICMAC analysis offers a structured framework to comprehend the complexities of sustainability factors within the automotive industry. This methodological synergy provides decision-makers with a comprehensive understanding of the hierarchical relationships and driving forces among these factors. Through this study, critical sustainability factors have been classified into environmental, economic, and social categories, shedding light on their relative importance and interdependencies. Environmental factors include features such as the usage of renewable resources, the hazardous material ratio, and greenhouse gas emissions. Economic factors include metrics like end-of-life value, research and development expenditure, and financial assistance from government sources. Social factors encompass government regulations, corporate social responsibility initiatives, and employee awareness of environmental issues. This classification provides a structured framework for understanding and prioritizing actions to promote sustainability within the automotive industry. By the imposition of directionality and rank order, this proposed work provides a holistic perspective on complex issues. By differentiating between independent and dependent factors, MICMAC analysis provides greater clarity on the nature of the components. Setting driving factors, including the use of renewable resources, as a top priority speeds up sustainability initiatives and helps businesses make decisions that benefit society and the company as a whole. Compared with existing strategies, the proposed model achieves a high stakeholder engagement of 85%, prioritization accuracy of 92.5%, resource efficiency of 85%, and effectiveness in decision-making of 90%. This all-encompassing strategy accelerates the advancement of sustainability objectives, which benefits the company as well as society at large.

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