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Moving the Circular Economy Forward in the Mining Industry: Challenges to Closed-Loop in an Emerging Economy

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Abstract

Resource scarcity and ecosystem damage are putting pressure on the mining industry to increase the circularity of its operations. This study analyses the critical challenges to a circular economy in the Indian mining industry, applying an integrated decision-making approach. The identified challenges were obtained from a detailed literature review as well as experts' opinions, and were then ranked. The interrelationships among the key challenges are established and classified into a cause-effect grouping. According to a structured analysis of the challenges to the circular economy in the mining industry of an emerging economy and their interrelations, the trade-off between the prices of virgin materials and secondary waste materials could jeopardize circular economy principles in the mining industry. Primarily, this article raises the importance of tackling the lack of clear governance measures and implementation of waste management reporting for a closed-loop related to developing circular economy principles in the context of an emerging economy. Thus, adequate governance measures regarding closed-loops are vital to ensure a sustainable balance between the supply and demand of secondary minerals and metals, which can address the trade-off mentioned. Some suggested directions for policymakers and managers have also been provided to help formulate appropriate strategies for a transition to the circular economy.

Keywords: Circular Economy; Barriers; Sustainable Development; Mineral resources; Multicriteria decision-making

1. Introduction

Mining involves supplying core raw materials to global supply and value chains. Therefore, the mining industry plays an essential role in global economic and social development. This industry is intertwined with natural resource processes; thus, it has pursued a transition towards sustainable environmental management in recent years (World Economic Forum, 2015). The transition towards sustainable environmental management is also important because the demand for mining inputs is expected to double by 2030 (UNEP, 2013; Lovik et al., 2016), and minerals are finite and non-renewable resources. With such an increase in demand, both the quality and quantity of mined ores is likely to deteriorate, leading to scarcity of mineral resources (Giurco et al., 2014a). In addition, trade restrictions on minerals and metal require sustainable management of mineral resources (Korinek, 2019).

The existing linear model of production and consumption in the mining industry has a significant and long-lasting impact on the surrounding ecosystem (Yu, 2017). There are environmental and social risks related to the mining process, such as biodiversity depletion, soil degradation, and conflict minerals (UNDP and UN Environment, 2018).

The industry needs to adopt emerging approaches and methods for responsible production and consumption, as minerals are finite and non-renewable resources. One such approach could be the adoption of circular economy (CE) principles. However, to implement CE principles, the industry needs to make extensive efforts to decouple from its traditional linear production mode (Ghisellini et al., 2016), dealing with the challenges facing the transition towards circular approaches. Such a transition must improve the sustainability of the mining industry.

Relevant existing research on the aforementioned barriers to CE has been identified. For instance, through secondary sources (academic and grey literature), De Jesus and Mendonca (2018) find that a lack of technical solutions, financial resources, and a restricted market prevents CE adoption within various industries. Another study, which includes inputs from a survey and interviews with experts located in the European Union (EU), points out that the absence of consumers' interest and awareness, in addition to the closed mindset of leadership management, limits the shift from linear to circular business processes (Kirchherr et al., 2018). The recent work of Singh et al. (2020) shows that government policies and regulations are the most important barrier to the adoption of CE in the mining industry. However, this study also has some constraints, such as the list of barriers not being exhaustive.

The shift towards CE from the existing linear approach cannot be accomplished entirely without a detailed understanding of the relevant CE challenges. Considering the need for studies related to CE challenges, the present study provides an exhaustive list of significant challenges for the adoption of CE in the mining industry in the context of a developing economy, with the support of a case example.

It has been argued that it is important to identify specific challenges faced by different economic sectors (Kirchherr et al., 2018). Thus, research efforts towards identifying the challenges in the mining industry for a smooth transition towards CE and progress towards more sustainable practices become necessary. However, the existing literature lacks a structured decision-making methodology to understand the interrelations and relative priority of such challenges. This work fills this research gap in the literature related to challenges associated with the mining industry's transition towards CE, and tries to answer the following research questions:

RQ1: What are the critical challenges associated with the mining industry that affect the transition towards a CE?

RQ2: What are the contextual and cause-effect relationships among the CE challenges in the mining industry?

This study contributes significantly to the extant literature. First, it provides a detailed analysis of the existing studies related to CE in the mining industry. Second, it organises the key challenges that possibly affect the transition towards a CE from the existing literature. Third, with the help of contextual relationships between the identified challenges, it applies an Interpretive Structural Modelling (ISM) framework. Fourth, it classifies all the identified challenges into cause and effect groups, using the Decision-Making Trial and Evaluation Laboratory (DEMATEL) technique. On this note, one may note that the combined ISM-DEMATEL method has distinct advantages and can transform a weak, unclear, and complicated system into a well-structured and visible model.

The paper is structured as follows: Section 2 covers the literature review; Section 3 describes the methodology; Section 4 presents a mining case study along with its results; Section 5 includes the discussion; while Section 6 concludes the paper.

2. Literature Review

2.1 The Circular Economy and its Relevance for the Mining Industry

The Circular Economy (CE) provides opportunities for better utilization of available resources (Giurco et al., 2014b; EMF, 2017). The CE approach is both restorative and regenerative by design, and detaches industrial systems from the linear approach of "take, make and dispose of" (Haibin and Zhenling, 2010). By and large, the approach looks to transform a system by redesigning both production and consumption patterns (Preston, 2012). Therefore, this approach is fast emerging as an essential growth model for sustainable development (World Economic Forum, 2014; EMF, 2015; EMF et al., 2015; EC, 2015; Geissdoerfer et al., 2017).

CE is also a policy-driven concept, which mining organizations may choose in order to develop their sustainability visions and practices (D'Amato et al., 2019). The academic literature posits that achieving sustainability in the mining industry requires greater emphasis on CE. For instance, Upadhyay et al. (2021) examine sustainability reports from the mining industry and identify recycling/reuse and waste management as drivers, barriers, and triggers towards the transition to CE. Christmann (2021) outlines CE action plans for mineral resource governance in the EU, including reduction in demand for primary minerals and metals, collaborative working, enhancing investment, capacity building, and institutional strengthening. Kulczycka et al. (2020) analyze extractive waste management measures as per EU regulations to create industrial

symbiosis and a quicker transformation towards CE. They emphasize data collection regarding mining waste as an area for the adoption of CE principles. Moreover, the reuse of the waste stream from the mining industry via industrial symbiosis, which is in line with CE principles, also provides an avenue to realise the potential for possible uses of mining waste products (Balanay and Halog, 2016; Kristensen & Mosgaard et al., 2020). The international resource panel report stresses the reuse of old heaps and dumps, converting them into anthropogenic resources, and emphasising a recycling approach for better resource efficiency (UNEP, 2013, EC, 2020). Indeed, a successful transition to CE as per the EU regulations requires detailed information on anthropogenic resource availability, classification and challenges (Winterstetter et al., 2021)

The supply of minerals is vulnerable, and CE is expected to reduce the demand for virgin raw materials and increase their efficiency, both in Europe and across the world (EIT, 2020). The CE suits mining activities well because, for instance, waste from metallurgical processors can be reused or repurposed; this recycling, in turn, can combine new virgin materials with recovered metal (OECD 2019). Reverse logistics/closed-loop and suitable leadership in managing reverse flows are pillars of CE (Mokhtar et al., 2019). However, despite the possibilities offered for reuse and recycling, an earlier study comprising several managers from Finnish mining companies found that managers of these companies do not have a clear understanding and vision of how to adopt CE principles within their industry (Kinnunen and Kaksonen, 2019)

Very few studies have looked into the adoption of CE in mining industries. Furthermore, researchers have paid little attention in the past to delving into the details related to CE challenges, especially in the mining industry. Table 1 provides a summary of the existing literature on CE in the mining industry.

Table 1. Summary of studies related to Circular Economy (CE) in the mining industry

No.	Author and Year	Industry	Approach	Factors/category	Research questions/Research objectives	Country	Limitations	Remark
1.	Upadhyay et al., 2021	Mining	Content analysis of the sustainability reports	Recycling/Reuse; Waste management and reporting;	To understand the extent to which CE has penetrated the mining industry	United Kingdom	This study involved data from a small subset of large mining firms and content analysis of sustainability reports	Additional work focusing on critical barriers for adoption of CE using more advanced tools supporting case studies is required.
2.	Singh et al., 2020	Mining	Analytical hierarchy process (AHP) and graph-theoretic approach (GTA)	Financial, Market, Government Policies and Regulatory, Organizational, Operational	What are the important barriers for adoption of CE in the Indian mining sector and to prioritize them?	India	The expert's inputs were taken from small group.	Additional studies using more advance tool with support of case study is required.
3.	Pactwa et al., 2020.	Coal Mining	Analysis of databases and literature review	Policy and legal, economic, socioenvironmental	What is the existing scenario of waste management? How can the idea of CE be practically useful in the mining industry?	Poland	The challenges were identified by comparing mining waste sites after EC directives and historical mining waste sites. The comparison basis is EC directives.	The study is in region-specific coal mines. Further studies need to be extended for other regions and for other mining industries. The identified factors need further investigation using an appropriate tool.
4.	Kinnunen and Kaksonen, 2019	Mining industry (Tailing valorization)	In-depth semi-structured interviews of stakeholder and workshop	Mindset, Technology, Environmental, Institutional, Economic, Supply chain	What is the need, drivers, bottlenecks, challenges, benefits and opportunities, for CE in the mining industry?	Finland and Australia	The proposed methodology has a limited sample size collected during workshops and interviews.	It is necessary to have a sufficient sample size for collecting detailed information on CE factors.
5.	Mateus and Martins, 2019	Mining industry	Concise review	Social, Environmental, Economic	What are the main challenges to the mining industry? What are the opportunities and advances, which are very relevant to	Portugal	The identified factors consider the triple bottom line (TBL) dimension	Further work is needed to consider dimensions other than TBL. Suitable sophisticated

					identify weaknesses and threats?		only. The methodology /approach of the study is a generic review.	tool /approach is required to identify and prioritize the CE challenges
6.	Tayebi-Khorami et al., 2019	Mining industry	Review	Geo-environmental, Geo-metallurgy, Social, Economic, and Legal	To assess existing management strategies and frameworks for mining waste along with gaps and challenges.	Australia	The literature review is lacking with details information on CE challenges.	Further studies are essential to identify CE challenges. and their prioritization
7.	Liu et al., 2019	Mining area	Emergy analysis and Data envelopment analysis (DEA)	Ecoefficiency	To assess the eco-efficiency of Chinese mining areas.	China	The research was concentrated on analyzing the eco-efficiency of CE in the mining industry. The study has excluded the social system/ dimension.	Further studies by considering different systems and adding new parameters/dimensions will be meaningful.
8.	Kaźmierczak et al., 2019	Mining areas	Quantitative and qualitative analysis using Analytical Hierarchy Process (AHP)	Economic and Environmental	To use the multicriteria approach to determine the suitability of mining waste sites for potential reuse.	Poland	The research was focus on considering the economic and environmental dimension only.	Additional studies using more advance tool/approach other than AHP is needed, such as DEMATEL, etc.
9.	Geissler et al., 2018	Phosphate Rock Mining	Literature review	Geological, Technological and Economic	What are the phosphate rock mining innovation nexus? What are the best practices and case examples?	Austria, United Kingdom, and Germany	The literature review and cases are lacking with detailed information on CE challenges.	Further studies are required on CE challenges and their prioritization
10.	Kaźmierczak et al., 2018	Rock mining	Quantitative and qualitative analysis using Analytical Hierarchy Process (AHP)	Economic and Environmental	What are the problems associated with rock mining and proposed a criterion for assessment and potential use?	Poland	The study focusses on quantitative and qualitative research with the economic dimension only.	Further studies are essential to identify challenges associated with the mining industry using a more appropriate tool and dimensions.
11.	Wellmer and Scholz, 2018.	Phosphate rock mining	Review	Economic	What can be sustainable and optimal lifespan of a mine?	Germany and Switzerland	The review article addresses the economic dimension	Future studies emphasizing on a dimension other than

							of my life.	economics are required.
12.	Pactwa and Woźniak, 2017.	Mining	Analysis of different databases and literature review	Economic, Regulations/Policy	How is the Polish mining industry struggling with waste, and how CE can provide a solution?	Poland	The study emphasizes on a comparison of polish mining waste in EU with the support of different databases and cases	The review is region-specific. Thus, further studies need to be extended to other developing nations. Also, identified factors need to be explored further using an appropriate tool and case study.
13.	Yu, 2017.	Coal mining	Literature review and regional case study	Economic, Technology, and Environment	How the idea of CE and decoupling LE can work for sustainable coal mines?	China	The identified four sustainability and CE challenges are generic.	Future studies focusing on detailed information about different challenges and categorizing them in different dimensions is necessary.
14.	Lèbre et al., 2017	Mining industry	Material flow analysis (MFA) indicators	Natural resources	To identify challenges faced by the mining industry and understand the transition towards CE.	Australia	More complex cases and scenarios of mining industries are not studied	Further research should address the detail about the challenges encountered by the mining industry with the support of the case and scenario.
15.	Balanay and Halog, 2016	Mining industry	Literature review	Policy and Triple bottom line (TBL)	To discuss the CE approach for developing policy guiding actions for the mining industry	Australia and Philippines	The literature review emphasizes policy and TBL dimensions for implementing CE. However, much insight into TBL dimensions is not discussed in detail.	Additional insight about CE challenges faced by mining industries in different dimensions and in developing nations are required.
16.	Giurco et al., 2014b	Mineral and metal industry	Literature review	Supply Chain and TBL	To identify the CE implications during metal recycling?	Australia	The literature review is focused on general and lacks with case study support.	Additional work on understanding the CE challenges in developing regions with

								case based support is paramount.
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2.2. Extant Literature on the use of ISM and DEMATEL decision-making techniques in the Mining Industry

The existing literature shows some examples of the use of the DEMATEL method in the mining industry to achieve sustainable development, green supply chain management drivers, barriers, and their causal relationships (Muduli and Barve, 2013; Govindan et al., 2016; Norouzi Masir et al., 2018). Table 2 shows the studies identified which are relevant to ISM and the DEMATEL method in the mining industry.

There is a lack of existing studies on CE challenges associated with the mining industry, which is one of the research gaps identified. There is also a shortage of research on cause and effect relationships among these challenges. Barve & Muduli (2013) and Jia et al. (2015) use the ISM method to highlight challenges and benefits in the mining industry, respectively, but they do not assess cause and effect relationships among the challenges.

The ISM method uses the contextual relationships between variables to develop a final model. ISM-based analysis provides equal weighting to the degree of influence conveyed to or obtained from other elements of a particular factor or component (Muduli and Barve, 2013b). Nevertheless, the findings regarding the evaluated weights will be lower or higher than the actual scenario (Yang and Tzeng, 2011; Muduli and Barve, 2013b). Therefore, there is a need to use the DEAMTEL approach to also explore the cause-effect relationships. The DEMATEL process analyzes the dependence and feedback relationships among elements and provides an understanding of factors and criteria. This method offers an appropriate solution by constructing a hierarchical network system.

Hence, this study aims to bridge all the highlighted gaps using an approach which integrates ISM and DEMATEL, with the help of a case study.

Table 2. The use of ISM and DEMATEL method in the mining industry

No.	Technique/Method	Objective/Purpose	Authors
1.	ISM	To identify different challenges of Green Supply Chain Management (GSCM) in Indian mining industries	Barve and Muduli, 2013
2.	ISM	To explore the behavioral factors impacting the implementation of GSCM and develop a framework to analyze inter-dependencies.	Muduli et al. 2013
3.	ISM	To explore the GSCM drivers in mining industries and develop the interrelationship among them	Muduli and Barve, 2013a
4.	ISM	To identify the essential SSCM practice in the mineral and mining industry and study its relationship.	Jia et al., 2015
5.	ISM	To explore different important success factors related to GSCM in the mining industry and the contextual relationships.	Luthra et al., 2015
6.	DEMATEL	To find the GSCM barriers in Indian mining industries and develop the causal relationships among them.	Muduli and Barve, 2013b
7.	DEMATEL	To explore the GSCM drivers in the mining industry and examine the causal relationships and strength of influence among them.	Govindan et al., 2016
8.	DEMATEL	To identify the impacting factors for the SD of underground coal mining.	Norouzi Masir et al., 2018
9.	ISM-DEMATEL	To identify critical influencing factors in coal mine safety	Wang et al., 2018

3. Research Methodology

The combined ISM-DEMATEL method is employed in this study to establish the interrelationships among the identified challenges. Notably, the ISM-DEMATEL method has been gaining increasing attention among academicians and researchers in the recent past. The DEMATEL method assists in exploring the intensity of inter-relationships among the factors/challenges obtained in the ISM model.

The ISM and DEMATEL methods identify such inter-relationships by establishing mutual influences, the intensity of these influences, and those challenges with high influential power (Narwane et al., 2021). Both ISM and DEMATEL use graph and matrices theory to analyze the relationships among factors. The DEMATEL method emphasizes the identification of the direct relationship strength in the factors or system, characterizing cause and effect factors and crucial factors. At the same time, the ISM method highlights complicated factors or systems, categorizing them into several sub-factors (or sub-sub-factors) based on the interactions among factors or systems. It describes hierarchical relationships among them (Wang et al., 2020). The ISM method provides a comparison matrix with binary values (0, 1) among the identified factors to examine the causal relationships, while the DEMATEL method uses options such as (0, 1, 2, 3, 4, 5) between identified factors to investigate the cause-effect interrelationships (Kumar and Dixit, 2018).

A brief explanation of the ISM-DEMATEL methodology and the different steps involved is discussed in the subsequent section. A detailed research methodology flowchart is shown in Figure 1.

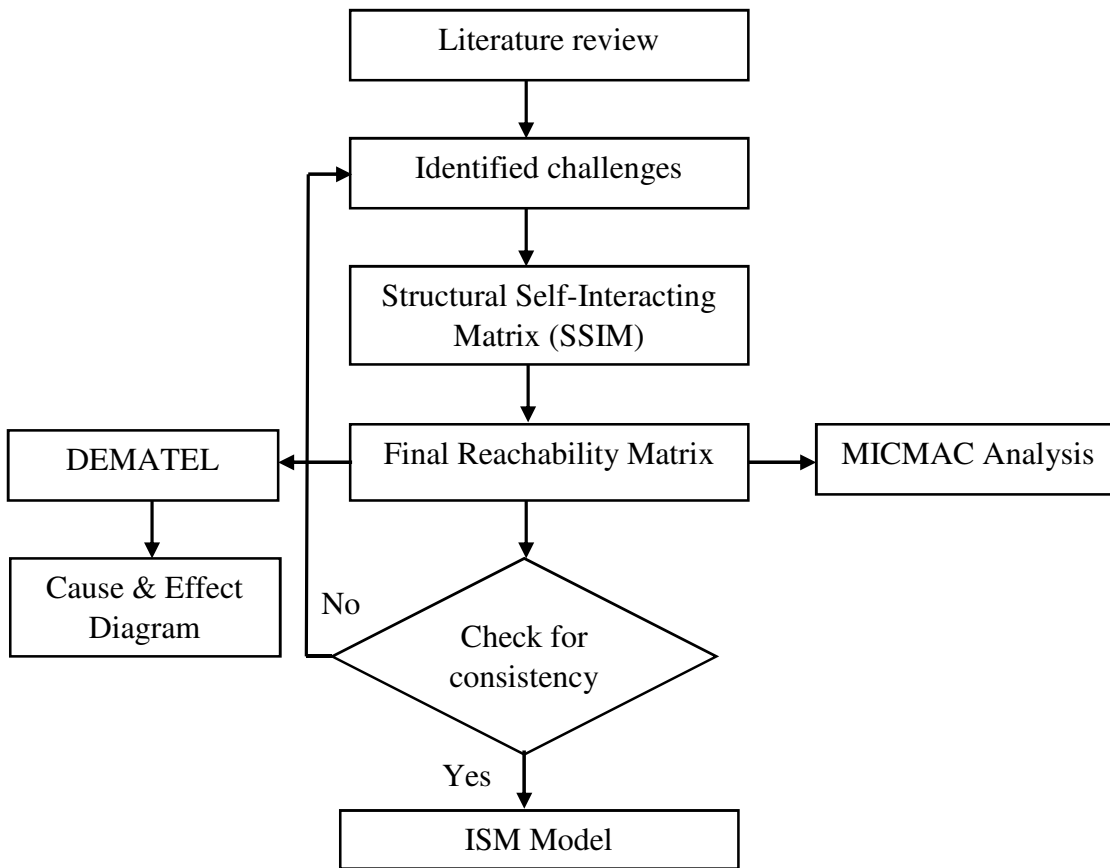


Figure 1: Research methodology

3.1 The ISM methodology

The ISM method was initially developed to understand socioeconomic systems (Warfield, 1973). The benefit of this method is that it converts poor and unclear approaches into clearer ones, by defining them thoroughly and producing visible models (Sage, 1977). This technique helps groups or individuals to illustrate information on a domain into interrelationship models, which can help in developing an understanding of its complexity. The various steps involved in the ISM methodology and the procedure of binary matrix formulation are enumerated below (Warfield, 1973).

Step 1 – Criteria identification: This first step includes identification of elements, whereby these elements are identified based on relevance to the problem. Notably, primary and secondary research approaches, such as field surveys, questionnaires and expert input are used for this purpose.

Step 2 – Creating contextual relations among factors or dimensions: In this step, contextual relationships must be clearly outlined as a likely framework of relationships between

identified elements. These relationships could be of different types; i.e., comparative, influencing, temporal or neutral.

Step 3 – Creating the Structural Self-Interaction Matrix (SSIM): This is the most important and most complicated step. Herein, experts/participants are required to agree upon the pairwise relationships among elements. The experts/participants are asked about the contextual relationships of every component, the relationships among any two sub-elements (u and v), and the detailed direction of these relationships. Notably, four different symbols are used to represent the relationship direction among these elements (u and v). They are:

O = Denotes a relationship from u to v ; however, the relationship does not work in both directions;

P = Denotes a relationship from v to u ; however, the relationship does not work in both directions;

Q = Denotes a relationship from u to v ; however, the relationship does work in both directions;

R = Denotes that the relationship between u to v is not valid.

Step 4 – Creating the reachability matrix from SSIM and checking transitivity: This step relates to the creation of the reachability matrix 'Z', a binary matrix, where the entries for O, P, Q and R in SSIM are mapped into values of 1 and 0. The mapping of entries is done as per the following rule:

If the (u, v) entry in SSIM is O, then the (u, v) entry in matrix 'Z' will be 1 and the (v, u) entry will be 0.

If the (u, v) entry in SSIM is P, then the (u, v) entry in matrix 'Z' will be 0 and the (v, u) entry will be 1.

If the (u, v) entry in SSIM is Q, then the (u, v) and (v, u) entries in matrix 'Z' will be 1.

If the (u, v) entry in SSIM is R, then the (u, v) and (v, u) entries in matrix 'Z' will be 0.

Step 5 – Reachability matrix level partition: In this step, the partitioning of levels is performed to understand the placement of 'level-wise elements' (Warfield, 1973). Further, the antecedent sets and reachability of all elements are calculated in this step.

Step 6 – Digraph development: In this step, the elements are organized graphically (Figure 2), and direct links are established, as shown in the reachability matrix relationship. The digraph is gained step by step, removing the transitive relationships, and examining the knowledge base behind their interpretation. Further, if the interpretation is thought to be crucial, then only critical transitive relationships are retained.

Step 7 – Interaction matrix development: In this step, the last digraph is decoded into a matrix of binary interactions, illustrating the full communication via a single entry. Each cell has a single entry, analyzed by picking the appropriate understanding from the information based on the interpretive matrix form.

Step 8 – Formation of digraph and transformation: The digraph is translated into the ISM framework, and conceptual inconsistency is further assessed. The resulting digraph from the 7th step is then transformed into the ISM model by incorporating nodes through quotes. Finally, to check discrepancies, the ISM model is reviewed.

Step 9 – Analysis of MICMAC: This is performed to understand the nature of the dependency between the study’s drivers and dependents. Based on the driving and dependency power of the factors in the present study, i.e., challenges, one of four labels – i.e., autonomous, dependent, independent, and linkage – is given to every criterion (Arcade et al., 1999).

3.2 The DEMATEL methodology

The DEMATEL method provides cause-effect relationships between factors. The DEMATEL method is preferred when linking indirect relationships into a cause-effect model. This approach also discloses the relationships between different factors in complex situations and determines indirect-direct dependencies among criteria/factors (Gandhi et al., 2015). The various stages of the DEMATEL method used in the present study are shown below (Fontela and Gabus, 1976).

Stage 1 – Defining the composition and scale of the direct relation matrix: A direct relation matrix is established. In this matrix, the responses provided by a sample population regarding direct effects among every pair of elements are used. A Likert scale with options 1 to 5 is used to calculate a pairwise comparison. The 1-5 scale is represented as Not important (NI), Equally important (EI), Equally to moderately important (EMI), Moderately more important (MMI), and Moderately to strongly important (MTSI). The matrix ‘X’ is an $e \times e$ direct relation matrix, where a_{ji} is the degree to which element j affects element i , which is formatted as $T = [a_{ji}]_{e \times e}$

$$T = \begin{bmatrix} a_{12} & a_{13} & \dots & a_{1e} \\ a_{21} & a_{22} & \dots & a_{2e} \\ a_{1e} & a_{2e} & \dots & a_{ee} \end{bmatrix} \quad \rightarrow \text{Eq.(I)}$$

Stage 2 – Normalized direct relation matrix W composition: The initial direct relation matrix is normalized during this stage. The normalized direct relation matrix $W = [b_{ji}]$ is obtained from Eq. II and Eq. III.

$$W = \frac{1}{L}T \quad \rightarrow \text{Eq. (II)}$$

$$L = \max \left[\max_{1 \leq j \leq e} \sum_{i=1}^e a_{ji}, \max_{1 \leq i \leq e} \sum_{j=1}^e a_{ji} \right], i, j \in \{1, 2, \dots, e\} \quad \rightarrow \text{Eq. (III)}$$

Eq. II shows the normalized direct relation matrix, while Eq. III shows the maximum sum values of all the rows and columns. The elements in matrix W conform with $0 \leq b_{ji} \leq 1$, and all the principal diagonal elements are equivalent to 0.

Stage 3 – Calculating the total relation matrix: During this stage, the matrix is calculated such that 1 to c shows power. Thus, the matrix will converge when c tends to infinity. Moreover, this will be the identity matrix. To integrate ISM with DEMATEL in this study, we have considered the final reachability matrix for further calculation.

$$D = W^1 + W^2 + \dots = W^f = W \times (1-W)^{-1} \quad \rightarrow \text{Eq. (IV)}$$

$$= [b_{ji}]_{e \times e}, f \rightarrow \infty \quad \rightarrow \text{Eq. (V)}$$

Stage 4 – Calculating sums of rows and columns: During this stage, the sums of rows and columns in the matrix is calculated. The vectors M and N denote the sums of rows and columns respectively.

$$D = [d_{ji}]_{e \times e}, j, i = \{1, 2, \dots, e\} \quad \rightarrow \text{Eq. (VI)}$$

$$M = \left[\left(\sum_{i=1}^e t_{ji} \right) \right]_{e \times 1} = [m_j]_{e \times 1} \quad \rightarrow \text{Eq. (VII)}$$

$$N = \left[\left(\sum_{i=1}^e t_{ji} \right) \right]_{1 \times e} = [n_i]_{1 \times e} \quad \rightarrow \text{Eq. (VIII)}$$

Stage 5 – Construction of cause-effect diagram: The ‘cause-effect diagram’ is created during this stage. In matrix D, d_j is the sum of every row; these rows highlight the degrees of both indirect and direct impacts on other criteria. Further, n_i is the addition of every column in matrix D, highlighting the degree of influence from different approaches. m_j is a numeric variable; it shows the factors that influence others, while n_i shows the relationship strength among factors. Combining $m_j - n_i$ shows the influential strength between factors. To put it differently, $m_j - n_i$ and $m_j + n_i$ show relations and prominences, respectively.

4. Results

4.1 Background of the Study

The existing literature has highlighted India as one of the most important countries for producing many minerals (Luthra et al., 2015). Mining and mineral operations are considered drivers for every country's sustainable economic growth and development (Sivakumar et al., 2014). Mining is a critical business in terms of community benefit and providing daily usable products to end-users. However, due to global competition, mining firms feel a pressure to

consider resource conservation within their supply chains. Notably, the Indian government has not paid much attention to the small-scale mining industry (Barve and Muduli, 2013). Therefore, taking into account this context, we chose to perform a case study of an Indian mining company.

4.2 Case study, demographic details, and data collection

XYZ Ltd. is a coal mining company; primarily, it works with open cast coal mining and is situated in ABC Maharashtra, India. Notably, there are 71 coal mines in Maharashtra, and ABC is one of the largest mining areas, spread across an area of about 75 km². XYZ Ltd. has been granted a geological mining block area of 1100 hectares and a mining lease area of 950 hectares for coal mining in the eastern part of Maharashtra for 20 years. Notably, the rated capacity of ABC is 2.5 Million Tons Per Annum (MTPA), with a coal washery capacity of 1.5 MTPA. XYZ Ltd. has a strong presence across the coal value chain, from coal extraction and production, to exports in the international market. Coal mining in the ABC region does damage the surrounding environment and degrades air, water, soil, vegetation, landform, land use/land cover, and human health. Due to this significant ecosystem impact and stringent environmental rules, XYZ Ltd. remains firmly dedicated to implementing CE approaches in their operations. Thus, understanding the CE challenges faced by the mining industry is paramount before implementing CE approaches.

To identify various challenges in the industry, we initially contacted four industry experts who had vast experience of CE. Originally, we asked them to share CE challenges based on their expertise of the challenges faced by the industry. After five days, we received the lists of challenges from the experts. We combined all their responses and removed the common challenges to avoid any duplication. After two days, we arranged a brainstorming session with the experts. We presented all the difficulties identified with a detailed explanation. After the brainstorming session, seventeen CE challenges were finalized (see Table 4) (Dubey & Singh, 2015; Hussain et al., 2016).

The seventeen challenges identified were used during the ISM-DEMATEL method detailed above. The list of seventeen challenges was then circulated to the teams of experts working and having experience in the mining sector. The expert teams consisted of five professors from a government academic institute with experience of a minimum of ten years; ten experts from the mining industry (including the four industry experts initially contacted), who were at the managerial level, and with a minimum experience of ten years; ten experts from a consultancy and policy background, with minimum experience of 10 years. Table 3

provides the demographic details of the expert teams. This entire team of experts analyzed the CE challenges (Table 4) and provided the required responses.

Table 3 Demographic details of expert teams.

Demographic factor	Particulars		
Expert team and numbers	5 professors	10 consultant and policymakers	10 managers
Age group (Average)	45 and above	45 and above	35 and above
Scholastic details	PhD	PhD and or MBA	MBA and or MTech
Experience in years (minimum)	10	10	10
Domain	Government academic institute	Consulting and policy	Mining industry
Gender	Male	Male and Female	Male and Female
Country origin	India	India	India

The responses were collected from the experts and developed using SSIM, as shown in Table 5. With the help of SSIM, the initial reachability matrix was developed. This conversion process was discussed in step 4 of the section explaining the ISM approach. The initial reachability matrix is reported in Table 6. The reachability matrix was used to calculate level partition according to step 5 of the ISM methodology. All the challenges were categorized depending on individual driving and dependence power. The challenges with a lower influence regarding the relative driving effect lie at the bottom level, and those with a higher level are placed at the top. The partition matrix is reported in Table 7. Finally, an initial reachability matrix and level partition were created to develop the ISM hierarchy that shows the relationships between challenges.

The final framework is shown in Figure 2. The ISM framework in Figure 2 is drawn using the level partition matrix shown in Table 7, showcasing the driving and dependence power of challenges.

It has been observed from Figure 2 that lack of governance, policy, consumer demand, high cost of investment and environmental protection lie at the bottom of the ISM framework, as these challenges have low driving power. The remaining challenges, such as lack of Acid Mine Drainage (AMD) plan, managing social issues, decommissioning program, etc., are set up at the top of the ISM framework.

Table 4. Proposed CE challenges in the present study

Dimension	Challenges	Summary	Reference
Financial and Infrastructure	<ul style="list-style-type: none"> • Lack of knowledge and facility (A-1) • Lack of economic benefits and high cost of investment (A-2) 	<ul style="list-style-type: none"> • The knowledge about the contents, amounts, and potential benefits of tailings/mine waste is lacking, leading to underutilization or no valorization of these waste streams. Further, the CE facility, economical method, and economic analysis of mining waste are not available with the organization. The utilization of CE concepts in the mining industry requires advancements in filling the knowledge gaps for business opportunities. • The presence of minimum mass and concentration of recoverable material in mine residues makes further valorization of mine residue uneconomical and requires high investment. In fact, further valorization of tailings/mine waste takes more time to break even. On the other hand, the virgin raw material is cheaper than secondary waste material, and thus, implementing CE for tailings/mine waste becomes difficult. 	EC, 2014; Kinnunen and Kaksonen, 2019; Mateus and Martins, 2019; Tayebi-Khorami et al., 2019
Team Management	<ul style="list-style-type: none"> • Lack of Acid Mine Drainage (AMD) management plan (A-3) • Lack of investment and availability of market (A-4) • Lack of encouragement and cooperation (A-5) 	<ul style="list-style-type: none"> • The generation of AMD during mining operations poses a substantial challenge to regulators, mine owners, and other stakeholders. Further, the management and treatment cost of AMD is high. Therefore, it is crucial to have an AMD management plan well in advance during the early phases of mining. • The market scale, investment, and benefits are minimal for CE-based new mine waste product. Due market uncertainty, lack of investment CE-oriented solutions for mining waste takes time to enter into the market, hindering its adoption. • The required cooperation and encouragement among different stakeholders to have mineral waste processing and extraction technologies are lacking. Further, cooperation and motivation from top management for CE related initiatives in the mining industry are also missing. 	Unger, 2017; De Jesus and Mendonca, 2018; Grande et al., 2018; Tayebi-Khorami et al., 2019; Kinnunen and Kaksonen, 2019; Singh et al., 2020
Economic	<ul style="list-style-type: none"> • Lack of governance measures and implementation (A-6) • Lack of consumer interest and demand (A-7) 	<ul style="list-style-type: none"> • The mineral waste management planned by mining industries is not appropriately reported to waste management systems. Adequate governance measures and their implementation is vital to ensure the sustainable balance between the supply and demand of secondary minerals and metals. The lack of government measure and performance related to transfer and application of the CE adoption ideas and data, information management system about mining waste hampers transformation of the mining industry towards CE. • The public and consumer demand is rising for environmentally friendly products. However, the people and consumer demand for environmentally friendly products from mineral production and mineral waste due to are still in infancy. The consumers are comfortable with the linear model. They have largely stuck with it for quite a long time because of a lack of consumers' interest and societal acceptance for products made from mining waste. 	Yu, 2017; Kirchherr et al., 2018; Geissler et al., 2018; Kinnunen and Kaksonen, 2019; Kulczycka et al., 2020; Singh et al., 2020
Supply Chain / Value Chain	<ul style="list-style-type: none"> • Lack of quality and management of value chain (A-8) • Lack of long-term resource consideration (A-9) • Lack of purity and 	<ul style="list-style-type: none"> • The management and quality of the entire value chain are prerequisites for successful side stream valorization of mining wastes. However, the value chains for tailings valorization are lacking and the value chain for small players such as Small and Medium-Sized Enterprises (SMEs) are not available. Further, the required expertise for waste valorization is unequally distributed among various companies and professionals who are un-willingness to collaborate in the value chain. • The lack of long-term consideration of mines' resources and premature closures leads to loss of valuable resources. Such a lack of long-term consideration and required planning results in resource sterilization. 	Giurco et al., 2014b; Lèbre et al., 2017; Kirchherr et al., 2018; Kinnunen and Kaksonen, 2019; Mateus and Martins, 2019

	homogeneity of mining tailings (A-10)	<p>The mine resources are left as it leading to waste generation and making the mining process uneconomical. Thus, it is essential to consider the long-term use of mine resources even after mine closure.</p> <ul style="list-style-type: none"> Mines tailings resources are heterogeneous, contain different impurities, and have a low metal grade, making it difficult to process via traditional processing methods. Thus, lack of purity and homogeneity in mine tailing makes mining tailings valorization uneconomical and requires appropriate technology to process further and bring back circularity. 	
Social	<ul style="list-style-type: none"> Lack of managing social issue (A-11) Lack of top-down and or bottom-up approach (A-12) 	<ul style="list-style-type: none"> Mining metals, minerals, and the closing of mines may affect communities' social lives, leading to social issues and conflicts. Such social issues and conflict between mining companies and local communities can make stakeholder dialogue and cooperation very difficult and resource-consuming. Further these conflicts and trade-offs are also poorly understood and managed by mining authorities and policy makers. Therefore, the mining industries and policymakers need to systematically identify, assess, and manage the social issues related to mining activity. The success in CE adoption in the mining industry requires top-down and or bottom-up approaches to maintain the interests and involvement of all stakeholders, i.e., mining industries, policymakers, and society. The top-down or bottom-up approach for implementation of CE is still in the initial stage and dominated by the recycling approach instead of reuse, consumption, etc. To drive CE in the mining industry requires extensive efforts in social awareness and new techniques or strategies or business models for initiating top-down and bottom-up movement, which is missing at present. 	Giurco et al., 2014b; Lieder & Rashid, 2016; Balanay and Halog, 2016; Mateus and Martins, 2019; Pactwa et al., 2021; Christmann, 2021
Technology and Policy	<ul style="list-style-type: none"> Lack of legislation/policy and permits (A-13) Lack of technology and innovation (A-14) 	<ul style="list-style-type: none"> There is a lack of legislation/policy measures and permits such as legal/policy frameworks, tax benefits, incentives, subsidies, etc., for establishing a conducive environment for CE adoption. Appropriate legislation/policy measure is required for recovering valuable resources from mine tailings and for successful, sustainable residue utilization. Developing and implementing CE policies for the mining industry requires long-term vision and political will, and leadership, which is lacking. Further, the continuous improvement in existing CE regulatory procedures and environmental permits is paramount for the circularity of mining tailings. Appropriate technologies and innovation for a successful refill of old mines and utilizing mining waste is not fully developed. The mine waste and secondary materials contain impurities, low grade, and heterogeneous. To address these issues, advancement in technology and innovation is required. Further, there is a gap between processes and product development, and the gap between invention and production i.e., technology readiness level for mining waste valorization is lacking. 	Yu,2017; De Jesus & Mendonça, 2018; Kirchherr et al., 2018; Tayebi-Khorami et al., 2019; Kinnunen and Kaksonen, 2019; Mateus and Martins, 2019; Pactwa et al., 2020; Singh et al., 2020; Christmann, 2021.
Environment	<ul style="list-style-type: none"> Lack of mine decommission plan and waste classification (A-15) Lack of diversified and responsible supply chains (A-16) 	<ul style="list-style-type: none"> Most of the mines are lacking with a detailed decommissioning plan before mining operations. Once the mine is shut down, the mine decommission program is paramount to manage the waste and mining reclamation. No one takes responsibility for mine waste management due to the lack of decommissioning plan. Further, the appropriate waste classification systems differ from country to country. The mine waste classification is vital to identify the practical application of the CE in the mining industry. The diversified and responsible supply chains with better and accurate access to primary-secondary raw materials are essential in the world market to ensure a stable supply of minerals. The value chain should be able to capture the waste and reintroduce the byproducts as resources. The valorization of mining waste is 	Yu,2017; Balanay and Halog, 2016; Kinnunen and Kaksonen, 2019; Liu et al., 2019;

	<ul style="list-style-type: none">• Lack of environmental protection (A-17)	<p>incomplete without a diversified and responsible supply chain where all supply chain stakeholders are equally involved and encompasses value capturing from waste streams.</p> <ul style="list-style-type: none">• The old and exhausted mines are environmentally unsafe, and there can be environmental risks in opening old heaps of waste for further valorization. There is a lack of sufficient waste treatment facilities and measures for waste management coming from the mining operation. There is a lack of penalty for unsafe mine closure, which leads to long-term environmental safety risks after the mining closure. If the mine tailings are stabilized and covered, reprocessing such stabilized mine tailing may pose additional ecological risks. Thus, the environmental impacts of recycling waste or mine tailings need proper assessment for ecological protection.	
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Table 5: Structural Self-Interaction Matrix (SSIM)

	A-2	A-3	A-4	A-5	A-6	A-7	A-8	A-9	A-10	A-11	A-12	A-13	A-14	A-15	A-16	A-17
A-1	R	O	P	R	O	P	O	P	O	R	P	R	R	O	O	R
A-2		R	R	O	P	O	R	O	P	R	O	R	P	O	R	Q
A-3			R	P	O	P	R	P	O	P	R	P	R	P	O	R
A-4				R	R	R	O	R	R	O	Q	R	O	R	R	P
A-5					R	R	R	R	Q	P	O	P	O	O	P	Q
A-6						R	R	R	R	Q	O	P	P	R	O	R
A-7							R	R	P	O	O	R	R	Q	P	Q
A-8								R	O	R	Q	R	R	R	Q	R
A-9									P	O	R	R	Q	R	R	R
A-10										P	R	P	R	O	P	Q
A-11											Q	P	P	P	O	P
A-12												O	P	R	R	P
A-13													Q	R	R	O
A-14														R	Q	R
A-15															R	P
A-16																P
A-17																

Table 6: Initial Reachability Matrix

	A-1	A-2	A-3	A-4	A-5	A-6	A-7	A-8	A-9	A-10	A-11	A-12	A-13	A-14	A-15	A-16	A-17
A-1	1	0	1	0	0	1	0	1	0	1	0	0	0	0	1	1	0
A-2	0	1	0	0	1	0	1	0	1	0	0	1	0	0	1	0	1
A-3	0	0	1	0	0	1	0	0	0	1	0	0	0	0	0	1	0
A-4	1	0	0	1	0	0	0	1	0	0	1	1	0	1	0	0	0
A-5	0	0	1	0	1	0	0	0	0	1	0	1	0	1	1	0	1
A-6	0	1	0	0	0	1	0	0	1	0	1	0	1	0	0	1	0
A-7	1	0	1	0	0	0	1	0	0	0	1	1	0	0	1	0	1
A-8	0	0	0	0	1	0	0	1	0	1	0	1	0	0	0	1	0
A-9	1	0	1	0	0	0	0	0	1	0	1	0	0	1	0	0	0
A-10	0	1	0	0	1	0	1	0	1	1	0	0	0	0	1	0	1

A-11	0	0	1	0	0	1	0	0	0	1	1	1	0	0	0	1	0
A-12	1	0	0	1	0	0	0	1	0	0	1	1	0	1	0	0	0
A-13	0	0	1	0	1	0	0	0	0	1	0	1	1	1	0	0	1
A-14	0	1	0	0	0	1	0	0	1	0	1	0	1	1	0	1	0
A-15	0	0	1	0	0	0	1	0	0	0	1	0	0	0	1	0	0
A-16	0	0	0	0	1	0	0	1	0	1	0	0	0	1	0	1	0
A-17	0	1	0	1	1	0	1	0	0	1	1	1	0	0	1	1	1

Table 7: Level partition matrix.

Variable	Reachability	Antecedents	Intersection	Level
A-1	A-1 A-2 A-5 A-6 A-8 A-9 A-12 A-13	A-1 A-2 A-4 A-5 A-6 A-7 A-8 A-9 A-12 A-13 A-14 A-17	A-1 A-2 A-5 A-6 A-8 A-9 A-12 A-13	2
A-2	A-2 A-7 A-17	A-2 A-6 A-7 A-13 A-17	A-2 A-7 A-17	5
A-3	A-2 A-3 A-5 A-6 A-7 A-8 A-9 A-10 A-11 A-13 A-14 A-15 A-16 A-17	A-1 A-2 A-3 A-4 A-5 A-6 A-7 A-8 A-9 A-10 A-11 A-12 A-13 A-14 A-15 A-16 A-17	A-2 A-3 A-5 A-6 A-7 A-8 A-9 A-10 A-11 A-13 A-14 A-15 A-16 A-17	1
A-4	A-4 A-5 A-8 A-12	A-2 A-4 A-5 A-7 A-8 A-12 A-13 A-17	A-4 A-5 A-8 A-12	4
A-5	A-2 A-4 A-5 A-7 A-8 A-12 A-17	A-2 A-4 A-5 A-6 A-7 A-8 A-12 A-13 A-17	A-2 A-4 A-5 A-7 A-8 A-12 A-17	4
A-6	A-6	A-6	A-6	7
A-7	A-2 A-7 A-17	A-2 A-6 A-7 A-13 A-17	A-2 A-7 A-17	5
A-8	A-4 A-5 A-8 A-12 A-17	A-2 A-4 A-5 A-7 A-8 A-12 A-13 A-17	A-4 A-5 A-8 A-12 A-17	4
A-9	A-2 A-6 A-9 A-13 A-14	A-2 A-4 A-5 A-6 A-9 A-12 A-13 A-14 A-17	A-2 A-6 A-9 A-13 A-14	3
A-10	A-1 A-2 A-3 A-4 A-5 A-7 A-9 A-10 A-11 A-12 A-14 A-15 A-16 A-17	A-1 A-2 A-3 A-4 A-5 A-6 A-7 A-8 A-9 A-10 A-11 A-12 A-13 A-14 A-15 A-16 A-17	A-1 A-2 A-3 A-4 A-5 A-7 A-9 A-10 A-11 A-12 A-14 A-15 A-16 A-17	1
A-11	A-1 A-2 A-3 A-4 A-5 A-6 A-7 A-8 A-9 A-10 A-11 A-12 A-13 A-14 A-15 A-16 A-17	A-1 A-2 A-3 A-4 A-5 A-6 A-7 A-8 A-9 A-10 A-11 A-12 A-13 A-14 A-15 A-16 A-17	A-1 A-2 A-3 A-4 A-5 A-6 A-7 A-8 A-9 A-10 A-11 A-12 A-13 A-14 A-15 A-16 A-17	1
A-12	A-4 A-5 A-8 A-12	A-2 A-4 A-5 A-6 A-7 A-8 A-12 A-13 A-17	A-4 A-5 A-8 A-12	4
A-13	A-13	A-6 A-13	A-13	6

A-14	A-2 A-5 A-6 A-7 A-9 A-12 A-13 A-14 A-17	A-2 A-4 A-5 A-6 A-7 A-8 A-9 A-12 A-13 A-14 A-17	A-2 A-5 A-6 A-7 A-9 A-12 A-13 A-14 A-17	3
A-15	A-1 A-3 A-6 A-7 A-10 A-11 A-12 A-15 A-16 A-17	A-1 A-2 A-3 A-4 A-5 A-6 A-7 A-8 A-9 A-10 A-11 A-12 A-13 A-14 A-15 A-16 A-17	A-1 A-3 A-6 A-7 A-10 A-11 A-12 A-15 A-16 A-17	1
A-16	A-2 A-3 A-5 A-6 A-7 A-8 A-9 A-10 A-11 A-12 A-13 A-14 A-15 A-16 A-17	A-1 A-2 A-3 A-4 A-5 A-6 A-7 A-8 A-9 A-10 A-11 A-12 A-13 A-14 A-15 A-16 A-17	A-2 A-3 A-5 A-6 A-7 A-8 A-9 A-10 A-11 A-12 A-13 A-14 A-15 A-16 A-17	1
A-17	A-2 A-7 A-17	A-2 A-6 A-7 A-13 A-17	A-2 A-7 A-17	5

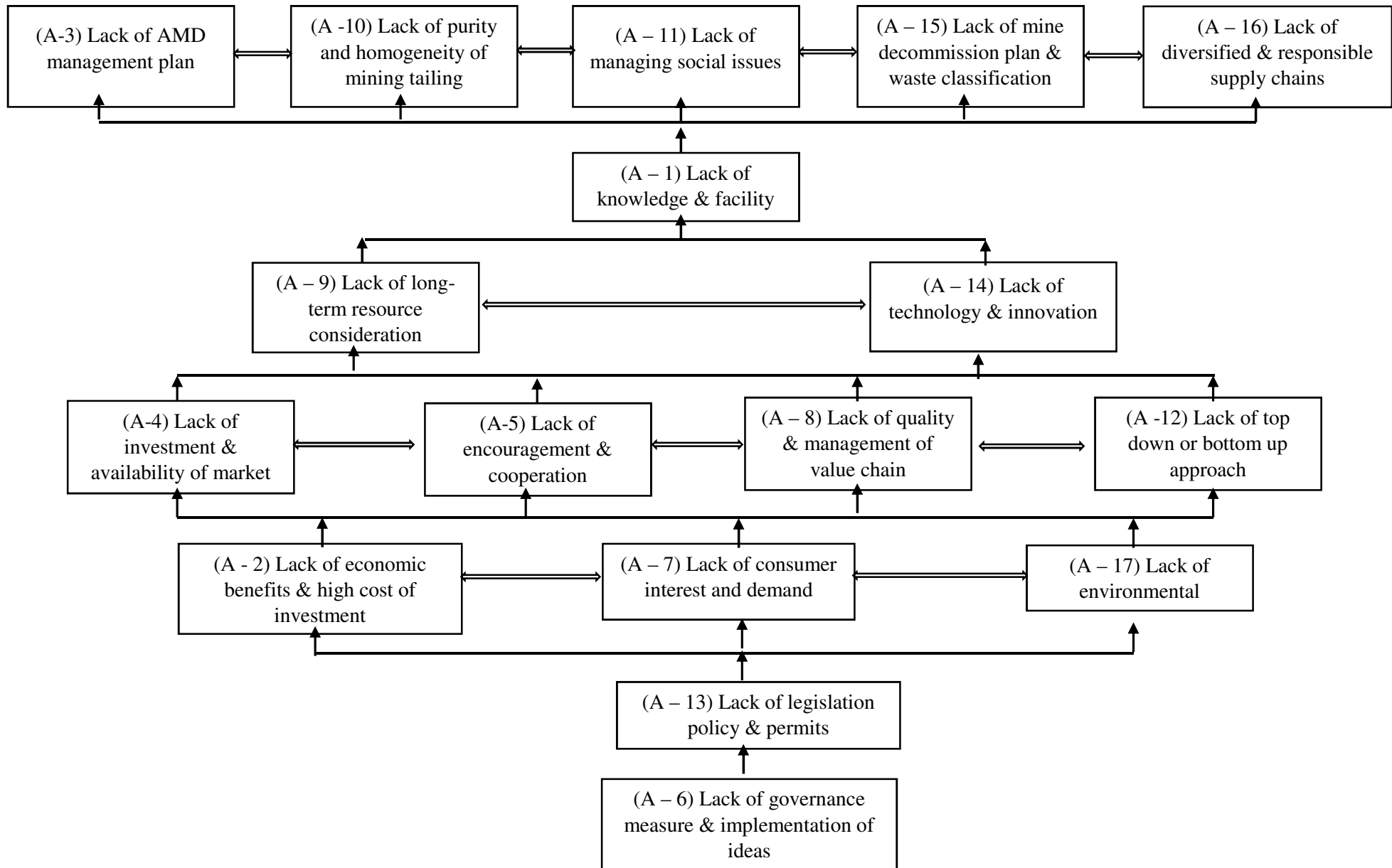


Figure 2: ISM framework

4.3 MICMAC Analysis

MICMAC analysis was used to analyze the dependence and driving power of the challenges. In this analysis, challenges are categorized into 4 clusters, namely: (4) independent, (3) linkage, (2) dependent, and (1) autonomous.

The autonomous cluster has low dependence and driving power; challenges that are part of this cluster are effectively detached from the system. The dependent cluster has low driving power and high dependence power. The third cluster includes challenges that have both high dependence and driving power; such challenges are volatile. Therefore, any action taken to address them would affect the other challenges. The independent cluster contains high driving power and low dependence power. The final representation of the MICMAC analysis is shown in Figure 3.

Further, to get a degree of influence, all seventeen challenges were calculated using the DEMATEL technique. The DEMATEL procedure is explained in detail in stages 1 to 5 in the previous section. To obtain the final cause and effect diagram, the degrees of influences, total relation matrix, normalized matrix, and direct relation matrix were calculated. All such matrices are shown in Tables 8, 9, 10 and 11, respectively.

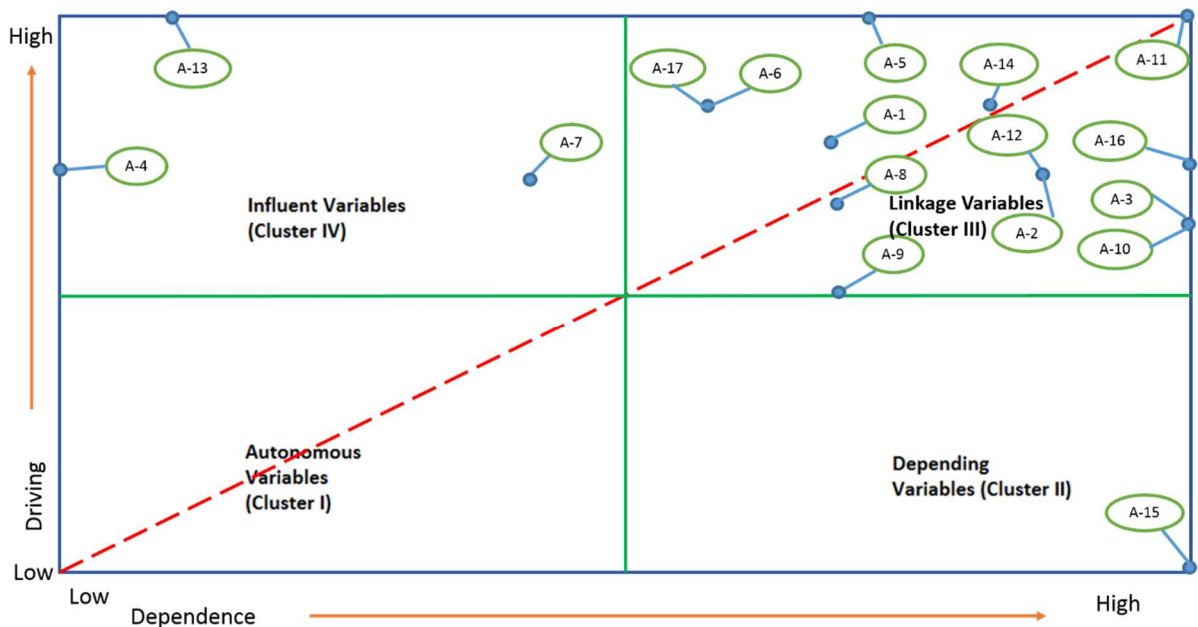


Figure 3: MICMAC Analysis

4.3.1 Causal Diagram

The purpose of the causal diagram shown in Figure 4 is to highlight the relationships between the challenges identified. The relationships are categorized into cause group (P1, P2, P3, P4, P5, P6, P7, P11, P16), and effect group (P8, P9, P10, P12, P13, P14, P15, and P17). At the same time, P denotes the x and y coordinates in the cause-effect diagram. The causal diagram gives vital information that helps to make better decisions.

Table 8: Direct relation matrix

	A-1	A-2	A-3	A-4	A-5	A-6	A-7	A-8	A-9	A-10	A-11	A-12	A-13	A-14	A-15	A-16	A-17
A-1	0	3	3	4	3	2	3	3	1	3	3	4	3	2	3	3	2
A-2	3	0	2	3	2	3	3	3	3	2	2	3	2	3	3	3	1
A-3	3	2	0	4	2	2	4	4	3	2	3	4	2	2	4	4	2
A-4	2	2	2	0	2	2	2	2	2	2	2	4	2	2	2	2	2
A-5	3	1	2	3	0	2	4	2	3	1	2	3	3	2	4	2	3
A-6	2	3	4	3	4	0	3	2	2	3	4	3	4	2	3	2	2
A-7	2	3	3	4	2	3	0	3	2	3	3	4	2	3	1	3	1
A-8	2	3	4	3	3	3	3	0	2	3	4	3	3	3	3	2	1
A-9	3	3	4	3	2	3	3	2	1	2	3	4	3	2	4	2	3
A-10	1	2	3	2	3	3	3	3	3	0	2	3	2	3	3	3	1
A-11	2	2	4	2	2	4	4	4	3	2	0	4	2	2	4	4	2
A-12	2	2	3	2	2	2	2	3	2	2	2	0	2	2	2	2	3
A-13	1	2	3	2	2	4	2	1	3	1	2	3	0	2	4	2	3
A-14	3	4	3	4	2	3	2	2	2	3	4	3	4	0	3	2	2
A-15	3	3	4	2	3	1	3	3	2	3	3	4	2	3	0	3	2
A-16	3	4	3	3	3	3	2	4	2	3	4	3	3	3	3	0	2
A-17	1	2	2	3	4	4	3	2	1	1	2	2	3	4	3	2	0

Table 9: Normalized direct relation matrix

	A-1	A-2	A-3	A-4	A-5	A-6	A-7	A-8	A-9	A-10	A-11	A-12	A-13	A-14	A-15	A-16	A-17
A-1	0.00	0.06	0.06	0.07	0.06	0.04	0.06	0.06	0.02	0.06	0.06	0.07	0.06	0.04	0.06	0.06	0.04
A-2	0.06	0.00	0.04	0.06	0.04	0.06	0.06	0.06	0.06	0.04	0.04	0.06	0.04	0.06	0.06	0.06	0.02
A-3	0.06	0.04	0.00	0.07	0.04	0.04	0.07	0.07	0.06	0.04	0.06	0.07	0.04	0.04	0.07	0.07	0.04
A-4	0.04	0.04	0.04	0.00	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.07	0.04	0.04	0.04	0.04	0.04
A-5	0.06	0.02	0.04	0.06	0.00	0.04	0.07	0.04	0.06	0.02	0.04	0.06	0.06	0.04	0.07	0.04	0.06
A-6	0.04	0.06	0.07	0.06	0.07	0.00	0.06	0.04	0.04	0.06	0.07	0.06	0.07	0.04	0.06	0.04	0.04
A-7	0.04	0.06	0.06	0.07	0.04	0.06	0.00	0.06	0.04	0.06	0.06	0.07	0.04	0.06	0.02	0.06	0.02
A-8	0.04	0.06	0.07	0.06	0.06	0.06	0.06	0.00	0.04	0.06	0.07	0.06	0.06	0.06	0.06	0.04	0.02
A-9	0.06	0.06	0.07	0.06	0.04	0.06	0.06	0.04	0.02	0.04	0.06	0.07	0.06	0.04	0.07	0.04	0.06
A-10	0.02	0.04	0.06	0.04	0.06	0.06	0.06	0.06	0.06	0.00	0.04	0.06	0.04	0.06	0.06	0.06	0.02
A-11	0.04	0.04	0.07	0.04	0.04	0.07	0.07	0.07	0.06	0.04	0.00	0.07	0.04	0.04	0.07	0.07	0.04
A-12	0.04	0.04	0.06	0.04	0.04	0.04	0.04	0.06	0.04	0.04	0.04	0.00	0.04	0.04	0.04	0.04	0.06
A-13	0.02	0.04	0.06	0.04	0.04	0.07	0.04	0.02	0.06	0.02	0.04	0.06	0.00	0.04	0.07	0.04	0.06
A-14	0.06	0.07	0.06	0.07	0.04	0.06	0.04	0.04	0.04	0.06	0.07	0.06	0.07	0.00	0.06	0.04	0.04
A-15	0.06	0.06	0.07	0.04	0.06	0.02	0.06	0.06	0.04	0.06	0.06	0.07	0.04	0.06	0.00	0.06	0.04
A-16	0.06	0.07	0.06	0.06	0.06	0.06	0.04	0.07	0.04	0.06	0.07	0.06	0.06	0.06	0.06	0.00	0.04
A-17	0.02	0.04	0.04	0.06	0.07	0.07	0.06	0.04	0.02	0.02	0.04	0.04	0.06	0.07	0.06	0.04	0.00

Table 10: Total relation matrix

	A-1	A-2	A-3	A-4	A-5	A-6	A-7	A-8	A-9	A-10	A-11	A-12	A-13	A-14	A-15	A-16	A-17	M Sum
A-1	0.6	-0.2	-0.1	-1.0	0.5	-0.1	-0.4	-0.2	0.5	-0.1	-0.1	0.7	-0.2	-0.2	-0.1	-0.1	-0.4	-0.80
A-2	-0.4	-0.5	-0.2	-2.2	1.5	-0.5	-0.8	-0.4	0.4	-0.2	-0.2	2.1	-1.1	0.5	-0.2	-0.2	-0.8	-2.80
A-3	-1.1	0.1	-1.2	-1.6	0.2	1.1	-0.8	-0.7	-0.4	-0.2	-0.2	3.5	-1.1	0.1	-0.2	-0.2	-0.8	-3.46
A-4	-0.6	0.2	0.0	0.3	-0.1	0.2	0.1	-0.1	-0.3	0.0	0.0	0.0	-0.1	0.2	0.0	0.0	0.1	0.07
A-5	1.1	-0.4	-0.1	-0.6	0.2	-0.4	-0.2	0.2	0.7	-0.1	-0.1	-0.1	0.2	-0.4	-0.1	-0.1	-0.2	-0.38
A-6	-0.2	0.1	0.0	-0.1	0.1	0.1	-0.1	-0.1	-0.1	0.0	0.0	0.2	-0.1	0.1	0.0	0.0	-0.1	-0.24
A-7	-0.3	-0.1	-0.3	-3.6	2.4	1.0	-2.3	-0.8	0.8	-0.3	-0.3	3.0	-2.6	-0.1	-0.3	-0.3	-1.3	-5.54
A-8	-0.1	0.1	0.1	0.9	-0.5	0.0	0.4	0.2	-0.3	0.1	0.1	-0.9	0.3	0.1	0.1	0.1	0.4	0.82
A-9	-0.9	0.3	0.0	0.4	0.0	0.3	0.1	-0.1	-0.5	0.0	0.0	0.0	-0.2	0.3	0.0	0.0	0.1	-0.08
A-10	-5.6	1.9	1.7	22.1	-11.5	-0.5	8.8	3.9	-6.6	0.7	1.7	-20.3	7.1	1.9	1.7	1.7	8.8	17.75
A-11	11.9	-4.1	-1.1	-16.9	7.9	-1.5	-6.4	-0.5	8.8	-1.1	-2.1	10.7	-3.2	-4.1	-1.1	-1.1	-6.4	-10.42
A-12	-0.7	0.2	0.1	1.5	-0.8	0.2	0.5	0.2	-0.6	0.1	0.1	-1.1	0.4	0.2	0.1	0.1	0.5	1.05
A-13	-0.4	0.1	0.1	0.5	-0.3	0.0	0.2	0.0	-0.3	0.1	0.1	-0.2	0.1	0.1	0.1	0.1	0.2	0.43
A-14	-0.4	0.8	0.2	2.1	-1.4	0.7	0.7	0.2	-0.7	0.2	0.2	-1.5	0.8	-0.2	0.2	0.2	0.7	2.75
A-15	-18.8	6.4	2.0	18.4	-6.9	3.8	6.5	0.1	-12.0	2.0	2.0	-8.9	1.2	6.4	1.0	2.0	6.5	11.95
A-16	15.6	-5.0	-1.6	-23.7	11.0	-3.3	-8.7	-2.7	11.5	-1.6	-1.6	15.9	-4.0	-5.0	-1.6	-2.6	-8.7	-15.95
A-17	-0.4	0.4	0.4	3.9	-2.5	-0.8	2.4	0.7	-1.2	0.4	0.4	-2.9	2.5	0.4	0.4	0.4	1.4	5.71
N Sum	-0.65	0.27	0.09	0.38	-0.05	0.25	0.15	-0.05	-0.33	0.09	0.09	0.12	-0.07	0.27	0.09	0.09	0.15	

Table 11: Degree of influence.

Challenges	M	N	M+N	M-N	Coordinates
A-1	-0.80	-0.65	-1.44	0.14	P1 (-1.44, 0.14)
A-2	-2.80	0.27	-2.53	3.06	P2 (-2.53, 3.06)
A-3	-3.46	0.09	-3.37	3.54	P3 (-3.37, 3.54)
A-4	0.07	0.38	0.44	0.30	P4 (0.44, 0.30)
A-5	-0.38	-0.05	-0.42	0.32	P5 (-0.42, 0.32)
A-6	-0.24	0.25	0.009	0.49	P6 (0.009, 0.49)
A-7	-5.54	0.15	-5.39	5.69	P7 (-5.39, 5.69)
A-8	0.82	-0.05	0.77	-0.87	P8 (0.77, -0.87)
A-9	-0.08	-0.33	-0.40	-0.24	P9 (-0.40, -0.24)
A-10	17.75	0.09	17.83	-17.65	P10 (17.83, -17.65)
A-11	-10.42	0.09	-10.33	10.50	P11 (-10.33, 10.50)
A-12	1.05	0.12	1.16	-0.93	P12 (1.16, -0.93)
A-13	0.43	-0.07	0.35	-0.49	P13 (0.35, -0.49)
A-14	2.75	0.27	3.02	-2.48	P14 (3.02, -2.48)
A-15	11.95	0.09	12.04	-11.86	P15 (12.04, -11.86)
A-16	-15.95	0.09	-15.86	16.04	P16 (-15.86, 16.04)
A-17	5.71	0.15	5.85	-5.55	P17 (5.85, -5.55)

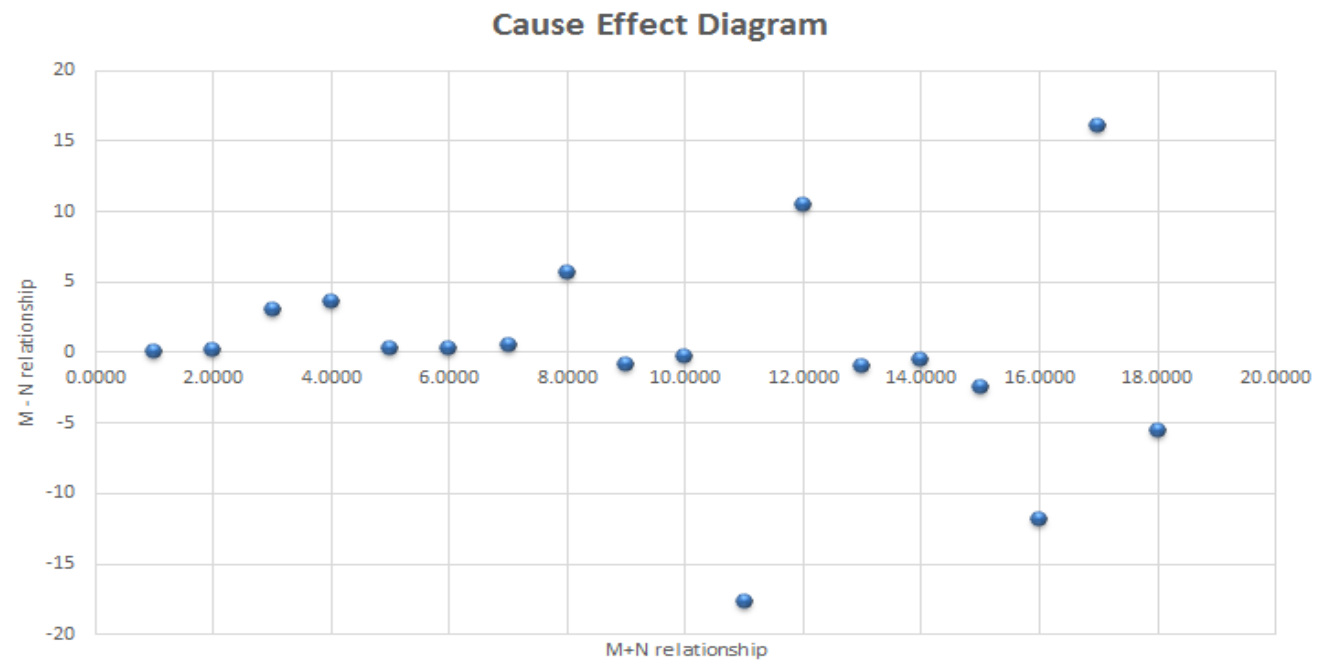


Figure 4: Cause Effect Diagram

5. Discussion

The ISM framework indicates that lack of governance measures and implementation (A-6) in amalgamation is an independent challenge, as it lies at the model's bottom. Lack of legislation/policy and permits (A-13) is driven by governance measures, which effectively means that good governance automatically improves the rules and regulations in the mining industry. Further, the lack of an AMD management plan (A-3), lack of purity and homogeneity of mining tailings (A-10), lack of managing social issues (A-11), lack of mine decommissioning plan and waste classification (A-15) and lack of diversified and responsible supply chains (A-16) are considered to be completely dependent on other challenges, as all of them lie at the top of the ISM framework. The identified CE challenges matched with the challenges faced by the case company.

Despite the importance of CE in driving sustainability in the mining industry, limited studies related to overcoming CE barriers are available. Further, the studies provide a different set of barriers. For example, Yu, (2017) asserts that the main challenges encountered by the mining industry for adoption of CE include lack of post-decommission management, lack of technology for mine refilling, poor pollution control, lack of environmental and socio-economic pressures in the mining industry. The lack of technical aspects, lack of financial resources, and lack of market are significant challenges derailing CE according to De Jesus and Mendonca (2018). Kinnunen & Kaksonen (2019) identify lack of CE knowledge, lack of CE mindset, lack of legislation, lack of value chains, and lack of technological, environmental, and economic benefits as the most crucial barriers to CE adoption. At the same time, lack of consumer interest, awareness, and lack of leadership are the most important challenges hampering CE according to Kirchherr et al. (2018). In contrast, Singh et al., (2020) find that government policies and regulations are the most important barriers among all barriers, followed by market and operational barriers for the adoption of CE in the mining industry. Further, Kulczycka et al. (2020) also argue that lack of data and information collection about mining waste hampers the mining industry's transformation towards CE. The very recent work of Upadhyay et al. (2021) implies that the lack of communication or practice related to recycling processes is a crucial CE challenge in the mining industry. Thus, a detailed understanding of CE challenges must overcome these and implement sustainable practices in the mining industry. Henceforth, the proposed work provides a comprehensive list of seventeen CE challenges encountered in the mining industry in an emerging economy according to seven different dimensions, as specified above.

The MICMAC analysis categorizes all the challenges into four clusters as per their driving power and dependence. The autonomous cluster has low driving power and low dependence; variables that are relatively disconnected from the system form part of this cluster. This study does not have any independent variables. Further, the categorization of challenges shows that challenges,

A-4, A-7, A-9, A-13, and A-15 are part of cluster 3. These challenges have high driving power and high dependence, and the variables herein are unstable; therefore, any changes in these variables affect others. Thus, a firm needs to take care of variables like management planning, encouraging stakeholders, technology and innovation, top-down/bottom-up approach, etc.

To make optimal decisions, the cause group challenges first need to be identified and improved, which would eventually improve the effect group challenges. Table 11 shows the influence levels of each challenge in the mining system. Based on $m_j - n_i$ values, all the challenges have been categorised into the two cause and effect groups. The variables (A-1) lack of knowledge and facility, (A-2) lack of economic benefits and high cost of investment, (A-3) lack of AMD management plan, (A-4) lack of investment and availability of market, (A-5) lack of encouragement and cooperation (A-6) lack of governance measures and implementation, (A-7) lack of consumer interest and demand, (A-11) lack of managing social issues, (A-16) lack of diversified and responsible supply chains fall into the cause group, due to having positive $m_j - n_i$ values. Such variables have a significant effect on the whole system.

The variables with negative $m_j - n_i$ values fall into the effect group variables, which include variables (A-8) lack of quality and management of value chain, (A-9) lack of long-term resource consideration, (A-10) lack of purity and homogeneity of mining tailings, (A-12) lack of top-down or bottom-up approach, (A-13) lack of legislation/policy and permits, (A-14) lack of technology and innovation, (A-15) lack of mine decommission plan and waste classification and (A-17) lack of environmental protection. Such variables tend to be easily influenced by other variables.

The cause-and-effect analysis also revealed the importance of variables such as the cause group, having positive $m_j - n_i$ values with high importance and significantly affecting the whole system. Among all the challenges, the lack of diversified and responsible supply chains (A-16) has the highest ($m_j - n_i$) value, at 16.04, which implies significant importance in the mining industry. The analysis of the ($m_j + n_i$) values found that challenge A-10 (lack of purity and homogeneity of mining tailings) is an essential variable.

Further, after brainstorming with experts from the case company, the case company is keen to adopt CE in its operations. The prioritization of the identified challenges is aligned with the challenges faced by the case. The cause-effect relationships and the prioritization of the identified challenges are expected to help the case company to plan appropriate strategies to overcome the identified CE challenges. However, mining industries in emerging economies will require many efforts to overcome CE barriers and require equal support from government organisations.

5.1 Managerial and Academic Contributions

The present research captures the CE challenges associated with the mining industry by developing a system model using the ISM approach and divides complex criteria into cause and effect groups using DEMATEL. Using the support of a case study, this research demonstrates the important CE challenges faced by the mining industry. Some of the important managerial implications that emerge are listed below.

- The outcome of the ISM methodology gives a framework with seven stages; each stage contains a couple of challenges. The variables located at the bottom of Figure 2 should be prioritised as the primary challenges to be tackled, because those in the top of Figure 2 are dependent on the bottom variables. Thus, for instance, lack of governance measures and implementation (A-6) is the first challenge to be tackled by managers in the mining industry. Therefore, adequate governance measures and their implementation are vital to ensure a sustainable balance between the supply and demand of secondary minerals and metals. These measures are related to adequate control of closed-loop CE actions.
- The MICMAC analysis shows that no variable is part of an autonomous cluster; this signifies that all the variables are interconnected as a system. Further, most of the variables are part of cluster 3; therefore, action on any one of the variables in this cluster would trigger the others, which have high driving and dependence power. Some of these challenges/variables include lack of economic benefits & high cost of investment (A-2), lack of encouragement & cooperation (A-5), lack of quality & management of value chain (A-8), lack of top-down or bottom-up approach (A-12), and lack of environmental protection (A-17). Thus, this result can help academics and industry consultants take decisions related to CE in the mining industry.
- Using the DEMATEL technique, all the variables are characterized into cause and effect groups. This can encourage decision-makers to find the appropriate cause group that needs to be controlled (Lin et al., 2011). Whereas the variables which form the cause group face challenges, those involved in the effect group can be moved effortlessly (Wu and Lee, 2007).
- The causal diagram (Figure 4) highlights that lack of economic benefits and high cost of investment (A-2), lack of consumer interest and demand (A-7), and lack of governance measures and implementation (A-6) lie in the cause group. These challenges also lie at the bottom level of the ISM framework. Therefore, top management of the case company and other mining companies should focus on these challenges as areas for improvement because such variables automatically improve several other variables. Notably, these challenges are related to trade-offs between investing in recoverable material from mine residues or in virgin raw materials, which is cheaper compared to secondary waste material (A-2); lack of

societal acceptance of products made from mining waste (A-7), and adequate governance measures and their implementation to ensure the sustainable balance between the supply and demand of secondary minerals and metals (A-6).

According to a structured analysis of challenges to CE in the mining industry and their interrelations, the trade-off between virgin material and secondary waste material prices can jeopardize CE principles in the mining industry. Such a trade-off does affect public and consumer demand regarding CE products in the mining industry. These two findings are similar to the work of Kirchherr et al. (2018). However, this article raises the importance of tackling the lack of governance measures and implementation (A-6). This article also increases the clarity regarding CE challenges associated with the mining industry.

Economic viability may be a hurdle to adopting CE principles (Genovese et al., 2017). Thus, bottom-up or even top-down actions are necessary to support CE implementation. In the mining industry, adequate governance measures and their implementation are vital to ensure a sustainable balance between the supply and demand of secondary minerals and metals, which can address the trade-off mentioned. Perhaps, as Mokhtar et al. (2019) argue, a balance between trust and power regarding waste management systems among primary and secondary markets within the mining industry could help deal with the trade-off mentioned.

6. Conclusion

The systematic adoption of CE in industrial systems would lead to a sustainable ecosystem and improve firms' performance. CE adoption in the case company and other mining companies will only be possible if each individual firm identifies challenges and develops suitable strategies to deal with them.

The mining industry is continually growing, and it is crucial to identify CE challenges for emerging economies. This study depicts CE challenges in the mining industry and assists business professionals and policymakers by identifying essential challenges related to CE adoption. The findings of this study highlight the importance of adequate governance measures. Adequate governance measures regarding CE are vital to ensure the sustainable balance between the supply and demand of secondary minerals and metals, which can deal with the trade-off between virgin materials and secondary waste materials.

Ultimately, adopting systematic methodologies, like ISM, helps the industry put into place suitable strategies for tackling priority challenges. The existing literature is flooded with more

technical studies of the mining industry. However, there is a gap regarding the utilization of a robust methodology for adopting CE challenges in the mining industry, which this work addresses.

6.1 Implications for Managers and Policymakers

This study has possibly suggested a few solutions for industry problems by identifying seventeen CE challenges in the mining industry. It has used robust techniques, namely ISM and MICMAC analysis. While ISM develops the contextual relationships between identified challenges, MICMAC categorizes challenges into four different clusters, based on their dependence and driving power. The outcome of the ISM method, i.e., lack of governance measure and lack of legislation policy, influences all other challenges. Therefore, policymakers and industry associations should focus on such variables seriously and take appropriate decisions, mainly to deal with the likely low economic viability of CE actions using governmental support. Significantly, improvement in such variables would help the mining industry to achieve sustainable performance.

The outcome of our MICMAC analysis revealed that most of the challenges lie in cluster 3, which signifies that all the identified challenges are essential for the industry. Any action on these factors would bring positive results to move towards CE adoption.

6.2 Limitations and Future Research

Like any other research study, this work has certain limitations. Analyzing the conceptual relationships using a combined ISM and DEMATEL method, we have used experts' opinions. However, an expert's judgment could be biased, which could influence the reliability of the framework.

This study could further be extended using fuzzy DEMATEL, which captures intuitions with the help of natural language and gives the freedom to experts to share their genuine opinions (Xia et al., 2015). Further, the research could also be combined with other Multiple-Criteria Decision Making (MCDM) techniques such as AHP, Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), etc., providing further exciting results.

Abbreviations

CE	Circular Economy
EU	European Union
ISM	Interpretive Structural Modelling
DEMATEL	Decision-Making Trial and Evaluation Laboratory
AHP	Analytical hierarchy process
GTA	Graph-Theoretic Approach
TBL	Triple Bottom Line
DEA	Data Envelopment Analysis
GSCM	Green Supply Chain Management

MCDM	Multiple-Criteria Decision Making
TOPSIS	Technique for Order of Preference by Similarity to Ideal Solution
AMD	Acid Mine Drainage
SMEs	Small and Medium-Sized Enterprises
SSIM	Structural Self-Interaction Matrix

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