An ISM-MICMAC Analysis for the Assessment of Barriers to Adopting Sustainable Practices in the Mineral Industry

Saleem Raza Chalgri[1], Muhammad Saad Memon[2], Fahad Irfan Siddiqui[1], Shakil Ahmed Shaikh[2], Muhammad Raheel Bawani[1]

[1]Department of Mining Engineering, Mehran University of Engineering and Technology, Pakistan
[2]Department of Industrial Engineering and Management, Mehran University, of Engineering and Technology, Pakistan
Email: saleem.raza@faculty.muet.edu.pk

Abstract: The mineral industry of Pakistan possesses great potential and may contribute significantly to industrial development, infrastructure growth, and employment. Various sustainable challenges and new global market changes push the mineral industry to initiate sustainability in the sector. To address the sustainability concerns globally, mineral extraction policies were revised and implemented in many developed countries. However, developing countries could not foster sustainable development in the mineral sector. Therefore, the current study assessed the key barriers to implementing sustainable mineral extraction practices. An interpretive structure model (ISM), a well-established technique, was used to analyze the barriers and the interlinking of barriers with each other. The stockholders' input in understanding the barriers and a systematic literature survey suggested 11 leading barriers that hinder sustainable practices. Next, an ISM model was created based on those 11 barriers, revealing the hierarchy structure with four levels of influence. Finally, a MICMAC analysis was performed to classify those barriers into four clusters based on their driving and dependence power. The model results revealed that the independent cluster was characterized by weak dependence and strong driving power, lacking government support and a lack of government policy. Therefore, both barriers impact most of the other barriers to full implication sustainable practices in the mineral industry of Pakistan.

Keywords: Mineral Industry, Interpretive Structure Model, Sustainability, MICMAC Analysis, Barriers.

1. Introduction

Regardless of the sustainable development in the mineral sector, developing countries like Pakistan face difficulty initiating and practicing sustainable mining operations [1]. The mineral sector of Pakistan possesses great potential and may contribute significantly to industrial development, infrastructure growth, and employment. Previous studies suggested that more than 92 minerals having good mineable reserves are found in Pakistan [2,3]. However, the extraction of these minerals might lead to degradation of the environment, deforestation, soil erosion, and contamination in the water, while the social challenges cannot be overlooked [3,4]. The absence of sustainable strategies might worsen these problems and result in long-term consequences for the industry and community regarding these resources [5]. Therefore, it is important to evaluate the barriers to implementing sustainable practices to initiate sustainability in the mineral sector. The mineral sector of Pakistan has serious sustainable challenges and new changes in the global market, pushing the industry to initiate sustainability in the sector [6-8].

As per the United Nations 2030 vision, all 17 sustainable development goals (SGDs) must be addressed in the country. [9,10]. To address the sustainability concerns globally, mineral extraction policies were revised and implemented in many developed countries. However, developing countries have been unable to foster the SDGs in the mineral sector, especially Pakistan, where mineral extraction operations have been performed manually to date [11-14]. The mineral sector of Pakistan may become an essential part of the economic growth if sustainable practices are adopted. Because Pakistan's mineral resources have not yet been adequately explored and developed [15]. New environmental laws, social issues, and economic challenges may hinder sustainable solutions. However, to overcome these concerns, effective mitigating measures may robust sustainable practices. The absence of a comprehensive sustainability strategy exacerbates these problems, resulting in long-term consequences for the industry and the communities dependent on these resources. Therefore, to initiate sustainable practices, there is a dire need to assess the barriers to implementing sustainable practices in the mining industry.

Several studies have already assessed the challenges of sustainable development practices in the mineral industry. Most existing studies focusing on developed and developing countries' mineral sectorfall short in the race for sustainable practices [11]. The reasons behind this lack are unique, as the challenges and problems faced by countries are different. Most developing countries like Pakistan, despite having huge mineral resources, lack the global mineral supply [16] the main reason behind this is the lack of sustainable mineral practices [17]. These unsustainable practices provoke the unsafe extraction method, thus causing fatalities and severe injuries in the industry [18]. This study assesses the key barriers to implementing sustainable mineral extraction practices in Pakistan. This study may help policymakers to formulate strategies to mitigate the barriers to a sustainable mineral industry. Addressing the barriers is essential for guaranteeing long-term viability in the mineral sector while balancing the adverse environmental and socio-economic effects. Therefore, a unique methodology should be applied to identify critical barriers and how these barriers are influenced and influence by each other.

2. Materials & Methods

Interpretive Structure Modeling (ISM)

The selection of many elements and their interaction may affect any system due to complexity. Direct or indirect elements complicate the system's structure and may increase its complexity. To overcome such complexities in selecting various elements, unique methodology interpretive structure Modeling (ISM) is useful [19]. ISM is a well-established technique to identify elements defining the problem [20]. This technique gained attention in various fields, especially in identifying sustainability barriers. Since it is difficult to describe a situation without knowing the direct and indirect relationship between the factors. Therefore, ISM provides insights into the collective understanding of these relationships. To proceed for the ISM, a panel of experts in the relevant field with good exposure to the field is required. These experts provide feedback about the relationship among elements through a well-structured questionnaire [21]. This study collected responses from the panel of experts via email. Still, before collecting the data, experts were properly communicated regarding the study's objective and the sensitivity of the selection of critical elements. ISM started by identifying the relevant variables and extended to problem-solving techniques. Afterward, a contextually subordinate relation was established, and the pairwise comparison of elements developed a structural self-interaction matrix (SSIM) furthermore, the methodology flow chart is shown in Figure 1.

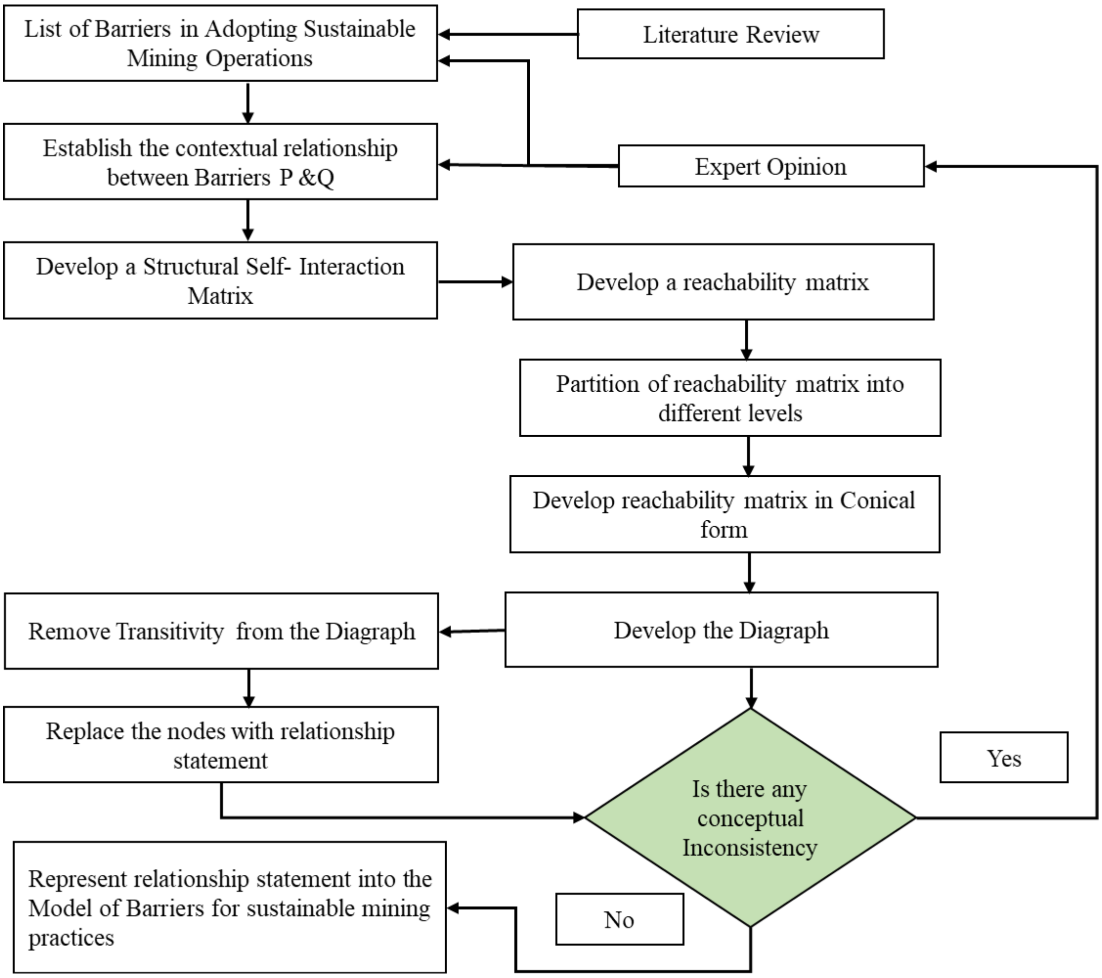

Figure 1 An ISM-based methodology framework for barriers to sustainable mining Practices

The steps suggested by Warfield [22] for the ISM model were followed accordingly in the SmartISM software developed by Ahmed [23].

Step 1: Identify the elements that are relevant to the problem. This was done by a literature survey and discussion with the panel of experts; the identified barriers are shown in Table 1 below.

Table 1: List of Barriers to implementing sustainable practices in the mineral industry

Code	Barrier	Description	Source
B1	Lack of Financial Investment	Countries like Pakistan always lack financial investment due to inflation and fluctuation in the price of commodities. Since mining projects need a good capital investment, this challenge is considered the major constraint in adopting sustainability practices.	[24][25][12]
B2	Lack of Government Support	To promote sustainability in the mineral sector, the government should support sustainability initiatives.	[26][27][28]
B3	Lack of Government Policy	Long-term sustainable policies foster sustainability in the industries.	[27][12][29]
B4	Organizational Barriers	To promote overall sustainability, organizations may play a role in the sustainability in implementing and promoting transparency.	[30][31]
B5	Mine Legislation	Outdated regulations are hindering sustainable practices the implementation of modern and SDGs-aligned laws promotes sustainability.	[32][33][34]
B6	Lack of sustainable education	The curriculum design and vocational training centers may bridge the gap between academia, industry, and government. Promoting safe and efficient practices in industries is possible by raising awareness of sustainability.	[35][36]

B7	Operational Barriers	In implementing sustainability in the mineral sector, operational barriers are one of the major causes in developing nations. Operational barriers include the adoption of environmentally friendly technologies that may lead to efficient sustainability in mining operations.	[37][33]
B8	Political Interruption	Nepotism and corruption within the government bodies often affect the implication of mine & environmental laws in the mineral industries. Delays in the decision-making regarding sustainable initiatives are mostly caused by conflict between political parties, local governments, and stakeholders in developing nations.	[38][35]
B9	Lack of Technical Staff	Limited availability of technical staff poses a significant barrier to the adoption of sustainable practices in developing countries. Mining companies in developing countries often fail to recruit and retain qualified personnel due to the unavailability of modern technologies.	[26][39][40]
B10	Lack of Health & Safety awareness	Mining, being a dangerous occupation, poses threats to the health and safety of workers. Therefore, workers who are unaware of the health and safety issues may hinder safe and sustainable practices. In developing countries, the awareness of health and safety regulations and practices is very common, thus leading to accidents. This gap in the awareness of safe practices jeopardizes the worker's general well-being and also undermines the promotion of a safe and sustainable culture in the industry.	[24][41]
B11	Lack of Innovation and Ideas	It is impossible to achieve sustainability in the mining industry with outdated and manual operations. The importance of innovation and ideas implication are the major contributors to sustainable practices.	[42][12][43]

Step 2: Establish a contextual relationship between elements concerning which pairs of elements were examined, then develop a structural self-interaction matrix (SSIM) of elements. This matrix indicates the pair-wise relationship among elements of the system. The dependencies between factors i & j are marked by four symbols: A, O, X & V, and their relationship is defined as
"V" if Parameter (P) leads to Parameter (Q);
"A" if Parameter (Q) leads to Parameter (P);
"X" if Parameter (P) & Parameters (Q) both lead to each other; and
"O" if Parameter (P) & Parameter (Q) show no relationship
These parameters were used to know the interrelationship between the elements and were incorporated into the questionnaire. The panel of experts was given the proper instructions about this relationship for better understanding and collection of accurate data.

Table 2: Structural Self-Interaction Matrix (SSIM)

Barriers	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11
B1		A	A	V	O	V	X	X	V	V	V
B2			A	O	V	V	V	V	V	O	V
B3				O	V	V	O	V	V	V	V
B4					A	O	X	A	V	V	V
B5						X	O	O	A	V	V
B6							V	O	O	V	V
B7								A	A	V	V
B8									V	V	V
B9										V	V
B10											X
B11											

Step 3: A binary matrix called "Adjacency Matrix" was created using SSIM. In SSIM, each symbol was replaced by binary numbers in the software, as per the substitution rules shown in Table 2.

Table 3 Substitution rule in structural self-interaction matrix (SSIM)

SSIM	Reachability Matrix	
(i, j)	(i, j)	(j, i)
V	1	0
A	0	1
X	1	1
O	0	0

Then, the initial reachability matrix was developed, as shown in Table 2. 1* entries were incorporated to fill the gap of transitivity, if any, collected during the development of the structural self-instructional matrix. With the inclusion of this transitivity concept, the final reachability matrix was obtained, as shown in Table 3 below.

Table 4 Initial Reachability Matrix

Barriers (i/j)	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11
B1	1	0	0	1	0	1	1	1	1	1	1
B2	1	1	0	0	1	1	1	1	1	0	1
B3	1	1	1	0	1	1	0	1	1	1	1
B4	0	0	0	1	0	0	1	0	1	1	1
B5	0	0	0	1	1	1	0	0	0	1	1
B6	0	0	0	0	1	1	1	0	0	1	1
B7	1	0	0	1	0	0	1	0	0	1	1
B8	1	0	0	1	0	0	1	1	1	1	1
B9	0	0	0	0	1	0	1	0	1	1	1
B10	0	0	0	0	0	0	0	0	0	1	1
B11	0	0	0	0	0	0	0	0	0	1	1

Note: B (i/j) – barriers in line i or column j

Table 4 Final Reachability Matrix

Barriers (i/j)	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11
B1	1	0	0	1	1*	1	1	1	1	1	1
B2	1	1	0	1*	1	1	1	1	1	1*	1
B3	1	1	1	1*	1	1	1*	1	1	1	1
B4	1*	0	0	1	1*	1*	1	1*	1	1	1
B5	1*	0	0	1	1	1	1*	1*	1*	1	1
B6	1*	0	0	1*	1	1	1	1*	1*	1	1
B7	1	0	0	1	1*	1*	1	1*	1*	1	1
B8	1	0	0	1	1*	1*	1	1	1	1	1
B9	1*	0	0	1*	1	1*	1	1*	1	1	1
B10	0	0	0	0	0	0	0	0	0	1	1
B11	0	0	0	0	0	0	0	0	0	1	1

Step 4: Once the final reachability matrix was obtained, reachability sets and antecedent sets were derived from this matrix for each element. The reachability set includes the element itself and another element it may impact, whereas the antecedent sets include the element itself and another element that may impact it. Then, the intersection of these sets was derived for all the elements, and the levels of different elements were assigned [22]. At the top level, those elements having the same reachability and intersection set may occupy the ISM process. These top-level factors did not lead to any other factors above their level. Once top-level elements were identified, then they were removed from the calculation. This process was repeated to find out the next level elements and continue for the further levels. Thus, finally, these levels help build the Diagraph and ISM models.

Table 4 Reduced Conical Matrix

Barriers	10	11	1	4	5	6	7	8	9	2	3	Driving Power	Level
B10	1	1	0	0	0	0	0	0	0	0	0	2	I
B11	1	1	0	0	0	0	0	0	0	0	0	2	I
B1	1	1	1	1	1*	1	1	1	1	0	0	9	II
B4	1	1	1*	1	1*	1*	1	1*	1	0	0	9	II
B5	1	1	1*	1	1	1	1*	1*	1*	0	0	9	II
B6	1	1	1*	1*	1	1	1	1*	1*	0	0	9	II
B7	1	1	1	1	1*	1*	1	1*	1*	0	0	9	II
B8	1	1	1	1	1*	1*	1	1	1	0	0	9	II
B9	1	1	1*	1*	1	1*	1	1*	1	0	0	9	II
B2	0	0	1	1*	1	1	1	1	1	1	0	10	III

B3	0	0	0	0	0	0	0	0	0	1	1	11	IV
Dependence Power	11	11	9	9	9	9	9	9	9	2	1		
Level	I	I	II	II	II	II	II	II	II	III	IV		

Note: B (i/j) – barriers in line i or column j

Step 5: Using the conical form of the reachability matrix, a primary digraph, which consists of the transitive links, was obtained. Once the primary digraph was generated, then a final digraph was gen erated by removing the indirect links. In the digraph, the most critical factor was positioned at the top, then the second position and so on until the lowest level in the digraph.

Step 6: The ISM model was generated by converting the Digraph into a model by replacing the elements with the statement.

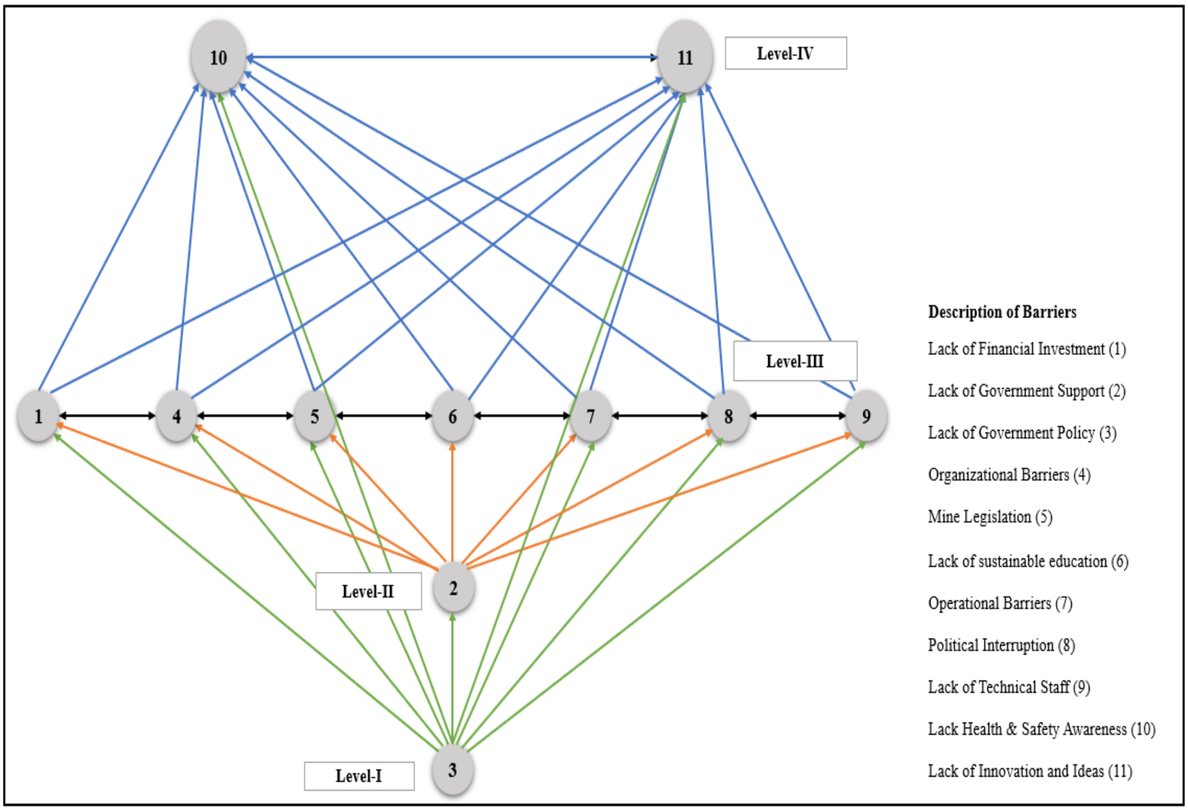

Figure 2 The ISM Model for barriers to sustainable practices in the mineral industry

Finally, in the last step, the experts analyzed and discussed the ISM model and agreed upon its consistency. Fig 2 highlights the four levels of barriers to implementing sustainable practices in Pakistan's mineral industry and their interrelationship.

3. Results & Discussion

The ISM methodology determined how sustainability barriers in mining industries relate. Expert consultants and literature research served as the initial method for identifying the barriers. The stockholders' input in understanding the barriers and, with the help of an extensive literature survey, enabled a complete understanding of various concerns [44] [45]. A self-interaction matrix structure (SSIM) provided visual context on how the barriers relate. A transition from SSIM to a reachability matrix occurred before constructing the hierarchical framework. The SSIM development process used expert opinions and literature research to build its foundation. Each relationship between different barriers is represented in the implemented matrix design. Expert opinions formed the basis for setting pairwise relationship dependencies which symbols V, A, X represented, and O The final model of ISM was distributed into four levels.

Level IV, the lowest level, includes a Lack of Health and safety awareness (B10) and lack of innovation and ideas (B11). These barriers are also considered the main barriers to adopting sustainable practices. Evidence suggests that most of the accidents in Pakistan occur due to unawareness of health and safety

[1]. Outdated practices and lack of innovation and ideas also hinder the implementation of sustainable practicesn the mineral industry of Pakistan [46]. Level III comprises lack of financial investment (B1), organizational barriers (B4), mine legislation (B5), lack of sustainable education (B6), operational barriers (B7), political interruption (B8), and lack of technical staff (B9). Barriers like financial investment and organizational barriers highly affect the implication of sustainability in the mineral sector [47]. Outdated mine legislation and its implementation are the major hindering factors in sustainability in the mineral sector [48]. The barriers, like political interruption in the mining industry, might not be neglected in developing countries. In most countries, the government issues a license for mining mineral commodities. Local contractors always influence the licensing process; thus, political involvement interrupts transparent distribution [49].
Furthermore, due to a lack of technical staff, mining operations are highly affected, leading to conventional mining techniques. Mineral-rich zones, technical staff is always lacking, and the mining companies hire technical staff from other regions, thus leading to conflict in the mineral region's Indigenous employment [50]. Thus, these barriers are interlinked, which means if one barrier is managed, the other may easily be managed. The experts corroborate these barriers and aggravate the impact of barriers on level IV, i.e. B10 and B11. Level II has only one barrier, Lack of government support (B2), and is considered the major influencer on level III and level IV barriers. As per the expert input, it is the prime job of the government to support the mineral commodity on the path of sustainable practices [51].

MICMAC Analysis

The dependence and driving power for each barrier in implementing sustainability in the mineral sector of Pakistan are presented in Table (). Every 1 or 1* in the entry (i, j) indicates that barrier "i" influences barrier "j" and vice versa. Therefore, barrier dependence is determined by adding each column, and barriers driving power is added by adding each row. Finally, a dependence-driving power diagram was created, and barriers were placed in four clusters, as shown in Figure (). The clusters are classified as autonomous, linkage, dependent, and independent. [52].

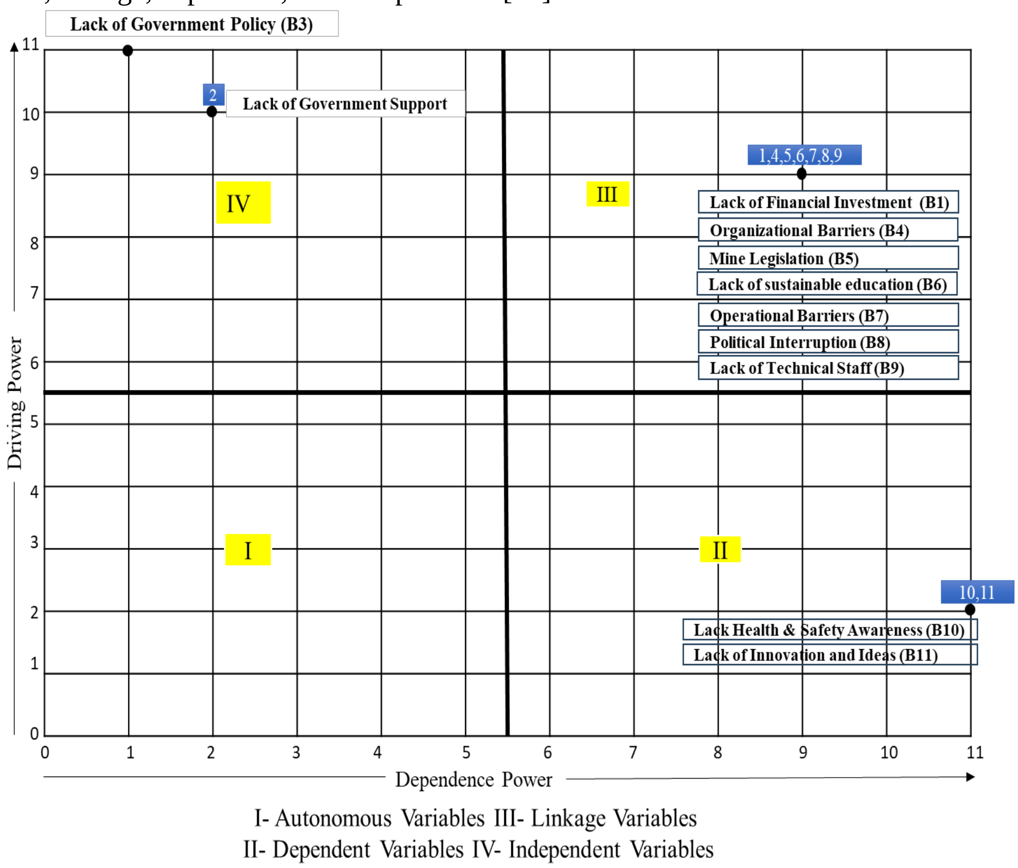

Figure 3 MICMAC analysis for barriers to sustainable practices in Pakistan

In Figure 3, the Autonomous cluster is empty, which indicates that all the barriers to sustainable development in the mineral sector are interrelated. Being an empty cluster is not new to the literature as in the previous studies. [53], [54]. Then, dependent clusters have the barriers "Lack of Health and safety awareness (B10) and Lack of innovation and ideas (B11). A strong dependence and weak driving power portray these barriers. Thus, these barriers strongly influence but do not significantly impact the other barriers to sustainability [13], [55]. The linkage cluster comprises the barriers "lack of financial investment (B1), organization barrier (B4), mine legislation (B5), lack of sustainable education (B6), operational barriers (B7), political interruption (B8) and lack of technical staff (B9). These barriers present a strong driving power and dependence; they arbitrate the interrelations between the barriers of independent and dependent clusters [5], [50], [56]. Finally, the independent cluster includes the barriers of "lack of Government Support (B2) and "lack of government policy (B1), which are characterized by weak dependence and strong driving power. Therefore, both barriers impact most of the other barriers to full implication sustainable practices in the mineral industry of Pakistan [14], [57]. Thus, per the MICMAC analysis, B1 and B2 are the root causes hindering sustainable mining operations.

4. Conclusion

This study aimed to propose the combined ISM-MICMAC methodology to identify the barriers to implementing sustainable practices within the mineral industry of Pakistan. A systematic literature survey helped identify the 11 leading barriers that hinder sustainable practices. Next, an ISM model was created based on those 11 barriers, which revealed the hierarchy structure with four levels of influence, and a MICMAC analysis was performed to classify those barriers into four clusters based on their driving and dependence power. The result suggests two root barriers: a lack of government support and a lack of government policy-provoking sustainable practices in Pakistan's mineral industry. Longitudinal studies must be conducted to assess the long-term effectiveness of sustainable policies and regulatory interventions. Furthermore, regional-specific barriers analysis for sustainable mining industries must be performed to understand better how challenges vary in different mining regions. Also, to address these challenges, effective strategies should be introduced to overcome these barriers. This research allows the researchers to map the strategy by the barriers.

References

[1] I. M. Jiskani et al., "Overcoming mine safety crisis in Pakistan: An appraisal," Process Safety Progress, vol. 38, no. 4, pp. 1–5, Dec. 2019, doi: 10.1002/prs.12041.

[2] Z. M. M SadiqMalkani, "Mineral Resources of Pakistan : Provinces and Basins wise Government of Pakistan PROVINCES AND BASINS WISE," Geological Survey of Pakistan, no. January 2017, 2018.

[3] A. Asghar, M. Umer, and A. Afzal, "Effective Implementation of Environmental Laws in Pakistan," Qlantic Journal of Social Sciences and Humanities, vol. 5, no. 1, pp. 9–14, 2024, doi: 10.55737/qjssh.739687440.

[4] A. Barve and K. Muduli, "Challenges to Environmental Management Practices in Indian Mining Industries," vol. 14, no. May, pp. 297–301, 2011.

[5] B. Hopwood, M. Mellor, and G. O'Brien, "Sustainable development: Mapping different approaches," Sustainable Development, vol. 13, no. 1, pp. 38–52, 2005, doi: 10.1002/sd.244.

[6] A. Bluszcz and A. Kijewska, "Challenges of sustainable development in the mining and metallurgy sector in Poland," Metalurgija, vol. 54, no. 2, pp. 441–444, 2015.

[7] T. Zvarivadza, "Artisanal and Small-Scale Mining as a challenge and possible contributor to Sustainable Development," Resources Policy, vol. 56, no. February, pp. 49–58, 2018, doi: 10.1016/j.resourpol.2018.01.009.

[8] K. Pactwa, J. Woźniak, and A. Strempski, "Sustainable mining – Challenge of Polish mines," Resources Policy, vol. 74, no. July 2018, 2021, doi: 10.1016/j.resourpol.2018.09.009.

[9] H. Hatayama, "The metals industry and the Sustainable Development Goals: The relationship explored based on SDG reporting," Resour Conserv Recycl, vol. 178, no. November 2021, p. 106081, 2022, doi: 10.1016/j.resconrec.2021.106081.

[10] O. Janikowska and J. Kulczycka, "Impact of minerals policy on sustainable development of mining sector – a comparative assessment of selected EU countries," Mineral Economics, vol. 34, no. 2, pp. 305–314, 2021, doi: 10.1007/s13563-021-00248-5.

[11] N. U. Khan, P. Zhongyi, A. Ullah, and M. Mumtaz, "A comprehensive evaluation of sustainable mineral resources governance in Pakistan: An analysis of challenges and reforms," Resources Policy, vol. 88, no. August 2023, p. 104383, 2024, doi: 10.1016/j.resourpol.2023.104383.

[12] D. Ali and A. Ur Rehman, "Adoption of autonomous mining system in Pakistan – Policy, skillset, awareness and preparedness of stakeholders," Resources Policy, vol. 68, Oct. 2020, doi: 10.1016/j.resourpol.2020.101796.

[13] I. M. Jiskani, Q. Cai, W. Zhou, and X. Lu, "Assessment of risks impeding sustainable mining in Pakistan using fuzzy synthetic evaluation," Resources Policy, vol. 69, 2020, doi: 10.1016/j.resourpol.2020.101820.

[14] I. M. Jiskani, S. A. A. Shah, C. Qingxiang, W. Zhou, and X. Lu, "A multi-criteria based SWOT analysis of sustainable planning for mining and mineral industry in Pakistan," Arabian Journal of Geosciences, vol. 13, no. 21, 2020, doi: 10.1007/s12517-020-06090-3.

[15] M. S. Malkani, M. I. Alyani, M. H. Khosa, F. Saeed, G. Khan, and J. Faiz, "Mineral Resources of Pakistan-an update Mineral Resources of Pakistan-an update," Lasbela University Journal of Science and Technology, vol. 5, no. January, pp. 90–114, 2016.

[16] S. H. Ali et al., "Mineral supply for sustainable development requires resource governance," Nature, vol. 543, no. 7645, pp. 367–372, 2017, doi: 10.1038/nature21359.

[17] S. Akhtar and H. Shah, STRATEGY FOR MINERAL SECTOR DEVELOPMENT IN PAKISTAN Member (Private Sector Development & Competitiveness) Planning Commission of Pakistan Ministry of Planning, Development & Reform Government of Pakistan. 2018.

[18] N. M. Shahani et al., "Statistical analysis of fatalities in underground coal mines in Pakistan," Energy Sources, Part A: Recovery, Utilization and Environmental Effects, vol. 47, no. 1, pp. 2189–2204, 2020, doi: 10.1080/15567036.2020.1841340.

[19] T. Raj, R. Shankar, and M. Suhaib, An ISM approach for modelling the enablers of flexible manufacturing system: The case for India, vol. 46, no. 24. 2008. doi: 10.1080/00207540701429926.

[20] R. Attri, N. Dev, and V. Sharma, "Interpretive structural modelling (ISM) approach: an overview," Research Journal of Management Sciences, vol. 2319, no. 2, p. 1171, 2013.

[21] M. S. Usmani, J. Wang, N. Ahmad, Z. Ullah, M. Iqbal, and M. Ismail, "Establishing a corporate social responsibility implementation model for promoting sustainability in the food sector: a hybrid approach of expert mining and ISM–MICMAC," Environmental Science and Pollution Research, vol. 29, no. 6, pp. 8851–8872, 2022, doi: 10.1007/s11356-021-16111-7.

[22] J. N. Warfield, "Developing Interconnection Matrices in Structural Modeling," IEEE Trans Syst Man Cybern, vol. SMC-4, no. 1, pp. 81–87, 1974, doi: 10.1109/TSMC.1974.5408524.

[23] N. Ahmad, "SmartISM : Implementation and Assessment of Interpretive Structural Modeling," 2021.

[24] Y. Berberoglu, S. K. Mangla, and Y. Kazancoglu, "Towards sustainable mining in an emerging economy: Assessment of sustainability challenges," Resources Policy, vol. 97, no. September, p. 105288, 2024, doi: 10.1016/j.resourpol.2024.105288.

[25] M. Chu, B. Li, W. Gu, and X. Dai, "Role of green finance in enhancing the sustainability in the mining sector in Asia," Resources Policy, vol. 88, no. October 2023, p. 104473, 2024, doi: 10.1016/j.resourpol.2023.104473.

[26] D. Giurco, G. Evans, C. Cooper, L. Mason, and D. Franks, "Mineral Futures Discussion Paper: Sustainability Issues, Challenges and Opportunities," pp. 1–71, 2009.

[27] A. Endl, "Addressing 'Wicked Problems' through governance for sustainable development-A Comparative analysis of national mineral policy approaches in the European Union," Sustainability (Switzerland), vol. 9, no. 10, 2017, doi: 10.3390/su9101830.

[28] W. Alves, P. Ferreira, and M. Araújo, "Challenges and pathways for Brazilian mining sustainability," Resources Policy, vol. 74, no. March, p. 101648, 2021, doi: 10.1016/j.resourpol.2020.101648.

[29] T. Nicholaus Chusi, M. B. Bouraima, M. Yazdani, S. Jovčić, and V. D. Hernández, "Addressing the Challenges Facing Developing Countries in the Mining Sector: Moving Towards Sustainability," Journal of Applied Research on Industrial Engineering, vol. 11, no. 3, pp. 333–349, 2024.

[30] B. Virakul, "Global challenges, sustainable development, and their implications for organizational performance," European Business Review, vol. 27, no. 4, pp. 430–446, 2015, doi: 10.1108/EBR-02-2014-0018.

[31] V. Osei, C. Bai, D. Asante-Darko, and M. Quayson, "Evaluating the barriers and drivers of adopting circular economy for improving sustainability in the mining industry," Resources Policy, vol. 86, no. PB, p. 104168, 2023, doi: 10.1016/j.resourpol.2023.104168.

[32] V. Husain, "Obstacles in the sustainable development of artisanal and small-scale mines in Pakistan and remedial measures," Geol Soc Spec Publ, vol. 250, pp. 135–140, 2005, doi: 10.1144/GSL.SP.2005.250.01.13.

[33] I. M. Jiskani, Q. Cai, W. Zhou, and X. Lu, "Assessment of risks impeding sustainable mining in Pakistan using fuzzy synthetic evaluation," Resources Policy, vol. 69, 2020, doi: 10.1016/j.resourpol.2020.101820.

[34] S. R. Chalgri, M. R. Bawani, A. A. Rajput, and M. Ali, "MINING POLICIES IN PAKISTAN AND DEVELOPING COUNTRIES : A REGULATORY PERSPECTIVE," vol. 2, no. 4, pp. 1735–1746, 2024.

[35] T. Zvarivadza, "Artisanal and Small-Scale Mining as a challenge and possible contributor to Sustainable Development," Resources Policy, vol. 56, no. January, pp. 49–58, 2018, doi: 10.1016/j.resourpol.2018.01.009.

[36] C. M. Gomes et al., "Management for sustainability in companies of the mining sector: An analysis of the main factors related with the business performance," J Clean Prod, vol. 84, no. 1, pp. 84–93, 2014, doi: 10.1016/j.jclepro.2013.08.030.

[37] Y. Yihdego, H. S. Salem, B. Ayongaba, and Z. Veljkovic, "Mining sector challenges in developing countries, Tigray, Ethiopia and inspirational success stories from Australia," Int J Min Miner Eng, vol. 9, no. 4, pp. 321–367, 2018, doi: 10.1504/IJMME.2018.097440.

[38] I. M. Jiskani et al., "Implications to secure mineral supply for clean energy technologies for developing countries: A fuzzy based risk analysis for mining projects," J Clean Prod, vol. 358, Jul. 2022, doi: 10.1016/j.jclepro.2022.132055.

[39] R. Maconachie and F. Conteh, "Artisanal mining policy reforms, informality and challenges to the Sustainable Development Goals in Sierra Leone," Environ Sci Policy, vol. 116, no. July 2020, pp. 38–46, 2021, doi: 10.1016/j.envsci.2020.10.011.

[40] B. S. Pimentel, E. S. Gonzalez, and G. N. O. Barbosa, "Decision-support models for sustainable mining networks: Fundamentals and challenges," J Clean Prod, vol. 112, pp. 2145–2157, 2016, doi: 10.1016/j.jclepro.2015.09.023.

[41] I. M. Jiskani et al., "Distinctive Model of Mine Safety for Sustainable Mining in Pakistan", doi: 10.1007/s42461-020-00207-8/Published.

[42] J. A. Aznar-Sánchez, J. F. Velasco-Muñoz, L. J. Belmonte-Ureña, and F. Manzano-Agugliaro, "Innovation and technology for sustainable mining activity: A worldwide research assessment," J Clean Prod, vol. 221, pp. 38–54, Jun. 2019, doi: 10.1016/j.jclepro.2019.02.243.

[43] C. Chatterjee, R. Sindhwani, S. K. Mangla, and N. Hasteer, "Digitization of the mining industry: Pathways to sustainability through enabling technologies," Resources Policy, vol. 100, no. February 2024, p. 105450, 2025, doi: 10.1016/j.resourpol.2024.105450.

[44] K. K. Ganguly and D. Das, "Analysing the barriers in Indian stone crushing industries: An ISM and fuzzy AHP approach," International Journal of Applied Management Science, vol. 12, no. 3, pp. 242–264, 2020, doi: 10.1504/IJAMS.2020.108072.

[45] M. S. Memon, S. I. Mari, and W. A. Shaikh, "Interpretive Structural Modeling Based Approach for Sustainable Supplier Evaluation and Selection in Textile Supply Chains," International Journal of Science and Engineering Investigations, vol. 7, no. January, 2018, [Online]. Available: www.IJSEI.com

[46] J. A. Aznar-Sánchez, J. F. Velasco-Muñoz, L. J. Belmonte-Ureña, and F. Manzano-Agugliaro, "Innovation and technology for sustainable mining activity: A worldwide research assessment," J Clean Prod, vol. 221, pp. 38–54, Jun. 2019, doi: 10.1016/j.jclepro.2019.02.243.

[47] A. Ediriweera and A. Wiewiora, "Barriers and enablers of technology adoption in the mining industry," Resources Policy, vol. 73, no. June, p. 102188, 2021, doi: 10.1016/j.resourpol.2021.102188.

[48] N. B. R. Monteiro, A. K. L. Bezerra, J. M. Moita Neto, and E. A. Da Silva, "Mining law: In search of sustainable mining," Sustainability (Switzerland), vol. 13, no. 2, pp. 1–16, 2021, doi: 10.3390/su13020867.

[49] J. R. Owen and D. Kemp, "Social licence and mining: A critical perspective," Resources Policy, vol. 38, no. 1, pp. 29–35, 2013, doi: 10.1016/j.resourpol.2012.06.016.

[50] D. Laurence, "Establishing a sustainable mining operation: An overview," J Clean Prod, vol. 19, no. 2–3, pp. 278–284, 2011, doi: 10.1016/j.jclepro.2010.08.019.

[51] G. Hilson, "Sustainable development policies in Canada's mining sector: An overview of government and industry efforts," Environ Sci Policy, vol. 3, no. 4, pp. 201–211, 2000, doi: 10.1016/S1462-9011(00)00086-1.

[52] R. Attri, N. Dev, and V. Sharma, "Interpretive structural modelling (ISM) approach: an overview," Research Journal of Management Sciences, vol. 2319, no. 2, p. 1171, 2013.

[53] X. Gan, R. Chang, J. Zuo, T. Wen, and G. Zillante, "Barriers to the transition towards off-site construction in China: An Interpretive structural modeling approach," J Clean Prod, vol. 197, pp. 8–18, 2018, doi: 10.1016/j.jclepro.2018.06.184.

[54] P. P. Senna, L. M. D. F. Ferreira, A. C. Barros, J. Bonnín Roca, and V. Magalhães, "Prioritizing barriers for the adoption of Industry 4.0 technologies," Comput Ind Eng, vol. 171, no. August 2021, 2022, doi: 10.1016/j.cie.2022.108428.

[55] J. Chen, I. M. Jiskani, C. Jinliang, and H. Yan, "Evaluation and future framework of green mine construction in China based on the DPSIR model," Sustainable Environment Research, vol. 30, no. 1, 2020, doi: 10.1186/s42834-020-00054-8.

[56] A. Bebbington and D. Humphreys Bebbington, "Mining, movements and sustainable development: Concepts for a framework," Sustainable Development, vol. 26, no. 5, pp. 441–449, 2018, doi: 10.1002/sd.1888.

[57] I. M. Jiskani, Q. Cai, W. Zhou, and X. Lu, "Assessment of risks impeding sustainable mining in Pakistan using fuzzy synthetic evaluation," Resources Policy, vol. 69, no. July, p. 101820, 2020, doi: 10.1016/j.resourpol.2020.101820.