Managing Operations for Circular Economy in the Mining Sector: An Analysis of Barriers Intensity

Abstract

The rapid development of industrialization has created significant opportunities for economic growth and development, but its operational activities have impulsively degraded the environment. Circular Economy (CE) practices may help industries, and particularly extracting industries such as mining, to optimize the use of its resources and minimize waste. This would further help to overcome the threats which the traditional linear model poses to the economic growth and development of any healthy economy. This paper aims to identify the barriers to executing the CE model within the context of the Indian mining industry. The five major categories of barriers (i.e. financial, market, government policies and regulations, organizational and operational) and their respective sub-barriers which are responsible for hindering the implementation of CE in the mining sector are identified through an extensive literature review and experts' opinion. To determine the priority of the barriers and their intensity index, a hybrid technique comprising of the analytical hierarchy process (AHP) and graph-theoretic approach (GTA), is employed. The AHP analysis indicated that *'government policies and regulations'* was the main barrier to the implementation of CE in the Indian mining sector (43.8%), followed by '*market barriers'* with a weighting score of 24.6%. However, based on GTMA, the highest intensity was observed for *'operational'*, category of barriers followed by the *'organizational'* category of barriers. The outcomes of the study would help managers from the mining industry not only to overcome the identified barriers for managing operations for CE but also to optimize and effectively meliorate the consumption and extraction of resources.

Keywords: Circular Economy; Sustainability; Mining Industry; Analytical Hierarchy Process; Graph-Theoretic Approach; Resources Melioration.

1. Introduction

In the present era of the circular economy, the entire world is showing its consciousness about climate changes and proper utilization of the resources. Main reasons behind it are an environmental threat and lack of resources (Soleimani, 2018; Panda et al., 2020; Mangla et al., 2020a). The circular economy (CE) is in stark contrast with the intensive linear economic activity that has been using up the environmental resources (Rosa et al., 2019). In CE, organizations are searching for more environmentally-friendly business models (Mangla et al., 2020b). After the industrial revolution, corporate houses and consumers adopted the linear model and have largely stuck with it for a longer time. , In this process, the industry begins with the extraction of the value that a commodity can offer and after its use, discarding the whole commodity itself (Schroeder et al., 2019; Panda et al., 2020). The CE is intertwined with various other concepts, some of which existed before the emergence of this model such as industrial symbiosis (Chertow and Ehrenfeld, 2012; Schroeder et al., 2019). Another point is eco-city, a concept which is closely related to CE. The main objective of this closed-loop model of the economy is to build on the material flow and striking a balance between economic progress and preservation of the environment and resource use (Schroeder et al., 2019). These days, CE practices are adopted widely by businesses in Europe and China. It promotes certain aspects including flow designs and material assessment, among others (Peck et al., 2015; Xavier et al., 2019).

A shift to the CE model requires technological advancements and eco-innovations to disrupt the current use and throw production cycle and minimize waste etc. (Bouzon et al., 2015; Xavier et al., 2019). Eco-innovation being at the heart of the CE concept, there is a need to define eco-innovation. CE would require the society to have an altogether different approach to changes the volatile nature of resources and an ever-increasing demand with lack of supply of natural resources (Peck et al., 2015; Schroeder et al., 2019).

This study is related to the mining industry which is one of the most crucial industries across the globe on which significant variables of sustainable growth depends. The mining industry is presently valued at an astonishing $326 million and is expected to grow to be worth $401 million by the year 2024 (Reportlinker, 2019). The mining industry in India is a major contributor to the GDP with its standalone of around 2.3% and gives around 11% to the local industrial sector. In the past 5 years, the industry has grown with an impressive CAGR of 6% and has a GVA of around $ 28 billion. As important and engaging the industry gets, it also now becomes one of the major contributors in the waste generating avenues on the planet. For instance, the mining industry on an average generates around 1.8 billion tons of waste every year in the United States of American alone (Trash in America, 2018). Serval transformations i.e. adoption of CE practices, digitization of functions, technological innovations etc. are happening in the Indian mining industry. The government of India is implementing some effective plans to make the mining sector sustainable and encouraging the mining companies such as CIL, Hindustan Zinc, Vedanta etc. to adopt sustainability initiatives (Sustainable Mining, 2019). For instance, the Govt of India developed a legal and regulatory framework to promote environmentally sustainable mining, so that the industry makes minimum waste and negative environmental impact. The adoption of CE practices in the mining industry can be a major help as its principle of utilising the resources optimally can enhance the extraction of resources at the mining place. To manage operations for CE, the Indian mining industry is facing several barriers. In the literature, there are many studies available to understand the barriers to adoption of circular business models (Rizos et al., 2016; Masi et al., 2018; Frederiksen, 2018; Vermunt et al., 2019). But in the context of mining industry perspectives, limited literature is available. In the context of the Indian mining industry, limited research has been done for analysis of the different category of barriers. Therefore, to fulfil this literature gap, we are trying to answer the following research questions in this study:

RQ1: What are the major barriers that Indian mining industry is facing in the adoption of Circular Economy (CE) practices for managing operations?

RQ2: How should managers prioritize these barriers while formulating strategies for sustainable operations in CE?

To give the answers of the above - mentioned questions, the following objectives of the study are set:

1) To recognize the barriers in managing operations for Circular Economy (CE) in the context of the Indian mining industry
2) To know the priority weight and intensity of each barrier so that the industry managers can make a proper plan to overcome them.

The study is organized into five sections. The introduction is given in the first section and literature review in section two. The research methodology is illustrated in section three. Section 4 deals with results and discussion with managerial implications of the study. Conclusion of the study presents in section 5.

2. Literature review

In literature, there are many studies available related to the identification of barriers for adoption of circular economy practices and systematic approach provides insight for the future course of action (Tranfield et al., 2003; Yadav and Desai, 2016; Yadav et al., 2018b). For instance, Rizos et al. (2016) discussed how the CE business model can be implemented in SMEs. Govindan and Hasanagic (2018) in their literature review paper discussed how CE has received considerable attention worldwide and they also investigated different drivers, barriers and practices in the context of government, customers and business perspectives. In the same year, Masi et al. (2018)

discussed how we can explore more about CE through creating awareness and their study was based on a case study of a focal firm. Mangla et al. (2018) investigated the barriers to effective circular SCM in the context of a developing country. Especially in developing countries, organizations have no estimative about the challenges in adapting their processes to ensure CE. Most organizations are not able to implement CE practices due to financial and economic, organizational, market and operational barriers. Zvarivadza (2018) discussed how sustainability can be achieved in the mining industry. They mentioned that no doubt environmental stewardship is a keystone to sustainability in the mining industry but to achieve it, cooperation among the industry, communities and government is essential.

Ma et al. (2019) examined how government regulation impacts the mining industry and support them to reduce CO2 emissions in their operations by adopting CE practices. Kumar et al. (2020) analyzed the critical success factors for implementing industry 4.0 integrated circular supply chain. They observed that industry 4.0 and circular economy practises are impacting businesses significantly. Gruenhagen and Parker (2020) conducted systematic literature in the mining industry and mentioned that innovation is key to explore for the industry. Alves et al. (2020) examined the challenges and pathways for the Brazilian mining sector to achieve sustainability in their operations. As per their study, the negative environment is a major challenge to achieve sustainability and community engagement is a key factor to achieve a truly sustainable mining sector.

After doing the extensive literature review and experts' discussion, the major barriers and their respective sub-barriers are finalised. A brief description of each category of barriers and its sub-barriers are provided in the following sections and their support references are shown in Table 1.

2.1 Financial Barriers

The cost of implementing the concept of CE has been one of the most prominent barriers which are faced by many organizations (Lawrence et al., 2006; Vasilenko and Arbačiauskas, 2012; Govindan and Hasanagic, 2018). The reason behind is that most of the organizations give higher priority to different dealings which are the primary source of revenue generations (Hollins, 2011; Rademaekers et al., 2011). Hence, they are not able to invest a lot in the implementation of the concept. Apart from these direct financial costs, there are some other kinds of investments which are reserved for different activities such as human resources etc. Access to finance seems quintessential for the organizations that aspire to work on the aspect of sustainability, wish to bring in innovative projects at a larger scale and revolutionizing their whole system by bringing in reforms such as CE. As far as bank financing is concerned, organizations face serious impediments in obtaining guarantees and also banks consider organizations a shaky business and tend to not invest in them (Hyz, 2011; Müller and Tunçer, 2013). Under this barrier there are many barriers which are described below section:

2.1.1 Lack of initial capital: Investment will be required for making a transition from the linear model to the CE model (Müller and Tunçer, 2013). While banks interest in CE is increasing, the actual investment remains quite limited. Many banks and financial institutions have problems for risk evaluation while supporting the adoption of CE practices (Bhandari et al., 2019). Many factors impact risk assessment such as government policies, uncertainty, environmental changes, which influence directly market dynamics (Mangla et al., 2018; Bhandari et al., 2019).

2.1.2 Lack of funds for R&D: The direct consequence of the lack of funds is the compromise on the research and development aspect of CE business model (Bhandari et al., 2019) and also for CE. The model which is itself an epitome of innovation requires massive funding to establish a setup that is sustainable for the businesses. Till now no concrete mechanism has been established for the society which can be taken note of universally and employed in all parts of the world and that itself invites the need of spending more and more on research and development amidst lack of capital (Mangla et al., 2018). The benefits from CE will be realized in the long term and banks are consciously positioned, but conservatively regarding the implementation of CE (Müller and Tunçer, 2013).

2.1.3 Lack of funds for training: To understand the CE model properly, training is the most important factor but to give training to the employees it requires huge money. Funds are the main barrier for the organization to conduct proper training for their employee (Mangla et al., 2018). Because of it, all the organizations are not able to implement CE model properly.

2.1.4 Lack of funds for CE operations: To implement CE in the operations, the business requires huge money because they have to change their liner model to circular model. Therefore, lack of funds is a barrier for the businesses to adopt CE model in their operations properly (Govindan and Hasanagic, 2018).

2.2 Market Barriers

It has been proven that market barriers are hampering the transition of the industry towards CE (Preston, 2012a; Kumar et al., 2019). There were several arguments made by different people about the current market situation in the context of CE (Mont et al., 2017). Though the concept of CE is proven to be beneficial for the industry, the demand in the market for this concept is very less. There could be many reasons for this such as the short-term perspective of industries, financial demands of the concept are quite high, insufficient awareness among people etc. Studies have mainly been able to chalk out four impediments which lie under the category of market barriers, which have created many difficulties in enacting this model, namely low virgin material prices, lack of awareness for sustainable products, lack of products standardization market, and high cost of marketing for CE operations:

2.2.1 Low virgin material prices: The root cause of the occurrence of the market barrier is low virgin material prices as compared to the recycled (Pheifer, 2017). The reason behind the high cost of refurbished products is that they need a lot of processing before being able to be made in a usable form. Hence, people prioritize virgin material over refurbished material.

2.2.2 Lack of awareness for sustainable products: The products which are refurbished are generally more sustainable than the products which are made up of cheap material but named as virgin material (Govindan and Hasanagic, 2018) but in the market, there is a lack of awareness for sustainable products.

2.2.3 Lack of products standardization market: It refers to the lack of *products standardization market which is related to products uniformity* (Kumar et al., 2019).

2.2.4 High cost of marketing for CE operations: CE operations require high cost of marketing therefore, it is very difficult to implement CE practices in operations (Kumar et al., 2019).

2.3 Government Policies and Regulatory Barriers

The government support and encouragement in providing funding opportunities and training have been widely recognized (Studer et al., 2006; Pedersen et al., 2014; Ma et al., 2019). Another prime issue is the lack of strict legislative framework, it is believed that the lack of legislation heavily impacts the organization's will to amalgamate green solution into their operations (Seidel et al., 2008b; Pedersen et al., 2014). A study which was prepared for the European Commission pointed out that there is a lack of clarity on various areas of European Union legislation such as re-use and recovery (Mudgal et al., 2010). The concept of waste hierarchy also needs to be more precise in its nature as due to its implicit nature, the member states have the freedom to divert from the hierarchy. After the analysis of the government policy as a barrier to the CE, studies have been able to draw out four points that seem sufficient to elucidate this classification of the barriers. The points are:

2.3.1 Lack of infrastructure: There is lack of support by the governments especially in developing countries (Geng and Doberstein, 2008; Xue et al., 2010; Kumar et al., 2019) when it comes to promotion of environment-friendly economic measures and when this problem is coupled with the lack of initial capital there seems a very less possibility that organizations or firms would be inclined to bring in reforms to their existing system. As far as the promotion of CE, the government should be generous in giving industrial sops to the firms who try and implement environment-friendly policies (Gaustad et al., 2018).

2.3.2 Lack of stringent regulation: This problem largely depends on the political will, policy of the political party, which is at the helm and its agenda. CE is not even in the agenda of many governments in the world and countries that have reached the stage of making legislation there is lack of clarity on various issues as pointed out (Gaustad et al. (2018).

2.3.3 Lack of compliance mechanism: There is a very limited set of countries that have given the CE model a form of legislation. Even those limited set of countries have not been able to make the firms or organizations accountable for not implementing the CE model. The reason behind this failure is that no mechanism can ensure compliance of the set rules, even if there exists a mechanism it has severely failed to make it necessary for an organization to follow the directives by the legislature of the country (Xue et al., 2010). The responsibility of this problem can be laid on the government and legislature to not provide a mechanism that can ensure the strict compliance of the orders and offenders must face consequences.

2.3.4 Lack of promotion: There are insufficient promotion and marketing of measures and in many cases, the potential benefits derived from the participation in the programmes, while adopting environmental technologies (Hoevenagel et al., 2007). In many cases, it is not communicated what benefits entrepreneurs will enjoy when participating in the scheme (Hoevenagel et al., 2007).

2.4 Organizational Barriers

This barrier is related to the barriers which are related to organizational perspectives. For implementing CE operations, there are many challenges which many organizations are facing (Vermunt et al., 2019). The organizations have to adopt a new model of closed-loop; therefore, many changes are required. The identified barriers from literature are mentioned below.

2.4.1 Lack of expertise & decision making at the top management level: This barrier is related to the lack of expertise and decision making at the top management level. For implementing CE practices, along with expertise a strong sense of accountability, confidence, integrity, and comfort with risk are required from the top management side (Agyemang et al., 2019; Kumar et al., 2019; Gruenhagen and Parker, 2020).

2.4.2 Lack of culture for CE: The culture of an organization is very important to implement CE practices. If organization culture is not supportive and flexible, then it is very difficult to adopt CE practices successfully (Gruenhagen and Parker (2020).

2.4.3 Lack of use of CE measures: There is no proper CE measurement tool, therefore it is very difficult to implement and measure the intensity of CE practices (Chand et al., 2018).

2.4.4 Lack for support from top-management level: Before any plans about reskilling of the labour are implemented, there is a need for the top-level management and higher officials to get an in-depth understanding of the subject at hand (WEF, 2016). Top managers need to have a deeper understanding of the activities that are undertaken for supporting the circular economic model and the people in higher position need to understand the ways through which they may enable the work of the labour force in the industry.

2.4.5 Lack of skilled workforce: CE Major shifts in the economic model of any state does require substantial efforts in the direction of acquainting the labour force of both the private and public sector with a new set of skills considered necessary for the able implementation of the proposed economic model (Gruenhagen and Parker, 2020). Therefore, lack of skilled workforce to implement CE is of the organizational barrier (Ghebrihiwet, 2019).

2.5. Operational Barriers

Zhu and Sarkis (2006) and Lai et al. (2011) founded that Green SCM emerged as a corporate strategy for companies to be successful in implementing the concept of CE in an eco-friendly manner. Dawei et al. (2015) founded that the aim of the GSCM is cost reduction and consumption of resources, decreasing the environmental pollution which occurs through green production, building a strong brand image in the industry. This business strategy could be proposed in CE to raise economic benefits and increase the efficiency of resource consumption. Now, coming to the fact why there is a lack of green operations in the implementation of CE. Many businesses are not even aware of CE concept and implementation of CE practices requires a lot of time to give positive results, due to which many companies show very less interest by taking it up.

2.5.1 Lack of green manufacturing process: This barrier is related to the lack of green manufacturing process; therefore, it is a major barrier in CE operations (Rusinko, 2007).

2.5.2 Lack of green procurement: This barrier is related lack of green procurement, but there is a shortage of these products in the market, therefore, green procurement is a major barrier in CE operations (Wong et al., 2016; Vijayvargy et al., 2017).

2.5.3 Lack of green logistics: This barrier is related to lack of awareness and green practices followed by logistics organizations engaged in mining operations.

2.5.4 Lack of sustainable product design: There are many problems in designing a sustainable product. It may be due to lack of R&D for designing sustainable products and processes. Thus, the lack of sustainable product design is also a barrier for implementation of CE in mining operations.

2.5.5 Lack of use of advanced technology: This barrier is due to lack of application of advanced technologies in mining operations. It is very difficult and challenging to adopt all emerging technologies i.e. IoTs, Cloud computing, Artificial intelligence Blockchain etc. due to operational and financial constraints.

2.5.6 Lack of integration of functions: For implementing CE operations, a strong integration of each function is very much required. Thus, the lack of integration of functions can be a major problem in CE concept implementation in the mining industry.

Table 1: List of barriers and support references

Barriers	References
1. Financial (B1)	
• Lack of initial capital (B11) • Lack of funds for training (B12) • Lack of funds for R&D (B13) • Lack of funds for CE operations (B14)	Rademaekers et al. (2011); Vasilenko and Arbačiauskas (2012); Trianni and Cagno (2012); Müller and Tunçer (2013); Gaustad et al. (2018); Gruenhagen and Parker (2020)
2. Market (B2)	
• Low virgin material prices (B21) • Lack of products standardization market (B22)	Ranta et al. (2018); Agyemang et al. (2019); Kumar et al. (2019)

• Awareness of sustainable products (B23) • The high cost of marketing for CE operations (B24)	
3. Government Policies and Regulatory (B3)	
• Lack of infrastructure (B31) • Lack of stringent regulation for CE operations (B32) • Lack of compliance mechanism (B33) • Lack of promotion (B34)	Hillary (2004); Studer et al. (2006); Seidel et al. (2008); Geng and Doberstein (2008); Xue et al. (2010); Pedersen et al. (2014); Gaustad et al. (2018); Ma et al. (2019)
4. Organizational (B4)	
• Lack of skilled workforce for CE (B41) • Lack of Support from top management for sustainability initiatives (B42) • Lack of expertise & decision making at the top management level (B43) • Lack of culture for CE (B44) • Lack of use of CE measures (B45)	Circle Economy and EHERO (2016); Circular Revolution (2018); Govindan and Hasanagic (2018); Vermunt et al. (2019); Ghebrihiwet (2019); Agyemang et al. (2019); Kumar et al. (2019); Gruenhagen and Parker (2020)
5. Operational (B5)	
• Lack of green manufacturing process (B51) • Lack of green procurement (B52) • Lack of green logistics (B53) • Lack of sustainable product design (B54) • Lack of use of advanced technology (B55) • Lack of integration of functions (B56)	Dawei et al. (2015); Ghisellini et al. (2016); Vijayvargy et al. (2017); Gruenhagen and Parker (2020)

3. Research methodology

A research methodology framework of this study is presented in Fig.1. The first technique deals with the prioritization of barriers and the second technique deals with calculations of intensity of barriers. Hence, this methodology is divided into two parts: the first section describes the calculation by using analytic hierarchy process (AHP) (Saaty, 1980a, b) and the second section describes the steps involved in graph-theoretic approach (GTA) (Zhang, 2015; Bhandari et al., 2019). This technique helps to take an excellent decision by decreasing the complexity of a problem or a barrier.

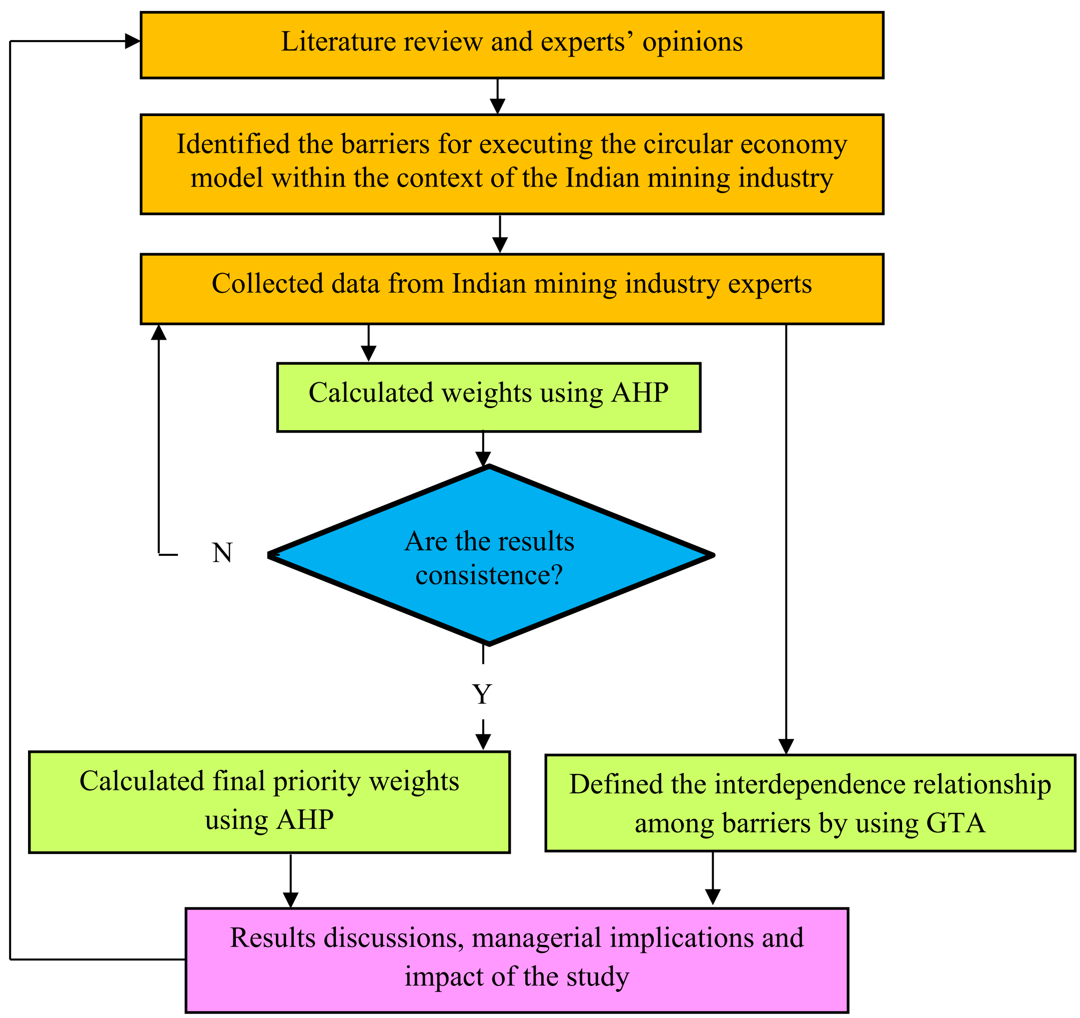

Fig. 1: Research methodology framework

4. Results and discussion

The objective of this study is to know the priority weight of each barrier and direction relationship among them. Therefore, a combined approach of AHP-GTA is used. AHP is developed by (Saaty, 1980a) to do the comparison within criteria and find their importance weights. This method helps to do the weight wise comparison of criteria and rank them accordingly (Jain et al., 2015; Yadav and Desai, 2017). But AHP is not able to do direction relationship among the criteria. Therefore, to understand the direct relationship between the criteria, the GTA method is used in this study. GTA is a well-established method in the literature to visualize the relationship among criteria through digraph representation (Reinschke and Reinschke, 1988; Franceschini et al., 2006; Bhandari et al., 2019; Luthra et al., 2019). With the help of this method, a digraph reflecting relationships among criteria can be created. A combination of AHP integrated with relationship approach *i.e.* DEMATEL has been applied by many researchers (Wu and Tsai, 2012; Gandhi et al., 2016; Kumar et al., 2018); Bhandari et al., 2019). In literature, many researchers have advocated hybrid approach for analyzing complex problem involving many criteria (Yadav et al., 2018). Therefore, in this study, a combined approach of AHP-GTA is employed. In this study, we have considered seven experts for deciding relative weights to different criteria for detailed analysis. Out of seven, five are from the mining industry and two are from academia. Experts from industry are currently working at the level of plant managers in different mines located in Orissa and Chhattisgarh states of India. These industry experts are having more than fifteen years of experience. Experts from academia are working at the position of professor in reputed B schools located in NCR Delhi, India region. Experts from academia are having more than twenty years of teaching and research experience. We had various meetings with experts to decide with consensus. In case of any difference of opinion, the majority decision was accepted. Results are analysed in two parts. In the first part, results are analysed based on AHP analysis and in the second part, results are analysed based on GTA.

4.1 Analysis based on AHP

A step-by-step standard approach of AHP (Saaty, 1980a) is applied in this section for prioritization of sub barriers in each category.

In the first step, was organized a hierarchy model for prioritization of factors. After this, a pairwise comparison of different category of barriers was done. The same procedure was done for sub barriers of the particular barrier category. Data was collected based on a nine-point scale (Saaty, 1980a). If the rating is assigned 1, then it signifies equal importance of both factors and if 9 then it indicates absolute importance over the other factor. This is a relative scaling *i.e.* the factors are ranked or rated relatively or based on relative importance.

Then, the local and global weights of the barriers and the sub barriers were calculated. The calculation of this would be done with the help of the rating provided in the AHP framework. For the calculation of the global weights, the local weights of the sub barriers to the local weight of the primary barrier were multiplied. Due to this, pairwise comparison matrices of all categories of barriers i.e. financial and economic barrier (B1), market barrier (B2), government, policies, and regulatory barriers (B3), organizational barriers (B4) and operational barriers (B5) and their sub barriers were calculated. Table 2-Table 5 shows the pairwise comparison of the main categories of barriers and their respective sub-barriers.

Table 2: Pairwise judgement matrix of main barriers

	B1	B2	B3	B4	B5	PV
B1	1	1/4	1/5	½	1/3	0.070
B2	4	1	½	3	2	0.246
B3	5	2	1	4	3	0.438
B4	2	1/3	¼	1	1/2	0.098
B5	3	1/2	1/3	2	1	1.48

TOTAL	15	4.08	2.28	10.5	6.83	CR = 0.02

Table 3: Pairwise judgment matrix of sub-barriers of finance

	B11	B12	B13	B14	PV
B11	1	1/4	1/2	1/3	0.103
B12	4	1	3	2	0.480
B13	2	1/3	1	1/2	0.155
B14	3	1/2	2	1	0.262
TOTAL	10	2.08	6.5	3.83	CR = 0.02

Table 3: Pairwise judgement matrix of sub-barriers of Government Policies and Regulatory

	B21	B22	B23	B24	PV
B21	1	1/4	1/3	½	0.103
B22	4	1	2	3	0.480
B23	3	1/2	1	2	0.262
B24	2	1/3	1/2	1	0.155
TOTAL	10	2.08	3.83	6.5	CR = 0.02

Table 3: Pairwise judgement matrix of sub-barriers of Government Policies and Regulatory

	B31	B32	B33	B34	PV
B31	1	1/3	2	1/2	0.156
B32	3	1	3	2	0.462
B33	½	1/3	1	1/3	0.119
B34	2	1/2	3	1	0.263
TOTAL	6.5	2.16	9	3.83	CR = 0.04

Table 4: Pairwise judgement matrix of sub-barriers of organizational

	B41	B42	B43	B44	B45	PV
B41	1	4	3	½	2	0.247
B42	1/4	1	1/2	1/5	1/3	0.069
B43	1/3	2	1	1/3	1/2	0.112
B44	2	5	3	1	3	0.424
B45	1/2	3	2	1/3	1	0.149
TOTAL	4.08	15	9.5	2.36	6.83	CR = 0.03

Table 5: Pairwise judgement matrix of sub-barriers of operational

	B51	B52	B53	B54	B55	B56	PV
B51	1	½	1/3	4	3	2	0.144
B52	2	1	1/2	5	4	3	0.234
B53	3	2	1	6	5	4	0.408
B54	1/4	1/5	1/6	1	1/2	1/2	0.051
B55	1/3	¼	1/5	2	1	1/2	0.067
B56	1/2	1/3	1/4	3	2	1	0.095
TOTAL	7.08	4.28	2.44	21	15.5	11	CR = 0.03

Now, after building a framework for AHP, a check consistency ratio (CR) of the matrix of all matrix were checked. The CR value of a matrix should be less than 0.1 for the framework to be consistent (Saaty, 1980a, b).

Table 6: Global weights of barriers and their respective sub-barriers

Barriers	Local weights and Ranks	Global weights
B1	**0.070 (5)**	
• B11	0.103 (4)	0.007
• B12	0.480 (1)	0.033
• B13	0.155 (3)	0.011
• B14	0.262 (2)	0.018
B2	**0.246 (2)**	
• B21	0.103 (4)	0.025
• B22	0.480 (1)	0.118
• B23	0.262 (2)	0.064
• B24	0.155 (3)	0.038
B3	**0.438 (1)**	
• B31	0.156 (3)	0.068
• B32	0.462 (1)	0.202
	0.119 (4)	0.052

• B33		0.263 (2)	0.115
• B34			
B4	**0.098 (4)**		
• B41		0.247 (2)	0.024
• B42		0.069 (5)	0.007
• B43		0.112 (4)	0.011
• B44		0.424 (1)	0.042
• B45		0.149 (3)	0.015
B5	**0.148 (3)**		
• B51		0.144 (3)	0.021
• B52		0.234 (2)	0.035
• B53		0.408 (1)	0.060
• B54		0.051 (6)	0.008
• B55		0.067 (5)	0.010
• B56		0.095 (4)	0.014

Table 6 shows the global weights of different barriers. Inferring from the table, government policies and regulatory barriers (0.438) is the most severe barrier among barrier i.e. it affects the implementation of the concept of CE in the most severe manner. It is followed by the market barrier (0.246) and operational barrier (0.148). In sub barriers, lack of stringent regulation, lack of promotion for CE & incentives and lack of products standardization market are the most pressing barriers.

4.2 Analysis based on GTA

Here we are trying to quantify the intensity of each category of barriers considered in this study through GTA approach. GTA is a method, which helps to know the directional relationship and interdependence among factors. With the help of this method, a digraph among factors can create and relationship can develop. A brief description of the mathematical formulation of this method is given below.

Digraph Representation

Digraph shows the interdependency of each barrier to the other barrier. The representation for permanent function for four elements digraph can be represented (Jurkat and Ryser, 1966).

$$Per(A) = \prod_{i=1}^{4} A_i + \sum_i \sum_j \sum_k \sum_l a_{ij} a_{ji} A_k A_l + \sum_i \sum_j \sum_k \sum_l (a_{ij} a_{ji} a_{ki} + a_{ik} a_{kj} a_{ji}) A_l$$
$$+ \sum_i \sum_j \sum_k (\sum_l (a_{ij} a_{ji}).(a_{kl} a_{lk}) + \sum_i \sum_j \sum_k \sum_l (a_{ij} a_{jk} a_{kl} a_{li} + a_{ij} a_{lk} a_{kj} a_{ji}))$$

Here giving an illustration of a digraph, were construct a digraph as pictured in Fig.2 of the financial and economic barrier (A) where A_1, A_2, A_3, A_4 are its sub barriers. The interdependencies are represented by a_{12}, a_{23} etc.

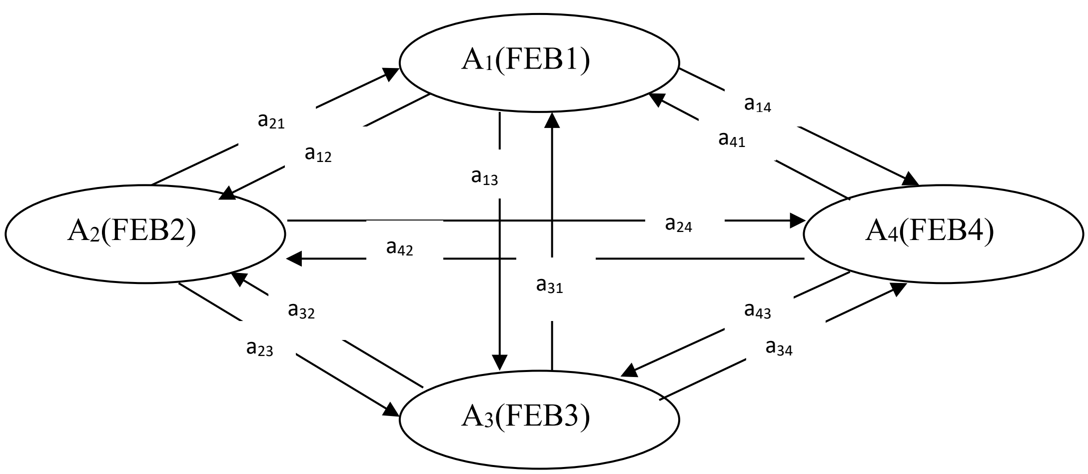

Fig 2. Digraph of different categories of barriers

Matrix Representation

Matrix representation of CE barriers gives one-to-one representation.

Representation of all matrices

$$Per(Z)=\begin{pmatrix} A & z_{12} & z_{13} & z_{14} & z_{15} \\ z_{21} & B & z_{23} & z_{24} & z_{25} \\ z_{31} & z_{32} & C & z_{34} & z_{35} \\ z_{41} & z_{42} & z_{43} & D & z_{45} \\ z_{51} & z_{52} & z_{53} & z_{54} & E \end{pmatrix}$$

$$Per(B1)=\begin{pmatrix} A_1 & a_{12} & a_{13} & a_{14} \\ a_{21} & A_2 & a_{23} & a_{24} \\ a_{31} & a_{32} & A_3 & a_{34} \\ a_{41} & a_{42} & a_{43} & A_4 \end{pmatrix}$$

$$Per(B2)=\begin{pmatrix} B_1 & b_{12} & b_{13} & b_{14} \\ b_{21} & B_2 & b_{23} & b_{24} \\ b_{31} & b_{32} & B_3 & b_{34} \\ b_{41} & b_{42} & b_{43} & B_4 \end{pmatrix}$$

$$Per(B3)=\begin{pmatrix} C_1 & c_{12} & c_{13} & c_{14} \\ c_{21} & C_2 & c_{23} & c_{24} \\ c_{31} & c_{32} & C_3 & c_{34} \\ c_{41} & c_{42} & c_{43} & C_4 \end{pmatrix}$$

$$Per(B4)=\begin{pmatrix} D_1 & d_{12} & d_{13} & d_{14} & d_{15} \\ d_{21} & D_2 & d_{23} & d_{24} & d_{25} \\ d_{31} & d_{32} & D_3 & d_{34} & d_{35} \\ d_{41} & d_{42} & d_{43} & D_4 & d_{45} \\ d_{51} & d_{52} & d_{53} & d_{54} & D_5 \end{pmatrix}$$

$$Per(B5) = \begin{pmatrix} E_1 & e_{12} & e_{13} & e_{14} & e_{15} & e_{16} \\ e_{21} & E_2 & e_{23} & e_{24} & e_{25} & e_{26} \\ e_{31} & e_{32} & E_3 & e_{34} & e_{35} & e_{36} \\ e_{41} & e_{42} & e_{43} & E_4 & e_{45} & e_{46} \\ e_{51} & e_{52} & e_{53} & e_{54} & E_5 & e_{56} \\ e_{61} & e_{62} & e_{63} & e_{64} & e_{65} & E_6 \end{pmatrix}$$

Where Z - circular economy, B1 - financial and economic barriers, B2 - market barriers, B3 -government, policies and regulatory barriers, B4 - organizational barriers, B5 - operational barriers. Now for further calculations, the financial and economic barriers matrix can be calculated as follows:

$$Per(A) = \begin{pmatrix} A_1 & a_{12} & a_{13} & a_{14} \\ a_{21} & A_2 & a_{23} & a_{24} \\ a_{31} & a_{32} & A_3 & a_{34} \\ a_{41} & a_{42} & a_{43} & A_4 \end{pmatrix}$$

The matrix can be expanded as

$A_1A_2A_3A_4+(a_{12}a_{21}A_3A_4+a_{13}a_{31}A_2A_4+a_{14}a_{41}A_2A_3+a_{23}a_{32}A_1A_4+a_{24}a_{42}A_1A_3+a_{34}a_{43}A_1A_2)+(a_{23}a_{34}a_{42}A_1+a_{24}a_{43}a_{32}A_1+a_{13}a_{34}a_{41}A_2+a_{14}a_{43}a_{31}A_2+a_{12}a_{24}a_{41}A_3+a_{14}a_{42}a_{21}A_3+a_{12}a_{23}a_{31}A_4+a_{13}a_{32}a_{21}A_4)+(a_{12}a_{21}(a_{34}a_{43}+a_{13}a_{31}a_{24}a_{42}+a_{14}a_{41}a_{23}a_{32}+a_{12}a_{23}a_{34}a_{41}+a_{14}a_{43}a_{32}a_{21}+a_{13}a_{34}a_{42}a_{21}+a_{12}a_{24}a_{43}a_{31}+a_{14}a_{42}a_{23}a_{31}a_{13}a_{32}a_{24}a_{41})$

Barriers intensity index of GTA

In this section, were calculated the intensity of each barrier with help of the matrix representation, with five barriers i.e. B1, B2, B3, B4 and B5. For the interdependencies were rated the barrier relatively i.e. how much a barrier affects another.

$$Per(B1)=\begin{pmatrix}1&2&4&3\\8&4&7&6\\6&3&2&4\\7&4&6&3\end{pmatrix}$$

Expanding the matrix

1.4.2.4+(2.8.2.3+4.6.4.3+3.7.4.2+7.3.1.3+6.4.1.2+4.6.1.1)+(7.4.4.1+6.6.3.1+4.4.7.4+3.6.6.4+2.6.7.2+3.4.8.2+2.7.6.3+4.3.8.3)+(2.8(4.6+4.6.6.4+3.7.7.3+2.7.4.7+3.6.3.8+4.4.4.8+2.6.6.6+3.4.7.6 +4.3.6.7) = 6960

Similarly, were calculated the intensity of other barriers

$$Per(B2)=\begin{pmatrix}1&2&3&4\\8&4&6&7\\7&4&3&6\\6&3&4&2\end{pmatrix}=6960$$

$$Per\left(B3\right)=\begin{pmatrix}2&3&6&4\\7&4&8&6\\4&2&1&7\\6&4&3&3\end{pmatrix}=8176$$

$$Per(B4)=\begin{pmatrix}4&8&7&4&6\\2&1&4&2&3\\3&6&2&2&4\\6&8&8&5&7\\4&7&6&3&3\end{pmatrix}=162903$$

$$Per(B5)=\begin{pmatrix}4&4&4&8&7&6\\6&5&5&9&8&7\\6&5&5&9&8&7\\2&1&1&1&4&3\\3&2&2&6&2&4\\4&3&3&7&6&3\end{pmatrix}=3933900$$

Now putting all these values in the permanent matrix of Z i.e. circular economy

$$Per(CE) = \begin{pmatrix} 6960 & 2 & 1 & 4 & 7 \\ 8 & 6960 & 4 & 7 & 6 \\ 9 & 6 & 8176 & 8 & 7 \\ 6 & 3 & 2 & 162903 & 4 \\ 3 & 4 & 3 & 6 & 3933900 \end{pmatrix} = 2.54X10^{23}$$

Table 7: Intensity Index values of barriers

Barriers	**B1**	**B2**	**B3**	**B4**	**B4**	**B5**
Index value	6960	6960	8176	162903	3933900	$2.54X10^{23}$

4.3. Findings and Managerial Implications

In a present competitive environment, businesses are facing many social and industrial challenges due to scarcity of natural resources, climate change etc. The implementation of circular practices plays a very important role in saving of our limited resources. Therefore, the outcomes of the present study would help the mining industry managers in the evaluation of barriers intensity while managing operations for Circular Economy (CE). There are many barriers but after doing an extensive literature review and experts' discussion, the five major category of barriers are identified i.e. financial, market, government policies and regulatory, organizational and operational. Their respective sub-barriers are also identified. These barriers are responsible for the non-implementation of CE practices in the mining industry.

To know the priority of the barriers and their intensity index, a hybrid technique comprising of AHP and graph-theoretic approach (GTA) is employed. From the AHP, we found that Govt. policies and regulatory barrier (0.438), is the most severe barrier among all barriers considered for the mining industry. It is followed by the market barrier (0.246) and operational barrier (0.148). In sub barriers, lack of stringent regulation, lack of promotion for CE & incentives and lack of products standardization market are the most pressing barriers. The findings indicate that government policies and regulatory barrier, is the major barrier to implement CE practices in the mining industry. Therefore, the government should come forward to help the industry to overcome this by understanding what the challenges they are facing for adopting CE policy. The government should support and encourage in providing funding and training supportfor CE initiatives.

From the GTA technique, we calculated the intensities of major five categories of barriers considered in this study. We found that the operational category barriers had the highest intensity i.e. 3933900. Following that, organizational category barriers got the second-highest intensity i.e. 162903. One of the major reasons that they had such high intensities in comparison with the other barriers was that these two categories of barriers are driven by more factors. After that, we had Govt. policies and regulatory barriers and at the end we had financial and market barriers which had equal intensities. The study provides the following unique contributions and recommendations to the mining industry and other stakeholders:

- ✓ In this study, five major categories of barriers in managing operations for Circular Economy (CE) in the context of the mining industry are identified with the help of experts' discussion and literature review. Findings of this the study will help the industry to understand the impact of all the barriers accordingly and the industry will prepare their strategic action plan to overcome on these barriers.
- ✓ To find the priority and relationship among the barriers, a hybrid approach comprising of AHP and GTA is employed. Through this hybrid approach, this study recommends to the industry that priority weight of each barrier and its relationship with other barriers need to be considered for developing the strategic plan to overcome these barriers with optimum use of resources. For instance, to overcome financial barriers, they can go for

public funding with proper justification for how the industry is going to use that fund and what will be the outcome benefits.

- ✓ The study has a unique contribution to the research, where a hybrid approach has been used to know the priority rank and intensity of barriers in managing operations for CE in the context of mining industry perspectives.
- ✓ In the form of outcomes, this current study has offered many practical and managerial implications to show the applicability of the work for CE. The findings of the study recommend that industry should adopt a balanced approach to overcome these barriers.
- ✓ The outcomes of the study would help the mining industry managers to prioritize their action plans for managing operations for CE in their respective industry to optimize and meliorate basic resource consumption.

5. Conclusion and limitations of the study

A rapid transformation is happening in the Indian mining industry and the industry management is putting efforts in this direction to adopt circular economy (CE) practices for sustainable operations. CE practices may help industries, and particularly extracting industries such as mining, to optimize the use of its resources and minimize waste. This would further help to overcome the threats which the traditional linear model poses to the economic growth and development of any healthy economy. But the industry is facing several obstacles to adopting CE practices. Findings of this study would help significantly to the Indian mining industry in overcoming such obstacles. In the first phase of the study, the barriers are identified for executing the CE model within the context of the Indian mining industry through extensive literature review and experts' opinions.

To know the priority of the barriers and build a network relationship map among them, a hybrid technique that consists of a combination of the analytical hierarchy process (AHP) and graph-theoretic approach (GTA) methods, is employed. The findings of the study show that the *'government policies and regulations'* is the main obstacle to the implementation of CE in the Indian mining industry, followed by '*market'*. However, based on GTA, the highest intensity was observed for *'operational'*, followed by the *'organizational'* category of barriers. Based on the findings of this study, the managerial implications along with recommendations are provided to the industry so that they can make a strategic plan to overcome the barriers in the adoption of CE practices.

This study is also not free from the limitations. The study has several limitations, which may lead to future research directions. As results of this study are based on inputs taken from a limited number of experts. In future, the data can be collected from different industries to generalize the study results. AHP and GTA approaches have been used in this study but in the future, other MCDA tools may be also used to do a comparative analysis of findings. Findings may be further validated with the help of few case-based studies.

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