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Exploring barriers towards effective coal supply-A non-core perspective using ISM-DEMATEL

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ABSTRACT

While other energy sources are becoming more popular, India is expected to continue to depend on coal in the coming years. This study aims to identify and assess barriers to the efficient supply of coal to non-core industries reliant on this energy source. Employing a hybrid approach combining Interpretive Structural Modeling (ISM) and Decision-Making Trial and Evaluation Laboratory (DEMATEL), we analyse the hierarchical structure and causal relationships among barriers affecting the coal sourcing process. The hybrid model emphasizes that the ’biased government approach’ and ’lack of mining technology and infrastructure’ are crucial barriers. These key barriers exert a substantial influence on other factors within the scope of our study. Unlike earlier studies, this research enhances theoretical understanding by thoroughly exploring barriers to effective coal sourcing strategies. Policymakers engaged in decision-making for the non-core coal-dependent sector in India can benefit from this research. Attention should be directed towards addressing key barriers influencing effective coal sourcing, specifically focusing on ‘biased approach by the government’, ‘lack of mining technology and infrastructure’, ‘social and political constraints’, ‘low research and development’, and ‘lack of skilled personnel’.

1. Introduction

Coal has played a significant role in shaping the energy landscape of India. It remains a dependable and cost-effective energy source for both domestic and commercial purposes. Coal-based power generation has contributed approximately 70–80 percent to the nation’s overall power production. Projections indicate that over the next decade, coal is anticipated to account for more than 50% of the country’s power generation, playing a pivotal role in driving India’s economic growth (Anand and Narayanaswamy, 2021). Consequently, the consistent and affordable supply of coal is intricately linked to the objective of ensuring energy security in India Bobrikov et al., 2018.

With the substantial surge in power demand expected in India over the next decade, there is considerable pressure on thermal power generation. As per Chikkatur et al. (2009), it is estimated that coal mines will sustain coal production for up to six decades based on current production and consumption trends.

Presently, the total coal reserves in India stand at 352125.97 million tonnes (Ministry of Coal, 2021), positioning the country as the second-largest coal producer globally (Global Data, 2021), as illustrated in Table 1. The core sector, encompassing power-producing companies, consumes over 70% of the coal in the country. In contrast, the non-core sector comprises industries such as chemicals, cement, iron and steel, aluminium, among others Kumar and Dixit (2018). The term "non-core" is used by authors to these industrial sectors which are dependent on coal. The thermal power plants are considered as the core sector, primarily due to their reliance on coal for energy production. In this categorization, other industrial sectors that heavily depend on coal, such as aluminium and iron ore industries, are termed "non-core" as their primary focus and significance in the energy landscape are perceived as secondary compared to the core sector, represented by thermal power plants Anand and Narayanaswamy (2021). This distinction helps to emphasize the varying degrees of dependence on coal across different industrial segments within the broader energy framework. In 2015–16, the Government of India initiated a dedicated spot e-auction for the non-core sector. Under this program, there is a discernible decline in the quantity of coal allocated to the non-core sector from 2020 to 21 to 2021–22, dropping from 31.23 to 25.66 million tonnes (Ministry of

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Table 1
Top 5 coal producing countries in 2021.

S. No	Countries	Coal production in million tonnes
1	China	3942
2	India	767
3	Indonesia	550
4	USA	544
5	Australia	544

NOTE: It shows the top five nations in terms of coal production.
(Source: Ministry of Coal, 2022b)

Coal, 2022b).

The authors conducted a comprehensive review of literature within the coal supply chain and logistics field spanning the last five years. This review encompasses a diverse range of studies examining various aspects of coal transportation, terminal operations, logistics management, and supply chain optimization. To present the research trends in this field over the past five years systematically, the authors have created Table 2, highlighting selected papers. This helps in understanding the evolution of research priorities, methodologies, and findings in coal supply chain and logistics research, providing insights into emerging challenges and opportunities in the field. The motivation to conduct a study on effective coal supply to non-core coal-dependent industries stems from the recognition of the significant role these industries play in the overall coal consumption landscape, and the potential implications of disruptions or inefficiencies in coal supply chains on their operations.

Table 2 reveals several trends and potential research gaps in the domain of coal supply for non-core industries. A recurring theme is the persistent challenges associated with coal consumption, encompassing environmental impacts, sustainability concerns, and the complex logistics of coal transportation. Despite the global push towards renewable energy, these papers highlight the importance of understanding the ongoing role of coal, especially in countries like India and China. Also, it can be seen that the majority of the articles focus on various aspects of coal utilization within the power sector. These include examining challenges and strategies related to coal phase-out, coal quality improvement for thermal power plants, coal transportation for power generation, and the economic and environmental impacts of coal policies on power generation.

While some articles touch upon broader energy landscape issues and logistical challenges in coal mining, the emphasis seems to be on the power sector's role in coal utilization. Additionally, there is a lack of explicit mention of coal supply to non-core sector industries. However, a notable gap in the existing literature is the lack of specific exploration into the barriers hindering effective coal supply in non-core industries. Investigating the challenges and impediments faced by non-core industries in securing an effective coal supply is crucial for comprehensive insights into the dynamics of the coal sector. This perspective represents a vital research gap that, once addressed, can contribute significantly to policymaking and industry strategies, ensuring a more nuanced and balanced approach to energy transitions.

The coal production in India is dominated by the public sector companies. One of the major coal producers is facing a high production target owing to the recent energy crisis. Apart from the uncertain demand trajectory there are other challenges associated with coal supply which include the low quality of domestic coal production. The non-core coal dependent industries bear the brunt of this coal supply crunch. Along with the issues in captive coal production, these industries are forced to opt for imported coal which is a costlier option and is marked by higher lead time for supply as well (Naik and Ghatak, 2020). It is observed that the total coal imported in the last three years in India is decreasing. However, the coal import for the non-core sector has increased over the last 2 years as presented in Table 3. The dependency on the imported coal in case of the non-core sector portrays the inconsistency of the coal supply process.

Table 2
Research trends in coal supply and logistics sector in last 5 years.

Sl. no	Authors & Year	Country focus	Scope
1.	Yu et al. (2023)	China	The article explores challenges in China's coal phase-out amid global climate action. It stresses the need for resilient coal supply chains during the shift to a low-carbon economy. Using a system dynamics model, it analyzes China's power-coal supply from 2021 to 2060. Key findings highlight increasing coal mine capacity redundancy, the importance of coal stock in demand surges, and the significance of coal transport capacity, especially during demand fluctuations. The study recommends short-term improvements and long-term planning for a successful transition.
2.	Srikanth and Bhatt (2023)	India	The study delves into India's intricate energy landscape, marked by surging electricity demand and a transition to non-fossil fuel sources to achieve Net Zero by 2070. Despite India's modest per capita energy consumption and emissions, challenges arise from the reliance on intermittent renewable energy (IRE) due to price fluctuations, supply chain constraints, geopolitical tensions, and environmental concerns. The coal sector's pivotal role in major industries necessitates a balanced energy transition strategy. Advocating for sustainable coal practices, it aligns with UNFCCC principles to combat climate change globally.
3.	Zonailo (2023)	Panama	This study provides a comprehensive analysis of coal transportation, from mine to end-user. It examines crucial aspects such as terminal operations, including rail car loading and dust emissions mitigation. The study also discusses shiploading systems, transhipping, safety at sea, and methods for optimizing the coal chain, alongside future transportation trends.
4.	Grishin and Serhiivna (2023)	Ukraine	This study tackles suboptimal coal quality's impact on thermal power plant efficiency by proposing a coal supplier selection model. It accounts for transport delays and backup fueling to enhance reliability. Additionally, it develops a dynamic coal quality determination model, adjusting sampling based on real-time combustion results, aiming to reduce low-quality coal usage and improve operational efficiency.
5.	Walker (2023)	Australia	This ACARP-commissioned study focuses on logistical challenges in underground coal mining, offering a strategic system to identify bottlenecks. Integrated into XPAC mine scheduling software, it predicts material delivery loads, evaluates impacts using FlexSim simulation, and suggests relief mechanisms. Experimentation and application in a real-world mine demonstrate predictive capabilities and practical utility.
6.	Hia et al. (2023)	Russia-Indonesia	The article examines competitiveness management in global coal enterprises, focusing on Russia and Indonesia's roles in coal exports.

(continued on next page)

Table 2 (*continued*)

Sl. no	Authors & Year	Country focus	Scope
			Amidst market instability and environmental concerns, challenges include financial stability, labor productivity growth, and environmental impact. Improving financial stability is critical due to export dependence, low competitiveness, changing demand dynamics, rising costs, and mining constraints.
7.	Yao et al. (2022)	China	This study employs a dynamic computable general equilibrium model to assess the impacts of output-controlled and investment-controlled coal capacity cut policies on the economy and environment in Shanxi province, China. Results indicate that the output-controlled policy reduces emissions and fosters economic growth and household income, suggesting its prioritization to mitigate coal-related challenges in resource-centric regions.
8.	Baskoro et al. (2021)	Indonesia	This study examines Indonesia's significant position in the global coal market, emphasizing its production and export rankings. Despite limited domestic utilization, coal production is projected to rise to meet growing electricity demand. Employing a system dynamics model, the study assesses future production scenarios, aiming to balance economic growth and environmental sustainability, recommending the "EO" scenario for optimal alignment with government energy mix targets.
9.	Yang et al. (2021)	China	This study investigates the repercussions of significant deviations in China's coal production capacity on the economy, environment, and energy security. Analyzing diverse policies like tax adjustments, de-capacity initiatives, and market access management, it identifies varying effects, recommending tailored policy mixes based on future deviation levels to address multiple objectives effectively.
10.	Belov et al. (2020)	Australia	This study examines the Hunter Valley coal export supply chain in New South Wales, Australia, crucial for the national economy. It tackles complex logistics challenges through a metaheuristic planning system integrating train, stockpile, and vessel scheduling. Computational analyses identify bottlenecks, informing operational policies and investment decisions. Solver-independent modeling technology highlights performance differences between constraint programming and mixed-integer programming.
11.	Oskarsson et al. (2021)	India	This study examines coal's enduring significance in global energy production, constituting 40% of heat and power generation, despite renewable energy trends. Investigating India's increasing coal consumption and the emergence of a "new coal geography," the research reveals drivers such as energy shortages and public controversy, highlighting infrastructural investments and policy influences from diverse public- and private-sector entities.
12.	Janardhanan and Tamura (2020)	India	This study scrutinizes India's strategic challenge amid an energy transition, balancing rising fossil fuel demand with sustainable growth objectives. Evaluating global discourse on shifting away from coal, it examines sociopolitical impacts on coal-dependent communities. Contrary to expectations, employment declines in coal stem mainly from mechanization rather than energy transition policies.
13.	Pudasainee et al. (2020)	India-China	This study examines current challenges in coal utilization, focusing on operational and environmental issues. Depletion of high-grade reserves and increased moisture and ash content in remaining coal pose hurdles. Environmental concerns, notably carbon emissions, threaten sustainability. Advanced coal characterization, beneficiation, and post-combustion technologies address regulatory limits but highlight the ongoing challenge of mitigating greenhouse gases for coal's sustainable future, essential for major coal-dependent countries like India and China.
14.	Yadav et al. (2019)	India	This study compares environmental impacts of coal transport by rail versus road, focusing on air and soil pollution in coalfield and siding areas. Through comprehensive monitoring and analysis, it evaluates air pollutants, meteorological parameters, and trace metals. Results reveal rail-dominated areas are more polluted, stressing the necessity for mitigation measures in railway transport projects.

NOTE: It shows the research trends in the last five year in the coal supply chain logistics sector across nations.

Table 3
Coal imported in the last three years.

	(In million tonnes)		
Year	**2019–20**	**2020–21**	**2021–22**
Total Coal Import	248	215	209
Year	**2019–20**	**2020–21**	**2021–22**
Non-core Coal Import	127	119	125

NOTE: It shows the total coal imported by India in last three years and the coal imported by Indian non-core sector.
(Source: Ministry of Coal, 2022a)

Several industrial sectors, such as aluminum and iron ore, are characterized by high energy consumption. A continuous and reliable supply of coal is imperative for these non-core industries. Currently, coal allocation is unevenly skewed towards the power, i.e., the core sector. This disparity in allocation poses challenges for non-core industries during instances of demand-supply mismatch, as they heavily rely on public sector companies for coal supply. The unresolved issue of coal supply to non-core industries motivated the authors to conduct a study which addresses the challenges in coal sourcing practices in India. Consequently, this research aims to identify and analyse critical barriers hindering effective coal supply in the non-core sector. The study addresses the following research questions.

RQ1. What are the barriers impeding effective coal supply to non-core industries in India, and how are these barriers interrelated?
RQ2. What is the degree of influence of each barrier in the effective coal supply process?
RQ3. What policy recommendations can be proposed for stakeholders in the coal supply process?

A set of 14 barriers were chosen based on their relevance to effective coal supply in the non-core sector. Initially, an Interpretive Structural Modeling (ISM)-based method is proposed to determine the dependence and driving power of these barriers. Subsequently, Decision-Making and Trial Evaluation Laboratory (DEMATEL) is employed to identify the degree of influence each barrier exerts. The hybrid ISM-DEMATEL approach proves robust in analyzing barriers obstructing effective coal supply. This study, focused on the non-core coal-dependent sector in India, is among the few of its kind. Based on the analysis, the study offers a set of policy recommendations for all stakeholders involved in the coal supply process.

The paper is organized as follows: Section 2 provides a literature review to identify barriers to effective coal supply in the non-core sector. Section 3 outlines the research methodology and its application. Findings and discussion are presented in Section 4, while Section 5 concludes the study and provides policy implications.

2. Literature review

The coal mining industry plays a vital role in global electricity generation, with at least 85% of total global coal production consumed domestically. China remains the largest coal producer, accounting for 45% of global production, with other leading nations like the USA, Australia, and Indonesia contributing 32% collectively (Kong and Gallagher, 2021; International Energy Agency, 2021). The process of coal sourcing and supply is characterized by high uncertainty and volatility. Despite efforts to diversify energy sources, India is expected to rely on coal for the foreseeable future due to global uncertainties and supply chain disruptions in the energy sector (Economic Times, 2022).

Following the reopening of markets post-COVID-19, economies grappled with addressing their energy deficits, with coal serving as a low-cost solution to fill the supply gap. The primary driver of coal shortage in India is the escalating demand for power, which surged from 106.6 billion units per month in 2019 to 124.2 billion units per month in 2021, further increasing to 132 billion units in 2022 (Nath, 2022). The decline in demand during the pandemic led to the cessation of production in various small-scale industries, resulting in reduced demand for coal. However, the responsiveness of coal producers to the sharp post-pandemic demand increase did not meet expectations, particularly impacting mega producers reliant on migrant contract labor (Vanamali, 2021).

Persistent coal shortages in India stem from multiple factors, including slow environmental clearance processes, inadequate logistics infrastructure, and technological challenges (Jiang et al., 2007). Legislative environments, skills shortages, and low research and development in revitalizing the coal sector further exacerbate these constraints (Ray et al., 2022; Wang et al., 2016, 2018). A disruption in coal supply to non-core industries would not only impede production levels but also negatively impact India's industrial landscape. Despite various studies addressing logistics and supply chain gaps in coal trade, research from the perspective of non-core coal-dependent sectors remains scarce, highlighting an important area for future investigation (Benalcazar et al., 2017; Magda et al., 2014; Bogacz, 2017; Belov et al., 2020).

2.1. Research gaps

While surveying the literature, authors found that there is a dearth of research done on coal supply barriers in the Indian context. Secondly, no study has addressed the coal supply process from the perspective of the non-core coal dependent sector. Thirdly, authors have contributed three more barriers to the literature as per the discussions held with the experts. Apart from categorizing the barriers as per their dependence and driving power, there is also a need to classify the barriers into cause-and-effect groups for which the paper uses the hybrid ISM-DEMATEL approach. These are the challenges that the paper addresses. The following section describes the barriers in detail.

2.2. Barriers impacting coal supply

This study was carried out in the context of the non-core coal dependent sector in India. Existing literature was reviewed to identify the coal supply barriers impacting the non-core sector. The detail discussion of these barriers are as follows.

2.2.1. Inconsistent supply

There is an acute coal supply crisis in India, largely due to the decline in domestic coal production plus the dependency on imports in the last five years (Kant, 2021). Recently, the factors responsible for elevating the global coal prices are the climatic irregularities, pandemic related under production, and rising power consumption pattern in the countries like Indonesia, India, and China respectively. Lastly, the most affected sector due to this inconsistency in coal supply is the non-core sector of India.

2.2.2. Biased approach by the government

The government has been facing backlashes due to its biasness in coal allocation to various coal dependent sectors in India. For instance, the southeast central zone of railways (SECR) which is responsible for rake allotment for coal transport (Press Trust of India, 2022) state that due to the new coal stocking norm for the core sector, they are automatically taking the higher priority in rakes allocation. At present the coal related government policies are biased toward public and core sector industries. These policies include improper coal allocation, restriction on commercial coal production, control over production and the like (Khanna, 2013).

2.2.3. Dependency on imported coal

India is the second largest producer, consumer, and importer of coal (Powell et al., 2022). There has been a dependency on imported coal especially by the non-core sector due to the inconsistent availability and poor quality of indigenous coal in India (Ministry of Coal, 2022a). Recently, the world underwent an energy crisis which worsened the conditions of coal supply for the Indian non-core sector increasing the dependency on imported coal.

2.2.4. Lack of mining technology and infrastructure

Coal mining is the primary objective for coal producing public sector companies. However, financial constraints and unavailability of low-cost mining technologies for the non-core sector makes the captive coal production inefficient. Furthermore, a lack of mining technology, leads the usage of traditional coal extraction techniques, resulting in wasteful mining and generation of mine waste (overburden) (Baruya, 2012; Muduli et al., 2013). Inadequate infrastructure affects the storage and warehousing of machinery, worker health and safety, etc. The non-core sector is directly affected by this lack of mining technology and infrastructure leading to inconsistent supply of coal.

2.2.5. Logistics bottlenecks

India is way behind in terms of a decent logistics infrastructure. It is facing difficulty in developing the logistics infrastructure dedicated to transport coal from sources to consumption points which ultimately leads to inconsistent supply of coal especially for the non-core sector. The logistics bottlenecks for coal in India are due to lack of budgetary provisions for developing logistics infrastructure; high logistics costs owing to inherent characteristics of coal transport; shortage of wagons and congestion on the rail network; lack of alternate transportation models; improper logistics planning in multi-modal transport (Muduli et al., 2013; Coal Logistics Policy, 2022).

2.2.6. Underutilization of allocated captive coal block

This barrier is a contribution from the authors as it was identified while holding discussions with the industry practitioners from the non-core sector. A Coal India Limited report suggests that the captive coal production is limited to 270–325 million tonnes per annum (MTPA) against the 500 MTPA capacity due to various reasons at the non-core side (Coal India Limited, 2017). However, authors strongly believe that the underutilization of captive coal block needs government intervention. As they are subjected to various approvals on local land and other social issues, there are a lot of unaddressed administrative, regulatory and policy bottlenecks that leads to government intervention.

2.2.7. Monopoly of coal market

This is the second barrier that the authors have proposed. The leading coal producers in India belong to public sector. Due to the increasing demand for coal, the coal production is continuous and highly standardised process which is more inclined towards the need of the core sector. In May 2020, the Indian Finance Minister announced that the government aims to bring competition, transparency, and participation from private players in the coal mining space on a revenue-sharing basis. However, the authors strongly believe that such breakthroughs will end the monopoly, yet it is still far from implementation which is contributing to the inconsistency in coal supply to the non-core.

2.2.8. Delay in environmental clearance and land acquisition

Practitioners state that 'land' is as good as a raw material for the production of coal. The process of land acquisition is complicated and time intensive as the companies need to coordinate with the locals, forest officers, land owners, and other stakeholders for their approval (Wu et al., 2017). Thus, challenges like allotment of land, environmental clearance, rehabilitation, and resettlement contribute to underutilization of allocated captive coal block to non-core.

2.2.9. Higher mining cost of captive coal

This is the third barrier proposed by the authors. The captive coal blocks currently located far from the existing infrastructure of the major coal producer in India. The non-core sector is unable to source and share the existing technology and equipment from the producer side as their captive coal blocks are in remote areas devoid of all basic infrastructure like road, rail links, electricity, etc. This is a major reason for the higher cost of mining of captive coal. Further, captive coal production is a secondary objective for the non-core sector industries which limits their expertise in coal excavation indirectly making the captive coal mining process complex and cost intensive.

2.2.10. Lack of linkage rationalization -

In the current situation the linkage rationalization policies in India are lagging in implementation (Kamboj and Tongia, 2018). This process involves the reallocation of the coal supply source of a power plant from a coal block situated at a farther distance to a nearby one. This strategy aims to help the power plants by reducing the transportation costs. It also leads to faster supply of fuel and better availability of railway rakes. However, the linkage rationalization is lacking with a non-core sector focus.

2.2.11. Low research and development

There is a dearth of research done on the various challenges in coal production which includes logistics optimization, indigenous technologies for coal excavation, coal infrastructure etc. (Wu et al., 2017). Although there is a thrust from the government, on research and development in the coal sector, there is still scant research available on low-cost solutions for captive coal mining for the non-core sector. Recently, some developed countries have invested in digital technologies such as Internet of Things (IoT), automated drones, collaborative robots etc. for their mining operations (Olvera, 2022). These digital technologies have the potential to transform mining processes while complying with stricter regulations. However, in India, research and development in this field is lacking.

2.2.12. Social and political constraints

It has been observed that frequent law and order issues like political intrusion, labour gheraos (strike), and involvement of local mafia significantly hamper the coal mining process. Authors have stated that local and transnational social movements have fractured the growth and development of the coal sector (Delina, 2021). Coal being the backbone of India's energy security has witnessed several political interventions in the past as well as present. This adversely impacts the coal production and its supply to the non-core.

2.2.13. Lack of skilled personnel

The coal mining process is a labour-intensive process. Currently, there is a lack of skilled personnel in the coal sector (Bobrikov et al., 2018). Training and development are essential for personnel engaged in coal production. There is a lack of training initiatives on handling mining technologies and dealing with personnel management and industrial relations issues. Wylie (2013) has suggested that the mining sector companies need to establish collaborative measures with educational institutions for training the personnel.

2.2.14. Grade slippage

Coal is graded into different groups according to its calorific value. Primary reason for grade variations in Indian coal is due to its inherent heterogeneous nature and difference in calorific value of coal extracted within the same seam but different points (Press Trust of India, 2021). Further, when coal is exposed for long stretches to the atmosphere, its calorific value decreases as it undergoes oxidation (Benalcazar et al., 2017; Tang and Wang, 2019). Hence, overproduction and stocking huge piles is not recommended. Since, quality of coal is critical in determining the life of equipment like boilers, crushers, conveyor belts etc. the non-core sector is adversely affected by grade slippage.

Therefore, this research tries to address these gaps and specifies the list of all barriers related to coal sourcing with their literature references, that is given in Table 4.

3. Research methodology and application

The proposed research framework adopted in this study is presented in Fig. 1.

3.1. Research protocol and data collection

Firstly, we meticulously reviewed the literature on the coal sector, then narrowed down the focus to non-core coal-dependent sectors, initially identifying twenty-eight barriers. Secondly, authors contacted sixteen industry experts from power, metal, aluminium, coal mining, and steel sectors, and one academic expert from the strategy and policy area through email and phone calls. Out of sixteen, only twelve experts consented to be part of this discussion. The demographic profile of the twelve experts is provided in Table 5. Thirdly, authors discussed these twenty-eight barriers with nine experts over phone calls and in-person meetings with three experts. Experts were consulted both offline and online, and barrier selection was based on the significance of barriers to non-core coal-dependent sectors, statement clarity, and the existence of identical barriers. Following this rigorous process, eleven barriers were selected from the list of twenty-eight barriers, and three more barriers were added by the authors after consulting with the experts. Finally, fourteen barriers were finalized for further study, as shown in Table 4.

In the next step, data were collected for the ISM and DEMATEL

Table 4
References of barriers in literature.

S. No.	Barriers	Source
1	Inconsistent supply	Wu and Chen (2018)
2	Biased approach by the government	Muduli et al. (2013); Khanna (2013); Mathu (2014); Wu et al. (2017); Huo et al. (2013)
3	Dependency on imported coal	Wu and Chen (2018)
4	Lack of mining technology and infrastructure	Baruya (2012); Muduli et al. (2013); Huo et al. (2013); Xue et al. (2023)
5	Logistics bottlenecks	Baruya (2012); Muduli et al. (2013); Mathu (2014)
6	Underutilization of allocated captive coal block	Authors' contribution
7	Monopoly of coal market	Authors' contribution
8	Delay in environmental clearance and land acquisition	Wu et al. (2017)
9	Higher mining cost of captive coal	Authors' contribution
10	Lack of linkage rationalization	Kamboj and Tongia (2018); Li et al. (2020)
11	Low research and development	Wu et al. (2017)
12	Social and political constraints	Baruya (2012); Muduli et al. (2013)
13	Lack of skilled personnel	Muduli et al. (2013); Mathu (2014); Wu et al. (2017); Li et al. (2020)
14	Grade slippage	Baruya (2012); Benalcazar et al. (2017); Tang and Wang (2019)

NOTE: It shows the barriers shortlisted for the study along with the papers which contributed in identifying them.

methods. Two separate questionnaires were prepared for both the ISM and DEMATEL methods. For the ISM method, opinions were solicited from experts online through a brainstorming session with the twelve experts for the structural self-interaction matrix (SSIM) (refer step 3 under section 3.2.1, and for responses, refer to Table 5). Details of the experts' gender, education, industry, experience, and designation were also collected during the discussion. For the DEMATEL method, a second questionnaire was sent to all twelve experts via email after a couple of days. However, only six responses were received out of twelve. For this method, responses were rated on a scale of 0–4 (refer step 1 under section 3.2.3) for all six respondents, then an average was calculated for further DEMATEL analysis.

In this study, the sample size was limited as it was difficult to find experts having the relevant experience. According to Liu et al. (2016), there is no predefined criteria to get minimum number of responses for the ISM method. Novakowski and Wellar (2008) proposed that minimum 5 and maximum 15 experts could be a good sample size to get the quality results. It has been advocated by Shen et al. (2016) that criteria for the respondents' selection should be aligned with quality over quantity. According to Olawumi and Chan (2018), the group of respondents should consist of at least seven members. However, in one of the articles by Shen et al. (2016), four experts were considered for the ISM analysis. On the other hand, Hsu et al. (2013) and Fu et al. (2012) have conducted studies using the DEMATEL method where three to four experts were considered respectively. Priyadarshini et al. (2022) used the ISM technique for investigating the interactions of factors with only seven industry and academia experts. Therefore, the sample size of 12 experts for ISM and 6 experts for DEMATEL is sufficient.

3.2. Hybrid ISM-DEMATEL approach

The objective of this study is to identify and analyse the barriers towards effective coal supply for the non-core coal dependent sector. The hybrid ISM-DEMATEL technique was used to evaluate the mutual interactions among barriers and further to develop the causal relationship between them. The ISM method is a refined technique where a connection among the barriers is established leading to a hierarchical model which has been used for solving complex relationship problems (Jharkharia and Shankar, 2005). ISM does not require information on the strength of relationships between the variables, unlike other MCDM techniques. Additionally, a DEMATEL method is used to describe the overall effects of barriers by dividing them into cause-and-effect groups (Bag, 2017). The strength of DEMATEL over other popular methods (BWM, ANP, AHP, ELECTRE, VIKOR, and TOPSIS) for barrier analysis is that it considers direct as well as indirect relationships. In comparison to DEMATEL, other MCDM methods fail to consider the causal relationship between variables (Gardas et al., 2019; Menon and Ravi, 2022). Also, the DEMATEL method calculates the weight of the variables by identifying the significant ones over others. However, ANP and AHP methods can perform this action similarly but, these two methods do not examine the interrelationships and the underlying nature of the variables under study (Kumar and Anbanandam, 2020). Therefore, the primary reason for choosing this hybrid approach over other approaches is its pertinence to the problem in hand, as both ISM-DEMATEL are powerful tools which have been frequently used by past researchers to analyse a causal relationship for effective decision-making. Another reason for selecting this hybrid method is that both the methods can work well with small sample size (Lee et al., 2013). ISM being a computational method uses a macro approach (0 and 1) involving qualitative and interpretive analysis (Yu et al., 2022). Further, DEMATEL uses micro approach of 0–4 scale (Chuang et al., 2013; Mishra, 2020). In the recent past, integrated ISM-DEMATEL technique has been extensively used in the field of social sciences such as green supply chain (Hsu et al., 2013), adoption of IoT (Kamble et al., 2019), food supply chain (Yadav et al., 2022), sustainability (Patel et al., 2021), and sustainable transportation mode (Trivedi et al., 2021), etc.

The procedural steps for the hybrid ISM-DEMATEL method are described below.

3.2.1. ISM method

This method was developed by Warfield (1974). It is a well-established method to identify and analyse the interrelationships among the factors (Sage, 1977). The following steps ae involved in the ISM method (Parida et al., 2022; Govindan et al., 2015; Katiyar and Barua, 2014) Table 6, Table 7 and Table 8.

Step 1	Identifying coal sourcing barriers through literature review and experts' opinion.
Step 2	After the first step, the contextual relationships between barriers are established.
Step 3	Further, 14 barriers were mapped onto a structural self-interaction matrix (SSIM) presented in Table 6, which specifies pairwise relationship among the barriers. For establishing the contextual relationships among barriers, experts were consulted and asked for any relation between two barriers (i, j) and the direction of relationship. Four symbols are utilized to establish the appropriate relationship between barriers which are: V = If barrier i influences barrier j; A = Barrier j influences barrier i; X = Barrier i and barrier j influence each other; and O = When barrier i and barrier j are not related.
Step 4	After this, initial, and final reachability matrix are developed from SSIM as presented in Tables 7 and 8 respectively. Final reachability matrix is formed by removing the transitive links form the initial reachability matrix. The transitivity concept states that if a barrier 'X' affects barrier 'Y' and barrier 'Y' affects barrier 'Z', then barrier 'X' will necessarily affect barrier 'Z'. Initial reachability matrix is computed by transforming the SSIM through replacing the symbols with binary digits (i.e., 0s and 1s). The following are the rules which transforms the SSIM to obtain the initial reachability matrix. •If (i, j) position in the SSIM is 'V', then in the reachability matrix, (i, j) position will be 1 and (j, i) position will be 0. •If (i, j) position is 'A' in the SSIM, then (i, j) position will be 0 and (j, i) position will be 1. •If (i, j) position in the SSIM is 'X', both (i, j) and (j, i) positions will be 1. •For the case of symbol 'O' in the SSIM, both (i, j) and (j, i) positions become 0.
Step 5	Level partitioning into various levels is done after achieving the final reachability matrix. The reachability set and antecedent set are developed for each barrier by examining the final reachability matrix. The reachability set contains the barriers (including itself) which are impacted by it. The antecedent set comprises the barrier itself and the other barriers which

(*continued on next page*)

(*continued*)

	impact it. Consequently, the intersection set is obtained for each barrier. Further, the levels for which reachability set and intersection set are same that barrier is allocated at the top level in the ISM hierarchy. From Tables 9 and it is seen that Inconsistent Supply (B1) is allocated at top level. This is an iterative process which stops only when all barriers are allocated at a level. Total fourteen barriers are grouped into six different levels.
Step 6	Further, an ISM model is formed using the final reachability matrix as illustrated in Fig. 2.

NOTE: Using the four symbols, the experts were consulted to make paired comparisons among the barriers to analyse their interrelationships.

3.2.2. MICMAC analysis

The aim of Cross-Impact Matrix Multiplication Applied to Classification (MICMAC) is to assess the driving power and dependence power of the barriers Table 9. Driving and dependence power of each barrier are presented in Table 7. The driving power and dependence power are calculated while considering the 1's row wise and column wise respectively Fig. 2. The MICMAC diagram is depicted in Fig. 3. The four clusters in Fig. 3 are called autonomous, dependent, linkage, and driver (Katiyar et al., 2018).

3.2.3. DEMATEL method

DEMATEL is a commonly used method for modelling relationships between variables. This method is considered practical and effective for representing the structure of complex causal relations with matrices or digraphs (Gabus and Fontela, 1973). DEMATEL is developed by Battelle Memorial Institute of Geneva. This method involves a mind mapping exercise in which the responses collected from the experts for the barriers are presented in a visual impact-map. This helps in determining the course of action to address a problem in real world scenario.

The steps of DEMATEL method are outlined next (Kaur et al., 2018; Mishra, 2020).

Step 1. Developing Average Matrix

In this step, h responses from the experts are collected to determine the relationships between the variables (here, the barriers) on the scale of 0–4; where 0 implies no influence, 1 implies low influence, 2 implies medium influence, 3 implies high influence, and 4 implies very high influence. The value assigned by experts generates an $n\times n$ matrix X^k, with $1 \leq k \leq h$. Therefore, $X^1, X^2, \ldots X^h$ are resultant matrices developed from h experts where every entry of X^k is an integer, represented as x^k_{ij}. The diagonal entries of each resultant matrix X^k are marked 0. Now, the average matrix A is generated as follows:

$$a_{ij} = \frac{1}{h}\sum_{k=1}^{h} x^k_{ij}$$

The average matrix generated in this study is presented in Table 10.

Step 2. Determining the normalised initial direct matrix

Here, the average matrix Z is normalised to form the initial direct matrix A as follows:

$$Z = AS,$$

where, S is a constant given by the following expression:

$$S = \frac{1}{max_{1\leq i\leq n}\sum_{j=1}^{1} a_{ij}}$$

The initial direct matrix obtained is represented in Table 11.

Step 3. Deriving the total relation matrix

The total relation matrix (T) provides both direct and indirect influence of variables while the normalised initial direct matrix provided only the direct influence.

Total relation matrix is derived as follows:

$T = Z(I-Z)^{-1}$, where I is the $n \times n$ identity matrix.

The total relation matrix (T) obtained is shown in Table 12.

Step 4. Measuring the degree of influence

In this step, D_i and R_j are calculated which represent the sum of the *ith* row and sum of the *jth* column in matrix T.

If $i = j$, then the sum $(D_i + R_j)$ signifies the total effects given and received by variable i, thereby implying the degree of importance of variable i. The difference $(D_i - R_j)$ shows the net effect that variable i contributes to the system. When $(D_i - R_j)$ is positive, the variable i is called cause variable (net cause), and when negative, it is called effect variable (net receiver). The degree of influence is shown in Table 13.

Step 5. Developing an impact-relations map.

An impact-relations map is developed for subsequent analysis and decision-making. To identify the variables having negligible effects from matrix T, a threshold value is selected. Out of the several methods proposed for selecting the threshold value, one of the most common methods is averaging the values of the T matrix (Awasthi and Grzybowska, 2014). Therefore, this map is developed by considering all the values of $(D_i + R_j)$ and $(D_i - R_j)$ on coordinate sets to illustrate the interrelationships among the variables and understand their degree of influence. The impact-relations map is depicted in Fig. 4.

4. Findings and discussion

4.1. ISM method

This study focuses upon identifying and examining the barriers in non-core coal dependent sectors in India. After identifying the key barriers, suggestions were sought from academicians and industry experts which helped to finalise the barriers as per their suitability in the non-core coal sector. 'B2', 'B4', 'B11', 'B12', 'B13' and 'B14' have been analysed as the most substantial independent barriers in coal sourcing process in India. Similarly, 'B7', 'B8' and 'B10' are the next level crucial barriers. 'B7', 'B8' and 'B10' may further lead to 'B5' which comes at next level of the hierarchy. 'B5' leads 'B6' and 'B9'. Also, 'B6' and 'B9' lead to 'B3'. Finally, 'B3' leads to 'B1'. The further discussion can be summarized as follows.

- Lack of mining technology and infrastructure, low research & development, lack of skilled personnel, social and political constraints, grade slippage, and biased approach by the government are the most significant barriers to effective coal sourcing and supply process to the non-core sector. Fair approaches by the government, overcoming social and political constraints, giving proper training to the personnel, promoting research and development, and the use of advanced mining technology and infrastructure may help to resolve the issue of inconsistent supply. Poor quality coal or slippage in grade is a major concern in India. This issue can be addressed by investing in advanced technology or innovative ways to improve the quality of coal. Therefore, companies should employ more globally reputed third party sampling and testing agencies to address grade slippage. Therefore, the top management and policy makers should address these barriers more carefully.
- Next level barrier is related with delay in environmental clearance and land acquisition that need to be properly regulated. Good governance may help in getting the environmental clearance and acquiring the land on time, so that coal production and its supply will be regulated to meet the customers' demand on time. Therefore, removal of this barrier or sorting out the environmental clearance and land acquisition problem may improve the overall coal sourcing and its supply quickly to the non-core coal dependent industries in India. In this level, there are two more barriers namely monopoly of

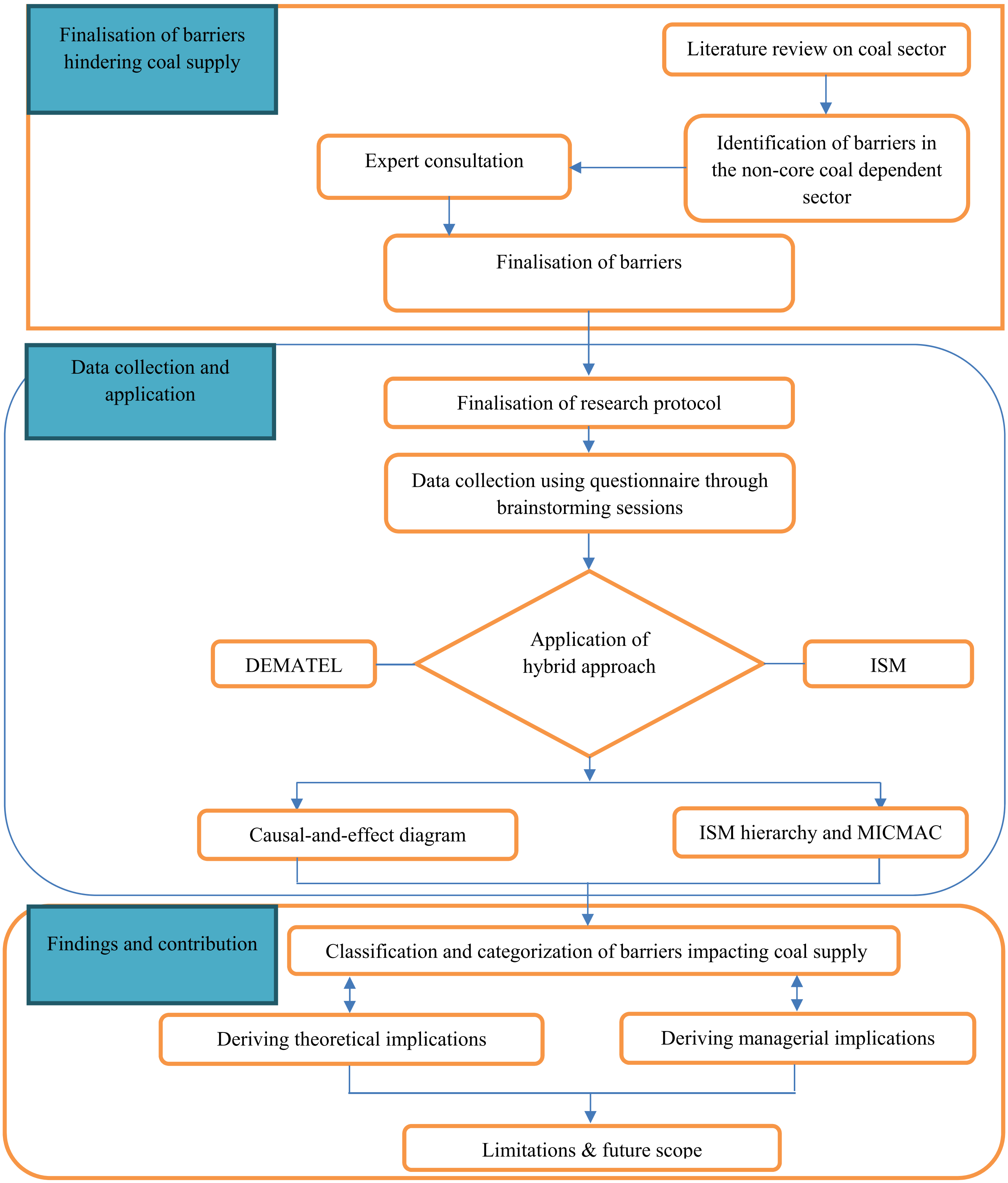

Fig. 1. Proposed research method framework. NOTE: The overall flow of research is presented for readers to have better clarity on how the study began along with the contributions.

Table 5
Experts' profile summary.

Expert	Gender	Education	Industry	Expert's Profile	Experience (in Yrs)
1st	M	Post-Graduate	Aluminium	Senior Manager-Coal Sourcing	13
2nd	M	Graduate	Coal	General Manager-Mining	17
3rd	M	Post-Graduate	Aluminium	General Manager-Coal Sourcing & Sales	25
4th	M	Post-Graduate	Steel & Power	VP-Procurement and Logistics	22
5th	M	Graduate	Power	Senior Manager-Procurement & Logistics	15
6th	M	Doctorate	Coal Mining	Former Director Personnel	39
7th	M	Graduate	Coal Mining	Former Director Project & Planning	37
8th	M	Graduate	Coal Mining	Former CMD	40
9th	M	Doctorate	Academia	Associate Professor	17
10th	M	Post-Graduate	Metal & Power	Lead Process Control	14
11th	M	Post-Graduate	Metal & Power	General Manager	21
12th	F	Post-Graduate	Metal & Power	Manager in Supply Chain	18

NOTE: The background of the twelve experts who participated in the study is presented here.

coal market and lack of linkage rationalization. Government should focus on linkage rationalization of coal and adopt strategies to address the current market monopoly for better coal supply to the non-core industries. Improving the linkage rationalization would help in transferring of coal source from a far end coal mines to nearer one. Such facilities will help in reducing the distance in transportation which will not only reduce the transportation cost but also ensure profits for all stakeholders.

- In the next level, logistics bottlenecks is the only barrier. This barrier can be addressed by resolving and improving all transportation related issues. Nowadays, coal crisis is the major challenge at the global as well as national level. The coal scenario in India is not any different as there is a huge demand from power sector which indirectly affects the coal supply to the non-core sector. One of the major reasons for the demand supply mismatch is the transportation issue. As the major mode of transportation of coal happens through roadways/railways. This creates lot of challenges in supplying coal from coal sourcing hub to non-core coal dependent sector. The reasons for ineffective coal supply are poor road infrastructure, inadequate railway capacity, silo loading and siding, lack of rack availability and capacity. Therefore, freight trains carrying coal can either be given priority over others or dedicated tracks can be developed for the effective coal supply.
- Underutilization of allocated captive coal block and higher mining cost of captive-coal barriers come at the next level which are driven by bottom level of the barriers. The non-core sector companies lack expertise in mining coal from the captive blocks allocated to them for varied reasons. This process consumes extra time and leads to higher cost of mining as well. Therefore, non-core sector becomes dependent on imported coal. Even though imported coal is costly, but in order to meet the grade requirement of coal, these companies are

Table 6
Structural self-interaction matrix (SSIM).

S. No.	Barriers	14	13	12	11	10	9	8	7	6	5	4	3	2	1
1	Inconsistent supply	A	A	A	A	A	A	A	A	A	A	A	A	A	
2	Biased approach by the government	O	V	X	X	V	V	V	V	V	V	V	V		
3	Dependency on imported coal	A	A	A	A	O	A	A	O	O	A	A			
4	Lack of mining technology and infrastructure	V	X	A	X	V	V	V	O	V	V				
5	Logistics bottlenecks	O	O	A	A	A	V	A	O	V					
6	Underutilization of allocated captive coal block	O	A	A	A	O	X	A	A						
7	Monopoly of coal market	A	O	O	O	X	O	X							
8	Delay in environmental clearance and land acquisition	O	A	A	A	X	V								
9	Higher mining cost of captive coal	A	A	A	A	O									
10	Lack of linkage rationalization	O	O	A	O										
11	Low research and development	O	X	X											
12	Social and political constraints	O	X												
13	Lack of skilled personnel	O													
14	Grade slippage														

Table 7
Initial reachability matrix.

S. No.	Barriers	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Inconsistent supply	1	0	0	0	0	0	0	0	0	0	0	0	0	0
2	Biased approach by the government	1	1	1	1	1	1	1	1	1	1	1	1	1	0
3	Dependency on imported coal	1	0	1	0	0	0	0	0	0	0	0	0	0	0
4	Lack of mining technology and infrastructure	1	0	1	1	1	1	0	1	1	1	1	0	1	1
5	Logistics bottlenecks	1	0	1	0	1	1	0	0	1	0	0	0	0	0
6	Underutilization of allocated captive coal block	1	0	0	0	0	1	0	0	1	0	0	0	0	0
7	Monopoly of coal market	1	0	0	0	0	1	1	1	0	1	0	0	0	0
8	Delay in environmental clearance and land acquisition	1	0	1	0	1	1	1	1	1	1	0	0	0	0
9	Higher mining cost of captive coal	1	0	1	0	0	1	0	0	1	0	0	0	0	0
10	Lack of linkage rationalization	1	0	0	0	1	0	1	1	0	1	0	0	0	0
11	Low research and development	1	1	1	1	1	1	0	1	1	0	1	1	1	0
12	Social and political constraints	1	1	1	1	1	1	0	1	1	1	1	1	1	0
13	Lack of skilled personnel	1	0	1	1	0	1	0	1	1	0	1	1	1	0
14	Grade slippage	1	1	1	0	0	0	1	0	1	0	0	0	0	1

NOTE: This table is derived from Table 6.

Table 8
Final reachability matrix.

S. No.	Barriers	1	2	3	4	5	6	7	8	9	10	11	12	13	14	Driving
1	Inconsistent supply	1	0	0	0	0	0	0	0	0	0	0	0	0	0	*1*
2	Biased approach by the government	1	1	1	1	1	1	1	1	1	1	1	1	1	1[a]	*14*
3	Dependency on imported coal	1	0	1	0	0	0	0	0	0	0	0	0	0	0	*2*
4	Lack of mining technology and infrastructure	1	1[a]	1	1	1	1	1[a]	1	1	1	1	1[a]	1	1	*14*
5	Logistics bottlenecks	1	0	1	0	1	1	0	0	1	0	0	0	0	0	*5*
6	Underutilization of allocated captive coal block	1	0	1[a]	0	0	1	0	0	1	0	0	0	0	0	*4*
7	Monopoly of coal market	1	0	1[a]	0	1[a]	1	1	1	1[a]	1	0	0	0	0	*8*
8	Delay in environmental clearance and land acquisition	1	0	1	0	1	1	1	1	1	1	0	0	0	0	*8*
9	Higher mining cost of captive coal	1	0	1	0	0	1	0	0	1	0	0	0	0	0	*4*
10	Lack of linkage rationalization	1	0	1[a]	0	1	1[a]	1	1	1[a]	1	0	0	0	0	*8*
11	Low research and development	1	1	1	1	1	1	1[a]	1	1	1[a]	1	1	1	1[a]	*14*
12	Social and political constraints	1	1	1	1	1	1	1[a]	1	1	1	1	1	1	1[a]	*14*
13	Lack of skilled personnel	1	1[a]	1	1	1[a]	1	1[a]	1	1	1[a]	1	1	1	1[a]	*14*
14	Grade slippage	1	1	1	1[a]	1[a]	1[a]	1	1[a]	1	1[a]	1[a]	1[a]	1[a]	1	*14*
	Dependence	*14*	*6*	*13*	*6*	*10*	*12*	*9*	*9*	*12*	*9*	*6*	*6*	*6*	*6*	

NOTE: This table is derived from Table 7 after applying transitivity.
[a] Entries show the transitivity.

Table 9
Final barriers level partitioning.

Barriers	Reachability Set	Antecedents Set	Intersection Set	Level
B1	1	1,2,3,4,5,6,7,8,9,10,11,12,13,14	1	I
B3	3	2,3,4,5,6,7,8,9,10,11,12,13,14	3	II
B6	6,9	2,4,5,6,7,8,9,10,11,12,13,14	6,9	III
B9	6,9	2,4,5,6,7,8,9,10,11,12,13,14	6,9	III
F5	5	2,4,5,7,8,10,11,12,13,14	5	IV
B7	7,8,10	2,4,7,8,10,11,12,13,14	7,8,10	V
B8	7,8,10	2,4,7,8,10,11,12,13,14	7,8,10	V
B10	7,8,10	2,4,7,8,10,11,12,13,14	7,8,10	V
B2	2,4,11,12,13,14	2,4,11,12,13,14	2,4,11,12,13,14	VI
B4	2,4,11,12,13,14	2,4,11,12,13,14	2,4,11,12,13,14	VI
B11	2,4,11,12,13,14	2,4,11,12,13,14	2,4,11,12,13,14	VI
B12	2,4,11,12,13,14	2,4,11,12,13,14	2,4,11,12,13,14	VI
B13	2,4,11,12,13,14	2,4,11,12,13,14	2,4,11,12,13,14	VI
B14	2,4,11,12,13,14	2,4,11,12,13,14	2,4,11,12,13,14	VI

NOTE: This table is derived from Table 8 after applying the rules for level partitioning.

bound to invest in imported coal due to unavailability of good quality coal in India.

4.2. MICMAC analysis

Finally, from this study, it is concluded that all barriers converge at 'inconsistent supply' which occurs at the top level and is driven by five more levels of barriers in the ISM hierarchy.

The following can be concluded from the MICMAC analysis.

- Cluster I (see Fig. 3) is called as 'autonomous' having barriers with weak driving as well as dependence power. In our study, no single barrier falls in this cluster which implies that all the barriers are significant.
- Cluster II is called as 'dependent'. It has low driving power but high dependence power. The results from this study show that there are 5 barriers i.e., 'B1', 'B3', 'B5', 'B6', and 'B9' which fall in this cluster.
- Cluster III is called 'linkage', which consists of the barriers that have high driving and high dependence power. In this study, there are 3 linkage barriers namely, 'B7', 'B8', and 'B10'.
- Lastly, Cluster IV is called 'driver/independent'. The barriers appearing in this cluster have low dependence power but very high driving power. In our case, a total of 6 barriers are identified namely, 'B2', 'B4', 'B11', 'B12', 'B13', and 'B14'.

4.3. DEMATEL method

In this section the study proposed the nature of each barrier and categorises the barriers into "cause-and-effect" groups.

4.3.1. Cause group

Eight barriers are recognized as cause. This implies that these barriers have more influence on the rest of barriers. The highest "D - R" value is for biased approach by government (B2), followed by lack of mining technology and infrastructure (B4), low research and development (B11), logistics bottlenecks (B5), lack of skilled personnel (B13), social and political constraints (B12), delay in environmental clearance and land acquisition (B8) and lack of linkage rationalization (B10). It is concluded that addressing the cause barriers will indirectly help in taking care of the effect group barriers. Thus, policy makers need to first emphasize on the barriers that belong to cause group to implement effective coal sourcing strategies. It is proposed that a strong involvement of the government by ensuring fair governance mechanism which will coordinate collective actions and address the demand supply mismatch in the coal sector (Dong et al., 2021).

4.3.2. Effect group

From the (D - R) score, six barriers affecting coal sourcing are categorized under effect group because they have strong dependency over the cause group barriers. The lesser score of −2.58 for dependency on imported coal (B3) implies that it has the highest dependency on barriers from the cause group. The rest of the barriers from the effect group in descending order are inconsistent supply (B1), underutilization of allocated captive coal (B6), higher mining cost of captive coal (B9), grade slippage (B14), and monopoly of coal market (B7).

While conducting the analysis, authors have observed that the cause

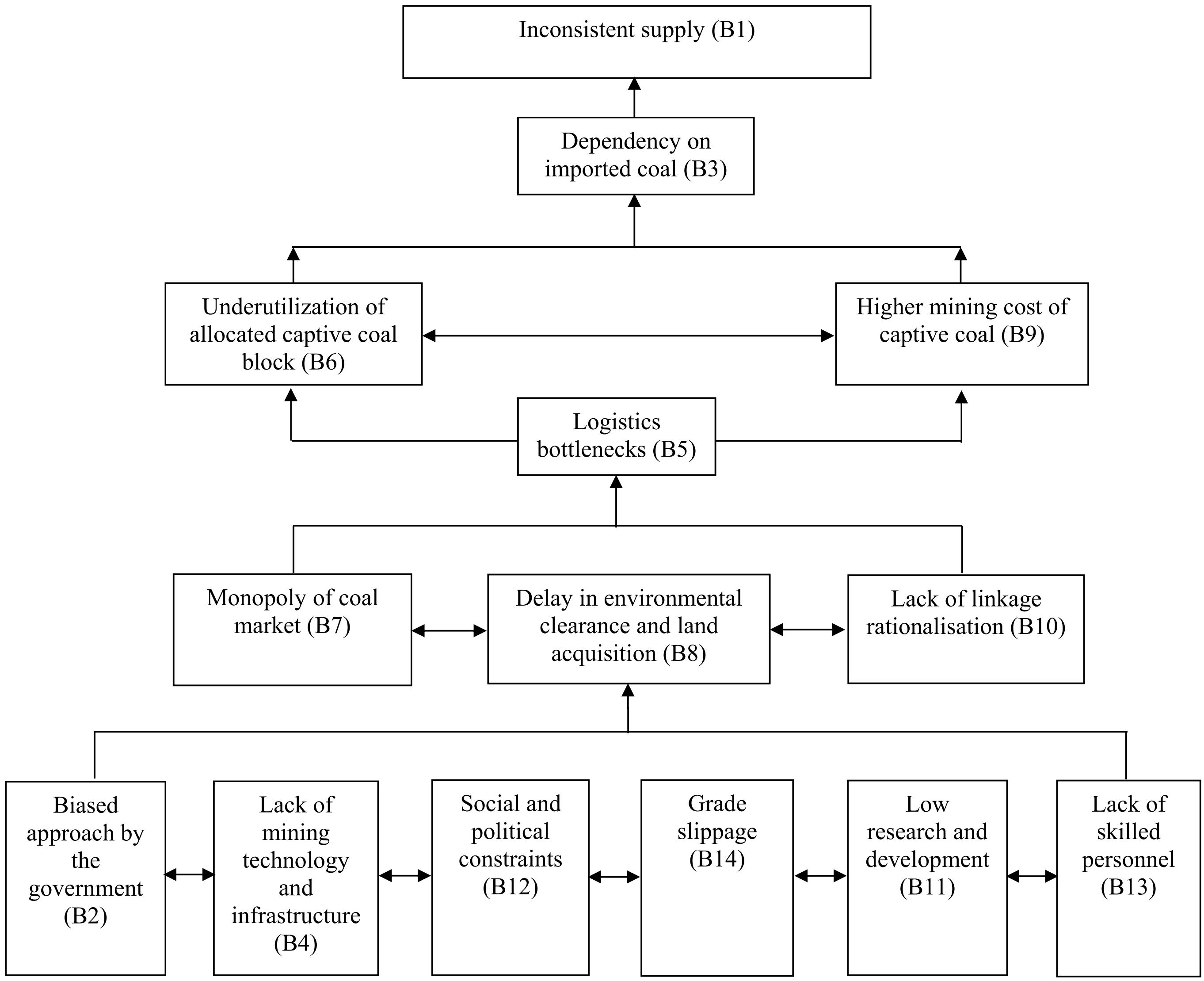

Fig. 2. Hierarchy structure showing the relationship between barriers. NOTE: This figure presents the structural model which is generated from the findings of Tables 8 and 9

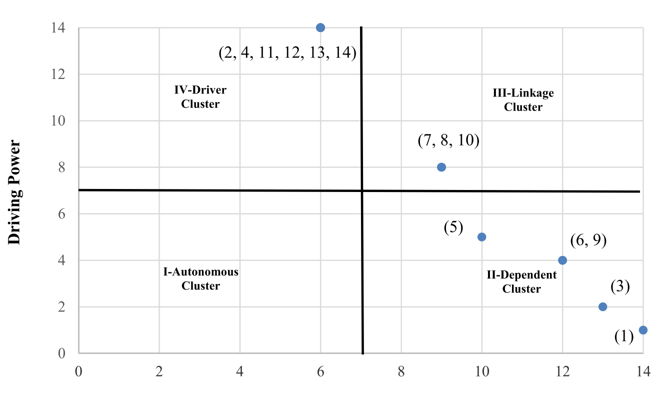

Fig. 3. Driving/dependence power diagram. NOTE: This figure is derived from Table 8 after calculating the driving and dependence powers.

group barriers can be further classified based on their influence on the effect group as *high, medium,* and *low*. This highlights the degree of influence of the cause group barriers. As per the study, B2 (cause group) has a *high* influence on B3 (effect group); B4 (cause group) has a *high* influence on B1 & B3 (effect group). Similarly, B11 & B12 (cause group) have a *high* influence on B1 & B3 (effect group). In addition to this, B5 (cause group) has a *medium* influence on B9 (effect group). Lastly, B8 (cause group) has a *low* influence on B14 (effect group) and B13 (cause group) has a *low* influence on B14 (effect group).

Therefore, top management of coal industries and policy makers must focus on these driving barriers more precisely and consider them as the most important obstacles. Any changes in these barriers will have an influence on other barriers at the hierarchical level.

5. Conclusion and policy implications

Apart from the power sector, coal has a high demand from non-core coal dependent industries in India. This study provides a comprehensive analysis of the barriers affecting coal sourcing and supply processes in these sectors in India. Through the ISM and DEMATEL methods, several unique findings have emerged, shedding light on the complexities of the coal supply chain and highlighting critical areas for intervention and improvement. This study highlights fourteen barriers hindering the efficient coal supply process to non-core coal dependent sectors. Employing a hybrid ISM-DEMATEL technique, the research addresses the research questions posed earlier by scrutinizing contextual

Table 10
Direct influence/average matrix.

Barriers	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12	B13	B14
B1	0.000	0.667	3.333	0.667	1.667	2.833	3.000	0.833	1.000	0.667	0.667	0.500	0.333	0.667
B2	3.333	0.000	2.833	0.667	0.500	0.833	3.500	2.667	0.833	3.333	1.667	2.500	0.667	1.333
B3	1.333	0.333	0.000	0.667	1.000	1.333	1.000	0.833	1.167	0.833	0.500	0.833	0.667	0.833
B4	3.167	0.500	2.500	0.000	2.833	3.500	1.167	1.833	3.833	1.333	1.333	1.167	0.667	1.667
B5	3.667	0.833	3.167	1.000	0.000	2.000	2.167	0.667	2.500	1.667	0.167	1.333	0.333	1.333
B6	3.167	0.333	3.000	0.333	0.500	0.000	0.667	0.333	2.000	0.500	0.167	1.167	0.333	0.667
B7	3.833	1.833	3.333	1.333	0.667	0.333	0.000	1.167	1.167	2.167	0.667	2.167	0.500	1.000
B8	3.833	0.333	3.500	0.167	0.500	1.833	2.000	0.000	2.333	0.500	0.000	2.167	0.167	1.167
B9	1.833	0.667	2.000	0.833	0.500	2.667	1.500	0.500	0.000	0.333	0.500	0.167	0.167	0.167
B10	3.667	1.000	2.167	0.500	0.833	1.333	2.833	0.333	1.833	0.000	0.167	1.167	0.167	1.000
B11	2.500	0.500	2.000	3.167	2.167	2.000	1.167	0.667	1.167	1.000	0.000	0.333	1.333	0.667
B12	3.167	2.333	2.000	0.167	1.000	1.167	1.833	3.667	0.667	0.833	0.833	0.000	0.333	0.833
B13	1.667	0.333	1.333	0.833	0.500	1.833	0.000	0.667	1.333	0.667	1.000	0.333	0.000	1.000
B14	1.167	0.667	3.667	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.333	0.667	0.500	0.000

NOTE: This table shows the average of responses collected from the expert panel.

Table 11
Normalised direct influence matrix.

Barriers	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12	B13	B14
B1	0.000	0.026	0.131	0.026	0.065	0.111	0.118	0.033	0.039	0.026	0.026	0.020	0.013	0.026
B2	0.131	0.000	0.111	0.026	0.020	0.033	0.137	0.105	0.033	0.131	0.065	0.098	0.026	0.052
B3	0.052	0.013	0.000	0.026	0.039	0.052	0.039	0.033	0.046	0.033	0.020	0.033	0.026	0.033
B4	0.124	0.020	0.098	0.000	0.111	0.137	0.046	0.072	0.150	0.052	0.052	0.046	0.026	0.065
B5	0.144	0.033	0.124	0.039	0.000	0.078	0.085	0.026	0.098	0.065	0.007	0.052	0.013	0.052
B6	0.124	0.013	0.118	0.013	0.020	0.000	0.026	0.013	0.078	0.020	0.007	0.046	0.013	0.026
B7	0.150	0.072	0.131	0.052	0.026	0.013	0.000	0.046	0.046	0.085	0.026	0.085	0.020	0.039
B8	0.150	0.013	0.137	0.007	0.020	0.072	0.078	0.000	0.092	0.020	0.000	0.085	0.007	0.046
B9	0.072	0.026	0.078	0.033	0.020	0.105	0.059	0.020	0.000	0.013	0.020	0.007	0.007	0.007
B10	0.144	0.039	0.085	0.020	0.033	0.052	0.111	0.013	0.072	0.000	0.007	0.046	0.007	0.039
B11	0.098	0.020	0.078	0.124	0.085	0.078	0.046	0.026	0.046	0.039	0.000	0.013	0.052	0.026
B12	0.124	0.092	0.078	0.007	0.039	0.046	0.072	0.144	0.026	0.033	0.033	0.000	0.013	0.033
B13	0.065	0.013	0.052	0.033	0.020	0.072	0.000	0.026	0.052	0.026	0.039	0.013	0.000	0.039
B14	0.046	0.026	0.144	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.013	0.026	0.020	0.000

NOTE: This table is derived by normalizing Table 10.

Table 12
Total relation/influence matrix.

Barriers	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12	B13	B14
B1	0.180	0.081	0.302	0.079	0.129	0.215	0.221	0.102	0.140	0.099	0.064	0.098	0.045	0.087
B2	0.390	0.088	0.374	0.105	0.123	0.199	0.306	0.211	0.179	0.231	0.121	0.209	0.072	0.143
B3	0.172	0.051	0.125	0.061	0.085	0.130	0.116	0.080	0.114	0.079	0.046	0.083	0.046	0.074
B4	0.371	0.097	0.357	0.077	0.204	0.303	0.211	0.167	0.291	0.148	0.104	0.149	0.070	0.149
B5	0.344	0.100	0.335	0.100	0.083	0.215	0.222	0.112	0.212	0.148	0.055	0.140	0.050	0.123
B6	0.241	0.055	0.244	0.051	0.072	0.091	0.114	0.068	0.147	0.070	0.037	0.096	0.036	0.070
B7	0.354	0.138	0.341	0.113	0.113	0.158	0.151	0.139	0.165	0.170	0.077	0.173	0.058	0.114
B8	0.320	0.074	0.318	0.059	0.091	0.190	0.197	0.078	0.187	0.091	0.042	0.158	0.039	0.106
B9	0.194	0.063	0.203	0.069	0.069	0.181	0.137	0.069	0.074	0.064	0.047	0.061	0.029	0.050
B10	0.312	0.098	0.267	0.073	0.102	0.167	0.226	0.089	0.167	0.075	0.048	0.121	0.038	0.099
B11	0.294	0.079	0.280	0.179	0.166	0.216	0.173	0.105	0.170	0.119	0.047	0.097	0.087	0.098
B12	0.326	0.151	0.290	0.067	0.116	0.176	0.211	0.223	0.142	0.119	0.078	0.096	0.049	0.105
B13	0.176	0.046	0.169	0.068	0.067	0.149	0.075	0.070	0.119	0.069	0.064	0.059	0.021	0.078
B14	0.147	0.058	0.240	0.051	0.062	0.089	0.088	0.064	0.080	0.063	0.038	0.071	0.039	0.038

NOTE: This table provides both direct and indirect influence of barriers.

relationships, discerning cause-and-effect dynamics, and proposing a set of policy recommendations aimed at facilitating an effective coal sourcing process in the non-core sector. Figs. 3 and 4 offer valuable guidance for top-level management in the coal sector and policy makers regarding prioritization of barriers for intervention. It was seen that, ‘Inconsistent supply’ emerges at the apex of the hierarchy. Barriers namely ‘biased approach by the government’, ‘lack of mining technology and infrastructure’, ‘low research and development’, ‘social and political constraints’, ‘lack of skilled personnel’, and ‘grade slippage’ constituted the bottom level which denoted as the most significant barriers. Further, utilizing DEMATEL, barriers were classified as either cause or effect group barriers, offering a nuanced understanding of how to address coal sourcing challenges more effectively by understanding their nature of relationships. It is imperative for top management and policy makers to assume a pivotal role in mitigating these barriers to facilitate the implementation of effective coal sourcing strategies. The critical concluding remarks of this study can be highlighted as follows-

- Fourteen critical barriers to effective coal supply in non-core sectors are identified, emphasizing the need for targeted policy interventions.
- Recommendations include fostering collaborations, investing in technology, and promoting fair governance to address key challenges.

Table 13
Degree of influence.

Barriers	D	R	D + R	D-R	Identity
B1	1.84	3.82	5.66	−1.98	Effect
B2	2.75	1.18	3.93	1.57	Cause
B3	1.26	3.85	5.11	−2.58	Effect
B4	2.70	1.15	3.85	1.55	Cause
B5	2.24	1.48	3.72	0.76	Cause
B6	1.39	2.48	3.87	−1.09	Effect
B7	2.26	2.45	4.71	−0.18	Effect
B8	1.95	1.58	3.53	0.37	Cause
B9	1.31	2.19	3.50	−0.87	Effect
B10	1.88	1.55	3.43	0.34	Cause
B11	2.11	0.87	2.98	1.24	Cause
B12	2.15	1.61	3.76	0.54	Cause
B13	1.23	0.68	1.91	0.55	Cause
B14	1.13	1.33	2.46	−0.21	Effect

NOTE: This table showcases the degree of importance of barriers.

- ISM and DEMATEL analyses provide insights into barrier clustering and cause-and-effect relationships, guiding strategic interventions.
- Collaboration between top management and policy makers is crucial for developing targeted strategies to enhance coal supply chain resilience.
- Stakeholders must remain proactive in addressing emerging barriers to ensure long-term sustainability.

5.1. Theoretical implications

This research analyses the interrelationships among the barriers influencing effective coal sourcing strategies. The proposed barriers in this study are an outcome of rigorous literature review and concurrent brainstorming sessions with the experts. Three unique barriers towards coal sourcing especially from the perspective of the non-core coal dependent sector are a direct contribution by the authors to the literature in this domain. This work evaluates the cause-and-effect type relationships among them. Coal sourcing in non-core sector has received very little attention from the researchers. This study contributes to theory building by justifying the relationships among the barriers under study. The proposed model not only evaluates the barriers but also provides an understanding of the degree of influence of certain barriers. This is done by further assessing the relationships among these barriers through the 'how' and 'why' questions. In response to the dearth of empirical studies done in this field, this study provides a basis to develop statistical models on coal sourcing for future researchers.

5.2. Managerial implications

This study is crucial in the coal sector for implementing effective coal sourcing practices. The implementation of the effective coal sourcing strategies is greatly affected by mutual interactions of the barriers. The idea of the hindering impact of the barriers will assist practitioners and policy makers in their decision making. They may decide to either take precautionary measures or devise strategies to improve in necessary areas. This assessment aims to assist policy makers in developing a roadmap that will address the barriers from the coal sourcing process.

The ISM-based hierarchy provides an overview of the interrelationships among barriers that hinder effective coal sourcing. This work classifies barriers as per their driving and dependence power. The results from this study will assist policy makers to analyse the priority of barriers. In our research, no single barrier appears in the autonomous cluster which implies that policy makers cannot ignore any barrier for the implementation of effective coal sourcing. Since it is difficult for policy makers to focus on every barrier simultaneously, our study offers a set of managerial implications based on the findings for assistance in their decision making.

- It is recommended that government must focus on implementing unbiased approaches that help in addressing social and political constraints.
- Facilitating training and development initiatives, promoting research and development towards developing indigenous mining technologies and infrastructure shall be beneficial for effective coal sourcing in the long run.
- The identified causal relationship among the barriers can support policy makers in their decision-making regarding the effective coal sourcing. The classification of barriers as cause and effect in this study shall help policy makers in developing policies to facilitate effective coal sourcing.
- It is recommended that government should allocate more funds in augmenting the existing logistics infrastructure which will have a direct bearing on linkage rationalization.
- It is further recommended that the fast tracking the process of obtaining environmental clearance shall help in reducing the lead time of coal production thereby meeting the customer demand on time.

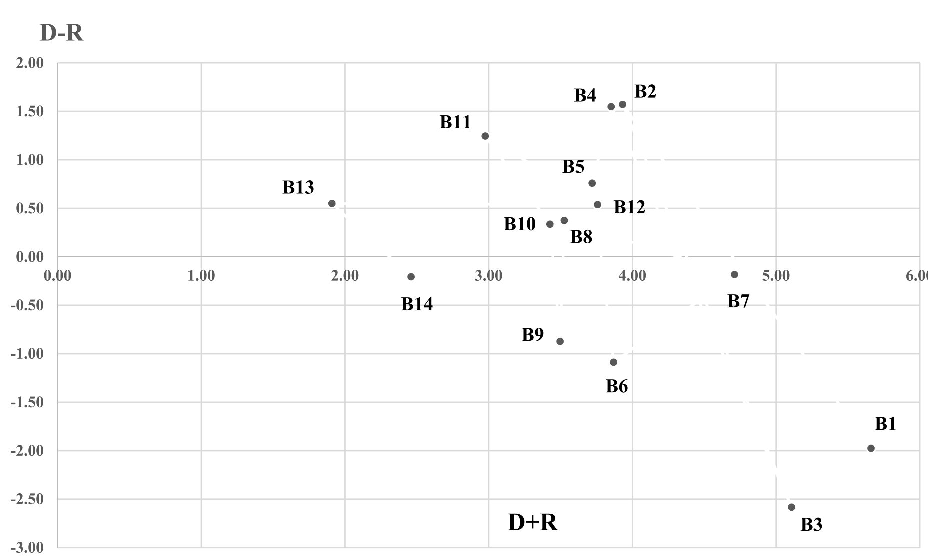

Fig. 4. Causal diagram using DEMATEL. NOTE: This figure showcases the degree of importance of barriers as a graphical representation.

Research limitations and future research directions

In this study, total fourteen barriers were examined that hindered the effective coal sourcing process in the non-core coal dependent sector of India. Since the study focuses only on a specific sector i.e., non-core coal dependent sector, therefore, the implications of the study may vary in different scenario. Correspondingly, the hierarchical model could certainly be constructed with other related sectors. Nowadays, coal supply is a big challenge not only for the coal dependent sectors in India but also at the global level. Thus, these barriers may be assessed in the context of other countries as well. In this study, we have not statistically validated the model but in future, it may be checked through structural equation modelling (SEM) to test the validity and its applicability to same or other sectors. Furthermore, identified barriers may be added or deleted as needed, or their contextual relationships may be different according to the number of experts and their opinions. Developed model can successfully be extended with fuzzy ISM, fuzzy MICMAC, fuzzy DEMATEL, total ISM (TISM) etc. which could be a future research direction.

CRediT authorship contribution statement

Rajesh Katiyar: Conceptualization, Formal analysis, Data curation, Validation, Visualization, Methodology, Supervision, Writing – original draft, Writing – review & editing. **Swayam Sampurna Panigrahi:** Data curation, Visualization, Conceptualization, Formal analysis, Supervision, Writing – original draft, Writing – review & editing. **Ranjit Roy Ghatak:** Conceptualization, Supervision. **Ritu Singh:** Data curation, Conceptualization, Writing – original draft.

Declaration of competing interest

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Data availability

Data will be made available on request.

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