Futurology of Iran's Mining Industries with a Focus on Circular Economy

Ebrahim Ghanavati[1], Mohammad Hasan Maleki[2]*, Mohammad Reza Pourfakharan[3], Mozhgan Safa[3]

1.PhD Student, Department of Management, Qom Branch, Islamic Azad University, Qom, Iran.
2. Associate Professor, Department of Management, University of Qom, Qom, Iran (Corresponding Author).
3. Assistant Professor, Department of Accounting, Qom Branch, Islamic Azad University, Qom, Iran.

*** Corresponding author email address**: bozorgmehr.maleki1363@gmail.com

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Abstract

In today's world, the application of circular economy policies and programs plays a significant role in guiding the mining industries toward sustainable development. However, efforts to achieve sustainable development in Iran's mining industries have not been sufficiently serious. This study aims to explore the future of Iran's mining industries with a focus on the circular economy. Methodologically, this research employs a mixed-method approach and is exploratory in purpose. The study uses fuzzy Delphi, CoCoSo, and focus group interviews to assess the drivers and develop scenarios. In the first step, 33 drivers were identified through a literature review and interviews with experts in the mining industries. The drivers were then screened using expert validation questionnaires and the fuzzy Delphi technique. Nine drivers were selected for the final assessment using the CoCoSo method. These final drivers were prioritized through preference questionnaires and the CoCoSo method. Finally, future scenarios for the mining industries, focusing on the circular economy, were developed based on two prioritized drivers and interviews with focus groups. Based on the CoCoSo method scores and expert opinions, the drivers of government and large financial institutions' support, such as banks for waste management and recycling projects, and energy pricing policies in the country were the most prioritized factors influencing the future of mining industries with a focus on the circular economy. Four scenarios were developed based on the two final drivers and interviews with focus groups. These scenarios included: Generous Supporter, Sustainable Mining Industries, Dark Era, and Future-Oriented Policymakers. Practical recommendations were developed based on the most important drivers and the optimal scenario (Sustainable Mining Industries). Key recommendations include prioritizing waste management and recycling projects for financing by banks, shifting from directive policy-making to market-based and competitive policy-making, and leveraging green startups in research and development projects in the mining industries.

Keywords: *Futurology, Scenario Planning, Mining Industries, Circular Economy*

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1. Introduction

The circular economy is a modern economic concept that has attracted considerable attention from scholars in recent years. The essence of the circular economy lies in the optimal and efficient use of limited resources, the elimination of waste, and the reuse of such waste in production processes or for producing by-products. Traditionally, under the linear economy model in production, the primary goal of economic units is to maximize profits. However, in a circular economy, waste management also becomes a central consideration alongside profit maximization. The circular economy fosters increased added value and profit margins, cost savings, improved competitiveness, reduced environmental pollution, and the creation of new job opportunities [1].

The circular economy, also known as circularity, is an economic system aimed at minimizing waste and maximizing the use of resources [2]. It has emerged as a strategy for achieving more effective conservation of non-renewable resources and transforming global production and consumption models into a more impactful economic model, which has become a priority for international policymakers. For example, the European Commission has developed an action plan for the circular economy [3].

However, achieving the goals of a circular economy remains a critical challenge. For instance, in the waste management system, Germany, which has one of the most successful waste management systems globally, has derived a maximum of 20% of the raw materials used in industries from recycling processes in recent years. The remaining industrial raw materials still largely consist of primary, non-renewable resources [4].

In the European Union, the production of non-mineral waste increased at an annual rate of approximately four percent from 2004 to 2018, reaching around 800 million tons, whereas the rate of resource utilization from waste recycling remains slow. From 2004 to 2020, recycled materials in production increased from about eight percent to 13 percent, yet approximately 90% of production still relies on primary resources [5]. In developing economies, factors such as rapid population growth, the need for processing natural and virgin underground resources, and inefficient industrial structures are crucial drivers toward the circular economy [6].

The circular economy believes in the use of all impacts of industrial activities and their reintegration into the production cycle. In a circular economy, even mining and urban wastewater can be recycled. Wastewater from most factories, production units, and industrial facilities contains significant amounts of heavy metals [7]. This wastewater contributes to soil and water pollution and poses a risk of bioaccumulation of metals in the food chain. Consequently, the role of startups in the future of the mining industries is expected to grow. Startups enhance metal recovery solutions to filter metals from wastewater streams [8]. Such solutions not only benefit the environment but also reduce material costs for producers.

The circular economy represents an economic system based on business models that replace the concept of material and product end-of-life with a focus on reduction, reuse, recycling, and recovery throughout the production, distribution, and consumption cycles [9]. It emphasizes production and consumption processes that limit the use of non-renewable resources and eliminate waste, as production and consumption residues are recycled [10]. This industrial strategy, with its long-term design principles, involves the repair, recycling, or reuse of products to maximize profit while preventing adverse effects [11]. The circular economy operates under three fundamental principles: conserving natural capital by balancing renewable and non-renewable resources, extending resource lifespan through biological and technical cycles, and minimizing the negative impact of production systems [12]. Unlike a linear economy, the circular economy prioritizes environmental protection by increasing the share of renewable or recyclable resources and reducing raw material and energy consumption. Transitioning to a circular economy requires fundamental changes in the value chain, from product design and manufacturing processes to innovative business models and consumption patterns. Circular economy practices transform waste into new resources, extend product lifespans, and contribute to the preservation of natural resources [13].

Various manufacturing firms can implement circular economy models through different strategies, commonly categorized into three types [14, 15]. First, product ownership retention involves manufacturers leasing rather than selling their goods, thus retaining responsibility and ownership after customers have finished using them. This approach suits companies offering complex, high-value products, such as Xerox, which leases printers and copiers to corporate clients. Second, extending product lifespan encourages companies to design durable products, enabling a secondary market. This approach counters a trend over the past five decades where companies have intentionally reduced product durability to encourage repeat purchases, leading to resource depletion and fostering consumerism. Third, design-for-recycling strategies involve revising product designs and production processes to maximize the recyclability of materials used. Such strategies often involve partnerships with specialized technology firms. Adidas, for example, collaborates with Parley to repurpose ocean plastic waste into fibers for shoes and apparel, reducing plastic pollution. Overall, the circular economy brings substantial benefits to industries, businesses, societies, and the environment, including reduced greenhouse gas emissions, biodiversity conservation, enhanced ocean and water quality, and economic growth through waste reduction and recycling innovations [16, 17].

Recent studies highlight the significance of circular economy practices in diverse sectors. For example, Yu et al. (2024) examined the role of recycling and sustainable chemical engineering in transforming mining waste into valuable resources, focusing on sustainable solutions for environmental impact mitigation. Dey et al. (2022) explored circular economy adoption in European small and medium-sized enterprises (SMEs), identifying the pivotal role of design in achieving circular economy objectives and emphasizing the need for enhanced waste management and resource recovery in SMEs across France, Greece, Spain, and the United Kingdom [18]. Kusumowardani et al. (2022) focused on a circular capability framework for addressing food waste in agricultural supply chains [19]. Additionally, Jia et al. (2020) investigated circular economy challenges in the textile industry, highlighting factors like drivers, barriers, and sustainable performance metrics [20]. In the mining sector, research remains relatively nascent, primarily focusing on opportunities, barriers, and challenges related to circular economy integration [5, 14, 21-23]. Given the emerging nature of circular economy research, future-oriented studies on drivers and scenarios in Iran's mining industry could provide valuable insights into the sector's sustainable development potential through circular economy integration.

The role of the circular economy in the mining industries will become increasingly significant in the future. Identifying the drivers and future scenarios for the mining industries with a focus on the circular economy will help prepare these industries to meet sustainable development goals. The mining sector in Iran is an important economic area and also a major contributor to environmental pollution. Policymakers in this sector, with a clear understanding of the future of the industry, can design effective programs for sustainable development and movement toward a circular economy. This study aims to explore the future of Iran's mining industries with a focus on the circular economy using a scenario-planning approach. The research questions are as follows:

What are the key drivers impacting the future of Iran's mining industries with a focus on the circular economy?

What are the plausible future scenarios for Iran's mining industries with a focus on the circular economy?

2. Methodology

The primary objective of this study is to identify and analyze the drivers and future scenarios for Iran's mining industries, with a focus on the circular economy. For this purpose, the research employed the fuzzy Delphi, CoCoSo, and focus group interview methods to prioritize drivers and develop scenarios. Both fuzzy Delphi and CoCoSo are quantitative methods that utilize judgment-based quantitative data for analysis and evaluation. In contrast, focus group interviews are a qualitative technique. The fuzzy Delphi method was used to screen the drivers, while the CoCoSo technique was employed to evaluate and rank them. Given the combined use of quantitative and qualitative techniques, this study adopts a mixed-methods approach. Additionally, due to the practical applications and benefits of the research findings for the mining industry, this study has an applied orientation.

Two main tools, interviews and questionnaires, were used for data collection. Future drivers of Iran's mining industries were derived from a review of studies related to sustainable and circular economies. Subsequently, two questionnaires—a fuzzy screening (expert validation) questionnaire and a CoCoSo prioritization questionnaire—were distributed among experts to evaluate the drivers. The fuzzy Delphi method was used for expert validation questionnaires, and the CoCoSo technique was used for prioritization questionnaires. Because the drivers were derived from an extensive review of international and domestic articles on sustainable and circular economies and interviews with mining industry experts, both questionnaires demonstrated appropriate validity. Additionally, with an adequate sample size of 10 experts, the prioritization questionnaire showed satisfactory reliability. The sample size of 10 is considered suitable for judgment-based expert techniques.

The experts in this study consisted of senior managers and experts from Iran's mining industries (steel, copper, and aluminum) with specializations in sustainable and circular economy fields. A purposive sampling approach was used, selecting participants based on their expertise in sustainable economy, mining industries, and circular economy.

The research was conducted in four stages. In the first stage, drivers for the future of Iran's mining industries, focusing on the circular economy, were identified through a literature review and interviews with mining industry experts. In the next stage, these drivers were screened using the fuzzy Delphi method and the distribution of expert validation questionnaires. In the third stage, the main drivers were identified using the CoCoSo method. Finally, in the fourth stage, future scenarios for Iran's mining industries with a focus on the circular economy were developed through focus group interviews.

In this study, the fuzzy Delphi method was used to screen drivers impacting the future of mining industries with a focus on the circular economy. The fuzzy Delphi algorithm initially requires a suitable fuzzy scale to fuzzy-translate the experts' linguistic statements. This study utilized a five-point Likert scale, as shown in Table 1.

Table 1. Fuzzy Delphi Method Scale

Verbal Variable	Fuzzy Value	Triangular Fuzzy Number
Very Low	$\tilde{1}$	(0, 0, 0.25)
Low	$\tilde{2}$	(0, 0.25, 0.5)
Medium	$\tilde{3}$	(0.25, 0.5, 0.75)
High	$\tilde{4}$	(0.5, 0.75, 1)
Very High	$\tilde{5}$	(0.75, 1, 1)

After screening the drivers for the future of Iran's mining industries with a focus on the circular economy, the drivers were ranked. The current study used the COCO-SO technique for ranking, a recent and reliable ranking method that combines information from the fuzzy best-worst and fuzzy WASPAS methods. The steps of the COCO-SO method include:

Step 1: Collect experts' opinions on the importance of research factors on a 10-point scale.

Step 2: Normalize decision matrix values using the fuzzy method.

Step 3: Calculate the weighted sum (S) and weighted product (P) for each option using the formulas below. Here, W_j represents the weight of the indicators, with S_i derived from the SAW method and P_i from the WASPAS method.

$$S_i = \sum_{j=1}^{n} (w_j r_{ij}),$$

$$P_i = \sum_{j=1}^{n} (r_{ij})^{w_j},$$

Step 4: Calculate option scores based on three strategies. The first relation describes the arithmetic mean of WSM and WPM scores, the second compares relative WSM and WPM scores with the best, and the third is a compromise between WSM and WPM models, where λ is specified by the decision-maker, often set to 0.5 for flexibility.

$$k_{ia} = \frac{P_i + S_i}{\sum_{i=1}^{m} (P_i + S_i)},$$

$$k_{ib} = \frac{S_i}{\min_i S_i} + \frac{P_i}{\min_i P_i},$$

$$k_{ic} = \frac{\lambda(S_i) + (1-\lambda)(P_i)}{\left(\lambda \max_i S_i + (1-\lambda) \max_i P_i\right)}, \quad 0 \le \lambda \le 1.$$

Step 5: Obtain the final score using the relation below, representing the sum of the geometric and arithmetic means from the previous step. A higher *k* score indicates a superior option.

$$k_i = (k_{ia} k_{ib} k_{ic})^{\frac{1}{3}} + \frac{1}{3}(k_{ia} + k_{ib} + k_{ic}).$$

Finally, future scenarios for Iran's mining industries with a focus on the circular economy were developed using focus group interviews, a common foresight method for scenario development. This method, based on focused group discussions, aims to gather participants' views without threat or pressure. Focus groups typically include 6 to 12 participants; in this study, seven experts participated in collaborative sessions. These sessions were led by a moderator responsible for guiding the discussion and creating an environment where participants could freely express their opinions.

3. Findings and Results

The influential drivers for the future of Iran's mining industries, with a focus on the circular economy, were obtained through an analytical literature review and expert interviews in circular economy fields. A total of 33 drivers were identified, 26 from the literature and the remainder from interviews. Table 2 lists these key drivers. To identify these drivers, research related to sustainable and circular economies was thoroughly reviewed.

Table 2. Future Drivers of Mining Industries with a Focus on the Circular Economy

Research Sources	Research Drivers
[24]	Promoting a culture to reduce consumerism
[25]	Development of recycling technologies and redesign in the country
Interview	Technology transfer limitations to the country
Interview	Energy portfolio diversification in the country
[26]	Foreign investment in renewable energy
Interview	Obsolescence of production equipment and technology
[5, 23, 27]	Training on sustainable and circular economy principles for employees and managers
[28]	Maintenance and repair policies for industries and companies
[20]	Optimization of production methods
[20]	Nature of processes and work methods in companies
Interview	Government support for energy efficiency projects, such as smart equipment
[12, 16]	Interest of large financial institutions, such as banks, in sustainable financing
[29]	Government support for green projects in the country
Interview	Energy pricing policy in the country
[30]	Capital market focus on corporate governance development in the country
[31]	Focus of industries and companies on sustainable reporting
[32]	Depth of capital market expansion
[31]	Emphasis on good governance in large mining companies
[33]	Campaigns and awareness-raising on energy and product consumption patterns
[34]	Diversity of financing methods in the country
[31]	Tax incentives for green industries and businesses
[35]	Environmental requirements and energy consumption considerations in financing and loans
[36]	Cooperation between large mining industries and green startups
Interview	Collaboration of large mining companies with universities and research centers for greater sustainability
[37]	Mandatory adherence to environmental standards for companies and industries
[38]	Country commitment to international environmental agreements
[39]	Corporate social responsibility awareness among companies and industries
[40, 41]	Penetration of digital technologies, such as big data and the Internet of Things, in mining industries
[42]	Emphasis on open innovation in mining industries
[43, 44]	Policies and methods for managing mining waste in the country
[45]	Government and major financial institutions support for waste management and recycling projects
Interview	Use of foreign companies' and experts' experiences in waste management and recycling
[46]	Development of Industry 4.0 in mining

The 33 drivers identified from the literature and expert interviews were screened using the fuzzy Delphi technique. In this phase, 24 drivers were eliminated, and nine were selected for final evaluation. Drivers with a defuzzified score above 0.7 were selected for final prioritization using the CoCoSo technique. In this study, nine drivers had a defuzzified score above 0.7, which was set as the threshold for driver screening. In most studies, the threshold ranges from 0.5 to 0.7; for this study, 0.7 was selected. Table 3 lists the final screened drivers with their defuzzified values.

Table 3. Fuzzy Delphi Output for Factors Influencing Supply Chain Finance

Defuzzified Value	Upper Bound	Median	Lower Bound	Drivers
0.81	0.9	0.84	0.7	Development of recycling and redesign technologies in the country (C1)
0.72	0.82	0.73	0.62	Foreign investment in renewable energy (C2)

0.75	0.86	0.75	0.64	Maintenance and repair policies for industries and companies (C3)
0.82	0.94	0.82	0.71	Energy pricing policy in the country (C4)
0.72	0.8	0.75	0.6	Awareness-raising on energy and product consumption patterns (C5)
0.72	0.83	0.76	0.57	Diversity of financing methods in the country (C6)
0.79	0.89	0.79	0.68	Collaboration with green startups by large mining industries (C7)
0.84	0.95	0.83	0.74	Government and major financial institutions' support for waste management and recycling projects (C8)
0.77	0.91	0.77	0.63	Development of Industry 4.0 in mining industries (C9)

Next, the screened drivers were ranked using the CoCoSo method. Experts were asked to rate the importance of each driver on a 10-point scale. A decision matrix was constructed based on the responses of 10 experts, and the data was normalized using the fuzzy approach as per Step 2 of the CoCoSo method. Table 4 displays the normalized decision matrix for the future drivers of Iran's mining industries.

Table 4. Normalized Matrix of Future Drivers for Iran's Mining Industries

Expert 10	Expert 9	Expert 8	Expert 7	Expert 6	Expert 5	Expert 4	Expert 3	Expert 2	Expert 1	Research Drivers
0.625	0.667	1	0.429	0.714	0.8	0.857	0.5	0.5	0.625	C1
0	0	0	0.143	0.143	0	0	0	0	0	C2
0	0	0	0.143	0.429	0	0.143	0	0	0	C3
0.625	0.833	0.8	0.857	1	1	0.714	0.833	0.833	0.875	C4
0.125	0	0	0.143	0.143	0.2	0.429	0	0	0	C5
0.25	0.667	0	0	0	0	0.286	0.167	0	0.125	C6
0.25	0.333	0.2	0.571	0.571	0.6	0.429	0.667	0.667	0.5	C7
1	1	0.6	1	1	1	1	1	1	1	C8
0.375	0.167	0	0	0.286	0.4	0.286	0.167	0	0.375	C9

Based on the normalized matrix, weighted sum (S) and weighted product (P) matrices were calculated using the formulas from Step 3 of the CoCoSo method. Table 5 displays the weighted sum matrix for the future drivers of the mining industry with a circular economy focus. Values in the weighted sum matrix were derived by multiplying the normalized matrix data by the expert weights. All expert weights were equally set at 0.1, obtained by dividing one by ten. The matrix data was then combined using the S index, representing the row sums of the weighted sum matrix, similar to the desirability of each option in the SAW method.

Table 5. Weighted Sum Matrix (S) for Future Drivers of Iran's Mining Industries

S Index	Expert 10	Expert 9	Expert 8	Expert 7	Expert 6	Expert 5	Expert 4	Expert 3	Expert 2	Expert 1	Research Drivers
0.673	0.063	0.067	0.1	0.043	0.071	0.08	0.086	0.05	0.05	0.063	C1
0.028	0	0	0	0.014	0.014	0	0	0	0	0	C2
0.071	0	0	0	0.014	0.043	0	0.014	0	0	0	C3
0.837	0.063	0.083	0.08	0.086	0.1	0.1	0.071	0.083	0.083	0.088	C4
0.104	0.013	0	0	0.014	0.014	0.02	0.043	0	0	0	C5
0.151	0.025	0.067	0	0	0	0	0.029	0.017	0	0.013	C6
0.479	0.025	0.033	0.02	0.057	0.057	0.06	0.043	0.067	0.067	0.05	C7
0.96	0.1	0.1	0.06	0.1	0.1	0.1	0.1	0.1	0.1	0.1	C8
0.208	0.038	0.017	0	0	0.029	0.04	0.029	0.017	0	0.038	C9

Simultaneously, the weighted product matrix (P) values were calculated. The formula for this matrix and the P index is similar to the WASPAS method calculations. For the weighted product matrix, each value in the normalized matrix is raised to the power of the experts' weight, which is set at 0.1 for all experts. Table 6 displays the weighted product matrix.

Table 6. Weighted Product Matrix (P) for Research Drivers

P Index	Expert 10	Expert 9	Expert 8	Expert 7	Expert 6	Expert 5	Expert 4	Expert 3	Expert 2	Expert 1	Research Drivers
9.583	0.954	0.96	1	0.919	0.967	0.978	0.985	0.933	0.933	0.954	C1

1.646	0	0	0	0.823	0.823	0	0	0	0	0	C2
2.565	0	0	0	0.823	0.919	0	0.823	0	0	0	C3
9.817	0.954	0.982	0.978	0.985	1	1	0.967	0.982	0.982	0.987	C4
4.228	0.812	0	0	0.823	0.823	0.851	0.919	0	0	0	C5
4.361	0.871	0.96	0	0	0	0	0.882	0.836	0	0.812	C6
9.232	0.871	0.896	0.851	0.946	0.946	0.95	0.919	0.96	0.96	0.933	C7
9.95	1	1	0.95	1	1	1	1	1	1	1	C8
6.162	0.907	0.836	0	0	0.882	0.912	0.882	0.836	0	0.907	C9

The final scores for the future drivers of Iran's mining industries were determined in the CoCoSo method using the K index, which requires calculating three indices, K_a, K_b, and K_c. The K_c index is a combination of K_a and K_b. The λ value was set to 0.5 in this study, a common choice in prior research. Finally, the K index was calculated as the arithmetic and geometric mean of K_a, K_b, and K_c. Table 7 presents the four evaluation indices in the CoCoSo technique along with the final ranking of each driver.

Table 7. Four Evaluation Indices for Drivers in CoCoSo

Research Drivers	KaK_aKa	KbK_bKb	KcK_cKc	KKK	Rank
Development of recycling and redesign technologies in the country	0.168	29.858	0.94	11.99	3
Foreign investment in renewable energy	0.027	2	0.153	0.929	9
Maintenance policies for industries and companies	0.043	4.094	0.242	1.808	8
Energy pricing policy in the country	0.174	35.86	0.976	14.16	2
Awareness campaigns on energy and product consumption patterns	0.071	6.283	0.397	2.81	7
Diversity of financing methods in the country	0.074	8.042	0.413	3.47	6
Collaboration with green startups by large mining industries	0.159	22.716	0.89	9.39	4
Government and major financial institutions' support for waste management and recycling projects	0.179	40.33	1	15.77	1
Development of Industry 4.0 in mining industries	0.104	11.17	0.583	4.83	5

Based on the K index, the top-priority drivers are government and major financial institution support for waste management and recycling projects, energy pricing policy, and the development of recycling and redesign technologies in the country. The higher the K index value for a driver, the more significant it is considered. Plausible future scenarios for Iran's mining industries will be developed based on these key drivers. The future scenarios for Iran's mining industries, focused on the circular economy, were developed based on two key drivers: government and major financial institutions' support (such as banks) for waste management and recycling projects, and energy pricing policy. Each driver includes two opposing conditions. For the first driver, the opposing conditions are extensive government and financial support versus minimal support for waste management and recycling projects. The second driver has two opposing conditions: regulated (command-based) versus unregulated energy pricing policies in the country. Experts were asked to provide their views on each scenario, and the facilitator collected their insights. From the interaction of these two drivers, four scenarios emerged.

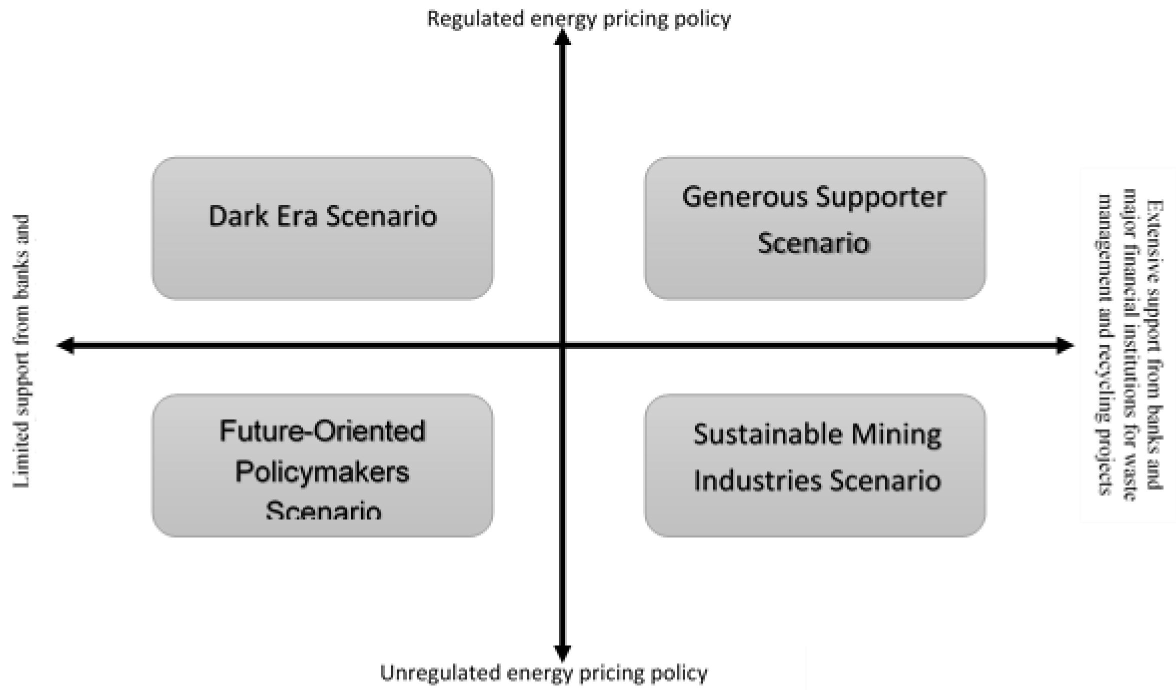

Figure 1. The Final Diagram of Study Model

A) Generous Supporter Scenario:

This scenario arises from the combination of extensive support from banks and financial institutions for waste management and recycling projects alongside regulated energy pricing policies. In this future, banks and financial institutions actively support startups, knowledge-based companies, and innovative waste management and recycling projects. Banks go beyond conventional large-scale economic projects, strengthening their expertise and showing a favorable attitude towards circular economy projects in the mining industries. This approach aligns with the banks' broader policies to achieve sustainability and green financing.

In this scenario, alongside bank financing, alternative financing methods, particularly from fintech firms and financial startups, will also expand. These methods will be well-suited for small-scale recycling projects and will benefit from collaboration and positive engagement from large financial institutions such as banks and insurance companies. Overall, there will be a diverse range of financing options.

However, a downside is that government policies on energy will remain regulated, meaning that many industries, due to access to cheap energy and raw materials, may lack motivation to move toward sustainability. Indeed, many major mining industries in Iran, benefiting from low-cost resources, may resist change. This resistance could neutralize or slow progress toward a circular economy in mining industries.

B) Sustainable Mining Industries Scenario:

This scenario represents the ideal outcome. In this future, diverse and innovative financing methods support waste management and recycling projects within the mining industries. The variety of financing options will enable broad access to affordable, innovative recycling solutions. Recycling technologies will experience significant growth, and the capital market will play an active role in financing through various financial instruments, such as green bonds, which will support the mining industry. Additionally, mining industries will make good use of foreign investment opportunities.

In this future, mining companies will collaborate effectively with green startups, especially in research and development, fostering advancements in local recycling technologies. Mining companies will develop various strategic frameworks for collaboration with green startups.

Another positive aspect of this scenario is the unregulated energy pricing policy, which is influenced by energy imbalances and seasonal shortages. Each year, industries face power outages in summer and gas shortages in winter, severely impacting operations. To address this costly issue, policymakers may move toward more realistic energy pricing, pushing mining industries toward smart energy initiatives and efficient raw material use. Such changes would promote the adoption of a circular economy within the mining industries.

C) Future-Oriented Policymakers Scenario:

This scenario results from the intersection of limited financial support for recycling and waste management projects with unregulated energy policies. Banks, constrained by limited financial resources, competing priorities, and sanctions, will be unable to support innovative recycling projects adequately. Additionally, with weak regulatory frameworks and limited fintech diversity, financing options will remain scarce.

Meanwhile, the government, under pressure from ongoing energy imbalances, will lean toward unregulated energy policies. Policymakers, despite industry resistance, will focus on long-term challenges and shift towards market-driven energy pricing. This decision may lead to short-term challenges, including potential bankruptcies of some mining industries.

In this future, due to restricted financing methods, limited bank lending, and scarce external resources, mining companies may allocate part of their own resources to recycling and waste management projects. However, the role of green startups in recycling technology development will be minor, and mining companies will have closed innovation systems.

D) Dark Era Scenario:

This scenario depicts the worst-case outcome. Here, banks lack the capacity or willingness to support innovative waste management and recycling projects. The limited range of financing options will deter many entrepreneurs and investors from engaging in the recycling and green technology sectors.

Despite widespread challenges, energy imbalances, and low-cost raw materials, policymakers show no intention of altering energy policies. Driven by populist policies, policymakers seek to postpone addressing core issues. Under these conditions, the circular economy's role within the mining industries will be minimal due to a lack of recycling technology development, inadequate financing methods, insufficient support for green startups, and mining companies' reluctance to invest in recycling technologies.

4. Discussion and Conclusion

The mining industry is a significant economic sector in the country, generating substantial foreign exchange and employment. However, the industry's development has notable social and environmental impacts. The concept of the circular economy and its policies have been extensively discussed in the mining sector. Implementing these policies plays a crucial role in achieving sustainable development, waste management, and recycling. Given the growing importance of international environmental standards and escalating environmental pollution, future studies on the circular economy's impact on the mining industry will gain more attention. This study aimed to explore the future of mining industries with a focus on the circular economy using scenario planning.

The study was conducted in four stages. In the first stage, 33 drivers were identified through a literature review and expert interviews. These drivers were screened in the next stage using expert validation questionnaires and the fuzzy Delphi method, resulting in the selection of nine drivers with a defuzzified score above 0.7. These selected drivers were prioritized using the CoCoSo method. Government and major financial institutions' support (e.g., banks) for waste management and recycling projects and energy pricing policies ranked highest. The study's scenarios were developed based on these two drivers using focus group interviews. The future scenarios for the mining industry focused on the circular economy were: Generous Supporter, Sustainable Mining Industries, Dark Era, and Future-Oriented Policymakers. The Generous Supporter scenario was considered the ideal scenario, and practical recommendations were developed based on this scenario and the prioritized drivers.

The first recommendation concerns the development of financing methods. Many projects related to recycling technologies and waste management in the mining sector require financial resources. Various options and solutions are available in this regard, with banks as a key solution. Banks need to broaden their perspective and go beyond supporting only conventional economic projects. Additionally, alongside the capital market, banks play a vital role in diversifying financing sources.

The next recommendation pertains to the development of fintech in Iran. Iranian fintech, primarily focused on payment systems due to regulatory challenges, lack of bank support, and financial constraints, should expand into financing and investment fintech. This expansion would diversify financing methods according to the type of project, increasing support for green startups and recycling projects.

Another recommendation involves implementing open innovation policies. Instead of a closed approach, mining industries could adopt an open innovation network to leverage the services and capabilities of green startups and knowledge-based companies active in recycling technologies. Collaboration between mining industries and green startups would help advance recycling technologies and strengthen green startups.

The next point concerns energy pricing policies. Cheap raw materials and energy in Iran have prevented many industries and companies from pursuing sustainable development. As a result, energy and raw material wastage rates are very high in Iranian industries, especially in the mining sector. Moving policymakers toward competitive and unregulated pricing would increase industries' inclination to collaborate with green startups and allocate some resources to recycling technologies.

Finally, data-driven digital technologies such as big data, the Internet of Things (IoT), and business intelligence could play an essential role in reducing waste and enhancing coordination by integrating the supply chain in mining industries. These technologies are beneficial in areas like forecasting, risk identification and management, and tracking waste across the supply chain. Implementing Industry 4.0 technologies depends on factors such as senior management support, employee training, and compatibility with existing technologies and infrastructure. Mining companies need to develop models for effectively adopting these technologies, and managers must understand their benefits tangibly.

For future research, suggestions include exploring the role of the circular economy in other industries, such as plastics or automotive. Additionally, following future studies, strategic planning for the mining industry in the field of the circular economy and its effective implementation could be conducted.

Authors' Contributions

Authors equally contributed to this article.

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Declaration of Interest

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Ethical Considerations

All procedures performed in this study were under the ethical standards.

References

[1] M. Davoodabadi, S. H. Sajadi Far, A. A. Ghanei, and S. Shalposh, "Approaches to circular wastewater economy in sustainable development," *Water and Sustainable Development Journal*, vol. 4, no. 2, pp. 1-12, 2017.

[2] O. Dovgal, T. Borko, N. Miroshkina, H. Surina, and D. Konoplianyk, "Circular economy as an imperative for sustainable development," *Scientific Bulletin of Mukachevo State University. Series "Economics"*, vol. 1, no. 11, pp. 19-28, 2024, doi: 10.52566/msu-econ1.2024.19.

[3] M. A. Camilleri, "European environment policy for the circular economy: Implications for business and industry stakeholders," *Sustainable Development*, vol. 28, no. 6, pp. 1804-1812, 2020, doi: 10.1002/sd.2113.

[4] T. Tomić and D. R. Schneider, "Circular economy in waste management-Socio-economic effect of changes in waste management system structure," *Journal of Environmental Management*, vol. 267, p. 110564, 2020, doi: 10.1016/j.jenvman.2020.110564.

[5] A. Upadhyay, T. Laing, V. Kumar, and M. Dora, "Exploring barriers and drivers to the implementation of circular economy practices in the mining industry," *Resources Policy*, vol. 72, p. 102037, 2021, doi: 10.1016/j.resourpol.2021.102037.

[6] A. Halog and S. Anieke, "A review of circular economy studies in developed countries and its potential adoption in developing countries," *Circular Economy and Sustainability*, vol. 1, pp. 209-230, 2021, doi: 10.1007/s43615-021-00017-0.

[7] L. A. Cisternas, J. I. Ordóñez, R. I. Jeldres, and R. Serna-Guerrero, "Toward the implementation of circular economy strategies: An overview of the current situation in mineral processing," *Mineral Processing and Extractive Metallurgy Review*, vol. 43, no. 6, pp. 775-797, 2022, doi: 10.1080/08827508.2021.1946690.

[8] M. Henry, T. Bauwens, M. Hekkert, and J. Kirchherr, "A typology of circular start-ups: An Analysis of 128 circular business models," *Journal of Cleaner Production*, vol. 245, p. 118528, 2020, doi: 10.1016/j.jclepro.2019.118528.

[9] A. Motevalli, A. Mobini Dehkardi, and H. Sadeghi, "A meta-synthesis of the relationship between the circular economy and entrepreneurial ecotourism," *Tourism Management Studies Journal*, vol. 17, no. 60, pp. 145-175, 2022.

[10] C. Rodríguez, C. Florido, and M. Jacob, "Circular economy contributions to the tourism sector: A critical literature review," *Sustainability*, vol. 12, no. 11, p. 4338, 2020, doi: 10.3390/su12114338.

[11] C. Garrido-Hidalgo, F. Ramirez, T. Olivares, and L. Sanchez, "The adoption of Internet of Things in a Circular Supply Chain framework for the recovery of WEEE: The case of Lithium-ion electric vehicle battery packs," *Waste Management*, vol. 103, pp. 32-44, 2020, doi: 10.1016/j.wasman.2019.09.045.

[12] S. Sharifian Jozi, A. Mohammadi, A. Abasi, and M. Ali Mohammadi Lou, "Identifying and prioritizing challenges in implementing circular supply chain management at Premium Bond Company," *New Research in Decision Making Journal*, vol. 8, no. 3, pp. 24-53, 2023.

[13] A. Murray, K. Skene, and K. Haynes, "The circular economy: an interdisciplinary exploration of the concept and application in a global context," *Journal of Business Ethics,* vol. 140, pp. 369-380, 2017, doi: 10.1007/s10551-015-2693-2.

[14] O. Marinina, N. Kirsanova, and M. Nevskaya, "Circular economy models in industry: Developing a conceptual framework," *Energies,* vol. 15, no. 24, p. 9376, 2022, doi: 10.3390/en15249376.

[15] P. Centobelli, R. Cerchione, D. Chiaroni, P. Del Vecchio, and A. Urbinati, "Designing business models in circular economy: A systematic literature review and research agenda," *Business Strategy and the Environment,* vol. 29, no. 4, pp. 1734-1749, 2020, doi: 10.1002/bse.2466.

[16] S. Sehnem, D. Vazquez-Brust, S. C. F. Pereira, and L. M. Campos, "Circular economy: benefits, impacts and overlapping," *Supply Chain Management: An International Journal,* vol. 24, no. 6, pp. 784-804, 2019, doi: 10.1108/SCM-06-2018-0213.

[17] V. Kumar, I. Sezersan, J. A. Garza-Reyes, E. D. Gonzalez, and M. D. A. Al-Shboul, "Circular economy in the manufacturing sector: benefits, opportunities and barriers," *Management Decision,* vol. 57, no. 4, pp. 1067-1086, 2019, doi: 10.1108/MD-09-2018-1070.

[18] P. K. Dey, C. Malesios, S. Chowdhury, K. Saha, P. Budhwar, and D. De, "Adoption of circular economy practices in small and medium-sized enterprises: Evidence from Europe," *International Journal of Production Economics,* vol. 248, p. 108496, 2022, doi: 10.1016/j.ijpe.2022.108496.

[19] N. Kusumowardani *et al.*, "A circular capability framework to address food waste and losses in the agri-food supply chain: The antecedents, principles and outcomes of circular economy," *Journal of Business Research,* vol. 142, pp. 17-31, 2022, doi: 10.1016/j.jbusres.2021.12.020.

[20] F. Jia, S. Yin, L. Chen, and X. Chen, "The circular economy in the textile and apparel industry: A systematic literature review," *Journal of Cleaner Production,* vol. 259, p. 120728, 2020, doi: 10.1016/j.jclepro.2020.120728.

[21] V. V. Gedam, R. D. Raut, A. B. L. de Sousa Jabbour, and N. Agrawal, "Moving the circular economy forward in the mining industry: Challenges to closed-loop in an emerging economy," *Resources Policy,* vol. 74, p. 102279, 2021, doi: 10.1016/j.resourpol.2021.102279.

[22] É. Lèbre, G. Corder, and A. Golev, "The role of the mining industry in a circular economy: a framework for resource management at the mine site level," *Journal of Industrial Ecology,* vol. 21, no. 3, pp. 662-672, 2017, doi: 10.1111/jiec.12596.

[23] P. H. M. Kinnunen and A. H. Kaksonen, "Towards circular economy in mining: Opportunities and bottlenecks for tailings valorization," *Journal of Cleaner Production,* vol. 228, pp. 153-160, 2019, doi: 10.1016/j.jclepro.2019.04.171.

[24] K. da Silva Duarte, T. A. da Costa Lima, L. R. Alves, P. A. do Prado Rios, and W. H. Motta, "The circular economy approach for reducing food waste: a systematic review," *Revista Produção e desenvolvimento,* vol. 7, 2021.

[25] H. Yu, I. Zahidi, C. M. Fai, D. Liang, and D. Ø. Madsen, "Mineral waste recycling, sustainable chemical engineering, and circular economy," *Results in Engineering,* vol. 21, p. 101865, 2024, doi: 10.1016/j.rineng.2024.101865.

[26] M. T. Majeed and T. Luni, "Renewable energy, circular economy indicators and environmental quality: global evidence of 131 countries with heterogeneous income groups," *Pakistan Journal of Commerce and Social Sciences (PJCSS),* vol. 14, no. 4, pp. 866-912, 2020.

[27] R. K. Singh, A. Kumar, J. A. Garza-Reyes, and M. M. de Sá, "Managing operations for circular economy in the mining sector: An analysis of barriers intensity," *Resources Policy,* vol. 69, p. 101752, 2020, doi: 10.1016/j.resourpol.2020.101752.

[28] P. Morseletto, "Targets for a circular economy," *Resources, Conservation and Recycling,* vol. 153, p. 104553, 2020, doi: 10.1016/j.resconrec.2019.104553.

[29] A. Khodaei, M. Hosseinpour, M. J. Jamshidi, and Y. Mohammadi-Far, "A meta-synthesis of the advantages of applying circular business models in the agricultural-food sector," *Journal of Entrepreneurship and Sustainable Agricultural Development Studies,* vol. 11, no. 2, pp. 1-16, 2024.

[30] N. Suchek, C. I. Fernandes, S. Kraus, M. Filser, and H. Sjögrën, "Innovation and the circular economy: A systematic literature review," *Business Strategy and the Environment,* vol. 30, no. 8, pp. 3686-3702, 2021, doi: 10.1002/bse.2834.

[31] K. Govindan and M. Hasanagic, "A systematic review on drivers, barriers, and practices towards circular economy: a supply chain perspective," *International Journal of Production Research,* vol. 56, no. 1-2, pp. 278-311, 2018, doi: 10.1080/00207543.2017.1402141.

[32] S. R. Paramati, N. Apergis, and M. Ummalla, "Financing clean energy projects through domestic and foreign capital: The role of political cooperation among the EU, the G20 and OECD countries," *Energy Economics,* vol. 61, pp. 62-71, 2017, doi: 10.1016/j.eneco.2016.11.001.

[33] D. M. Salvioni and A. Almici, "Transitioning toward a circular economy: The impact of stakeholder engagement on sustainability culture," *Sustainability,* vol. 12, no. 20, p. 8641, 2020, doi: 10.3390/su12208641.

[34] C. Karakosta, A. Papapostolou, G. Vasileiou, and J. Psarras, "Financial schemes for energy efficiency projects: Lessons learnt from in-country demonstrations," in *Energy services fundamentals and financing*: Academic Press, 2021, pp. 55-78.

[35] M. A. Urban and D. Wójcik, "Dirty banking: Probing the gap in sustainable finance," *Sustainability,* vol. 11, no. 6, p. 1745, 2019, doi: 10.3390/su11061745.

[36] O. Sadma, "The role of environmental-based "green startup" in reducing waste problem and its implication to environmental resilience," *Research Horizon,* vol. 1, no. 3, pp. 106-114, 2021, doi: 10.54518/rh.1.3.2021.106-114.

[37] D. H. Shih, C. M. Lu, C. H. Lee, S. Y. Cai, K. J. Wu, and M. L. Tseng, "Eco-innovation in circular agri-business," *Sustainability,* vol. 10, no. 4, p. 1140, 2018, doi: 10.3390/su10041140.

[38] T. Domenech and B. Bahn-Walkowiak, "Transition towards a resource efficient circular economy in Europe: policy lessons from the EU and the member states," *Ecological Economics,* vol. 155, pp. 7-19, 2019, doi: 10.1016/j.ecolecon.2017.11.001.

[39] A. Pons, C. Vintrò, J. Rius, and J. Vilaplana, "Impact of Corporate Social Responsibility in mining industries," *Resources Policy,* vol. 72, p. 102117, 2021, doi: 10.1016/j.resourpol.2021.102117.

[40] H. Lu, G. Zhao, and S. Liu, "Integrating circular economy and Industry 4.0 for sustainable supply chain management: A dynamic capability view," *Production Planning & Control,* vol. 35, no. 2, pp. 170-186, 2024, doi: 10.1080/09537287.2022.2063198.

[41] S. Sahoo and S. K. Jakhar, "Industry 4.0 deployment for circular economy performance-Understanding the role of green procurement and remanufacturing activities," *Business Strategy and the Environment,* vol. 33, no. 2, pp. 1144-1160, 2024, doi: 10.1002/bse.3542.

[42] V. Tornjanski, D. Petrović, and M. Milanović, "The effects of IT and open innovation strategies on innovation and financial

performances in the banking sector," *Bankarstvo,* vol. 45, no. 1, pp. 70-91, 2016, doi: 10.5937/bankarstvo1601070T.
[43] M. A. Nevskaya and O. A. Marinina, "Regulatory aspects of mining waste management in the Russian Federation," *Biosciences Biotechnology Research Asia,* vol. 12, no. 3, pp. 2619-2628, 2015, doi: 10.13005/bbra/1942.
[44] T. D. Yıldız, "Waste management costs (WMC) of mining companies in Turkey: can waste recovery help meeting these costs?," *Resources Policy,* vol. 68, p. 101706, 2020, doi: 10.1016/j.resourpol.2020.101706.
[45] A. Mies and S. Gold, "Mapping the social dimension of the circular economy," *Journal of Cleaner Production,* vol. 321, p. 128960, 2021, doi: 10.1016/j.jclepro.2021.128960.
[46] P. Rosa, C. Sassanelli, A. Urbinati, D. Chiaroni, and S. Terzi, "Assessing relations between Circular Economy and Industry 4.0: a systematic literature review," *International Journal of Production Research,* vol. 58, no. 6, pp. 1662-1687, 2020, doi: 10.1080/00207543.2019.1680896.