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Circular economy metrics in environmental management system for waste reduction; A case study of Isfahan's Mobarakeh Steel Company

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ABSTRACT

Climate change and resource scarcity have compelled industries to prioritize the needs of stakeholders (society, regulators, future generations, and shareholders) to ensure survival and competitiveness. Consequently, the circular economy has become a crucial strategy for manufacturing industries. By adopting and implementing this concept, industries can shift from a linear economy to a more sustainable model. This transition enhances material efficiency, optimizes resource consumption, reduces emissions into air, water, and soil, and helps move toward the goal of zero waste. Achieving these benefits requires a commitment to the principles of a circular economy. This research aims to explore the concept of a circular economy and identify relevant metrics within the environmental management system of Isfahan's Mobarakeh Steel Company. The study's statistical population includes vice presidents, managers, and experts, who were selected through snowball sampling until theoretical saturation was reached, resulting in a sample size of 16 individuals. Interviews were conducted to identify the circular economy metrics. The MAXQDA software was utilized for coding and analysis, which led to the development of a final model featuring five main criteria and 27 sub-criteria or categories. The content validity of the model was evaluated using the Content Validity Ratio (CVR) index, yielding a high coefficient of 49%, indicating sufficient validity. Additionally, inter-rater reliability was confirmed using Cohen's kappa coefficient, which resulted in a value of 0.78. These identified metrics can be employed by environmental management within organizations similar to Isfahan's Mobarakeh Steel Company to implement and execute the principles of a circular economy.

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1. Introduction

The scarcity of resources, combined with climate change, strict national and international regulations, and fierce competition for survival, has driven organizations to reduce their environmental impact and comply with increasingly stringent standards (Dechezlepretre and Sato, 2017; Farrukh et al., 2022; Bag et al., 2023). As a result, companies are not only managing their emissions but also setting ambitious reduction targets to minimize waste in their production processes (Hoffman, 2007; Plambeck, 2012; Rietbergen et al., 2015). This has led to a rise in research and initiatives aimed at reducing both direct and indirect carbon emissions and waste. Organizations have adopted sustainable development as a core principle and are exploring new strategies, such as implementing a circular economy (Suarez-Eiroa et al., 2019; Klein et al., 2020). The circular economy has the potential to revolutionize waste management, reduce pollution, and address challenges related to emissions (Sharma et al., 2021; Yang et al., 2023). The crucial question is: What approach should organizations adopt to achieve sustainability, and what metrics and concepts

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should guide them? The traditional linear economy, characterized by a take-make-dispose model, has significant negative impacts on the environment (Tambovceva and Titko, 2020; Rashid and Malik, 2023). In contrast, the circular economy emphasizes cost savings, increasing resource value, and designing products and processes that result in reduced emissions, longer product lifespans, and a safer return to nature. Therefore, organizations must align their operations to generate positive economic, social, and environmental impacts (Monticelli, 2020).

Kenneth Boulding, a systems theorist, introduced the concept of a closed economy in 1966 as an alternative to an open economy. He suggested that humanity exists on a spaceship without access to resources or energy beyond solar power. In this model, any waste generated during production must be repurposed as new resources. This idea implies that economic growth should not rely on natural resources but should focus on renewable energy, innovative business models, redesigned products with longer lifespans, improved recycling, repair, refurbishment, and collaboration within supply chains to establish a circular ecosystem. According to the Ellen MacArthur Foundation in the UK, this system has two significant cycles. The biological cycle includes environmentally friendly resources that can be returned to nature, while the technical cycle emphasizes products designed for longevity, minimal natural resource consumption, and reduced emissions (Elia et al., 2017).

The circular economy, with its innovative approach, features specific indicators that facilitate the ongoing use of waste in various processes, creating effective closed-loop material cycles. This approach can significantly enhance product lifecycles and, as a result, promote sustainability. The circular economy focuses on input materials, design, production, consumption, and managing finite resources. Environmental indicators that improve due to the circular economy include reductions in natural resource inputs and emissions, increased use of renewable resources, enhanced product durability, improved material and energy flows, reduced water footprint, and other important environmental metrics, as noted by institutions like the Ellen MacArthur Foundation (Di Maio and Rem, 2015; Elia et al., 2017; Kara et al., 2022). Given its potential to extend the lifespan of materials and increase return on investment, the circular economy has attracted considerable global interest. However, only a few companies have successfully integrated it into their business strategies and objectives (Antikainen et al., 2018). A prioritization study involving 26 experts employed a fuzzy approach indicated that companies aiming to implement the circular economy should primarily focus on managing their core business operations (Salvador et al., 2021).

A study was conducted at Mobarakeh Steel Company to implement the circular economy (an economic system that aims to eliminate wastes by reusing them) in the company. Research questions answered in this paper were, what are the most important factors of the circular economy in Mobarakeh Steel Company? Results showed that 7 factors were very important for the company. They were environmental-oriented design, industrial ecology, redistribution, reuse, redesign, recycling, and reduction (Rabbani and Zarfeshani., 2022).

Chenavaz and Dimitrov 2024, in a policy article, addressed the urgent need for a comprehensive policy framework to advance the circular economy, a crucial strategy in mitigating the global waste and pollution crisis. Through a synthesis of literature and case studies, the article examined the effectiveness of regulatory policies, economic incentives, and voluntary measures, and confronted the cultural, behavioral, economic, regulatory, technical, and logistical barriers to implementation. The findings highlighted the importance of integrated policy approaches, such as extended producer responsibility, environmental taxes, and corporate sustainability practices, and provided practical insights for stakeholders (Chenavaz and Dimitrov., 2024).

Rashid et al 2024, explored circular economy implementation challenges in industries that face significant environmental challenges, including inefficient resource consumption and waste generation. After evaluation, ‘inadequate leadership and top management commitment’, ‘lack of expertise and resources’, and ‘insufficient enforcement of environmental regulations’ emerged as the most significant barriers. The findings offered broader implications for emerging economies by providing valuable insights for policymakers and industry leaders, emphasizing the need for targeted strategies to address the significant barriers. This way, the circular economy can emerge as a promising pathway for achieving sustainable development by improving resource efficiency and reducing waste generation (Rashid et al., 2024). How can organizations identify the primary and localized metrics for a circular economy? Moreover, what model should industries adopt to effectively address the challenges of implementing a circular economy and to realize its benefits in key business performance indicators? Given the lack of successful circular economy implementation models in the country, as demonstrated by the absence of research on their impact on reducing industrial waste and pollutants, this research aims to determine the necessary circular economy metrics for minimizing industrial waste and pollutants. The central question is: How can organizations identify localized metrics to implement a circular economy within their structures?

This research aims to identify and localize suitable circular economy metrics for production processes in various industries and organizations. The study presents a model for organizations looking to implement a circular economy in the future, helping them tackle the challenges they may encounter. To illustrate this concept, Isfahan's Mobarakeh Steel Company is used as a case study to explore how a circular economy model can be implemented to reduce waste and environmental pollution.

2. Material and methods

2.1. Research Methodology

This research adopts an exploratory, descriptive, and survey-based methodology that employs qualitative research tools and interviews. The study population includes employees and experts at Isfahan's Mobarakeh Steel Company. All experts involved have over five years of work experience and possess a comprehensive understanding of operational activities related to production, the circular economy, and waste reduction processes. The snowball sampling technique was utilized, with the sample size determined at the point of saturation. This means that sampling continued until no new data emerged or existing data was repeated, signaling that the categories had reached a satisfactory level of comprehensiveness and the relationships between categories had been established and confirmed.

In this approach, coding occurred simultaneously with data collection and theoretical saturation was achieved with a sample size of 16 participants. As previously mentioned, the study employed semi-structured interviews with key experts and a literature review as qualitative tools. To assess the validity of the identified codes, the CVR formula was utilized, while Cohen's kappa coefficient was applied to evaluate the reliability of the codes. Following this, necessary analyses were conducted using content analysis coding methods.

Table 1 provides details about the experts who participated in the study. The data shows that 56% of the participants held postgraduate degrees or higher, while 44% held bachelor's degrees. In terms of their positions, 37% were managers, 44% were deputy managers, and 19% were specialists. Regarding work experience, 68% had more than 15 years of experience, 19% had between 10 and 15 years, and 13% had between 5 and 10 years of experience.

Table 1. Demographic characteristics of experts.

Demographic Characteristic		Frequency	Percentage	Cumulative Percentage
Education	Bachelor's	7	44	44
	Master's or PhD	9	56	100
Organizational Position	Deputy Manager	7	44	44
	Specialist	3	19	63
	Manager	6	37	100
Years of Experience	5-10 years	2	13	13
	10-15 years	3	19	32
	>15 years	11	68	100
Total		16	100	100

This study is conducted in three phases: identification, process improvement, and impact evaluation. In the identification phase, we pinpoint processes that contribute to waste generation in any form, using both inventory and financial data. Over a specified period, we assess the quantity of waste produced and the associated costs based on financial records. Additional variables are identified during the research process and incorporated into the initial model. Moreover, a comprehensive literature review is conducted, and, if possible, expert interviews are held to examine techniques for recycling waste back into the company's production and financial cycles. These techniques may include technological advancements or process modifications that align with the principles of digital transformation and the circular economy. In the identification phase, content analysis of interviews conducted using MAXQDA software was employed to identify processes and methods for reducing waste. MAXQDA is a specialized qualitative research software that provides a suitable environment for text content analysis. It is well-suited for qualitative research and foresight studies. This software serves as a universal tool for analyzing unstructured data such as interviews, articles, media, surveys, and qualitative studies. In the second phase of process improvement, robust optimization methods were utilized to evaluate and report the optimal combination and effects of implementing digital transformation with a circular economy approach in production processes (Radiker and Kuckartz, 2020). In the third phase, following the implementation of these initiatives, the impact of the results was assessed by comparing data before and after the implementation of the improvement projects. Based on this comparison, the initial process model developed in the first phase was refined in this stage to represent the optimal state. The refined model can be used as a recommendation for the company's future activities or as a benchmark for waste optimization in other steel companies.

3. Results and discussion

3.1. Data analysis using MAXQDA software

The methodology outlined that content analysis was used to analyze interviews conducted with experts, facilitated by MAXQDA software. MAXQDA is a professional data analysis software for qualitative or mixed methods. Interviews, focus groups, online surveys, web pages, images, audio and video files, etc. are transferred to this software. At the same time, the materials in MAXQDA are organized into groups, and similar quotes are linked together. After several thorough readings of the material, the initial coding of the text was performed (Radiker and Kuckartz, 2020). Meaningful units were identified, defined, and labeled. These units could be single words, phrases, or larger segments of text, collectively referred to as codes. Following this categorization, the meaningful units were organized into these codes. Strauss and Corbin (1998) referred to this process as open coding, emphasizing the importance of repeated questioning at this stage to clarify any ambiguities in the coding (Strauss and Corbin, 1998; Corbin and Strauss, 2014).

In the open coding phase, all interviews conducted with employees and experts were transcribed verbatim, and all phrases and sentences related to the core research themes were thoroughly identified and recorded. Subsequently, the researcher proceeded to code and interpret each of these key points. To ensure accurate and appropriate coding of these key points, after the initial open coding by the primary researcher, a second researcher was consulted.

This second researcher independently recorded all the comments based on their expertise. Through this analysis of expert interviews, over 441 codes were generated. As further interviews with experts and additional literature reviews were conducted, it became evident that no new codes related to the circular economy were emerging. Consequently, it was determined that further interviews were unnecessary. In collaboration with the experts, the codes were categorized to form a set of categories. These categories were then further classified and refined, resulting in the identification of five primary criteria or indicators, which are presented in Table 2.

Table 2. Number of codes, categories, and extracted indicators using MAXQDA software.

Code	Category	Criteria/Indicator
441	34	5

3.2. Identifying core concepts and determining content validity using CVR based on expert surveys

In this phase, all open codes extracted from the first stage were organized into main themes based on their relationship to the core research concepts. The results of this stage include core codes and their corresponding frequency counts, which are presented in relevant tables. Each row in these tables represents a concept that is essentially a combination of several codes. The adjacent column provides the codes associated with that concept along with their frequency in the interviews. Through the axial coding conducted in the qualitative research study, 38 concepts were identified. Importantly, all sub-indicators derived from the literature were included in the initial model using various expressions, reflecting the level of understanding and experience of the experts. This information is detailed in the table. Furthermore, content validity was assessed using the CVR index, calculated based on a survey of 16 experts. These experts included specialists in process networks and operations, design and development of production process networks, and supervisors in steel production lines. The formula for calculating the CVR is presented in Eq. 1:

$$CVR = \frac{n_e - N/2}{N/2} \quad (1)$$

In this formula:
N: Total number of experts
N_e: Number of experts who selected the "essential" option.

Additionally, Cohen's kappa coefficient was used to assess the inter-rater reliability of the coding. It was calculated using Eq. 2 (Vieira et al., 2010; Wieckowska et al., 2022):

$$\text{kappa} = Pi = (PA_o - PA_E)/ (1 - PA_E) \quad (2)$$

PAo signifies the observed agreement between two raters, whereas PAE denotes the agreement that would be expected by chance.
The results of the axial coding from the exploratory study, along with their frequencies and validated CVR values, are presented in Table 3.

Table 3. Axial coding of exploratory studies.

Theme	Illustrative Quotes	Frequency	CVR
Circular economic strategies	In my opinion, the critical factor in implementing a circular economy is selecting the appropriate strategy. In recent years, we have endeavored to integrate this concept into our processes through the adoption of a suitable circular economy strategy.	6	75
Circular economy life cycle management support	To successfully implement a circular economy within an organization, it is essential to effectively manage the circular economy lifecycle and ensure that managers have a thorough understanding of its benefits.	5	75
Information about circular economic benefits	I believe that the more our colleagues are informed about the benefits of a circular economy, the more supportive they will be.	8	87
Reduce waste	In my opinion, the most significant outcome expected from implementing a circular economy is waste reduction, which consequently leads to increased product efficiency.	4	87
Problems of wasting resources	The most significant challenge encountered in implementing the circular economy was the wastage of other resources.	4	63
Leveraging circular economy strategies	We endeavored to leverage circular economy strategies in our production processes to address the challenges encountered along the way.	5	75
Climate change	One of the environmental factors influencing the decision to adopt a circular economy is climate change.	4	75
Expert manpower	Human capital with sufficient expertise is a critical factor in the successful implementation of a circular economy.	5	87
Working groups	Working teams together can implement a circular economy with a working group	3	63
Financial capacities	The existence of adequate financial capacities can ensure the successful implementation of circular economy projects. We have been more successful in any process where we had a good financial budget.	3	100
Implementation of circular economy	In my opinion, implementing a circular economy is a crucial step in transforming theory into practice, and we will experience the results firsthand in our implementation.	4	75
Executive networks in the circular economy	In my opinion, implementation networks are indispensable for the successful implementation of a circular economy. Without their involvement, a comprehensive implementation would be virtually impossible.	3	63
Understanding and knowledge for successful implementation of a circular economy	For the successful implementation of a circular economy, managers must have a solid understanding of it. Without sufficient knowledge in the field of circular economy, I doubt its successful implementation.	3	63
Value creation resources	To implement a circular economy, it is essential to identify and effectively utilize resources that create value.	4	75

Renewable energy infrastructure	The utilization of renewable energy infrastructure has been of paramount importance in implementing a circular economy.	5	63
Remanufacturing infrastructure	We used the necessary infrastructure for remanufacturing in our production processes, which had a great impact on reducing waste.	4	100
Product design	Product design is very important in the successful implementation of the circular economy and in reducing production waste from products.	4	100
Strategic decision making	One of our most important supporting parts in the implementation of the circular economy has been strategic decisions.	4	63
Circular business model	To implement a circular economy, a circular business model must be adopted.	4	63
Rethinking	We consistently employ a rethinking approach to enhance circular economy systems.	4	87
Reducing the emission of pollutants	One of the outputs we constantly measure is the reduction in pollutant emissions, and the lower it is, the greater the success in reducing waste.	4	75
resource recovery	Our primary objective in a circular economy is to recover resources. By effectively recovering our resources, we can successfully implement a circular economy.	4	87
Product Manufacturing	All components of the circular economy must be effectively implemented in the product manufacturing process.	2	87
Transportation	One of the most critical aspects to consider in a circular economy is the status of raw material transportation.	4	63
Energy generation	We have implemented energy generation in the context of a circular economy in some of our production processes, such as recovery and waste reduction.	4	75
Creating closed loops in production	To implement a circular economy, we needed to utilize closed-loop production systems to return materials to the production chain.	5	87
Resources in the form of materials and energy	The necessary energy and material resources required for production with minimal waste have always been a focus.	3	100
Customer understanding and involvement in circular economy principles	When we implemented the circular economy, we reached an agreement with our contractors and suppliers regarding the coordination of this initiative.	4	87
Optimum production technologies	One strategy we employed to reduce waste was the utilization of optimized production technologies. By implementing technologies with proven efficacy and efficiency in our processes, we were able to significantly minimize waste generation.	4	87
Sustainable production and consumption technologies	The implementation of a circular economy greatly relies on the utilization of sustainable production technologies. Both economic and environmental sustainability of production technologies are crucial for the realization of a circular economy.	5	75
Process optimization	One of the most important tasks in the field of circular economy has been the optimization of production processes.	4	87
Operational activities in the production department	We have shifted all operational production activities towards a circular economy.	5	87
Reuse	The reuse of raw materials is a fundamental principle of the circular economy.	3	75
Recycling processes	The most significant aspect of our work has been improving recycling processes within the circular economy.	5	63
Ironmaking sector	We have four main sectors, one of which is the ironmaking area, which contains a large volume of process waste.	16	100
Steelmaking sector	By implementing a circular economy in the steelmaking sector, we are recycling a significant volume of metal scrap back into the production cycle.	16	100
Hot rolling sector	The hot rolling sector contains scrap coils and significant amounts of oxide scales and non-homogeneous materials.	16	100
Cold rolling sector	As we move towards the endpoints, the value-added waste increases and maximum effort is exerted to reduce waste in this area.	16	100

Given the above, a CVR of 49% or higher is considered appropriate for the 16 experts who participated in the survey. Based on the calculated CVR values in the table above, the validity of all the examined indicators is confirmed. Additionally, a neutral coder was involved in the analysis, and inter-coder reliability was measured using Cohen's kappa coefficient, which yielded a value of 0.78. This indicates a satisfactory level of reliability and adequacy in coding. The third step in qualitative analysis is selective coding. Selective coding is simply the act of choosing a core variable or concept among the existing categories you have created from the axial coding process to start forming the overarching theme that arises from your data and addresses your research question (Phillips et al., 2024). The term "selective" refers to the analyst's explicit choice of a central aspect of the data, known as the "core category," which becomes the focus of the analysis. In selective coding, we utilize the same techniques as in axial and open coding, but at a higher level of abstraction.

The attention now shifts to identifying a higher-level concept, which serves as the central conceptual category located at the second level of abstraction. Following the previous stage, core codes were categorized based on their relationship to the primary research concepts, resulting in a comprehensive table outlining variables and indicators as perceived by experts and managers. The selective coding table details the concepts associated with each category and their corresponding frequencies. Consequently, the 38 identified concepts were classified into four main categories, as shown in Table 4. Subsequently, by synthesizing these concepts, digital transformation indicators were developed under four primary dimensions:

Table 4. Dimensions and components of digital transformation with a focus on reducing industrial pollutants and waste at Isfahan's Mobarakeh Steel Company.

Main Dimensions (Primary Criteria)	Components (Sub-criteria)
Circular Economy	• Circular Economy Strategies • Supporting the Lifecycle of Circular Economy • Information on Circular Economy Benefits
Optimizing Raw Material Flow	• Waste Reduction • Resource Wastage Issues
Enablers	• Leveraging Circular Economy Strategies • Climate Change • Expert manpower • Working Groups • Financial Capacities
Circular Economy Operations	• Value Creation Sources • Renewable Energy Infrastructure • Remanufacturing Infrastructure • Product Design • Strategic Decision Making • Circular Business Model • Rethinking • Reducing Pollutant Emissions • Resource Recovery • Product Manufacturing • Transportation • Energy Generation • Creating Closed Loops in Production • Resources in the Form of Materials and Energy • Customer understanding and involvement in circular economy principles • Optimized Production Technologies • Sustainable Production and Consumption Technologies • Process Optimization • Operational Activities in the Production Sector • Reuse • Recycling Processes

Based on the primary and secondary criteria outlined in Table 4 and recognizing the importance of the circular economy, senior management in organizations must become well-acquainted with this concept. They must provide strong support for the circular economy throughout its lifecycle and across all stages. As a result, themes related to the circular economy should be integrated into broader organizational strategies and objectives. To promote a culture that encourages the adoption and teaching of circular economy concepts and techniques, appropriate strategies, goals, and actions should be implemented. It is essential to instill a fundamental understanding that waste is essentially raw material made unusable due to inefficient processes. Therefore, the potential for recycling and reintroducing these materials back into the production line should be embedded in the organization's culture. The circular economy plays a significant role in environmental preservation and reducing resource wastage (Ghisellini et al., 2016; Reddy et al., 2023). It can be effectively managed by utilizing advanced digital systems, such as smartphones and SIM cards, along with intelligent devices like cameras, probes, and sensors on production lines. Web-based technologies, including satellite antennas, network cables, modems, monitors, servers, transmitters, connectors, and the entire Internet of Things, also contribute to this effort. Organizations can implement a circular economy by redesigning and updating their processes (Preston, 2012; Awan and Sroufe, 2022).

For example, they can enhance water recycling systems using advanced technologies such as reverse osmosis, ultrafiltration, and Ultraviolet (UV) radiation to minimize the reliance on new water sources and lower environmental pollution. Additionally, addressing potential defects in process lines and adopting new technologies and design changes can further support this transition. This approach aligns well with sound economic practices, providing significant benefits not only for organizations but also for society and future generations.

Our primary focus is on optimizing the flow of raw materials, with particular attention to waste reduction. We are specifically analyzing the amounts of raw materials that do not convert into the final product, resulting in by-products that do not meet our qualitative and quantitative standards. These inefficiencies can often stem from several factors, including suboptimal process design, poor process performance, improper equipment utilization, low-quality raw materials, issues related to additives, and equipment wear and tear. All of these scenarios lead to unnecessary waste of materials, energy, and human resources. One important aspect of implementing a circular economy is the use of techniques and methodologies to identify and minimize material flows. For example, during cooking processes, some materials may be lost due to pulverization. Additionally, poorly designed equipment can lead to the degradation of both the quality and quantity of raw materials, which in turn requires disposal and results in significant storage and transportation costs. On the other hand, sourcing higher-purity or higher-grade raw materials from the start can help eliminate additional transportation and energy costs, as well as reduce excess waste. Consequently, through a series of operational measures such as reducing process defects, optimizing equipment, training personnel, conducting research projects to recycle waste, replacing equipment, implementing better quality control, sourcing higher quality raw materials, and modifying product design, the company has been able to minimize process waste and prevent resource wastage.

In the context of enablers, a circular economy serves as a powerful lever for organizations. It not only facilitates substantial financial gains but also requires less effort to achieve them. Companies should clearly define the role of the circular economy in their strategies to ensure its implementation can effectively reduce environmental pollution while providing economic benefits. For example, climate change is an undeniable global challenge that prompts nations and regions to commit to sustainable practices, making it a strong motivator for adopting a circular economy. Additionally, having skilled personnel within organizations and production processes is another critical factor in implementing a circular economy. Creating working groups and fostering a culture of collaboration among employees are also important enablers. However, alongside these factors, financial resources are essential. They are crucial for implementing changes, designing new processes, and engaging in various circular economy activities, such as establishing digital infrastructure and making necessary modifications to existing processes.

The ultimate benchmark is the operation of a circular economy. All aspects of circular economy operations aim to create value and reduce pollution for both employees and managers. Achieving this requires comprehensive communication and a collective effort to establish renewable energy infrastructure within organizations. These initiatives not only promote a culture of environmental awareness and education but also significantly contribute to pollution reduction. Moreover, production infrastructure is essential, including clean transportation, the use of circular economy techniques to minimize waste, and the development of supporting systems like digital transformation and process automation.

Additionally, creating new products and recovering resources are crucial components of effective circular economy operations. In a circular economy, the goal is to achieve zero waste by creating closed-loop systems. Recovery processes can involve not only materials but also energy, or a combination of both energy and materials, all of which can generate value. Increasing customer awareness and education about the circular economy, along with offering incentives for returning products to the production cycle, can greatly enhance consumer participation. The development and optimization of technologies for both existing and emerging processes are crucial for reducing waste and facilitating recycling, thereby contributing to the objective of zero waste (Pietzsch et al., 2017). Sustainable consumption should be viewed as a way to support ecosystems rather than destabilize them. By eliminating excessive resource extraction, we can help preserve ecosystems for future generations. For instance, the utilization of scrap in the steel industry serves a similar purpose, mitigating the need for extensive mining operations. Moreover, process optimization stands as one of the most critical steps to be undertaken following the identification and quantification of losses and waste generated within processes, with the ultimate goal of reduction and elimination. Furthermore, operational activities must be subject to rigorous review and even simulation. Concurrently with process optimization, operational activities, standard operating procedures, and workflows should be updated in alignment with the outcomes of benchmarking, experimentation, and research endeavors. The culture of reuse should be integrated as an integral part of production processes, tailored to the specific segments within which reuse is feasible. This is because waste generated in one or two processes before the production unit may still be usable, or could significantly impact the performance of subsequent stages. Therefore, a process-centric approach is crucial, rather than a segment-specific one. Additionally, it is essential to pay close attention to overall recycling processes, both within and outside the organization. When necessary, waste should be transferred to designated recipients under the supervision of relevant authorities, ensuring safe transportation and proper identification, to facilitate recycling. The implementation of a circular economy inherently involves value creation, pollution reduction, resource recovery, transportation efficiency, material reuse, and more, serving as powerful incentives for its adoption (Heshmati, 2017; Kandpal et al., 2024). To shift businesses towards a circular model and reduce resource consumption and energy usage, it is essential to consider infrastructure such as renewable energy, redesign, remanufacturing, and a circular mindset (Awan and Sroufe, 2022; Kandpal et al., 2024).

Businesses should integrate production, reuse, and recycling processes into their operations and, where necessary, employ new and optimized technologies to create closed-loop production systems (Kara et al., 2022). This approach can lead to increased value creation, the development of new products, energy generation, and enhanced reuse.

4. Conclusion

This study delves into the identification of enablers for implementing a circular economy within the specific context of Isfahan's Mobarakeh Steel Company processes. A comprehensive framework comprising four primary criteria and 31 sub-criteria has been developed to facilitate this implementation. These criteria are categorized under the broader themes of circular economy, raw material flow optimization, enablers, and circular economy operations. These criteria can be employed to implement a circular economy within the processes of Isfahan's Mobarakeh Steel Company. Furthermore, weights or scores can be assigned to each criterion and sub-criterion to enable the evaluation of implementation processes and progress. The findings of this study can facilitate the monitoring and control of environmental parameters such as pollutant emissions, waste generation, online assessment of production units, and environmental accounting. In other words, this infrastructure is essential for conducting environmental accounting, determining pollutant levels, and prioritizing and controlling them. It is important to note that the criteria and sub-criteria may vary in their implementation for different areas. Therefore, it is necessary to prioritize the criteria and determine the required sub-criteria for each unit, which can be the subject of a separate study within this case.

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