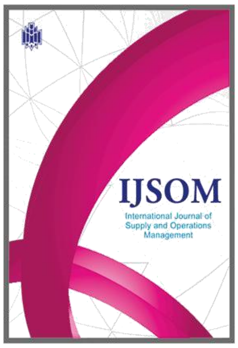
International Journal of Supply and Operations Management

IJSOM

2023, Volume 10, Issue 4, pp. 545-563
ISSN-Print: 2383-1359
ISSN-Online: 2383-2525
www.ijsom.com



A Comprehensive Approach to Evaluating the Effective Factors in Implementing a Circular Supply Chain by A Hybrid MCDM Method

Alireza Goli [a], Iman Shahsavani [a], Fereshte Fazli [b], Amir-Mohammad Golmohammadi [c], Reza Tavakkoli-Moghaddam [d]*

[a] *Department of Industrial Engineering and Future Studies, Faculty of Engineering, University of Isfahan, Isfahan, Iran*
[b] *Department of Business Administration, University of Science and Culture, Tehran, Iran*
[c] *Department of Industrial Engineering, Arak University, Arak, Iran*
[d] *School of Industrial Engineering, College of Engineering, University of Tehran, Tehran, Iran*

Abstract

The circular economy is one of the most important issues in the optimal use of resources all around the world. The combination of circular economy and supply chain creates a new concept called circular supply chain, which seeks to increase the efficiency of the supply chain by making the best use of resources. In this research, the main purpose is to apply a hybrid Multi-Criteria Decision-Making (MCDM) method to evaluate the effective factors in implementing the circular supply chain. First, the effective factors in the field of the circular supply chain are identified, and in the next step, the weight of the factors is obtained by implementing the Analytic Hierarchy Process (AHP) method. Next, the intensity of the effect of each factor is calculated. Moreover, the correlation between the factors affecting the circular supply chain and the effectiveness of the factors is analyzed using the Decision Making Trial and Evaluation Laboratory (DEMATEL) method. Finally, using the Simple Additive Weighting (SAW) method, the most important factors in the implementation of the circular supply chain are identified. The core results of this research show that the quality of final products is the most important factor in implementing a circular supply chain. Moreover, applying the circular economy approach leads to the zero-waste goal, which can increase the efficiency of supply chains.

Keywords: Circular Economy, Supply Chain Management, Circular Supply Chain, Multi-Criteria Decision-Making, DEMATEL Method.

1. Introduction

Many organizations deploy a sustainable approach in their supply chain to improve themselves in economic, environmental, and social aspects. Applying a supply chain sustainability approach faced with barriers. The main ones are insufficient awareness of sustainability benefits, inadequate rules and regulations in environmental standards, and a lack of senior management commitment (Darvazeh et al., 2022; Hossain et al., 2022; Menon et al., 2021). Moreover, many industries consume significant amounts of water, energy, and resources throughout their supply chain, which causes large amounts of waste (Akter et al., 2022; Hossain et al., 2022). The main reason for this can be considered the use of the dominant economy, which is mainly called a linear economy. For example, the textile industry generates 98

[*] Corresponding author:Email address: goli.a@eng.ui.ac.ir
DOI: 10.22034/IJSOM.2023.109683.2578

million tons of non-renewable waste, more than 93 billion cubic meters of water, and about 1.2 billion tons of carbon dioxide (CO_2) yearly (Bressanelli et al., 2022).

The Circular Economy (CE) concept can be recognized as a potential alternative to transition from the linear economy (Ogunmakinde et al., 2021). This approach goes through design, production, distribution, consumption, and end-of-life stages by considering 3R (Reuse-Repair-Recycle)(Syberg et al., 2022). Applying this new approach improves the sustainability of resource use, reduces waste, and reduces the harmful effects on the environment (Colasante et al., 2021). Integrating CE into the supply chain configuration makes a Circular Supply Chain (CSC) that improves supply chain sustainability (Orji et al., 2022).

One of the most important reasons for implementing CE in the supply chain is the increase in population and the growing demand for renewable resources (Govindan et al., 2018). Furthermore, according to a report from the Ellen MacArthur Foundation, integrating the CE can dramatically reduce carbon emissions by 2030. Also, greenhouse gas emissions in the UK would be reduced by 7.4 million tons per year if organic waste was managed in accordance with circular flows. In addition, Mehmood et al. (2021) conducted a systematic literature review on the benefits and drivers of CE implementation in the agri-food supply chain. The summary of the results is illustrated in Figure 1.

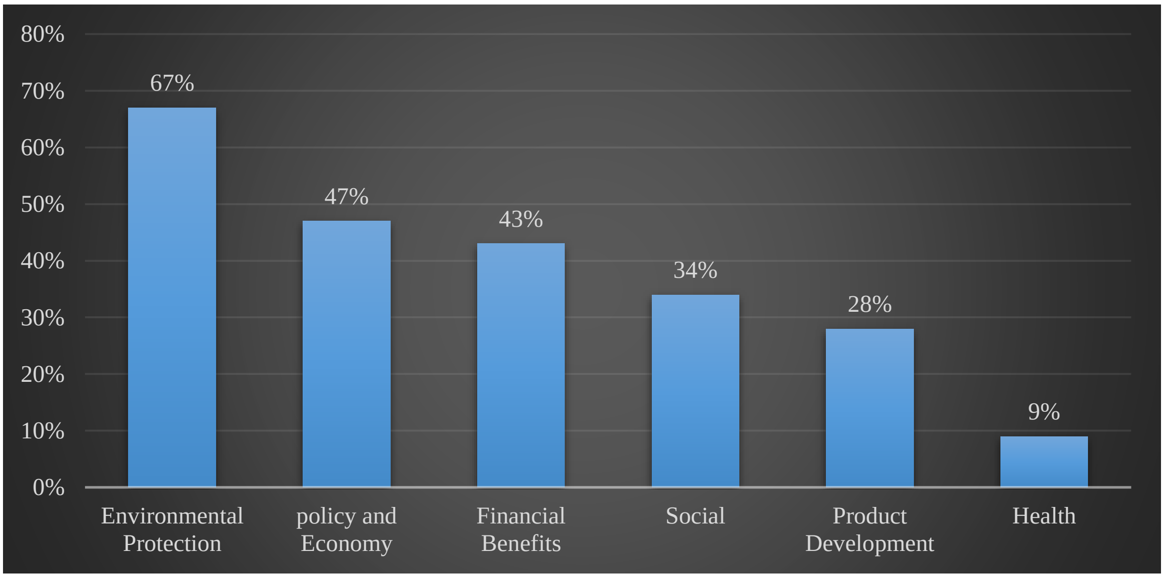


Figure 1. Circular Economy drivers and benefits in the agri-food supply chain.(Mehmood et al., 2021)

The CSC maximizes the value of goods and materials throughout the supply chain, increases resource productivity and profitability, and reduces adverse environmental, social, and economic effects (Luthra et al., 2022). The goal of the CSC is to reach zero waste, which is achievable by applying value preservation throughout the leading supply chain and using closed-and open-loop supply chains related to the main chain (Farooque et al., 2022).

Despite the many benefits of applying the CSC, its implementation includes barriers and constraints related to financial issues, government laws and regulations, etc. (Kazancoglu et al., 2022). Mangla et al. (2018) make an effort to analyze significant barriers to implementing CSC in India.

The main purpose of this study is to use MCDM techniques to rank the effective factors in implementing CSC. First, the influential factors in the field of the CSC are identified, and the weight of each factor is obtained. Moreover, the correlation between the factors affecting the CSC and the effectiveness of these factors is analyzed. According to the best of the authors' knowledge, no previous research has investigated the factors affecting the CSC using MCDM techniques, specially AHP-DEMATEl-SAW. In addition, rare studies have even focused on decision-making techniques for analyzing the factors influencing the CSC (Khandelwal et al., 2020; Mangla et al., 2018). This identification and classification of factors help various industries to implement CSC. Therefore, they can get better performance by knowing the most important influencing factors in adopting CSC. On the other hand, conducting the combination of three multi-criteria decision-making methods can be applied as a model for researchers to adopt in CSC or other fields.

The rest of the paper is organized as follows. In section 2, a review of research related to this study is provided. In section 3, the research methodology is described. Section 4 presents numerical results, section 5 discusses the results, and section 6 presents the conclusion, limitations, and future research areas.

2. Literature Review

The literature review presented in this section includes CE and CSC, barriers to implementing CSC, and research on identifying and prioritizing the factors affecting the CSC.

2.1. Circular economy and circular supply chain

The dominant economy implemented in organizations and industries is known as the linear economy, which is known for extracting and converting resources into products and disposing of end-of-life products. Due to increasing population and demand, the use of natural and non-renewable resources, waste production from the production process, and the cycle of end-of-life products are increasing (Machado et al., 2021). Moreover, recycling in the linear system is negligible. For example, plastic waste recycling is estimated at approximately 2% globally (Balwada et al., 2021). Recently, CE has been introduced as an alternative to the linear economy for implementation in industries and organizations. By implementing the concept of circularity and using it in the product life cycle, its materials, and components, waste production is reduced as much as possible (Darvazeh et al., 2022; Pieroni et al., 2019). The use of the CE has beneficial effects on the environmental and social aspects and the economy, which has led many countries to encourage legislation to implement the circular approach (Aytekin et al., 2022; Karman et al., 2022). Economic benefits include a net profit of € 1.8 trillion by 2030, more than a 3% annual increase in resource returns, and a 7% GDP growth (Sverko Grdic et al., 2020).

Integrating the CE approach into the supply chain creates the CSC. Implementing the CE approach in the supply chain has led organizations to consider the new procedure in product design, procurement, manufacturing, logistics, sales, product consumption, and information management (van Capelleveen et al., 2021). The supply chain strategy to integrate CE applications is summarized in Figure 2. Implementing the principles of CE in the supply chain improves the dimensions of sustainability (Mahroof et al., 2021). Achieving more sustainability benefits is possible based on maximizing the efficiency of input sources and reducing pollution emissions, energy consumption, and waste by using restoration and regeneration processes (Atabaki et al., 2020).

2.2. Effective factors of CSC

Despite the CSC beneficiary effects, implementing a CSC in industries involves different barriers and issues (Luthra et al., 2022). Barriers to CSC implementation include lack of experience/knowledge, lack of legitimacy (Chen et al., 2019), technological deficiencies (Kazancoglu et al., 2020), and government regulation (Lahane et al., 2020). The approach of organizations and industries in countries towards the CSC transition is different. According to the result presented by (Elia et al., 2020), 80% of the leading companies in the CSC transition are located in the EU and US. Govindan et al. (2018) examined the drivers, barriers, and CE methods in the supply chain. According to the results of that research, the government outlook will have the most positive impact on implementing CE in the supply chain.

2.3. Previous research

Based on the barriers and factors reviewed in the previous section, researchers have recently identified and prioritized the factors affecting implementing of the CSC and using the CE in various fields. The purpose of prioritizing factors is to facilitate the CSC implementation in organizations and assist senior managers in making strategic decisions in the transition to the CE. Prioritization and identification of influential factors in implementation have been evaluated and analyzed using various methods.

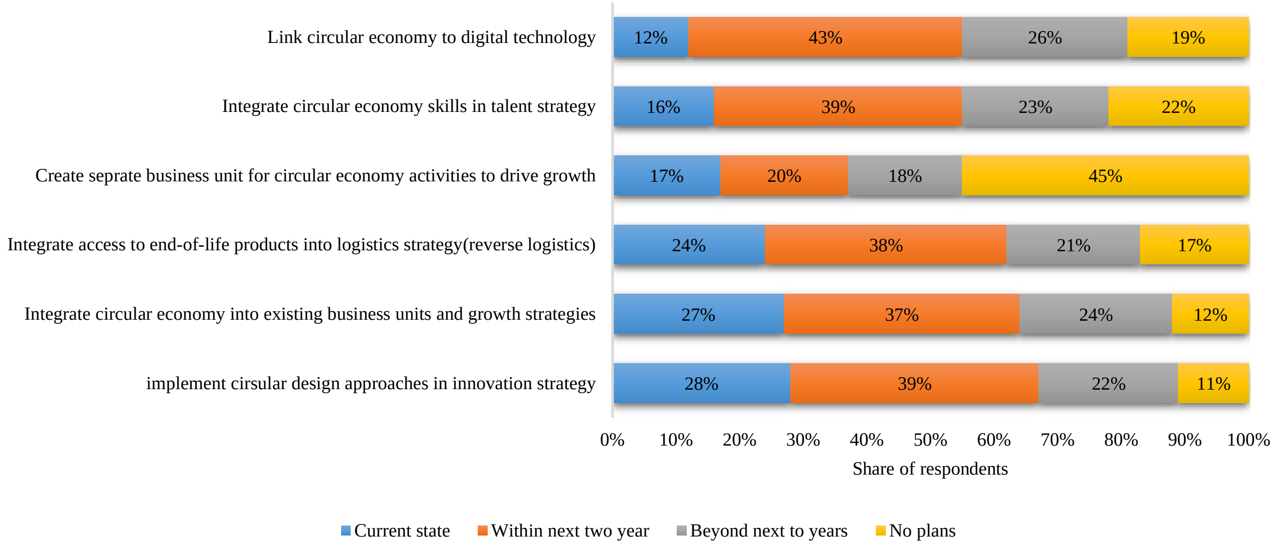


Figure 2. Strategy of supply chain firms to integrate circular economy practices worldwide in 2019 (Statista.com)

According to the resource-based view (RBV), Yan et al. (2022) investigated the CSC implementation's influential factors and its effect on the smart logistics ecology chain (SLEC). Factors based on RBV have been identified as valuable and unique resources in the SLEC development process. They found that smart budget investment and the ability in multi-scenario services will improve the CSC. Huang et al. (2022) examined the critical success factors of Blockchain implementation in the CSC. Factors are assigned to Blockchain technology, Blockchain integration, and CSC management. Subfactors in the first category include technological readiness and capabilities (Thakur, 2022; Sahoo and Thakur, 2022). Leadership, collaboration, and implementation are considered in the second category, and supply chain practices and circular management are analyzed in the last category. In this study, effective factors were identified and ranked using the AHP-DEMATEL method. Moreover, critical technology-related success factors such as technological capability, technological richness, and technology feasibility play an essential role in CSC management. Julianelli et al. (2020) evaluated the critical success factors of using reverse logistics in the CSC. The method used was a tertiary literature review using content analysis with 66 samples. This research identified resource management and fulfillment, life cycle assessment, sustainability, communication, industrial technology, and communications as critical success factors. Saroha et al. (2021) studied circular practices in implementing CSC management and its effect on sustainability. This study presented 32 practices and cause and effect groups, and the methods were ranked based on importance.

In the field of CSC, Orji et al. (2022) identified and prioritized enablers factors in the Nigerian manufacturing industry. These factors were classified as environmental, social, organizational, and supply chain categories. To identify and prioritize factors, BWM and EDAS methods were used. In this research, the amplification factors of environmental instruments were introduced as the most critical factor in the manufacturing sector of Nigeria. Nag et al. (2022b) identified and ranked drives in the field of the CSC; the Gray-DEMATEL method was used. Drivers include circular value marketing, circular services, circular product manufacturing, and reverse flow. Moreover, each driver has two or more sub-drivers. According to this research, companies should pay particular awareness to the essential drives, including circular value marketing, circular services, and circular product design. Lahane et al. (2021c) ranked the main results of the CSC in the direction of enabler factors using the combined method of PF-AHP and PF-CoCoSO. In this research, major enablers are categorized into organizational, operational, strategic, environmental, economic, social, and technological groups. Based on this study, environmental enablers and monitoring are the most critical factors.

Recently, numerous pieces of research have been conducted to identify and rank the implementation barriers in the CSC. Lahane et al. (2021a) identified, ranked, and classified barriers using the PF-AHP and PF-DEMATEL methods. In this investigation, 35 barriers to supply chain implementation were identified and ranked. Liu et al. (2021a) identified barriers to producing and consuming sustainable food by considering the CE. Barriers include weak legal enforcement, inadequate infrastructure, behavior, lack of investment, lack of expertise, lack of cross-sector collaboration, cost, lack of economies of scale, lack of environmental education and accountability, and lack of benchmarking. According to that study, "insufficient enforcement" and "lack of environmental education and accountability" are the main barriers. The review of other research in this field is summarized in Table 1.

2.4. Research gaps

A closer look at the literature on implementing CSC, however, reveals several gaps and shortcomings, which are expressed as follows:

- Previous studies have considered the identification and ranking of barriers and drives as two separate areas, making the interaction of factors not considered.
- Most of the related research items have focused on a specific organization or industry, and the concept of circularity has not been considered in the whole process of supply chains.
- Few studies have focused on the relationships between factors affecting the CSC and intensity of the relationships and the degree of influence (permeability) and effectiveness (permeability) of the factors.

According to the research gaps presented, this study aims to identify and evaluate the factors affecting CSC implementation and their relationships. In other words, the key contribution of this work is the provided approach to determine the significant factors affecting CSC implementation, which can be adopted in different supply chains. In this regard, to achieve the goal of this research, the hybrid AHP-DEMATEL-SAW method is applied. First, in the proposed approach, the factors are identified, and the structure between the influential factors is determined. Next, based on the calculated weights, the correlation of the factors is analyzed.

Table 1. A brief review of the literature related to this study

year	Author	Field		Focus				Target				Application	Methods
		CE	CSC	Drivers/	Barriers/chal	Solutions	Others	Identifying	Classifying	Ranking	The inter-		
2022	(Orji et al., 2022)		✓	✓				✓	✓	✓		SCM	BWM EDAS

2021	2021	2021	2021	2021	2021	2022	2022	2022
(Alavi et al., 2021)	(Alavi et al., 2021)	(Lahane et al., 2021d)	(Lahane et al., 2021b)	(Lahane et al., 2021a)	(Nag et al., 2021)	(Bal et al., 2022)	(Nag et al., 2022a)	(Asante et al., 2022)
						✓	✓	
✓	✓	✓	✓	✓	✓			✓
		✓			✓			
				✓				
			✓				✓	✓
Criterion of suppliers	Criterion of suppliers					Criterion of objective		
✓	✓	✓	✓	✓	✓		✓	✓
			✓	✓				
✓	✓	✓	✓	✓	✓	✓	✓	✓
				✓				
SCM	SCM	SCM	Risk management	SCM	Industrial Product-Service	Industrial Product-Service	Industrial Product-Service	SCM
Fuzzy AHP F-TOPSIS FIS	F-BWM FIS	PF-AHP PF-CoCoSo	PF-AHP PF-VIKOR	hybrid PF-AHP PF-DEMATE	Grey DEMATEL	AHP	F-AHP	BWM GRA

2020	**2020**	**2020**	**2020**	**2020**	**2020**	**2021**	**2021**	**2021**	**2021**
(Kazancoglu et al., 2020)	**(Moktadir et al., 2020)**	**(Govindan et al., 2020)**	**(Singhal et al., 2020)**	**(Singh et al., 2020)**	**(Ozkan-Ozen et al., 2020)**	**(Kumar et al., 2021)**	**(Patel et al., 2021)**	**(Yildizbasi, 2021)**	**(Liu et al., 2021b)**
	✓	✓	✓	✓			✓	✓	✓
✓					✓	✓			
						✓	✓		
✓	✓		✓	✓	✓			✓	✓
		Criterion of suppliers							
✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
✓				✓					
✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
✓							✓		✓
SCM	**VM**	**SCM**	**Re-manufacturing**	**Resource management**	**Resource management**	**SCM**	**SCM**	**Energy management**	**Food and WM**
F-DEMATEL	**BWM**	**F-ANP F-DEMATLE**	**F-DEMATEL**	**AHP GTA**	**F-ANP**	**F-DEMATEL**	**ISM fuzzy MICMAC**	**PF-AHP**	**F-DEMATEL**

2019	**(Zhang et al., 2019)**	✓			✓			✓		✓		**WM**	**F-DEMATEL**

- **ANP – Analytical Network Process**
- **GTA – Graph-Theoretic Approach**
- **ISM – Interpretive Structural Modeling**
- **TOPSIS – Technique for Order of Preference by Similarity to Ideal Solution**
- **AHP – Analytical Hierarchy Process**
- **DEMATEL – Decision Making Trial and Evaluation Laboratory**
- **FIS – Fuzzy Inference System**
- **GRA – Grey relational Analysis**

3. Research methodology

In this section, first, by using the AHP method, the weight of the factors affecting the CSC implementation is obtained, and their impact on the CSC is ranked. Next, using the DEMATEL method, the structure between the factors affecting the CSC, the intensity of the relationships, the impact (penetration), and the effectiveness (permeability) of the factors are obtained. The steps of this proposed method are represented in Figure 3.

3.1. Evaluating the factors affecting the CSC using the DEMATEL method

In this subsection, the aim is to investigate the impact or effectiveness and the penetration and permeability of the identified factors affecting CSC implementation. Moreover, the intensity of relations between the factors is obtained according to experts' opinions. According to the initial diagrams of the correlation relationships between factors affecting the CSC and the correlation of the factors with the CSC, pairwise comparisons are performed based on a researcher-made questionnaire. The final matrix of pairwise comparisons of experts in this study is represented as A. The steps of the DEMATEL method are performed as follows.

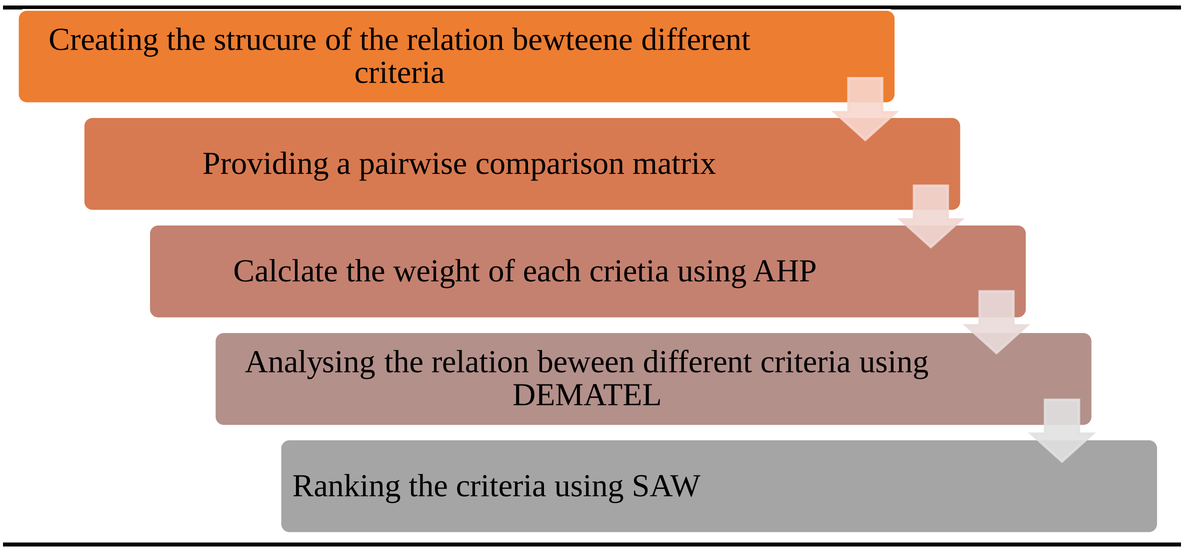


Figure 3. Research framework

The first step in implementing the DEMATEL method is normalizing the matrix table of pairwise comparisons. According to Eq. (1), after calculating the normalizer number, the direct effects of the measured factors are obtained. In this research, the matrix of direct relationships between factors is represented as TD using Eq. (1).

$$TD = s \times A = [d_{ij}]_{n*n} \tag{1}$$

After calculating the direct effects matrix, according to the DEMATEL calculation method, the total relations matrix is obtained as Eq. (2). The matrix of direct relationships between factors is displayed as TT.

$$TT = TD \times (I - TD)^{-1} = [t_{ij}]_{n*n} \tag{2}$$

In general, factors have a direct or indirect effect on each other. The matrix of indirect relationships between factors is represented as TID using Eq. (3).

$$TID = TD \times (I - TD)^{-1} \tag{3}$$

After fully calculating the impact of CSC factors on the CSC and on the factors, the impact/effectiveness or penetration and permeability of the factors on each other and the CSC should be measured. Eqs. (4)-(6) measure the factors' impact/effectiveness.

$$R = [r_i]_{n*1} = \left(\sum_{i=1}^{n} t_{ij}\right)_{n*1} \tag{4}$$

$$C = [c_j]'_{1*n} = \left(\sum_{j=1}^{n} t_{ij}\right)'_{1*n} \tag{5}$$

$$\begin{aligned} R + C &= [r_i]_{n*1} + [c_j]'_{1*n} \\ R - C &= [r_i]_{n*1} - [c_j]'_{1*n} \end{aligned} \tag{6}$$

3.2. Ranking of factors affecting the CSC using the SAW method

The SAW method is one of the widely used decision-making methods. According to Eq. (7), the weighted sum of each variable/factor is calculated, and large values of the weighted sum of each variable show that it has the most impact and the highest rank.

$$R_i = \sum_{l=1}^{m} W_i \times t_{i.j} \tag{7}$$

where $t_{i.j}$ is the object of the TT matrix.

4. Numerical results

After performing pairwise comparisons of criteria, experts' opinions are collected.

The experts' panel consists of five experts in the related field. The profile of the experts is given in Table 2.

Table 2. Profile of Experts

Expert No.	Filed	Designation	Experience (Years)	Education Qualification
1	Industrial Engineering	Professor	7	PhD
2	Industrial Engineering	Professor	11	PhD
3	Industrial Engineering	Professor	5	PhD
4	Production Management	Senior Scientist	9	PhD
5	Waste Management	Senior Scientist	6	PhD

A summary of the pairwise comparison results of the criteria is presented in Table 3, where the price has the highest advantage over the other main criteria. Next, pairwise comparisons are provided for each sub-criteria depending on its main criterion. Table 4 provides the pairwise comparisons between the quality factor and other factors affecting the CSC. Mean averages show that, according to experts, the most significant impact of quality will be on the price of the CSC. Pairwise comparisons between the environmental factor and other factors affecting the CSC are summarized in Table 5. Pairwise comparisons between service level criteria and other factors affecting the CSC are illustrated in Table 6. According to experts' opinion, the mean averages of this table illustrate that the service level has the most significant impact on environmental impacts.

Table 3. Pairwise comparisons of price criteria on other factors affecting the CSC

Criteria	Effect on	Criteria	Arithmetic Mean	Middle	Geometric Mean	Standard Deviation	Mean Averages
Price	→	Quality	3.125	2.5	2.8851	1.3562	2.8972
Price	→	Environmental	2.75	2.5	2.3593	1.4880	2.3643
Price	→	Service Level	4.125	4	4.0473	0.8345	4.0464

Table 4. Pairwise comparisons of quality criteria on other factors affecting the CSC

Criteria	Effect on	Criteria	Arithmetic Mean	Middle	Geometric Mean	Standard Deviation	Mean Averages
Quality	→	Price	2.875	3.5	2.5021	1.3562	2.4880
Quality	→	Environmental	3.375	4	2.9907	1.5059	2.9685
Quality	→	Service Level	3.75	4	3.4309	1.2817	3.3693

Table 5. Pairwise comparisons of environmental criteria on other factors affecting the CSC

Criteria Effect	On	Criteria	Arithmetic Mean	Middle	Geometric Mean	Standard Deviation	Mean Averages
Environmental	→	Price	3.25	3.5	2.8851	1.4880	2.8698
Environmental	→	Quality	2.625	2	2.2427	1.5059	2.2575
Environmental	→	Service Level	2.625	2.5	2.2760	1.4079	2.2814

Table 6. Pairwise comparisons of service level criteria on other factors affecting the CSC

Criteria	Effect on	Criteria	Arithmetic Mean	Middle	Geometric Mean	Standard Deviation	Mean Averages
Service Level	→	Price	1.875	2	1.7067	0.8345	1.7100
Service Level	→	Quality	2.25	2	1.9839	1.2817	1.9995
Service Level	→	Environmental	3.375	3.5	3.0351	1.4079	3.0063

Table 7 shows the pairwise comparisons between sub-criteria of quality factors. According to the mean average weight, the material quality criteria impact the quality factor the most. However, the average effect of the sub-quality criteria on the quality factor is not much different from each other.

Table 7. Pairwise comparisons between each sub-criteria of the quality factor

Criteria	Effect on	Criteria	Arithmetic Mean	Middle	Geometric Mean	Standard Deviation	Mean Averages
Material Quality	→	Performance Advantages	3.25	3.5	2.7832	1.5811	2.7587
Material Quality	→	Staff Skills	3.875	4	3.7114	1.1260	3.7053
Staff Skills	→	Performance Advantages	2.125	2	1.8612	1.1260	1.8711
Performance Advantages	→	Material Quality	2.75	2.5	2.3403	1.5811	2.3525
Staff Skills	→	Material Quality	2.125	2	1.8612	1.1260	1.8711
Performance Advantages	→	Staff Skills	3.875	4	3.7114	1.1260	3.7053

Table 8 provides the pairwise comparisons between the sub-criteria of environmental systems management on each other and the environmental management system factor. Based on these results, the mean averages of sub-criteria effects on environmental systems management factor is not significant. Pairwise comparisons between each sub-criteria of the service level factor are displayed in Table 9. It can be seen that the mean average effect of sub-criteria on the environmental management systems is not significant. Finally, the pairwise comparisons are normalized. According to the hierarchical analysis method, the weight of each criterion and then the weight of each sub-criteria are determined. These weights are shown in Tables 10 and 11.

Product price and financial strength have the most significant effects indicating the considerable impact of financial and monetary factors on the CSC. To implement the Dematel method, the indirect effects matrix is calculated.

Table 8. Pairwise comparisons between each sub-criteria of environmental factor

Criteria	Effect on	Criteria	Arithmetic Mean	Middle	Geometric Mean	Standard Deviation	Mean Averages
Environmental Requirements	→	Environmental Certificates	4.125	4	4.0801	0.6409	4.0796
Environmental Requirements	→	Environmental Plans	3.75	4	3.5280	1.2817	3.5219
Environmental Plans	→	Environmental Certificates	2.75	2.5	2.2247	1.7525	2.2530
Environmental Certificates	→	Environmental Requirements	1.875	2	1.7692	0.6409	1.7665
Environmental Plans	→	Environmental Requirements	2.25	2	1.9294	1.2817	1.9448
Environmental Certificates	→	Environmental Plans	3.25	3.5	2.7204	1.7525	2.7141

Table 9. Pairwise comparisons between each sub-criteria of a service level factor

Criteria	Effect on	Criteria	Arithmetic Mean	Middle	Geometric Mean	Standard Deviation	Mean Average
Timely Delivery	→	After Sales Service	3.125	3	3.0196	0.8345	3.0179
Timely Delivery	→	Supply Capacity	3.25	3.5	3.1302	0.8864	3.1267
After Sales Service	→	Supply Capacity	2	2	1.7321	1.0690	1.7440
After Sales Service	→	Timely Delivery	2.875	3	2.7690	0.8345	2.7702
Supply Capacity	→	Timely Delivery	2.75	2.5	2.6321	0.8864	2.6362
Supply Capacity	→	After Sales Service	4	4	3.8730	1.0690	3.8743

Table 10. Weight of each criterion

Criteria	Weight	Rank
Price	0.271911	1
Quality	0.26522	2
Environmental	0.231915	3
Service Level	0.230954	4

Table 11. Weight of each sub-criterion

Criteria	Weight	Rank
Timely Delivery	0.08184	7
After Sales Service	0.065582	11
Supply Capacity	0.083532	6
Requirements	0.098176	4
Plans	0.065685	10
Certificates	0.068053	9
Material Quality	0.100486	3
Performance Advantages	0.094876	5
Staff Skills	0.069858	8
Price Product	0.139836	1
Financial Power	0.132075	2

Table 12 is matrix *R* that is calculated based on Eq. (4), which shows the indirect effects of the measured factors on each other. The results of this table are similar to the impact of all factors and sub-criteria on each other. This table indicates that CSC (6% impact), price (4%), quality (3.77%), and environmental management systems (15.27%) are the most effective factors.

Table 12. Matrices *R* and *C*

Criteria Rank	Matrix *R*		Matrix *C*	
	R	***R*%**	***C***	***C*%**
CSC	2.139	6.16%	0.000	0.00%
Price	1.388	4.00%	6.639	19.12%
Quality	1.310	3.77%	7.699	22.18%
Environmental	1.517	4.37%	1.687	4.86%
Service Level	1.696	4.89%	5.251	15.12%
Price Product	1.605	4.62%	0.639	1.84%
Financial Power	1.599	4.61%	0.602	1.73%
Material Quality	2.606	7.51%	1.481	4.27%
Performance Advantages	2.765	7.96%	1.381	3.98%
Staff Skills	3.413	9.83%	1.057	3.04%
Environmental Requirements	1.861	5.36%	1.654	4.76%
Environmental Certificates	2.542	7.32%	1.069	3.08%
Environmental Plans	2.402	6.92%	1.204	3.47%
Timely Delivery	2.716	7.82%	1.533	4.41%
After Sales Service	2.819	8.12%	1.264	3.64%
Supply Capacity	2.337	6.73%	1.557	4.49%

According to Eq. (5), the values obtained for matrix C, which shows the quality factor (22.18%), price factor (19.13%), service level factor (15.13%), and environmental management (4.86%) are the most influential factors in implementing CSC.

Moreover, according to Eq. (6), the permeability and permeability of each factor are examined. The values obtained for the $R + C$ and $R - C$ vectors are shown in Table 13. According to the $R + C$ values, it can be said that the quality factor creates 8.9% of the total effects of the studied relationships, which means that this factor creates 8.4 interactions between criteria. In addition, the price and service level factors have the most interactions with other factors. Moreover, the $C - R$ value is a penetrating factor if positive and a permeable factor if negative.

Table 13. Matrices *R*+*C* and *C*-*R*

Ranked Criteria	$R + C$	Ranked Criteria	$C - R$
Quality	8.970	Quality	6.383
Price	7.999	Price	5.23
Service Level	6.890	Service Level	3.51
Staff Skills	4.458	Environmental	0.17
Timely Delivery	4.245	Environmental Requirement	-0.20
Performance Advantages	4.134	Supply Capacity	-0.78
After Sales Service	4.080	Price Product	-0.96
Material Quality	4.077	Financial Power	-0.99
Supply Capacity	3.892	Material Quality	-1.11
Environmental Certificates	3.609	Timely Delivery	-1.18
Environmental Plans	3.603	Environmental Plans	-1.19
Environmental Requirement	3.513	Performance Advantages	-1.37

Ranked Criteria	$R+C$	Ranked Criteria	$C-R$
Environmental	3.197	Environmental Certificates	-1.47
Price Product	2.242	After Sales Service	-1.55
Financial Power	2.199	Staff Skills	-2.34

Finally, factors affecting the CSC are ranked by using the SAW method. Table 14 displays the calculation results of the SAW method, which shows:

- According to the total weight effect of Table 14, it can be concluded that the quality factor is ranked as the most significant effect on the CSC. Moreover, the quality factor has the most significant impact on the CSC directly and indirectly.
- After the quality factor, the price has the most significant overall impact on the CSC.
- The service level is ranked third, while environmental management systems are ranked fourth in impact in all effects (total, direct, and indirect).

Table 14. Rank of factors affecting the CSC by the SAW methods

Item	Factor	Effect	Rank
Criteria	Price	1.7988	2
	Quality	2.0360	1
	Environmental	0.3909	4
	Service Level	1.2011	3
Sub-criteria	Price Product	0.0893	6
	Financial Power	0.0795	9
	Material Quality	0.1488	2
	Performance Advantages	0.1310	3
	Staff Skills	0.0738	10
	Environmental Requirement	0.1624	1
	Environmental Certificates	0.0702	11
	Environmental Plans	0.0820	8
	Timely Delivery	0.1254	5
	After Sales Service	0.0829	7
	Supply Capacity	0.1301	4

5. Discussion

After ranking the factors affecting the CSC implementation, it is found that the factors that have the most impact on the CSC are quality, price, service level, and environmental management systems, respectively. Moreover, the price factor accepts the maximum total impact from the sub-criteria product price and financial strength. Moreover, the quality factor accepts the maximum total impact from the sub-criteria material quality, performance advantages, and staff skills, respectively. Moreover, the results show that the highest impact of the fundamental factor of environmental management systems is the environmental requirements sub-criteria, and the plans and certifications of environmental management systems are in the following ranks. The service level factor is most affected by the timely delivery sub-criteria and after-sales service.

The material for production plays an essential role in describing the circularity of the economy. This importance should be considered from two aspects: the quality of recycled materials and the substance functionality of the components in the materials (Steinmann et al., 2019). The quality of materials in recycling operations is divided into two categories upcycling and downcycling. Upcycling includes the recycling of products to products of the same or higher quality. While in downcycling, the main product components are recycled into usable materials with low quality (Muthu, 2018). Substance functionality of the components in materials is considered downcycling, so CE is based on the statement that functionality is maintained as long as possible (e.g., recycling steel by remitting) (Iacovidou et al., 2017). In this recycling process, it is essential to lose both the substance functionality of the components in the raw materials and deal with the emergence of inefficient materials in the recycled product.

Based on the results obtained by this study, the quality factor is the most important factor among other factors in the CSC. Integrating a circular economy into the supply chain requires that recycling operations play a vital role in the supply chain. Special attention is paid to the waste management approach based on 3R, including Reuse, Repair, and Recycling. Applying this approach leads to the goal of zero waste. Quality is of particular importance in several respects, like recycling end-of-life products to other products with similar or higher quality in upcycling and recycling the main components of end-of-life products to energy and materials used in downcycling; for example, the use of higher quality materials in recycling in the CSC related to 3D printing platforms (Sun et al., 2020) and recycling electronic vehicle batteries in the framework of the CSC (Garrido-Hidalgo et al., 2020). The quality factor also adds this critical capability to the CSC so that reverse motion and closed loop can be used in the supply chain. The quality factor produces effective results in the supply chain, including material recycling, reduced waste production, and reduced over-harvesting of non-renewable resources. For example, the recycling of wind turbine blades in Europe in the CSC using reverse motion (Rentizelas et al., 2021). In general, the critical aspects of the quality factor in the CSC can be summarized as follows:

- Use of high-quality raw materials to better recycling operations in upcycling and downcycling
- Use of reverse motion and closed loops in the CSC network design
- Achieving the goal of zero waste following the basic principles of circular economics
- Facilitate waste management and positive environmental impacts

6. Conclusion

Circular supply chain (CSC) management involves incorporating circular thinking into the management of the supply chain and its surrounding industrial and natural ecosystems. The goal of CSC management is to systematically recycle technical materials and regenerate biological materials, ultimately moving towards a zero-waste approach. This requires innovation in the business model system and supply chain functions, from product/service design to end-of-life and waste management, and includes all stakeholders in the product/service life cycle such as parts/products produced, service providers, consumers, and users. The ideal CSC generates zero waste by systematically regenerating resources in the natural and industrial ecosystems in which it operates. While some authors have considered ways to improve supply chain performance, and others have suggested key performance indicators, there is still no general consensus on how to measure the performance of a CSC, as the concept is still relatively new and there is ongoing research in this area.

Accordingly, this study attempted to implement a combined approach of multi-criteria decision-making methods to evaluate effective factors related to CSC implementation. For this purpose, three methods of hierarchical analysis, DEMATEL, and SAW methods, are applied. Implementation results indicate that special attention to product quality plays a critical role in developing a sustainable supply chain. This subject is very circular in all aspects of the supply chain. A complete comparison between the sustainable supply chain and the CSC in terms of different indicators is suggested to develop this research.

Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

References

Akter, M. M. K., Haq, U. N., Islam, M. M., & Uddin, M. A. (2022). Textile-apparel manufacturing and material waste management in the circular economy: A conceptual model to achieve sustainable development goal (SDG) 12 for Bangladesh. *Cleaner Environmental Systems*, 100070.

Alavi, B., Tavana, M., & Mina, H. (2021). A Dynamic Decision Support System for Sustainable Supplier Selection in Circular Economy. *Sustainable Production and Consumption*, *27*, pp.905-920.

Asante, R., Agyemang, M., Faibil, D., & Osei-Asibey, D. (2022). Roles and actions of managers in circular supply chain implementation: A resource orchestration perspective. *Sustainable Production and Consumption*, *30*, pp.64-76.

Atabaki, M. S., Mohammadi, M., & Naderi, B. (2020). New robust optimization models for closed-loop supply chain of durable products: Towards a circular economy. *Computers & Industrial Engineering*, *146*, 106520.

Aytekin, A., Okoth, B. O., Korucuk, S., Karamaşa, Ç., & Tirkolaee, E. B. (2022). A neutrosophic approach to evaluate the factors affecting performance and theory of sustainable supply chain management: application to textile industry. *Management Decision*, *ahead-of-print*(ahead-of-print).

Bal, A., & Badurdeen, F. (2022). A simulation-based optimization approach for network design: The circular economy perspective. *Sustainable Production and Consumption*, *30*, pp.761-775.

Balwada, J., Samaiya, S., & Mishra, R. P. (2021). Packaging plastic waste management for a circular economy and identifying a better waste collection system using analytical hierarchy process (ahp). *Procedia CIRP*, *98*, pp.270-275.

Bressanelli, G., Visintin, F., & Saccani, N. (2022). Circular Economy and the evolution of industrial districts: A supply chain perspective. *International Journal of Production Economics*, *243*, 108348.

Chen, J., Zhang, F., Liu, L., & Zhu, L. (2019). Does environmental responsibility matter in cross-sector partnership formation? A legitimacy perspective. *Journal of environmental management*, *231*, pp.612-621.

Colasante, A., & D'Adamo, I. (2021). The circular economy and bioeconomy in the fashion sector: Emergence of a “sustainability bias”. *Journal of Cleaner Production*, *329*, 129774.

Darvazeh, S. S., Mooseloo, F. M., Aeini, S., Vandchali, H. R., & Tirkolaee, E. B. (2022). An integrated methodology for green human resource management in construction industry. *Environmental Science and Pollution Research*.

Darvazeh, S. S., Mooseloo, F. M., Vandchali, H. R., Tomaskova, H., & Tirkolaee, E. B. (2022). An integrated multi-criteria decision-making approach to optimize the number of leagile-sustainable suppliers in supply chains. *Environmental Science and Pollution Research*, *29*(44), pp.66979-67001.

Elia, V., Gnoni, M. G., & Tornese, F. (2020). Evaluating the adoption of circular economy practices in industrial supply chains: An empirical analysis. *Journal of Cleaner Production*, *273*, 122966.

Farooque, M., Zhang, A., Liu, Y., & Hartley, J. L. (2022). Circular supply chain management: Performance outcomes and the role of eco-industrial parks in China. *Transportation Research Part E: Logistics and Transportation Review*, *157*, 102596.

Garrido-Hidalgo, C., Ramirez, F. J., Olivares, T., & Roda-Sanchez, L. (2020). 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 Manag*, *103*, pp.32-44.

Govindan, K., & Hasanagic, M. (2018). A systematic review on drivers, barriers, and practices towards circular economy: a supply chain perspective. *International Journal of Production Research*, *56*(1-2), pp.278-311.

Govindan, K., Mina, H., Esmaeili, A., & Gholami-Zanjani, S. M. (2020). An Integrated Hybrid Approach for Circular supplier selection and Closed loop Supply Chain Network Design under Uncertainty. *Journal of Cleaner Production*, *242*, 118317.

Hossain, M. K., & Thakur, V. (2022). Drivers of sustainable healthcare supply chain performance: multi-criteria decision-making approach under grey environment. *International Journal of Quality & Reliability Management*, *39*(3), pp.859-880.

Huang, L., Zhen, L., Wang, J., & Zhang, X. (2022). Blockchain implementation for circular supply chain management: Evaluating critical success factors. *Industrial Marketing Management*, *102*, 451-464.

Iacovidou, E., Velis, C. A., Purnell, P., Zwirner, O., Brown, A., Hahladakis, J., Millward-Hopkins, J., & Williams, P. T. (2017). Metrics for optimising the multi-dimensional value of resources recovered from waste in a circular economy: A critical review. *Journal of Cleaner Production*, *166*, pp.910-938.

Julianelli, V., Caiado, R. G. G., Scavarda, L. F., & Cruz, S. P. d. M. F. (2020). Interplay between reverse logistics and circular economy: critical success factors-based taxonomy and framework. *Resources, Conservation and Recycling*, *158*, 104784.

Karman, A., & Pawłowski, M. (2022). Circular economy competitiveness evaluation model based on the catastrophe progression method. *Journal of environmental management*, *303*, 114223.

Kazancoglu, I., Kazancoglu, Y., Kahraman, A., Yarimoglu, E., & Soni, G. (2020). Investigating barriers to circular supply chain in the textile industry from Stakeholders' perspective. *International Journal of Logistics Research and Applications*, pp.1-28.

Kazancoglu, I., Kazancoglu, Y., Kahraman, A., Yarimoglu, E., & Soni, G. (2022). Investigating barriers to circular supply chain in the textile industry from Stakeholders' perspective. *International Journal of Logistics Research and Applications*, *25*(4-5), pp.521-548.

Khandelwal, C., & Barua, M. K. (2020). Prioritizing circular supply chain management barriers using fuzzy AHP: case of the Indian plastic industry. *Global Business Review*, 0972150920948818.

Kumar, A., Choudhary, S., Garza-Reyes, J. A., Kumar, V., Rehman Khan, S. A., & Mishra, N. (2021). Analysis of critical success factors for implementing Industry 4.0 integrated circular supply chain – moving towards sustainable operations. *Production Planning & Control*, pp.1-15.

Lahane, S., & Kant, R. (2021a). Evaluating the circular supply chain implementation barriers using Pythagorean fuzzy AHP-DEMATEL approach. *Cleaner Logistics and Supply Chain*, *2*, 100014.

Lahane, S., & Kant, R. (2021b). Evaluation and ranking of solutions to mitigate circular supply chain risks. *Sustainable Production and Consumption*, *27*, pp.753-773.

Lahane, S., & Kant, R. (2021c). A hybrid Pythagorean fuzzy AHP–CoCoSo framework to rank the performance outcomes of circular supply chain due to adoption of its enablers. *Waste Management*, *130*, pp.48-60.

Lahane, S., & Kant, R. (2021d). A hybrid Pythagorean fuzzy AHP – CoCoSo framework to rank the performance outcomes of circular supply chain due to adoption of its enablers. *Waste Management*, *130*, 48-60.

Lahane, S., Kant, R., & Shankar, R. (2020). Circular supply chain management: A state-of-art review and future opportunities. *Journal of Cleaner Production*, *258*, 120859.

Liu, Y., Wood, L. C., Venkatesh, V., Zhang, A., & Farooque, M. (2021a). Barriers to sustainable food consumption and production in China: A fuzzy DEMATEL analysis from a circular economy perspective. *Sustainable Production and Consumption*, *28*, pp.1114-1129.

Liu, Y., Wood, L. C., Venkatesh, V. G., Zhang, A., & Farooque, M. (2021b). Barriers to sustainable food consumption and production in China: A fuzzy DEMATEL analysis from a circular economy perspective. *Sustainable Production and Consumption*, *28*, pp.1114-1129.

Luthra, S., Sharma, M., Kumar, A., Joshi, S., Collins, E., & Mangla, S. (2022). Overcoming barriers to cross-sector collaboration in circular supply chain management: a multi-method approach. *Transportation Research Part E: Logistics and Transportation Review*, *157*, 102582.

Machado, N., & Morioka, S. N. (2021). Contributions of modularity to the circular economy: A systematic review of literature. *Journal of Building Engineering*, *44*, 103322.

Mahroof, K., Omar, A., Rana, N. P., Sivarajah, U., & Weerakkody, V. (2021). Drone as a Service (DaaS) in promoting cleaner agricultural production and Circular Economy for ethical Sustainable Supply Chain development. *Journal of Cleaner Production*, *287*, 125522.

Mangla, S. K., Luthra, S., Mishra, N., Singh, A., Rana, N. P., Dora, M., & Dwivedi, Y. (2018). Barriers to effective circular supply chain management in a developing country context. *Production Planning & Control*, *29*(6), pp.551-569.

Mehmood, A., Ahmed, S., Viza, E., Bogush, A., & Ayyub, R. M. (2021). Drivers and barriers towards circular economy in agri-food supply chain: A review. *Business Strategy & Development*, *4*(4), pp.465-481.

Menon, R. R., & Ravi, V. (2021). Analysis of barriers of sustainable supply chain management in electronics industry: an interpretive structural modelling approach. *Cleaner and Responsible Consumption*, *3*, 100026.

Moktadir, M. A., Ahmadi, H. B., Sultana, R., Zohra, F.-T., Liou, J. J. H., & Rezaei, J. (2020). Circular economy practices in the leather industry: A practical step towards sustainable development. *Journal of Cleaner Production*, *251*, 119737.

Muthu, S. S. (2018). *Circular Economy in Textiles and Apparel: Processing, Manufacturing, and Design*. Woodhead publishing.

Nag, U., Sharma, S. K., & Govindan, K. (2021). Investigating drivers of circular supply chain with product-service system in automotive firms of an emerging economy. *Journal of Cleaner Production*, *319*, 128629.

Nag, U., Sharma, S. K., & Padhi, S. S. (2022a). Evaluating value requirement for Industrial Product-Service System in circular economy for wind power-based renewable energy firms. *Journal of Cleaner Production*, *340*, 130689.

Nag, U., Sharma, S. K., & Padhi, S. S. (2022b). Evaluating value requirement for Industrial Product-Service System in circular economy for wind power-based renewable energy firms. *Journal of Cleaner Production*, 130689.

Ogunmakinde, O. E., Sher, W., & Egbelakin, T. (2021). Circular economy pillars: a semi-systematic review. *Clean Technologies and Environmental Policy*, *23*(3), pp.899-914.

Orji, I. J., U-Dominic, C. M., & Okwara, U. K. (2022). Exploring the determinants in circular supply chain implementation in the Nigerian manufacturing industry. *Sustainable Production and Consumption*, *29*, pp.761-776.

Ozkan-Ozen, Y. D., Kazancoglu, Y., & Kumar Mangla, S. (2020). SYNCHRONIZED BARRIERS FOR CIRCULAR SUPPLY CHAINS IN INDUSTRY 3.5/INDUSTRY 4.0 TRANSITION FOR SUSTAINABLE RESOURCE MANAGEMENT. *Resources, Conservation and Recycling*, *161*, 104986.

Patel, M. N., Pujara, A. A., Kant, R., & Malviya, R. K. (2021). Assessment of circular economy enablers: Hybrid ISM and fuzzy MICMAC approach. *Journal of Cleaner Production*, *317*, 128387.

Pieroni, M. P., McAloone, T. C., & Pigosso, D. C. (2019). Business model innovation for circular economy and sustainability: A review of approaches. *Journal of Cleaner Production, 215*, pp.198-216.

Rentizelas, A., Trivyza, N., Oswald, S., & Siegl, S. (2021). Reverse supply network design for circular economy pathways of wind turbine blades in Europe. *International Journal of Production Research*, 1-20.

Sahoo, P. B. B., & Thakur, V. (2022). Enhancing the performance of Indian micro, small and medium enterprises by implementing supply chain finance: challenges emerging from COVID-19 pandemic. *Benchmarking: An International Journal*.

Saroha, M., Garg, D., & Luthra, S. (2021). Identification and analysis of circular supply chain management practices for sustainability: A fuzzy-DEMATEL approach. *International Journal of Productivity and Performance Management*.

Singh, R. K., Kumar, A., Garza-Reyes, J. A., & de Sá, M. M. (2020). Managing operations for circular economy in the mining sector: An analysis of barriers intensity. *Resources Policy*, *69*, 101752.

Singhal, D., Tripathy, S., & Jena, S. K. (2020). Remanufacturing for the circular economy: Study and evaluation of critical factors. *Resources, Conservation and Recycling*, *156*, 104681.

Statisa(2022), https://www.statisa.com

Steinmann, Z., Huijbregts, M., & Reijnders, L. (2019). How to define the quality of materials in a circular economy? *Resources, Conservation and Recycling*, *141*, pp.362-363.

Sun, L., Wang, Y., Hua, G., Cheng, T., & Dong, J. (2020). Virgin or recycled? Optimal pricing of 3D printing platform and material suppliers in a closed-loop competitive circular supply chain. *Resources, Conservation and Recycling*, *162*, 105035.

Sverko Grdic, Z., Krstinic Nizic, M., & Rudan, E. (2020). Circular economy concept in the context of economic development in EU countries. *Sustainability*, *12*(7), 3060.

Syberg, K., Nielsen, M. B., Oturai, N. B., Clausen, L. P. W., Ramos, T. M., & Hansen, S. F. (2022). Circular economy and reduction of micro (nano) plastics contamination. *Journal of Hazardous Materials Advances*, 100044.

Thakur, V. (2022). Locating temporary waste treatment facilities in the cities to handle the explosive growth of HCWs during pandemics: A novel Grey-AHP-OCRA hybrid approach. *Sustainable Cities and Society*, *82*, 103907.

van Capelleveen, G., van Wieren, J., Amrit, C., Yazan, D. M., & Zijm, H. (2021). Exploring recommendations for circular supply chain management through interactive visualisation. *Decision support systems*, *140*, 113431.

Yan, X., Liu, W., Lim, M. K., Lin, Y., & Wei, W. (2022). Exploring the factors to promote circular supply chain implementation in the smart logistics ecological chain. *Industrial Marketing Management*, *101*, pp.57-70.

Yildizbasi, A. (2021). Blockchain and renewable energy: Integration challenges in circular economy era. *Renewable Energy*, *176*, 183-197.

Zhang, A., Venkatesh, V. G., Liu, Y., Wan, M., Qu, T., & Huisingh, D. (2019). Barriers to smart waste management for a circular economy in China. *Journal of Cleaner Production*, *240*, 118198.