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Blockchain Features for Facilitating Circular Economy Adoption in the Palm Oil Industry: A DEMATEL Approach

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Abstract

This study delves into the convergence of Circular Economy (CE) principles and Blockchain Technology (BCT) within Malaysia's pivotal palm oil sector. It emphasizes the potential of BCT to catalyze sustainability efforts, focusing on the significance of key BCT features in motivating palm oil industry stakeholders towards a more environmentally-conscious supply chain. This study employed the Decision-Making Trial and Evaluation Laboratory (DEMATEL) to dissect its attributes' influence. The analysis revealed transparency, immutability, and irreversibility as pivotal drivers, significantly enhancing traceability, integrity, and accountability within the sector. Decentralization, peer-to-peer networking, and distributed ledgers were identified as playing supportive roles, holding transformative potential in reshaping the industry's dynamics. The findings underscore the paramount importance of transparency, immutability, and irreversibility attributes in fostering a reliable palm oil ecosystem. This study not only provides a framework for strategic integration but also highlights the transformative potential of BCT features. This research offers valuable insights for palm oil business owners, emphasizing the benefits of adopting BCT for a more sustainable and efficient supply chain.

Keywords: Circular Economy, Blockchain Technology, Sustainability, Palm Oil Sector, Supply Chain Management

1. Introduction

The palm oil sector, a dominant player in Malaysia's economy, has secured its position as the globe's second-largest producer and exporter (MPOB, 2022). Spanning an expansive 4.49 million hectares, Malaysia's palm oil cultivation yields an impressive annual output of 17.73 million tons, constituting a significant proportion of the world's oils and fats production (The Star, 2021). Propelled by ecological stewardship, Malaysia leads the charge in promoting sustainable practices within the palm oil industry.

In alignment with this commitment to sustainability, Malaysia has embraced the principles of the CE as a catalyst for transforming palm oil production (MIDA, 2021). The CE model, an innovative departure from linear economies, centers on resource efficiency and waste minimization (Cheah, Pahri, Leng, Er, & Show, 2023). This paradigm shift emphasizes extending product lifecycles, minimizing reliance on virgin materials, and reintegrating repurposed resources into successive cycles (Liu, Chen, Kuo, & Lin, 2022). Amidst this transition, Industry 4.0 technologies, particularly BCT, stand poised to reshape supply chain management, traceability, and collaborative engagement (Basile, D'Adamo, Goretti, & Rosa, 2023; Ferreira, Godina, Pinto, Pinto, & Carvalho, 2023; Pai & Chandra, 2022).

Navigating the transition to a CE entail surmounting intricate challenges, encompassing intricate supply chain orchestration, traceability verification, and cooperative frameworks (Abdul-Hamid, Ali, Osman, & Tseng, 2021). The emergence of Industry 4.0 offers an opportune juncture for harnessing advanced technologies to drive the circular economy transformation within established business models (Agrawal, Wankhede, Kumar, Luthra, & Huisingh, 2022). BCT, among these innovative technologies, emerges as a catalyst for revolutionizing manufacturing systems and nurturing economic and environmental sustainability (Rejeb, Suhaiza, Rejeb, Seuring, & Treiblmaier, 2022). By enabling transparent and immutable record-keeping, BCT empowers organizations to monitor material, component, and product movements across supply chains, heralding a new era of transparency, traceability, and innovation (Böckel, Nuzum, & Weissbrod, 2021). As a decentralized digital ledger, BCT ensures the creation of tamper-resistant records, underpinning trust and accountability in supply chain transactions (Treiblmaier, 2018).

In the context of the Malaysian palm oil industry, a critical challenge persists in the underutilization of BCT to catalyze CE principles within the supply chain(Abdul-Hamid et al., 2021; Cheah et al., 2023). Notably, according to information gleaned from the Malaysian Palm Oil Board (MPOB), this transformative technology has yet to find application within the Malaysian context. This glaring gap underscores a pressing need for investigation, as no comprehensive study has hitherto examined the pivotal role of specific BCT attributes in influencing the adoption behavior of industry stakeholders. The potential impact of attributes such as transparency, immutability, and irreversibility remain unexplored, leaving a significant knowledge deficit that hampers progress towards a more sustainable and accountable palm oil supply chain (Khan, Haleem, Husain, Samson, & Pathak, 2023). This dearth of empirical understanding necessitates an urgent inquiry into the facilitative potential of BCT in the CE paradigm, urging a recalibration of strategies for a more sustainable palm oil industry.

This research endeavor delves into the untapped potential of BCT features in propelling the CE paradigm within the palm oil sector, with Malaysia as its focal point. Specifically, this study aims to unravel the intricate interplay of BCT features through the lens of industry experts. By dissecting how these BCT attributes play a pivotal role in motivating decision-makers within the palm oil industry to embrace this technology, the research underscores the nexus between BCT and CE. Employing the DEMATEL methodology, this study contributes to the discourse on sustainable practices and technological strides within the palm oil landscape.

2. Literature Review

2.1. BCT and features

Blockchain technology, introduced by Satoshi Nakamoto for cryptocurrencies like Bitcoin (Zheng, Xie, Dai, Chen, & Wang, 2017), is characterized by a range of fundamental features that underpin its widespread adoption. At its core is the principle of decentralization, which eliminates the need for intermediaries by enabling peer-to-peer transactions, thus fostering trust and reducing dependence on central authorities (Kouhizadeh, Saberi, & Sarkis, 2021). The technology's transparency is another defining aspect, as transactions are recorded on the blockchain with user identities hidden behind cryptographic techniques, ensuring accountability without compromising privacy (Rajasekaran, Azees, & Al-Turjman, 2022). The concept of immutability is intrinsic to blockchain, as verified transactions become permanent and unalterable once recorded, enhancing security and preventing unauthorized tampering (Dash, 2023). Operating within a peer-to-peer network, blockchain utilizes a distributed ledger system where participants each hold a copy of the ledger, ensuring reliability, resilience, and avoiding single points of failure (Rajasekaran et al., 2022). This distributed ledger concept not only guarantees data consistency across the network but also facilitates error detection and correction due to its redundancy. Lastly, the principle of irreversibility comes into play, with confirmed transactions becoming irreversible through cryptographic hashing, thereby establishing an unmodifiable transaction history (Irreversibility). Collectively, these features empower blockchain technology's potential to revolutionize diverse sectors beyond its initial cryptocurrency applications, offering secure, transparent, and decentralized solutions with the promise of transforming industries (Basile et al., 2023).

2.2. Circular Economy (CE)

The concept of a CE has been a subject of extensive discussion among scholars and practitioners, yet a comprehensive definition remains elusive. According to the Ellen MacArthur Foundation, CE represents an industrial system that places significant emphasis on eliminating waste through innovative design, monitoring and controlling harmful substances, restoration, and the utilization of renewable energy (MacArthur, 2013). In stark contrast to the conventional linear economy model of "create, consume, discard," CE advocates for iterative processes and resource utilization, aiming to stimulate economic growth while prioritizing environmental sustainability (Murray, Skene, & Haynes, 2017). By adopting the principles of "reduce, reuse, and recycle," CE aims to reduce waste generation and the excessive use of natural resources (Millar, McLaughlin, & Börger, 2019). Additionally, CE highlights the importance of social equity in conjunction with ecological and economic viability, offering a progressive approach to addressing social sustainability challenges (Leipold et al., 2023).

Given the scarcity of natural resources, the drive for economic expansion, and the imperative to create jobs, CE business models present a promising avenue for environmentally conscious production and consumption (Neves & Marques, 2022). Therefore, organizations are urged to embrace CE practices to integrate sustainability into their operations. Enterprises that prioritize sustainability and social well-being, while also generating economic value, contribute to the establishment of sustainable market value through transformative organizational strategies (Bîrgovan et al., 2022).

The Ellen MacArthur Foundation underscores three core pillars for CE: firstly, the conservation and enhancement of natural resources through the use of renewable energy and responsible management; secondly, optimizing yields by circulating materials without disrupting their technical and biological cycles; and thirdly, improving efficiency by mitigating harmful externalities. The Foundation also advocates for the ReSOLVE framework, which encompasses six practices that bolster CE efforts: Regenerate, Share, Optimize, Loop, Virtualize, and Exchange. These principles serve to preserve ecosystems, maximize product utilization, minimize waste, reduce inefficiencies, recycle resources, and foster the development of innovative business models leveraging cutting-edge technologies.

The realization of the CE framework can be achieved through the integration of digitalization and the

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incorporation of emergent technologies like BCT into CE initiatives (Dev, Shankar, & Qaiser, 2020; Umar, Khan, Yusoff Yusliza, Ali, & Yu, 2022). The potential of blockchain to facilitate the transition towards a CE is discussed in the subsequent section.

2.3. BCT and CE linkage

In a remarkable fusion of the CE and BCT, the CE concept aims to align economic growth with environmental sustainability by promoting cyclical processes to counter resource depletion and waste (Murray et al., 2017). Upholding 'reduce, reuse, recycle' principles, CE strives for cleaner production across sectors, embedding a dynamic balance that extends beyond economic gains to encompass social fairness and ecological stewardship. The Ellen MacArthur Foundation champions CE's ethos, advocating dematerialization, resource regeneration, and resilient resource adoption for sustainable growth, fortified by the ReSOLVE framework's pillars of regeneration, sharing, optimization, loop, virtualization, and exchange (MacArthur, 2013).

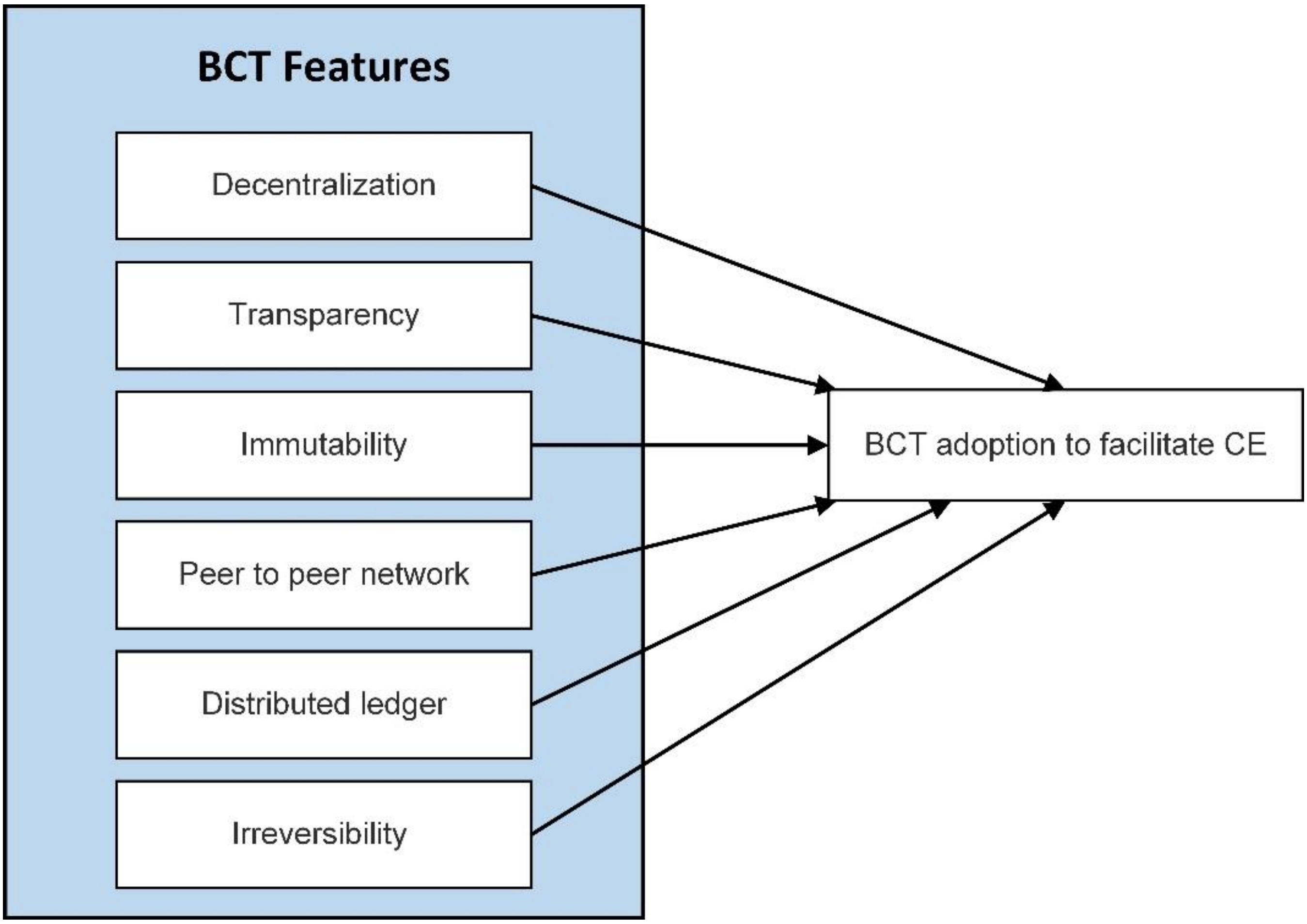

Fig. 1: Research model

Within this tapestry, BCT emerges as a pivotal linchpin, offering secure, tamper-proof data sharing across intricate networks, seamlessly resonating with CE's tenets of circulation, resource optimization, and inclusive participation. The potential of BCT in fulfilling CE's vision is evident as it orchestrates synchronized data sharing, harmonizing distributed databases to drive sustainable value creation, diminish waste, and amplify stakeholder engagement. The confluence of these forward-looking paradigms — CE's pursuit of sustainability and BCT's assurance of secure decentralization — envisions a future where regenerative economic ecosystems flourish, reinforcing CE's goals with technological might and ushering in an era of equity and sustainability.

2.4. Research model

Figure 1 illustrates the research model of the study. Accordingly, BCT features are considered as important predictors of palm oil supply chain decision-makers' adoption behavior to further facilitate CE principles by applying BCT.

3. Research method

3.1. DEMATEL

Multiple-criteria decision-making (MCDM) techniques have been effective in solving decision making problems (Ahmadi, Nilashi, & Ibrahim, 2015; Esfahani et al., 2018;

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Mardani et al., 2017; Nilashi et al., 2024; Nilashi, Ahmadi, Ahani, Ravangard, & bin Ibrahim, 2016; Nilashi et al., 2019; Nilashi et al., 2015; Safaei et al., 2022; Yadegaridehkordi, Nilashi, Nizam Bin Md Nasir, Safie Bin Mohd Satar, & Momtazi, 2023). As a MCDM technique, the Decision-Making Trial and Evaluation Laboratory (DEMATEL) framework, originally conceptualized by Fontela and Gabus (1976) in 1976, serves as a potent tool for unraveling intricate causal relationships within complex systems. This method, rooted in the insights of experts, not only translates factor interconnections into a comprehensive cause-and-effect network but also employs an impact relation diagram to spotlight pivotal elements within a system (Asadi et al., 2022; Dalvi-Esfahani, Niknafs, Kuss, Nilashi, & Afrough, 2019; Yadegaridehkordi et al., 2018). Embarking on the DEMATEL approach involves a structured process. Initially, the context of the problem is defined, followed by the extraction of crucial determinants essential for consideration, a task often accomplished through scholarly literature review or consultation with experts. In soliciting the perspectives of these experts, a meticulously crafted DEMATEL measurement questionnaire is deployed. This questionnaire is equipped with a range of scales, spanning from 0 (signifying negligible influence) to 4 (indicating substantial influence), prompting respondents to discern the relative significance of each factor vis-à-vis others. Sumrit and Anuntavoranich (2013)Sumrit and Anuntavoranich (2013) have meticulously outlined a robust series of steps to ensure the efficacy of a DEMATEL approach, solidifying its value as a methodological framework:

Step 1 initiates the process by delving into the rich pool of experts' insights $exp = \{exp_1, exp_2, \ldots, exp_l\}j$: These individuals contribute their valued perspectives on the significance attributed to each feature $f = \{f_1, f_2, \ldots, f_n\}$ in relation to its counterparts within the system. This input is meticulously gathered utilizing data gleaned from the DEMATEL questionnaire, coupled with pair-wise comparison matrices. As a result, each expert's response spawns the construction of a square matrix $Z_k = [z_{ij}^k]_{n\times n}$, its diagonal harmoniously adorned with zeros. Within this matrix, the value z_{ij}^k precisely quantifies the level of importance assigned by expert exp_k to feature f_i when juxtaposed with feature f_j.

Step 2 calculates the Mean Response Matrix $A_k = [a_{ij}^k]_{n\times n}$: Upon gathering input from a set of l experts, their individual responses are amalgamated to create an average response matrix. This matrix consolidation process is executed through the subsequent computation:

$$a_{ij} = \frac{1}{l}\sum_{k=1}^{l} z_{ij}^k \qquad i,j = 1,2,3,\ldots,n \tag{1}$$

Step 3 creates Normalized matrix N: matrix N is calculated from the matrix A using the following calculation:

$$N = \frac{A}{s} \tag{2}$$

where S is determined as the highest value between the maximum row sum and maximum column sum of A, as follows:

$$s = max(\max_{1\le i\le n}\sum_{j=1}^{n} a_{ij}, \max_{1\le i\le n}\sum_{i=1}^{n} a_{ij} \tag{3}$$

Step 4 computes Total influence matrix T: Furthermore, we compute the comprehensive influence matrix T based on matrix A. This matrix T of size (n×n), denoted as $[t_{ij}]_{n\times n}$, captures the interrelationships among the features in the system. Employing transition theory and considering both direct and indirect connections, we calculate T as:

$$T = N(I-N)^{-1}, \; I \; denotes \; the \; identity \; matrix \tag{4}$$

importance and role are determined from $R + C$ and $R - C$ values. Higher $(r_i + c_i)$ implies greater feature significance; features are categorized as 'cause' ($(r_i - c_i) > 0$) or 'effect' ($(r_i - c_i) < 0$). Plotting $R + C$ and $R - C$ generates the IRM diagram, showing factor relationships, with a threshold from T's average enhancing graphical depiction.

Step 5 develops Influence Relation Map (IRM): To construct the IRM, compute vectors R and C by summing matrix T's rows and columns. R signifies effects transmitted from feature f_i to others, while C indicates effects on f_i from other factors.

3.2. Data collection

The data collection phase of this research involved a strategic approach to tap into the insights of six accomplished academic experts. These experts were carefully chosen due to their profound understanding of supply chain dynamics and blockchain technology. It's important to highlight that the practical adoption of blockchain technology within the palm oil supply chain is still in its infancy, making it a challenging task to identify experts entrenched in its practical implementation. As a result, the selected academic experts offer a unique blend of theoretical acumen and academic expertise. Their perspectives, while not grounded in immediate practical exposure, play a pivotal role in shedding light on potential applications, addressing gaps, and shaping the trajectory of blockchain's integration in the palm oil supply chain landscape. Their valuable contributions are poised to bridge the divide between theory and practice, propelling the field forward. Profile of the respondents are exhibited in Table 1.

Table 1: Respondents' profile

		Frequency
Gender	Male	4
	Female	2
Age	30-40	3
	41-50	2
	Above 50	1
Area of expertise (*more than one selection per respondent were allowed*)	Supply chain management	4
	Logistics	2
	Agriculture economics	1
	Sustainability	5
	Information systems	3
Experience in BCT research	One year and less	1
	2-4 years	3
	More than 4 years	2

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4. Analysis and results

Following the DEMATEL technique's steps, an average matrix $A_k = [a_{ij}^k]_{n \times n}$ was constructed from responses, and a normalized direct relation matrix $D = [d_{ij}]_{n \times n}$ calculated. Table 2 presents the normalized matrix for the features of BCT. The resulting total relation matrix $T = [t_{ij}]_{n \times n}$ gauges dimension influence. In Table 3, matrix $T = [t_{ij}]_{n \times n}$ is displayed. Two vectors, *R* and *C*, extracted from *T*, underscore dimension significance. Table 4 highlights transparency, immutability, peer to peer network and irreversibility as the causal features (R-C>0), with decentralization and distributed ledger features as recipients (R-C<0).

In the quest to discern meaningful dimension relationships, a pivotal threshold value emerges through the averaging of matrix T values (0.887). This crucial metric acts as a compass, guiding us towards the influential relationships between dimensions and factors. This phenomenon is visually encapsulated in Figure 1, where the IRM diagram comes to life. Figure 1 illustrates the relationships among the features of BCT.

Conversely, the dimensions of decentralization, peer-to-peer networking, and distributed ledgers exhibit a contributory stance, albeit influenced by other facets. Within the intricate web of the palm oil supply chain, decentralization speaks to the equitable distribution of authority, potentially reducing the vulnerability of the system to single points of failure or malicious manipulation. Peer-to-peer networking, at a score of 10.163, carries a latent potential to foster direct interactions, optimizing transactional efficiency and minimizing intermediaries. The pertinence of distributed ledgers, albeit marked by a net effect score of -0.003, lies in its capacity to synchronize and democratize data accessibility while accommodating data integrity through consensus mechanisms.

Table 2: Normalized direct relation matrix D

	DEC	TRS	IMM	P2P	DSL	IRR
Decentralization	0.000	0.153	0.167	0.153	0.111	0.139
Transparency	0.278	0.000	0.167	0.181	0.194	0.167
Immutability	0.222	0.167	0.000	0.167	0.181	0.153
Peer to peer network	0.153	0.153	0.139	0.000	0.194	0.181
Distributed ledger	0.153	0.181	0.181	0.139	0.000	0.167
Irreversibility	0.194	0.153	0.194	0.139	0.153	0.000

Table 3: Total relation matrix

	DEC	TRS	IMM	P2P	DSL	IRR
Decentralization	0.781	0.780	0.820	0.762	0.763	0.767
Transparency	**1.229**	0.837	**1.018**	**0.965**	**1.014**	**0.976**
Immutability	**1.108**	**0.912**	0.804	**0.889**	**0.936**	**0.898**
Peer to peer network	**0.997**	0.853	0.876	0.698	**0.898**	0.871
Distributed ledger	**1.006**	0.878	**0.911**	0.826	0.739	0.864
Irreversibility	**1.042**	0.862	**0.926**	0.831	0.876	0.726

Table 4: Importance results

	R_i	C_i	$R_i + C_i$	$R_i - C_i$	Identify	Importance
Decentralization	4.674	6.163	10.837	-1.489	Effect	3rd
Transparency	6.039	5.122	11.161	0.917	Cause	1st
Immutability	5.547	5.345	10.892	0.202	Cause	2nd
Peer to peer network	5.192	4.971	10.163	0.221	Cause	6th
Distributed ledger	5.224	5.227	10.451	-0.003	Effect	4th
Irreversibility	5.263	5.102	10.365	0.161	Cause	5th

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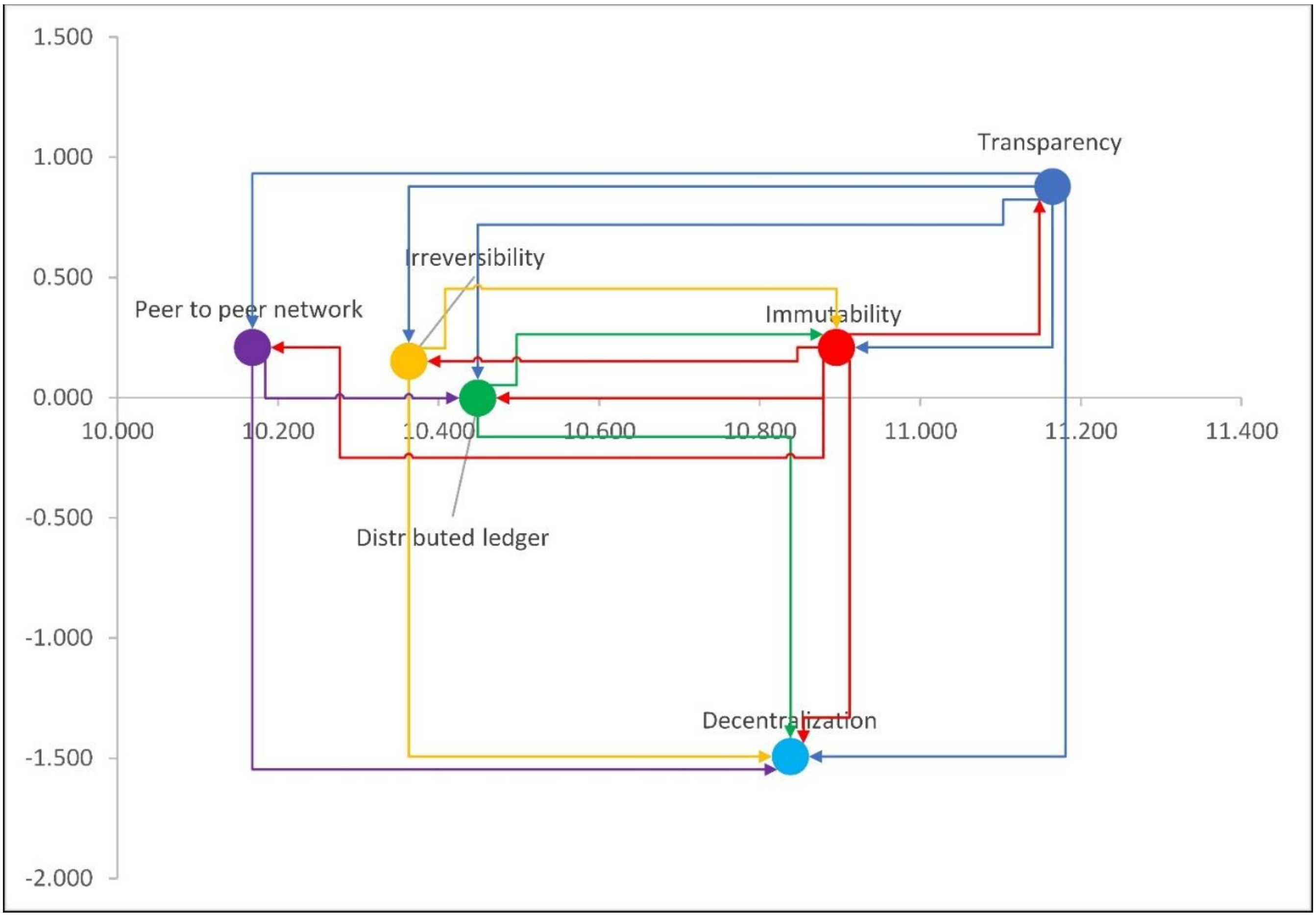

Fig. 2: IRM diagram of BCT features

5. Discussion

In corroboration, these findings crystallize into a compelling mandate for the palm oil supply chain stakeholders. Transparency, immutability, and irreversibility resonate as the cornerstone attributes warranting meticulous incorporation, not solely for their individual merits but for their collective fortification of the supply chain's integrity, accountability, and efficiency. The interplay of decentralization, peer-to-peer networking, and distributed ledgers, although ensconced within supportive roles, upholds the promise of recalibrating power dynamics, optimizing transactional efficiency, and elevating data governance paradigms. Collectively, these observations forge a cogent basis for strategic resource allocation and targeted intervention in the quest to seamlessly orchestrate the integration of blockchain technology within the palm oil supply chain.

BCT exhibits inherent characteristics that seamlessly harmonize with the fundamental tenets of a CE. BCT's decentralization, a defining trait, aligns synergistically with CE's primary objective of curbing waste and pollution. Through the dispersion of control and ownership across a network, BCT diminishes dependence on centralized authorities, thereby mitigating the likelihood of inefficiencies and resource misallocation. Moreover, BCT's transparency and immutability features assume pivotal roles in upholding the continuity of product and material usage, a linchpin of CE. The transparent ledger of blockchain transactions ensures swift verification of product history and provenance, fostering consumer confidence and spurring the elongation of product life cycles. Immutability secures recorded transactions against alteration or tampering, furnishing a robust framework for preserving the integrity and traceability of materials within the CE paradigm. Additionally, BCT's attributes of peer-to-peer networking and distributed ledgers contribute substantively to CE's regenerative ethos by nurturing collaborative endeavors in resource stewardship. These elements empower stakeholders to collectively engage in circular practices, spanning from initial product conception to end-of-life management, ultimately advancing the restoration of natural cycles and systems. In summary, the infusion of BCT attributes into CE methodologies not only amplifies the efficiency and efficacy of resource utilization but also furnishes a technological infrastructure for forging a more sustainable and regenerative economic blueprint.

6. Implications

The contributions of this study are twofold: theoretical and practical.

6.1. Theoretical implications

The unique theoretical contribution of this study lies in its comprehensive exploration of the pivotal role played by BCT attributes in influencing the adoption behavior of

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stakeholders within the Malaysian palm oil industry. By shedding light on the transformative potential of these attributes, the research not only fills a significant gap in the existing literature but also provides a novel framework for understanding the dynamics of BCT adoption in the context of CE principles. This contribution advances theoretical understanding by offering a nuanced perspective on the interplay between technology adoption behavior and sustainable supply chain practices, thereby informing strategic interventions to enhance the industry's resilience and ethical standing in an ever-evolving landscape.

6.2. Practical implications

The findings gleaned through the DEMATEL methodology offer direct and practical implications for the integration of BCT within the palm oil supply chain. The attributes of transparency, immutability, and irreversibility emerge as key drivers of technology adoption. These attributes hold the potential to revolutionize supply chain management by enhancing traceability, data integrity, and accountability. Additionally, while decentralization, peer-to-peer networking, and distributed ledgers contribute subtly, they pave the way for decentralized decision-making, streamlined transactions, and enhanced data sharing. Aligning technological strategies with these attributes stands to position the palm oil industry as a paradigm of sustainable and transparent supply chain practices.

7. Conclusion

In exploring blockchain's potential in the palm oil supply chain, this study employed DEMATEL to dissect its attributes' influence. Transparency, immutability, and irreversibility emerged as key drivers, enhancing traceability, integrity, and accountability. Decentralization, peer-to-peer networking, and distributed ledgers play supportive roles with transformative potential. While this study contributes insights, limitations include bias from expert opinions and the focus on theoretical experts. Future research can mitigate these by involving practical experts, empirical validations, and alternative methodologies. Investigating feasibility, regulatory hurdles, cultural impact, and longitudinal studies could deepen understanding. Guided by these findings and acknowledging limitations, the palm oil sector can navigate toward a resilient and ethical future in an ever-evolving landscape.

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