Chapter 12
Accelerating the Transition to a Circular Economy: An Investigation on the Enablers of Blockchain-Based Solar and Wind Energy Supply Chains

Ismail Erol, Iskender Peker, and Ilker Murat Ar

Abstract Solar and wind energy installations are growing rapidly to satisfy the clean energy need worldwide. It is suggested that to meet the rising demand for renewable energy in a resource-effective manner, solar and wind energy supply chains should be streamlined through a variety of means. It is also suggested that one of the most significant instruments to help improve a supply chain toward environmental sustainability is to ensure its circularity via information technology. Blockchain, for example, is a novel information technology that has the potential to improve the circularity of solar and wind energy supply chains. Blockchain can achieve that through its features including trust, traceability, immutability, and audibility. However, it is argued that ensuring an effective blockchain-based supply chain requires identifying and achieving the enablers of these ecosystems. This research, therefore, is aimed at scrutinizing the enablers of blockchain-based solar and wind energy supply chains systematically. To this end, first, a literature review was performed. Then, DEMATEL was used with the help of expert opinions. The findings of this research classify the enablers of blockchain-based solar and wind energy supply chains into two distinct groups: cause and effect. This categorization is invaluable because it provides decision-makers with a guideline to effectively improve their supply chains. The findings of this study concluded that cause enablers regarding regulatory structure, incentive scheme, and blockchain's technological readiness level should be improved to address the effect enablers on, for example, collaboration and policymaking.

I. Erol (✉)
Faculty of Economics and Administrative Sciences, Baskent University, 06790 Etimesgut, Ankara, Turkey
e-mail: ierol@baskent.edu.tr

I. Peker
Faculty of Economics and Administrative Sciences, Gumushane University, 29100 Gumushane, Turkey
e-mail: iskenderpeker@gumushane.edu

I. M. Ar
Ministry of Industry and Technology, Ankara, Turkey
e-mail: ilkermurat.ar@sanayi.gov.tr

S. A. Bandh et al. (eds.), *Renewable Energy in Circular Economy*, Circular Economy and Sustainability, https://doi.org/10.1007/978-3-031-42220-1_13

Keywords Supply chain · Blockchain · Wind energy · Solar energy · Energy security

12.1 Introduction

The emergence of renewable energy has a significant impact on "energy security", "environmental sustainability", "access to power", and "economic growth" Erol et al. (2021a). Among the renewable sources, 10% of the world's power was produced by wind and solar in 2021 (Ember 2022). The International Energy Agency (IEA) suggested that solar and wind energy had a significant role in the recent worldwide transition to renewable energy thanks to significant cost advantages in solar and wind installations. The IEA (2022) also suggested that secure supply chains in solar photovoltaic solar and wind overall must ensure that they are adequate, resilient, affordable, and sustainable. However, note that solar panels and wind turbines won't always be in use even though scholars have agreed to their contribution to overall sustainability globally. Instead, photovoltaic PV panels and turbine parts have already started to build up in landfills all over the world due to the existing linear supply chain approach that relies on the "take, make, dispose of" paradigm.

The circular economy (CE), on the other hand, is based on "the premise of closing the loop" in a supply chain. The CE is defined as "an industrial system that is restorative or regenerative by intention and design" (Ellen Mac Arthur Foundation 2013). Given the basis of CE, it is argued that individual components of solar panels and wind turbines, including solar panel aluminium and glass, and turbine steel towers may be reprocessed to pave the way for better resource efficiency (Erol et al. 2021a). Similarly, as information technology continues to evolve, businesses in the solar and wind energy supply chains try to come up with better means to streamline component trackability and recoverability. As the public's awareness of CE rises, further studies are being done about disruptive technology implementations to enable CE's effectiveness in solar and wind energy supply chains. For instance, it is suggested that the development of creative business models toward circularity can be facilitated by blockchain, which has the potential to disrupt the energy industry. In a nutshell, blockchain characterizes itself as the forthcoming technology that will support expansion in the energy sector due to its advantages including trust, immutability, auditability, and visibility (Teufel et al. 2019). Based on these characteristics, many cases such as "real-time data management", "carbon credits", and "renewable energy certificates" can be operated through blockchain.

Until recently, researchers have been working on several frameworks to implement blockchain across supply chains (Gupta et al. 2021). For example, it is argued that one of the most effective frameworks is to identify and use the relevant enablers to ensure successful implementations (Samad et al. 2022). An enabler is described as an aspect that upholds and facilitates any implementation process (Risk et al. 2019). In other words, enablers are actions required to ensure the efficacy and efficiency of core program activities. With that in mind, note that there are a number of enablers that may support the effectiveness of blockchain applications in solar and wind energy supply chains towards better circularity. However, to the best of our knowledge, researchers have not paid sufficient attention to this domain of research although some attempts have been made in various industries (Sahebi et al. 2022; Samad et al. 2022).

This chapter, therefore, is aimed at analyzing enablers of implementing blockchain in solar and wind supply chains towards improved circularity. To achieve that, the subsequent research questions are answered: (1) what is the list of enablers of implementing blockchain in solar and wind supply chains? (2) What are the associations among these enablers? (3) What are the suggestions for decision-makers in solar and wind supply chains to enable enhanced circularity?

To this end, in this chapter, a multi-criteria decision-making (MCDM) approach based on DEMATEL is employed systematically through expert opinions. The main contribution of this study is twofold: First, this is the first research attempt to scrutinize the enablers of blockchain-based solar photovoltaic and wind energy supply chains toward building improved circularity. Second, because of the integrated approach utilized in this research, which includes qualitative and quantitative analysis, the findings of this study may be useful to practitioners as well as researchers.

The rest of the chapter is organized as follows: Sect. 12.2 discusses blockchain and the enablers of blockchain-based solar and wind energy supply chains towards better circularity. Then, Sects. 12.3 and 12.4 provide Methodology and Application, respectively. Finally, Sect. 12.4 demonstrates discussion and implications followed by Conclusions in Sect. 12.5.

12.2 Background

12.2.1 Blockchain in Renewable Energy Towards Circular Economy

Blockchain is a secure database-sharing platform for computer networks. It is sometimes referred to as a digital ledger technology and may be compared to a spreadsheet that has been copied thousands of times and is kept in a distributed network spread out over several different places (Ar et al. 2018, 2020; Ozdemir et al. 2019; Erol et al. 2021b). By doing this, a network is built that automatically and often updates the spreadsheet wherever it may be. Hence, a database that cannot be changed without the consent of all members is formed. In other words, it is argued that one is left with a list of records that securely hold data that cannot be altered or damaged by any entity since it is maintained across a network of computers rather than by a single organization that has overall authority over the system (Ar et al. 2018).

Energy, logistics, health, food, agriculture, banking, government, and tourism are just a few of the sectors that blockchain is predicted to disrupt in the ensuing ten years (Önder and Treiblmaier 2018; Ar et al. 2018, 2020; Ozdemir et al. 2019; Erol et al. 2021b, 2022; Rajasekaran et al. 2022; Marchesi et al. 2022; Patel et al. 2022; Cao et al. 2022; Guo et al. 2022). Take renewable energy generation as an example. Note that the majority of electricity and power infrastructure worldwide is founded upon centralized energy systems. On the other hand, blockchain is projected to change this traditional framework as conventional consumers develop to concurrently consume, create, and sell energy, for example by installing solar panels and selling excess electricity through a P2P transaction using blockchain (Guo et al. 2022). With blockchain, energy sales transactions may be completed instantly and directly, as opposed to previous methods that call for a central middleman. This results in a decentralized energy supply system by allowing so-called "prosumers" to conduct transactions with a high degree of autonomy—free from intermediaries and regulators (Gawusu et al. 2022).

In addition, supply chains may become more sustainable with the help of blockchain. It is possible to track information about past products and resources as well as the entities in the supply chains. Blockchain data may show carbon footprint, nonrenewable resource use, and waste generated throughout supply chains. To guarantee that the environmental harm caused by supply chain operations is kept to a minimum, this information may be utilized for circular economy objectives (Erol et al. 2022; Kouhizadeh et al. 2022).

Until recently, a significant amount of research has been performed with respect to blockchain adoption in the energy industry. Some researchers, on the other hand, have conducted studies on blockchain in renewable energy supply chains with their main focus on CE and environmental sustainability. This literature review is based on the context of CE and environmental sustainability in renewable energy supply chains. For example, Gawusu et al. (2022) discussed the existing literature on the integration of renewable energy with blockchain. The authors finally argue that blockchain is a crucial instrument for achieving a future powered entirely by renewable energy sources. They also argue that for the transmission of power, the use of blockchain will necessitate considerable policy adjustments as well as regulatory action. In another study, Ahl et al. (2022) conducted interviews with experts to identify the challenges to adopting blockchain in energy supply chains towards sustainability. They conclude that factors including scalability, cost, interoperability, data availability etc. are the most important issues to address. They also conclude that more country-specific research is needed to elaborate on local challenges to blockchain adoption in the renewable energy industry. Erol et al. (2021a) explore critical success factors of blockchain applications in the solar energy supply chains of Turkey toward a circular economy. They maintain that blockchain can be used to generate renewable energy effectively as well as to address end-of-life materials in the supply chain to ensure improved circularity. They conclude that similar research should be performed in other developing countries. Yildizbasi (2021) investigate the challenges to blockchain implementations in renewable supply chains to ensure an improved circular economy.

To achieve that, the author uses a multi-criteria decision framework through expert opinions. He concludes that major investment is still needed to ensure blockchain helps improve circularity in renewable energy supply chains.

12.2.2 Enablers of Blockchain-Based Solar and Wind Energy Supply Chains Towards CE

Blockchain-based supply chain enablers towards CE are the factors that work to create better supply chain designs to allow for better circularity and environmental sustainability. However, note that enablers are sometimes confused with the advantages of a certain system. Therefore, one must ask the right questions to identify the true enablers of a system. To the best of our knowledge, until recently one research has been performed on the enablers of blockchain-based renewable energy supply chains towards CE. In that study, Sahebi et al. (2022) analyze the enablers of a supply chain in the renewable energy industry. To this end, they first identify the enablers by reviewing the literature. Then, they come up with the relationships among the enablers using the integration of DEMATEL and ISM. However, we argue that the main problem with this study is the way the authors identify enablers. The authors suggest that "immutability", "shared database" "auditability", "traceability", and "anonymity", "provenance", "decentralized database" among others are one of the main enablers of the blockchain-based renewable supply chain. Nevertheless, one should note that these factors that the authors listed in their study are not enablers. Rather, they are the inherent functions (characteristics) and (or) benefits of blockchain. Secondly, their analysis is only based on some technical factors. Therefore, additional research is needed for a thorough and true investigation of enablers.

In addition, despite their different industry focus, there are four studies worth discussing here. First, Bai et al. (2022) explored the enablers of blockchain-enabled supply chain transparency in the African cocoa industry. To this end, they first determine the enablers by reviewing the literature. Then, they use the best–worst method to prioritize the enablers. Finally, they conclude that the most important enabler is blockchain security. In another study, Zkik et al. (2022) investigate the enablers of the sustainable blockchain-enabled supply chain in agriculture. They first list the enablers based on the existing studies. Then, they employ multi-criteria decision-making to rank the enablers. The findings of the study indicate that collaboration among the partners and management commitment turns out to be the most important enablers. Finally, Samad et al. (2022) scrutinized the enablers of blockchain in the logistics industry. They used integrated ISM-DEMATEL to reveal the relationships among the enablers. The findings of their study suggested that "Real-time connectivity and information flow" was the most influential enabler. They concluded that new studies are needed using the alternative sets of enablers in various blockchain-enabled industries.

Given the existing studies on the enablers of blockchain-based supply chains towards CE and sustainability, a set of enablers are identified in Table 12.1. Table 12.1 includes enablers, their description and references.

12.3 Methodology

This study investigates the enablers that facilitate the adoption of blockchain in solar and wind supply chains to improve circularity. To this end, the process steps in Fig. 12.1 were carried out sequentially. As can be seen from Fig. 12.1, first of all, the list of enablers of implementing blockchain in solar and wind supply chains was identified through a literature review. Then, the relationships between these enablers were revealed using DEMATEL.

The DEMATEL method, created by "Battelle Memorial Institute's Geneva Research Center" (Braga et al. 2021), is a useful technique that offers the analysis of the types and magnitudes of direct and indirect relationships between components (Asadi et al. 2022). By analyzing the overall relationships between components, DEMATEL can offer a perfect method for better understanding the structural links and for resolving issues with congruent systems (Zhao et al. 2021). The followings demonstrate the steps of DEMATEL (Zhang and Deng 2019; Sharma et al. 2020):

Step 1: *Creating a Direct Relation Matrix*: To form a direct relation matrix for the experts' pairwise comparisons, a "0–4 scale" is used. Table 12.2 provides the pairwise comparison scale utilized in the DEMATEL approach.

Data gathered through pairwise comparisons are used to generate a $n \times n$ dimensional direct relation matrix (D). It is determined using the average rating from the "U" number of experts. To obtain a direct relation matrix, apply the following Eq. (12.1).

$$d_{ij} = \frac{1}{U} \times \sum_{k=1}^{U} a_{ij}^{k} \tag{12.1}$$

Step 2: *Obtaining the Normalized Direct Relation Matrix*: The normalized relation matrix with a diagonal value of 0 is computed after the direct relations matrix (D) is created. To obtain the normalized direct relation matrix (N), Eqs. (12.2) and (12.3) are used.

$$N = \lambda \times D \tag{12.2}$$

$$\lambda = \min\left(\frac{1}{\max_{1 \le i \le n} \sum_{j=1}^{n} d_{ij}}, \frac{1}{\max_{1 \le j \le n} \sum_{i=1}^{n} d_{ij}}\right) \tag{12.3}$$

Step 3: *Calculating Total Relation Matrix*: Total Relation Matrix (T) is calculated by using a unit matrix (I) via Eq. (12.4):

Table 12.1 The list of enablers

Enablers	Description	References
Effective legal and regulatory structure (E_1)	To develop a blockchain-based supply chain toward better circularity, regulations that are parallel to similar international laws should be passed or updated	Kumar et al. (2021)
A well-designed incentive system (E_2)	Incentives frequently encourage projects and information exchange. Simply put, an effective incentive framework is a prerequisite for effective blockchain-based projects toward CE	Wang et al. (2021)
Getting top management commitment (E_3)	One of the essential elements for successfully implementing any project is to get top management support. However, some senior managers may not show the essential commitment to applying new business models	Hina et al. (2022)
Improved interoperability (E_4)	To further boost CE effectiveness, several blockchain systems should be able to communicate with one another. Interoperability is thus one of the most significant enablers of blockchain adoption	Perrons and Cosby (2020), Gupta et al. (2021)
Creating a set of capabilities for blockchain (E_5)	For CE to be implemented more effectively, sufficient understanding and competence in the blockchain-based supply chain are required. Its presence and sufficiency should thus be carefully assessed	Teufel et al. (2019), Erol et al. (2021a)
Building a collaborative environment in the supply chain (E_6)	Collaboration is an important phenomenon that improves the performance of the supply chain by ensuring integration	Wang et al. (2019), Kouhizadeh et al. (2021)
Increasing the technological readiness level (TRL) of the blockchain (E_7)	TRLs evaluate the reliability level of technology during its research, development and implementation phase. It is measured in terms of cyber-security, data privacy, latency, scalability, and throughput	Gupta et al. (2021), Ranta et al. (2021)
Adopting effective supply chain policies toward blockchain implementation (E_8)	Organizations benefit from policies' direction, soundness, liability, effectiveness, and openness in how they do business. As a result, it is important to verify whether any new organizational policy exists regarding blockchain-based structure	Kouhizadeh et al. (2021)
Creating a supportive organizational culture (E_9)	Businesses are pushed to change their competitive mindsets to ones that value collaboration and partnership. Building an effective blockchain-based supply chain for CE also requires a culture that is based on collaboration	Ozen et al. (2020), Erol et al. (2021a)

(continued)

Table 12.1 (continued)

Enablers	Description	References
More emphasis on increasing stakeholder awareness of blockchain (E_{10})	Increasing stakeholder awareness of blockchain and CE is needed to effectively implement a blockchain-based supply chain	Milios (2021)
Picking the right blockchain platform (E_{11})	Blockchain applications can be created using appropriate blockchain platforms. Although there are several blockchain platforms, most of them lack a consistent design, a loyal user base, and implementation. Therefore, selecting the right one is crucial	Büyüközkan and Tüfekçi (2021)
Building an effective blockchain implementation plan (E_{12})	Implementation guides in general are needed to successfully apply a new business model. An effective guide for a blockchain-based supply chain should include tasks and actions	Rajasekaran et al. (2022)
Formulating a comprehensive performance management system (E_{13})	Blockchain-based supply chain performance management is the ongoing process of enhancing performance by establishing system goals that are in line with the long-term objectives of various organizations	Kouhizadeh et al. (2022)
Improved data validation and certification process (E_{14})	The issue of fraudulent information being recorded in the blockchain and the need for an external validation and certification procedure was the only difficulty that was discussed more in practice than in research and was also the subject that has received the greatest attention in practice	Böckel et al. (2021)
Building an effective blockchain-enabled reverse supply chain system (E_{15})	Improved circularity requires building the blockchain-enabled reverse network, including collection, inspection and recovery facilities	Erol et al. (2021a)
Effective financing of new business models toward blockchain-based CE (E_{16})	To continue playing their role in development, innovation, and employment, companies must have access to a wider variety of funding options. In the pursuit of better CE, financial stability, financial inclusion, and financial depth should be viewed as interdependent goals	OECD (2015), Erol et al. (2021)

$$T = N \times (I - N)^{-1} \tag{12.4}$$

Step 4: *Determining Causal Relations between Criteria (Influential Relation Map)*: T matrix is utilized to compute the values of D and R. D and R values are obtained from the sum of the rows and the sum of the columns of T matrix are calculated using Eqs. (12.5) and (12.6), respectively.

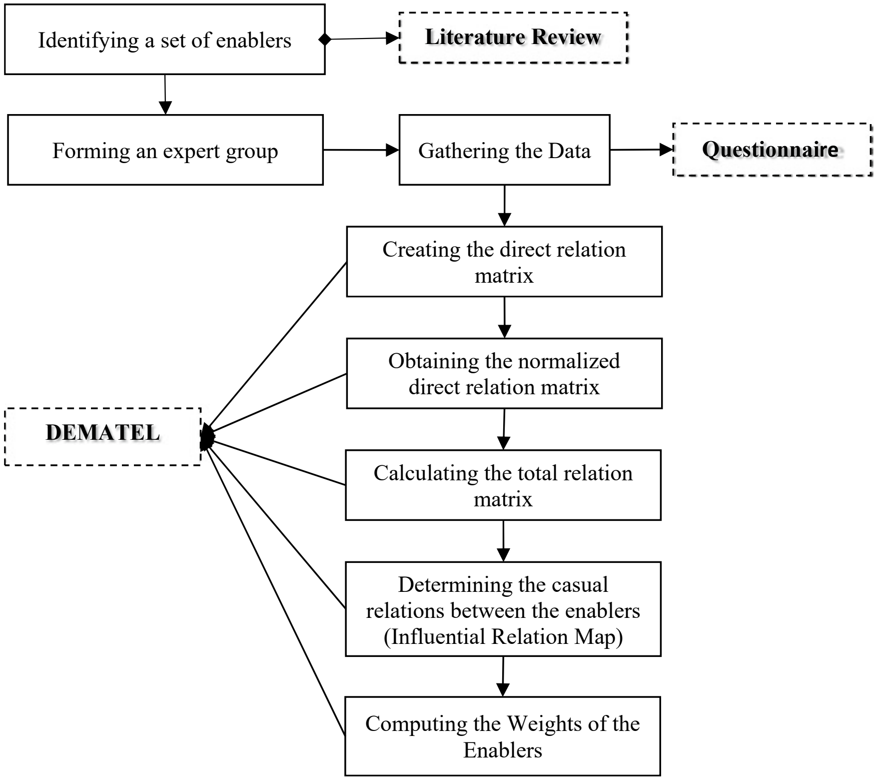

Fig. 12.1 Proposed methodology

Table 12.2 Pairwise comparison scale

Numerical values	Definitions
0	No effect (N)
1	Low effect (L)
2	Medium effect (M)
3	High effect (H)
4	Very high effect (VH)

$$D_i = \sum_{j=1}^{n} T_{i,j} \quad (i = 1, 2, \ldots, n) \tag{12.5}$$

$$R_j = \sum_{i=1}^{n} T_{i,j} \quad (i = 1, 2, \ldots, n) \tag{12.6}$$

The relevance and overall effects of the enablers are established through the values of $D + R$, whilst relationships between enablers are defined based on the values of $D - R$. A greater $D + R$ value for an enabler indicates that it interacts with other enablers to a greater extent. Additionally, $D - R$ enablers that are classified as positive are placed in the “sender (cause) group,” whereas $D - R$ enablers that are classified as negative are placed in the “receiver (effect) group.” Put simply, enablers with positive $D - R$ have an impact on other enablers, whereas enablers with negative $D - R$ are influenced by other enablers.

Step 5: *Computing the Weights of the Enablers (W):* The weights of the enablers are calculated using Eqs. (12.7) and (12.8).

$$W_i = \sqrt{\left(D_i + R_j\right)^2 + \left(D_i - R_j\right)^2} \tag{12.7}$$

$$W_i = \frac{w_i}{\sum_i^n w_i} \tag{12.8}$$

12.4 Application

In this research, the methodology demonstrated in Fig. 12.1 is employed. The details of the process are provided below:

12.4.1 Identifying the Enablers

The enablers of blockchain-based solar and wind supply chains presented in Table 12.1 were ascertained through an extensive literature review. Then, an expert group reviewed Table 12.1, and they concluded that no modifications to the list were required.

12.4.2 Forming the Expert Group

The data set, in this research, was collected with the help of an expert group through a DEMATEL questionnaire. This questionnaire allows experts to evaluate the degree of influence of the enablers on each other by taking into account the scale in Table 12.3. Note that it is vital to select participant experts who have sufficient theoretical and practical knowledge and experience in supply chains for solar and wind energy and blockchain. With that in mind, in this study, researchers, decision-makers, and practitioners who have a sufficient understanding of blockchain technology and the

Table 12.3 Expert group

Experts	Size	Features
Faculty members	7	They have published research on the application of blockchain in the renewable energy industry
Governmental decision-makers	5	They are responsible for initiating state projects on how disruptive technologies, such as blockchain can be used to ensure resilience in the renewable energy industry
Software company managers	3	They have more than 5 years of hands-on experience in the implementation of artificial intelligence, the internet of things, and blockchain in solar and wind energy supply chains
Energy company managers	7	They are employed in the information technology departments of major renewable energy companies. They have more than 10 years of experience in IT implementations

supply chains for solar and wind energy are referred to as experts. Therefore, to find the right experts who met the above criteria, purposive sampling improved by snowball recruitment was used in this study. To this end, an extensive search and investigation process was carried out. Once this investigation has been done, experts as displayed in Table 12.3 were found to establish a heterogeneous composition.

It is argued that there is no formula for determining the ideal sample size of experts. In other words, the size of an expert group is normally ambiguous in similar investigations (Bulut and Duru 2018).

12.4.3 Analysis (DEMATEL)

At this stage, the analysis was carried out by following the process steps of the DEMATEL method. The steps taken are provided as follows: first, the DEMATEL questionnaire was presented to the expert group. Then, the answers from the expert group were combined using Eq. (12.1), and the direct relation matrix was created. In the following step, a normalized relation matrix was obtained by using Eqs. (12.2) and (12.3). Next, Eq. (12.4) was used to calculate the total relation matrix. Lastly, $(D + R)$ and $(D - R)$ values of the enablers were calculated by using Eqs. (12.5) and (12.6), which are exhibited in Table 12.4. Table 12.4 also suggests the cause (C)-and-effect (E) groups of the enablers. The relationships between the enablers based on the Influential Relation Map are shown in Fig. 12.2.

Given Table 12.4, for example, while an Effective legal and regulatory structure (E_1), A well-designed incentive system (E_2) turns out to be cause enablers, Creating a set of capabilities for blockchain-based supply chain (E_5) and Building a collaborative environment in the supply chain (E_6) is effect enablers.

Table 12.4 "$D + R$ and $D - R$ values" of the enablers

Codes	Enablers	D + R	D − R	(C) /(E)
E_1	The effective legal and regulatory structure	10.562	4.962	C
E_2	A well-designed incentive system	10.195	3.181	C
E_3	Getting top management commitment	10.097	3.143	C
E_4	Improved interoperability	9.288	1.862	C
E_5	Creating a set of capabilities for blockchain	9.323	− 0.304	E
E_6	Building a collaborative environment in the supply chain	9.298	− 0.394	E
E_7	Increasing the technological readiness level of blockchain	9.175	1.862	C
E_8	Adopting effective supply chain policies for blockchain implementation	9.490	− 0.132	E
E_9	Creating a supportive organizational culture	8.310	− 0.856	E
E_{10}	More emphasis on increasing stakeholder awareness of blockchain	7.047	− 1.047	E
E_{11}	Picking the right blockchain platform	8.996	1.600	C
E_{12}	Building an effective blockchain implementation plan	9.573	− 0.103	E
E_{13}	Formulating a comprehensive performance management system	6.306	− 0.1246	E
E_{14}	Improved data validation and certification process	8.641	1.217	C
E_{15}	Building an effective blockchain-enabled reverse supply chain system	5.885	− 1.318	E
E_{16}	Effective financing of new business models	10.059	2.714	C

Figure 12.2 indicates that enablers with positive $D - R$ have an impact on other enablers, whereas enablers with negative $D - R$ are influenced by the rest.

Finally, the importance weights of the enablers were obtained by using Eqs. (12.7) and (12.8) as in Table 12.5.

As can be seen in Table 12.5, the most important enablers were discovered to be "E_1—Effective legal and regulatory structure, E_2—A well-designed incentive system, and E_3—Getting top management commitment" with the weight of 0.080, 0.074 and 0.073, respectively.

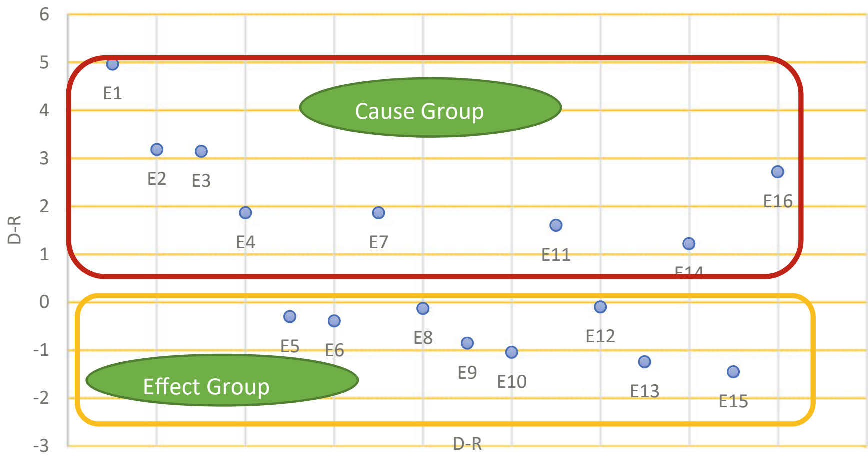

Fig. 12.2 Influential relation map

Table 12.5 The weights of the enablers

Criteria	Enablers	Weights
E_1	Effective legal and regulatory structure	0.080
E_2	A well-designed incentive system	0.074
E_3	Getting top management commitment	0.073
E_4	Improved interoperability	0.064
E_5	Creating a set of capabilities for blockchain	0.066
E_6	Building a collaborative environment in the supply chain	0.065
E_7	Increasing the technological readiness level of blockchain	0.061
E_8	Adopting effective supply chain policies for blockchain implementation	0.067
E_9	Creating a supportive organizational culture	0.056
E_{10}	More emphasis on increasing stakeholder awareness of blockchain	0.055
E_{11}	Picking the right blockchain platform	0.060
E_{12}	Building an effective blockchain implementation plan	0.068
E_{13}	Formulating a comprehensive performance management system	0.054
E_{14}	Improved data validation and certification process	0.058
E_{15}	Building an effective blockchain-enabled reverse supply chain system	0.052
E_{16}	Effective financing of new business models	0.072

12.5 Discussion and Implications

This study provides several findings that may pave the way for building effective blockchain-based solar and wind energy supply chains for the circular economy. In this section, more elaborate commentary on the results through referencing the previous research is provided. Specifically, first, the results of the existing studies are compared with the ones of this study. Note, however, that there are only a few studies conducted on the enablers of blockchain-based supply chains. Note also that since the existing studies have been performed in various industries along with a different set of enablers, their results are not exactly compatible with the results of our study.

With that in mind, for example, this study indicates that Effective legal and regulatory structure (E_1), A well-designed incentive system (E_2), Getting top management commitment (E_3), Effective financing of new business models toward blockchain-enabled CE (E_{16}), Adopting effective supply chain policies towards blockchain implementation (E_8), Adopting effective supply chain policies towards blockchain implementation (E_8), and Creating a set of capabilities for blockchain-based supply chain (E_5), Building a collaborative environment in the supply chain (E_6) turned out to be the most important enablers based only on the importance weights. Zkik et al. (2022) concluded that collaboration and top management commitment are the most crucial enablers among others. However, Bai et al. (2022) and Sahebi et al. (2022) fully focused on technical enablers of blockchain-based supply chains and revealed that transparency, improved risk management and security were discovered to be the most significant enablers.

In addition to the ordinary rankings of the enablers, this present study classified the enablers into cause and effect. Causality is the process by which one incident, activity, condition, or attribute influences the development of another incident, activity, condition, or attribute, where the cause and effect are both somewhat influenced by one another. A cause is an activity that leads to an event or incident. Given this definition, the findings of the present study concluded that Effective legal and regulatory structure (E_1), A well-designed incentive system (E_2), Getting top management commitment (E_3), Improved interoperability (E_4), Increasing the technological readiness level of the blockchain (E_7), Picking the right blockchain platform (E_{11}), Improved data validation and certification process (E_{14}), Improved data validation and certification process (E_{14}), and Effective financing of new business models towards blockchain-enabled CE (E_{16}) were found to be the cause enablers. That means building effective blockchain-based solar and wind energy supply chains toward better CE requires addressing these enablers first. Compared with the findings of previous research (Zkik et al. 2022; Bai et al. 2022; Sahebi et al. 2022; Samad et al. 2022) that focus mostly on the technical enablers of blockchain-enabled supply chains, the results of this present study reveal a significant emphasis on forming effective general legal structure and incentive systems towards blockchain-based networks in addition to increasing the technological readiness level of blockchain.

An effect, on the other hand, is the outcome or ramification of a cause. This implies that effect enablers can be ensured only after cause enablers are addressed. According to the findings of this study, Creating a set of capabilities for a blockchain-based supply chain (E_5), Building a collaborative environment in the supply chain (E_6), Adopting effective supply chain policies toward blockchain implementation (E_8), Creating a supportive organizational culture (E_9), More emphasis on increasing stakeholder awareness of blockchain (E_{10}), Building an effective blockchain implementation plan (E_{12}), Formulating a comprehensive performance management system (E_{13}), and Building an effective blockchain-enabled reverse supply chain system (E_{15}) were found to be the effect enablers. More specifically, for example, E_5 and E_6 can only be ensured only if the cause enablers with respect to, for example, legal and regulatory structure, incentive system, top management commitment, interoperability, technological readiness level of blockchain, and blockchain platform are achieved. On the other hand, Samad et al. (2022) indicated a different set of effect enablers since the list of the enablers they used is based on various technical features of blockchain. Therefore, they argued that the features of blockchain, including traceability and immutability, are the most important resulting (effect) blockchain enablers.

The findings of this study also provide several managerial implications. For example, more effective blockchain-based initiatives towards CE for solar and wind energy supply chains depend heavily on the regulatory and incentive climate of a country and the technical readiness level of blockchain. With that in mind, it can be argued that depending on the extent of support, procedures that directly provide incentives to blockchain-based supply chains can strengthen their business cases. Hence, note that governments worldwide should enact regulatory frameworks as well as build incentive schemes towards improving the technical readiness level of blockchain. To start with, direct incentives reduce the need for an initial investment, which immediately strengthens the economic case for blockchain-enabled solar and wind energy supply chains toward CE. While government loan guarantees subsidies, low-cost financing is typically granted during the initial investment phase. Other incentives may also be provided over several years.

However, indirect incentives seek to create a welcoming atmosphere for investment by fostering favourable circumstances for development or removing obstacles to blockchain-enabled supply chains for better CE. The first group consists of monetary incentives for innovation, R&D, and human capital. R&D funds may be used to create new blockchain technologies that have not yet reached the commercialization stage or to increase the efficiency of already existing ones. While innovation and skill development may not always lead to sustainable economic activity, they do contribute to a better supply chain infrastructure.

Furthermore, recently, there are several voluntary programs worldwide for recycling solar panels and wind turbines. Although such voluntary initiatives indirectly help firms and the industry by maintaining a good reputation, the non-profitability of present recycling techniques prevents their widespread adoption. Therefore, we argue that it is essential to build regulatory frameworks that specify stakeholder obligations, financial models for EoL management, and minimum standards for collection and recycling to expand solar panel and turbine recycling capabilities. Finally, more research based on blockchain-enabled networks towards CE is required to increase recovery rates and enhance material value conservation since solar panel and wind turbine recycling is still technologically challenging.

12.6 Conclusion

Researchers argue that solar and wind energy are vital for accomplishing net zero emissions. Therefore, installations of solar panels and wind turbines are exponentially growing worldwide, which ultimately raises concerns about the effectiveness and sustainability of solar and wind energy supply chains. The traditional linear supply chain approach, for example, is a recipe for resource inefficiency that leads to insecure supply chain performances in terms of sustainability. Researchers and decision-makers agree that a new paradigm is needed to address the current problems. The Circular Economy is a robust approach that may provide novel means to deal with resource inefficiencies. However, note that even if CE is based on a powerful foundation, it needs various types of support from several disciplines for its effectiveness. For example, information technology has the potential to provide invaluable assistance to pave the way for the effectiveness of supply chains. Blockchain through its impact on supply chain visibility, collaboration and trust is a novel technology that may uphold solar and wind supply chains towards their journey to circularity. To this end, it is argued that exploring critical enablers of blockchain-based supply chains is crucial. To the best of our knowledge, despite its importance, only a few studies have been conducted on this subject recently. Therefore, it is suggested that new studies on the enablers of blockchain-based supply chains in the context of CE are needed.

This study aims to scrutinize the enablers of blockchain-based solar and wind energy supply chains. To this end, first, a set of enablers was listed with the help of the current state of the art. Then, DEMATEL was used to reveal the associations among the enablers. The findings of this study indicated the cause and effect enablers of blockchain-based solar and wind energy supply chains. Specifically, while Effective legal and regulatory structure (E_1) and A well-designed incentive system (E_2) turned out to be the most important cause enablers, Creating a set of capabilities for a blockchain-based supply chain (E_5), Building a collaborative environment in the supply chain (E_6) and Adopting effective supply chain policies towards blockchain implementation (E_8) were the most significant effect enablers. Note that this set of findings is invaluable for decision makers because addressing effect enablers is only plausible once cause enablers have been achieved.

There are also future research opportunities, some of which are derived from the weakness of this study. For example, first, more conceptual studies are needed to clear up the concepts such as critical success factors, enablers, drivers, barriers etc. in the context of circular supply chains. Second, new empirical studies should be conducted in various industries of developing and emerging countries so that their findings can be compared to better analyze the associations among the alternative sets of enablers. Lastly, new quantitative methods based on operations research and statistics can be used to more effectively explore blockchain-based supply chain enablers.

References

Ahl A, Goto M, Yarime M, Tanaka K, Sagawa D (2022) Challenges and opportunities of blockchain energy applications: interrelatedness among technological, economic, social, environmental, and institutional dimensions. Renew Sustain Energy Rev 166:112623. https://doi.org/10.1016/j.rser.2022.112623

Ar IM, Erol I, Ozdemir AI (2018) Blockchain based supply chain systems: a review and future research directions. In: Proceedings of the 12th NCM international conference on new challenges in industrial engineering and operations management. 11–12 September 2018, Ankara, Turkey, pp 40–44

Ar IM, Erol I, Peker I, Ozdemir A, Medeni TD, Medeni IT (2020) Evaluating the feasibility of blockchain in logistics operations: a decision framework. Expert Syst Appl 158(15). https://doi.org/10.1016/j.eswa.2020.113543

Alghamdi A, Almulihi A, Mohd S (2022) Drivers and barriers of electric vehicle usage in Malaysia: a DEMATEL approach. Resour Conserv Recycl 177:105965. https://doi.org/10.1016/j.resconrec.2021.105965

Bai C, Quayson M, Sarkis J (2022) Analysis of Blockchain's enablers for improving sustainable supply chain transparency in Africa cocoa industry. J Clean Prod 358:131896. https://doi.org/10.1016/j.jclepro.2022.131896

Böckel A, Nuzum A.-K, Weissbrod I (2021) Blockchain for the circular economy: analysis of the research-practice gap. Sustain Prod Consump 25:525–539. https://doi.org/10.1016/j.spc.2020.12.006

Braga IFB, Ferreira FAF, Ferreira JJM, Correia RJC, Pereira LF, Falcão PF (2021) A DEMATEL analysis of smart city determinants. Technol Society66:101687. https://doi.org/10.1016/j.techsoc.2021.101687

Bulut E, Duru O (2018) Analytic hierarchy process (AHP) in maritime logistics: theory, application and fuzzy set integration. In: Lee TW, Yang Z (eds) Multi-criteria decision making in maritime studies and logistics: applications and cases. Springer International Publishing, pp 31–39. https://doi.org/10.1007/978-3-319-62338-23

Büyüközkan G, Tüfekçi G (2021) A decision-making framework for evaluating appropriate business blockchain platforms using multiple preference formats and VIKOR. Inf Sci 571:337–357. https://doi.org/10.1016/j.ins.2021.04.044

Cao Y, Yi C, Wan G, Hu H, Li Q, Wang S (2022) An analysis on the role of blockchain-based platforms in agricultural supply chains. Transp Res Part E163:102731. https://doi.org/10.1016/j.tre.2022.102731

Ellen Mac Arthur Foundation (2013) Towards the circular economy. https://emf.thirdlight.com/link/x8ay372a3r11-k6775n/@/preview/1?o. Retrieved 1 May 2022

Ember (2022) Global electricity review. https://ember-climate.org/app/uploads/2022/03/Report-GER22.pdf. Retrieved 5 June 2022

Erol PI, Ar IM, Turan İ, Searcy C (2021a) Towards a circular economy: investigating the critical success factors for a blockchain-based solar photovoltaic energy ecosystem in Turkey. Energy Sustain Dev 65(I):130–143. https://doi.org/10.1016/j.esd.2021.10.004

Erol I, Ar IM, Ozdemir AI, Peker I, Asgary A, Medeni TD, Medeni IT (2021b) Assessing the feasibility of blockchain technology in industries: evidence from Turkey. J Enterpr Inform Manag 34(3):746–769. https://doi.org/10.1108/JEIM-09-2019-0309

Erol I, Ar IM, Peker I (2022) Scrutinizing blockchain applicability in sustainable supply chains through an integrated fuzzy multi-criteria decision making framework. Appl Soft Comput 116:108331. https://doi.org/10.1016/j.asoc.2021.108331

Gawusu S, Zhang X, Ahmed A, Jamatutu SA, Miensah ED, Amadu AA, Osei FAJ (2022) Renewable energy sources from the perspective of blockchain integration: from theory to application. Sustain Energy Technol Assess 52:102108. https://doi.org/10.1016/j.seta.2022.102108

Guo Y, Wan Z, Cheng X (2022) When blockchain meets smart grids: a comprehensive survey. High-Confidence Comp 2(2):100059. https://doi.org/10.1016/j.hcc.2022.100059

Gupta H, Kumar S, Kusi-Sarpong S, Jabbour CJC, Agyemang M (2021) Enablers to supply chain performance on the basis of digitization technologies. Ind Manag Data Syst 121(9):1915–1938. https://doi.org/10.1108/IMDS-07-2020-0421

Hina M, Chauhan C, Kaur P, Kraus S, Dhir A (2022) Drivers and barriers of circular economy business models: where we are now, and where we are heading? J Clean Prod 333:130049. https://doi.org/10.1016/j.jclepro.2021.130049

IEA (2022) Solar PV global supply chains. https://www.iea.org/reports/solar-pv-global-supply-chains. Retrieved 8 June 2022

Kouhizadeh M, Saberi S, Sarkis J (2021) Blockchain technology and the sustainable supply chain: theoretically exploring adoption barriers. Int J Prod Econ 231. https://doi.org/10.1016/j.ijpe.2020.107831

Kouhizadeh M, Zhu Q, Alkhuzaim L, Sarkis J (2022) Blockchain technology and the circular economy: An exploration. In: Bals L, Tate WL, Ellram LM (eds) Circular economy supply chains: from chains to systems. Emerald Publishing Limited, pp 189–213. https://doi.org/10.1108/978-1-83982-544-620221010

Kumar P, Singh RK, Kumar V (2021) Managing supply chains for sustainable operations in the era of industry 4.0 and circular economy: analysis of barriers. Resour Conserv Recycl 164:105215. https://doi.org/10.1016/j.resconrec.2020.105215

Marchesi L, Marchesi M, Tonelli R, Lunesu MI (2022) A blockchain architecture for industrial applications. Blockchain: Res Appl 3(4):100088. https://doi.org/10.1016/j.bcra.2022.100088

Milios L (2021) Towards a circular economy taxation framework: expectations and challenges of implementation. Circular Econ Sustain 1(2):477–498. https://doi.org/10.1007/s43615-020-00002-z

Organization for Economic Co-operation and Development (2015) new approaches to SME and entrepreneurship financing: broadening the range of instruments. https://www.oecd.org/cfe/smes/New-Approaches-SME-full-report.pdf. Retrieved 5 June 2022

Önder I, Treiblmaier H (2018) Blockchain and tourism: three research propositions. Ann Tourism Res 72:180–182. https://doi.org/10.1016/J.ANNALS.2018.03.005

Ozdemir AI, Ar IM, Erol I (2019) Assessment of blockchain applications in travel and tourism industry. Qual Quant 54:1549–1563

Ozen O, Kazancoglu YD, Kumar Mangla S (2020) Synchronized barriers for circular supply chains in industry 3.5/Industry 4.0 transition for sustainable resource management. Resour Conserv Recycl 161(May):104986

Patel R, Migliavacca M, Oriani ME (2022) Blockchain in banking and finance: a bibliometric review. Res Int Bus Fin 62:101718. https://doi.org/10.1016/j.ribaf.2022.101718

Perrons RK, Cosby T (2020) Applying blockchain in the geo-energy domain: the road to interoperability and standards. Appl Energy262. https://doi.org/10.1016/j.apenergy.2020.114545

Rajasekaran AS, Azees M, Al-Turjman F (2022) A comprehensive survey on blockchain technology. Sustain Energy Technol Assess 52:102039. https://doi.org/10.1016/j.seta.2022.102039

Ranta V, Aarikka-Stenroos L, Väisänen JM (2021) Digital technologies catalyzing business model innovation for circular economy—multiple case study. Resour Conserv Recycl 164:105155. https://doi.org/10.1016/j.resconrec.2020.105155

Risk J, Mohammadi L, Rhee J, Walters L, Ward PR (2019, Sept 18) Barriers, enablers and initiatives for uptake of advance care planning in general practice: a systematic review and critical interpretive synthesis. BMJ Open 9(9):e030275. https://doi.org/10.1136/bmjopen-2019-030275. PubMed: 31537570, PubMed Central: PMC6756326

Sahebi IG, Mosayebi A, Masoomi B, Marandi F (2022) Modeling the enablers for blockchain technology adoption in renewable energy supply chain. Technol Society68:101871. https://doi.org/10.1016/j.techsoc.2022.101871

Samad TA, Sharma R, Ganguly KK, Wamba SF, Jain G (2022) Enablers to the adoption of blockchain technology in logistics supply chains: evidence from an emerging economy. Ann Oper Res. https://doi.org/10.1007/s10479-022-04546-1

Sharma M, Joshi S, Kumar A (2020) Assessing enablers of e-waste management in circular economy using DEMATEL method: an Indian perspective. Environ Sci Pollut Res Int 27(12):13325–13338. https://doi.org/10.1007/s11356-020-07765-w

Teufel B, Sentic A, Barmet M (2019) Blockchain energy: blockchain in future energy systems. J Electron Sci Technol 17(4). https://doi.org/10.1016/j.jnlest.2020.100011

Wang Y, Singgih M, Wang J, Rit M (2019) Making sense of blockchain technology: how will it transform supply chains? Int J Prod Econ 211:221–236. https://doi.org/10.1016/j.ijpe.2019.02.002

Wang Q, Li R, Zhan L (2021) Blockchain technology in the energy sector: from basic research to real world applications. Comp Sci Rev 39. https://doi.org/10.1016/j.cosrev.2021.100362

Yildizbasi A (2021) Blockchain and renewable energy: integration challenges in circular economy era. Renew Energy 176:183–197. https://doi.org/10.1016/j.renene.2021.05.053

Zhang W, Deng Y (2019) Combining conflicting evidence using the DEMATEL method. Soft Comput 23(17):8207–8216. https://doi.org/10.1007/s00500-018-3455-8

Zhao AGRI, Ahmad N, Yan C, Usmani MS (2021) Prioritizing critical success factors for sustainable energy sector in China: a DEMATEL approach. Energy Strategy Rev 35:100635. https://doi.org/10.1016/j.esr.2021.100635

Zkik K, Belhadi A, Rehman Khan SA, Kamble SS, Oudani M Touriki FE (2022) Exploration of barriers and enablers of blockchain adoption for sustainable performance: implications for e-enabled agriculture supply chains. Int J Logist Res Appl. https://doi.org/10.1080/13675567.2022.2088707