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Blockchain Technology and Sustainable Logistics: Integration in the Circular Economy

Blockchain Teknolojisi ve Sürdürülebilir Lojistik: Döngüsel Ekonomi Entegrasyonu

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ABSTRACT

Recycling, reuse and reduction, which are among the "3R" actions of the circular economy, have an important place in ensuring resource efficiency. Minimizing the use of resources, ensuring their reuse and obtaining gains by recycling them at high standards can contribute to the sustainability studies of the logistics sector. This study covers associating the circular economy with blockchain technology, taking into account sustainable logistics studies. From the circular economy perspective, the features of blockchain technology that are thought to affect sustainable logistics; carbon emission reduction, logistics cost reduction, ease of communication, hacking, increased performance, data immutability, effective information sharing, transparency, uncertain legal situation, new technology and trust. From this point of view, the place of blockchain technology on the road to circular economy has been examined in the current study.

Keywords: Blockchain technology, Circular Economy, Sustainable Logistics, Logistics, Entropy Method

ÖZ

Döngüsel ekonominin "3R" eylemleri arasında yer alan geri dönüşüm, yeniden kullanım ve azaltma, kaynak verimliliğinin sağlanmasında önemli bir yere sahiptir. Kaynakların kullanımının en aza indirilmesi, yeniden kullanılmasının sağlanması ve yüksek standartlarda geri dönüştürülerek kazanımların elde edilmesi lojistik sektörünün sürdürülebilirlik çalışmalarına katkı sağlayabilir. Bu çalışma, sürdürülebilir lojistik çalışmaları dikkate alınarak döngüsel ekonomiyi blockchain teknolojisi ile ilişkilendirmeyi kapsamaktadır. Döngüsel ekonomi perspektifinden bakıldığında, sürdürülebilir lojistiği etkilediği düşünülen blockchain teknolojisinin özellikleri; karbon emisyonunun azaltılması, lojistik maliyetlerinin azaltılması, iletişim kolaylığı, bilgisayar korsanlığı, artan performans, veri değişmezliği, etkin bilgi paylaşımı, şeffaflık, belirsiz yasal durum, yeni teknoloji ve güven. Bu noktadan hareketle mevcut çalışmada blockchain teknolojisinin döngüsel ekonomiye giden yolda yeri incelenmiştir.

Anahtar Kelimeler: Blockchain teknolojisi, Döngüsel Ekonomi, Sürdürülebilir Lojistik, Lojistik, Entropi Yöntemi

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1. INTRODUCTION

Logistics activity, which is the last link of supply chain management, has become more important when it is associated with sustainability. Logistics activities not only make a significant contribution to economic performance, but also contain elements that must be taken into account in terms of environmental and social aspects. The first is responsible for consuming significant energy resources and generating greenhouse gas emissions. On the other hand, it causes air and noise pollution. Again, with the increase of industrialization, increasing wastes due to the use of resources bring along various problems. The signal of depletion of resources, that resource use is expected to increase threefold globally until 2050 due to the increase in consumption (Jaeger and Upadhyay, 2020), and the circular economy, which is a sustainable model as a result of seeking solutions to the increasing environmental pollution, may be an idea for the sector at this stage.

The circular economy model, which ensures the use of resources as long as possible, energy savings and reduction of waste by keeping the resources in the loop, is based on sustainability and was born against the known linear economy model.

Recycle, reuse and reduce, which are among the “3R” actions of the circular economy, have an important place in ensuring resource efficiency. Reduce, reducing the use of raw materials; Reuse, the most efficient reuse of products and components; Recycle means high quality reuse of raw materials. Minimizing the use of resources, ensuring their reuse and obtaining gains by recycling them at high standards can contribute to the sustainability efforts of the logistics sector. In the circular economy, waste is minimized by properly designing products and industrial processes so that resources and materials are constantly flowing and in use; The wastes and residues that are inevitable to come out are recycled or recovered (EMF, 2014).

On the other hand, technological developments provide various benefits to businesses on the way to sustainability. Blockchain technology, which is one of them and has been frequently heard in studies in recent years, can be the subject of sustainable studies within the scope of circular economy. Blockchain is recognized as a cost-effective technology (using smart contracts) to control communication between multiple participants in a reliable, efficient and decentralized manner (Nesarani et al., 2020). Blockchain technology includes three core technologies: asymmetric encryption algorithms, distributed data storage, and consensus algorithms. This technology can actually be defined as a system that allows the flow of information to be done reliably and without any outside interference.

While blockchain technology benefits the supply chain line in many ways, it is considered to be capable of solving many problems, especially when logistics activities are taken into account. In the literature, studies using blockchain technology within the scope of logistics activities and associating it with sustainability have been examined (Table 1).

Table 1. *Literature reviews contributing to the study*

Authors	Scope	Methodology	Sector
Tektaş and Kırbaç (2020)	A case study is conducted on the use of blockchain technology in logistics and supply chain, and an application study of this case study is carried out in a logistics company using appropriate methodological methods.	Case study	Logistics
Orji et al. (2020)	It proposes a technology-organization-environment (TOE) theoretical framework of critical factors affecting the successful adoption of blockchain technologies in the transportation logistics industry and prioritizes it using ANP.	ANP	Logistics

Tijan et al. (2019)	"It explores the decentralized data storage represented by blockchain technology and the possibility of its development in sustainable logistics and supply chain management."	Case study	Logistics
Sundarakani et al. (2021)	It explores the need for blockchain in the Industry 4.0 environment from the perspective of Big Data in supply chain management.	Case study	Logistics
Andreou et al. (2018)	In this study, a smart contract mechanism over blockchain is presented for advantages in logistics.	Case study	Logistics
Yi (2019)	It offers techniques to leverage blockchain to secure logistics.	Case study	Logistics
Sunmola and Apeji (2020)	It focuses on blockchain technology and explores sustainable supply chain visibility and features of blockchains.	Literature review	General
Upadhyay et al. (2021)	Discusses the current and potential compatibility of blockchain with circular economy.	Case study	General
Rejeb and Rejeb (2020)	It explores the blockchain literature and its relevance to supply chain sustainability.	Literature review	General
Kouhizadeh et al. (2021)	Provides a comprehensive overview of the barriers to adopting blockchain technology to manage sustainable supply chains.	DEMATEL	General
Esmaeilian et al. (2020)	It provides an overview of Blockchain technology and Industry 4.0 to drive supply chains towards sustainability.	Literature review	General
Yadav and Singh (2020)	It allows the use of blockchain technology to be explored and supply chain management to develop efficient sustainable supply chain management.	Fuzzy DEMATEL	General
Tsolakis et al. (2021)	It examines the design of blockchain-based food supply chains that support the Sustainable Development Goals.	Case study	Food
Nandi et al. (2021)	Using blockchain technology and circular economy principle capabilities, it offers a potential solution by addressing localization, agility and digitization (LAD) features.	Case study	General

In the circular economy integration of blockchain technology, which is considered within the scope of sustainability, its compliance with the supply chain line has had a positive effect in many studies. Some of the benefits can be listed as follows;

- Faster and error-free process management
- Accelerating the physical flow of goods thanks to its transparency feature
- Efficient process operations
- Preventing fraud in resource management and tracking
- Increased trust as a result of effective information sharing among supply chain stakeholders
- Avoiding delivery delays
- While doing all this, reducing carbon emissions with optimum planning

In the current study, it is aimed to contribute to the literature by examining the place of blockchain technology on the road to circular economy. Blockchain technology allows the monitoring of all workflows, from the material selection point of the products to the distribution, when logistics activities are taken into account in designing the circular economy. Many parameters such as the material of the product purchased as raw material, whether it uses fossil fuels during production, the amount of carbon emissions exposed in the logistics processes, the amount of product and waste suitable for recycling can be provided with blockchain. These are positive developments that will contribute to the circular economy.

The aim of this study is to evaluate the compatibility of blockchain technology with the circular economy in sustainable logistics activities without being indifferent to technological developments. Considering the circular economy on the road to sustainability, the criteria that are among the features of blockchain technology have been evaluated in this context.

2. METHODOLOGY

In this section, the criteria determined by considering the concept of circular economy and its compatibility with the sustainable logistics sector by considering blockchain technology are tried to be explained. At this stage, Entropy Method, one of the Multi-Criteria Decision Making methods, is used.

2.1. Entropy Method

The entropy method is used to measure the amount of useful information provided by existing data (Wu et al., 2011). In the entropy method, the data in the decision matrix is used to calculate the weights of the criteria in the decision problem. The applicability of the method is made strong because there is no need for any other subjective evaluation. The entropy method consists of 5 steps (Wang and Lee, 2009).
Stage 1. Creation of the decision matrix; the decision matrix consisting of xij values (the value of the i. alternative according to the j. evaluation criterion) is included in Equation (1).

$$D = \begin{matrix} A_1 \\ .. \\ A_m \end{matrix} \begin{bmatrix} X_{11} & \cdots & X_{1n} \\ \vdots & \ddots & \vdots \\ X_{m1} & \cdots & X_{mn} \end{bmatrix} \quad (1)$$

Stage 2. Normalization of the decision matrix; the values are standardized with the help of Equation (2).

$$p_{ij} = \frac{x_{ij}}{\sum_{i=1}^{m} x_{ij}} \quad (2)$$

Stage 3. Finding the entropy values of the criteria; the entropy values (ej) of each evaluation criterion are calculated by the Equation (3).

$$e_{ij} = -k.\sum_{j=1}^{n} p_{ij}.\ln p_{ij} \qquad \text{i=1,2..m j=1,2..n} \quad (3)$$

Stage 4. Finding degrees of differentiation; using the ej values found in the 3rd stage, the dj values are found by Equation (4). A high dj value indicates that the distance or differentiation between alternative scores for the criteria is large.

$$d_j = 1 - e_j \quad \text{j=1,2..,n} \quad (4)$$

Stage 5. Calculation of entropy criterion weights; the weight values of the criteria are calculated with the help of Equation (5).

$$w_j = \frac{d_j}{\sum_{j=1}^{n} d_j} \quad (5)$$

3. RESULTS AND FINDINGS

Considering the “3R” headings of the circular economy, the criteria considered appropriate for the logistics sector and in the literature are brought together. (Table 2).

Table 2. *Definitions of the criteria that are the subject of the study*

Criteria	**Authors**	**Code**	**Description**
Reducing carbon emissions	Green, 2018	BC1	Blockchain technology can promote clean energy trade by improving carbon emissions with optimum transport management.
Reducing logistics costs	Tijan et al., 2019; Chang et al., 2019	BC2	It can significantly reduce logistics costs, additional costs, transportation costs.
Ease of communication	Author*	BC3	It provides accurate and reliable communication between the end-to-end stakeholders of the supply chain process.
Hacking	Min, 2019	BC4	It can prevent hacking, vulnerability disputes by increasing transaction security.
Increased performance	Author*	BC5	It increases the end-to-end speed of the supply chain process and provides performance increase.
Data immutability	Dutta et al., 2020	BC6	Data is immutable due to the need for verification by other nodes and traceability of changes.
Effective information sharing	Litke et al., 2019; Min, 2019	BC7	It can contribute effectively to information sharing among supply chain stakeholders.
Transparency	Wang et al., 2019; Saberi et al., 2019	BC8	It helps to keep track of the status of an item during a transaction
Uncertain legal status	Niranjanamurthy et al., 2018	BC9	The uncertain legal situation can be confusing and prohibitive.
New technology	Hughes et al., 2019; Johansson and Nilsson, 2018	BC10	The fact that it is a new technology may cause it to not be understood yet.
Trust	Saberi et al., 2018; Tijan et al, 2019	BC11	Trust among stakeholders can increase as data becomes more transparent.

* Created by the author.

As explained in Table 2, when the recycle, reuse and reduce activities of the circular economy are considered, the sustainable criteria in these stages are included in 11 studies. These are the blockchain features obtained from the literature by considering every stage of the logistics process (Reducing carbon emissions, Reducing logistics costs, Ease of communication, Hacking, Increased performance, Data immutability, Effective information sharing, Transparency, Uncertain legal status, New technology, Trust). These parameters in advanced technology are of a nature that will benefit the circular economy and explain its compliance with sustainability. Accordingly, a decision matrix is first created (Table 3) and normalized for the evaluation between criteria (Table 4).

Table 3. *Decision matrix of Entropy method*

	BC1	**BC2**	**BC3**	**BC4**	**BC5**	**BC6**	**BC7**	**BC8**	**BC9**	**BC10**	**BC11**
BC1	1.00	7.00	2.00	7.00	0.20	7.00	0.17	6.00	8.00	7.00	0.25
BC2	0.14	1.00	2.00	2.00	0.33	3.00	2.00	5.00	6.00	6.00	3.00
BC3	0.50	0.50	1.00	2.00	0.20	0.25	0.20	0.33	6.00	6.00	0.33
BC4	0.14	0.50	0.50	1.00	0.14	0.17	0.17	0.20	0.50	0.33	0.20
BC5	5.00	3.00	5.00	7.00	1.00	3.00	2.00	4.00	6.00	6.00	2.00
BC6	0.14	0.33	4.00	6.00	0.33	1.00	0.33	3.00	6.00	5.00	0.33

BC7	6.00	0.50	5.00	6.00	0.50	3.00	1.00	6.00	7.00	7.00	3.00
BC8	0.17	0.20	3.00	5.00	0.25	0.33	0.17	1.00	5.00	5.00	1.00
BC9	0.13	0.17	0.17	2.00	0.17	0.17	0.14	0.20	1.00	2.00	0.25
BC10	0.14	0.17	0.17	3.00	0.17	0.20	0.14	0.20	0.50	1.00	0.25
BC11	4.00	0.33	3.00	5.00	0.50	3.00	0.33	1.00	4.00	4.00	1.00

Table 4. *Normalized decision matrix of Entropy method*

	BC1	**BC2**	**BC3**	**BC4**	**BC5**	**BC6**	**BC7**	**BC8**	**BC9**	**BC10**	**BC11**
BC1	0.06	0.51	0.08	0.15	0.05	0.33	0.03	0.22	0.16	0.14	0.02
BC2	0.01	0.07	0.08	0.04	0.09	0.14	0.30	0.19	0.12	0.12	0.26
BC3	0.03	0.04	0.04	0.04	0.05	0.01	0.03	0.01	0.12	0.12	0.03
BC4	0.01	0.04	0.02	0.02	0.04	0.01	0.03	0.01	0.01	0.01	0.02
BC5	0.29	0.22	0.19	0.15	0.26	0.14	0.30	0.15	0.12	0.12	0.17
BC6	0.01	0.02	0.15	0.13	0.09	0.05	0.05	0.11	0.12	0.10	0.03
BC7	0.35	0.04	0.19	0.13	0.13	0.14	0.15	0.22	0.14	0.14	0.26
BC8	0.01	0.01	0.12	0.11	0.07	0.02	0.03	0.04	0.10	0.10	0.09
BC9	0.01	0.01	0.01	0.04	0.04	0.01	0.02	0.01	0.02	0.04	0.02
BC10	0.01	0.01	0.01	0.07	0.04	0.01	0.02	0.01	0.01	0.02	0.02
BC11	0.23	0.02	0.12	0.11	0.13	0.14	0.05	0.04	0.08	0.08	0.09

After the normalized matrix, the entropy values (ej) of the criteria are found (Table 5).

Table 5. *Entropy values for criteria*

	BC1	**BC2**	**BC3**	**BC4**	**BC5**	**BC6**	**BC7**	**BC8**	**BC9**	**BC10**	**BC11**
BC1	-0.16	-0.34	-0.20	-0.29	-0.16	-0.37	-0.09	-0.33	-0.29	-0.28	-0.08
BC2	-0.04	-0.19	-0.20	-0.14	-0.21	-0.28	-0.36	-0.31	-0.25	-0.26	-0.35
BC3	-0.10	-0.12	-0.13	-0.14	-0.16	-0.05	-0.11	-0.05	-0.25	-0.26	-0.10
BC4	-0.04	-0.12	-0.08	-0.08	-0.12	-0.04	-0.09	-0.04	-0.05	-0.03	-0.07
BC5	-0.36	-0.33	-0.32	-0.29	-0.35	-0.28	-0.36	-0.28	-0.25	-0.26	-0.30
BC6	-0.04	-0.09	-0.29	-0.27	-0.21	-0.14	-0.15	-0.24	-0.25	-0.23	-0.10
BC7	-0.37	-0.12	-0.32	-0.27	-0.27	-0.28	-0.28	-0.33	-0.28	-0.28	-0.35
BC8	-0.04	-0.06	-0.25	-0.24	-0.18	-0.07	-0.09	-0.12	-0.23	-0.23	-0.21
BC9	-0.04	-0.05	-0.03	-0.14	-0.14	-0.04	-0.08	-0.04	-0.08	-0.13	-0.08
BC10	-0.04	-0.05	-0.03	-0.18	-0.14	-0.04	-0.08	-0.04	-0.05	-0.08	-0.08
BC11	-0.34	-0.09	-0.25	-0.24	-0.27	-0.28	-0.15	-0.12	-0.20	-0.20	-0.21

Then, the weightings of each criterion are determined (Table 6).

Table 6. *Determination of weights*

	BC1	BC2	BC3	BC4	BC5	BC6	BC7	BC8	BC9	BC10	BC11
ej	0.654	0.658	0.870	0.941	0.917	0.774	0.773	0.799	0.912	0.931	0.811
dj	0.345	0.341	0.129	0.058	0.082	0.225	0.226	0.200	0.087	0.068	0.188
wj	0.177	0.1748	0.0661	0.0301	0.0421	0.1152	0.1159	0.1025	0.0446	0.0351	0.0965

Accordingly, the targeted reduction of carbon emissions in the circular economy is benefited by using blockchain technology from the logistics sector. Looking at the ranking between the criteria (Table 6) (Figure 1), the BC1 coded "Reducing carbon emissions" criterion proves this benefit.

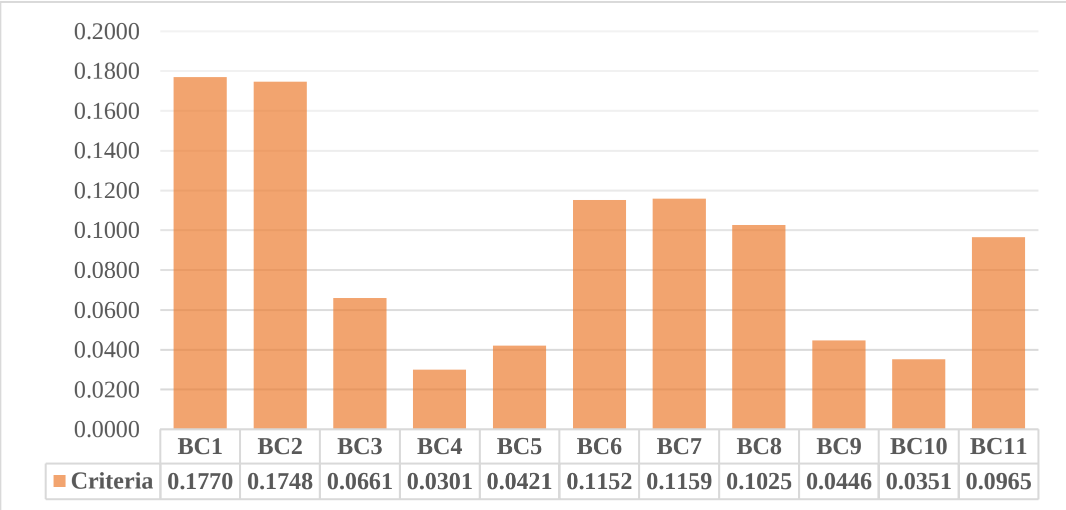

Figure 1. *Ranking of criteria*

In the same way, the circular economy BC2 coded "Reducing logistics costs", which calls for a source different from the linear economy to stay in the heart at the point of contributing to the economy, and when blockchain technology is used, it will help to reduce costs. These criteria are followed by BC7 "Effective information sharing" and BC6 "Data immutability" parameters. With effective information sharing and data immutability, stakeholders in the supply chain line will be able to assume more effective roles. The BC8 "Transparency" criterion that follows will provide a high-level impact on the resource management for the visibility and tracking system and will be able to decide on the evaluations of the resources within the economy. BC11 "Trust" criterion ensures trust between stakeholders. With the BC3 "Ease of communication" criterion, which comes later, it will again facilitate communication between stakeholders and provide the opportunity to produce fast solutions to problems that may arise. The BC9 "Uncertain legal status" criterion is currently considered negative for the cross-country adoption and enforcement of blockchain technology, so it is at the bottom of the list. It is inevitable that BC5 "Increased performance" will contribute to the increase in performance in logistics processes at the point of circular economy. The BC10 "New technology" criterion is that the technology is new and has low awareness among stakeholders, which negatively affects it. The BC4 "Hacking" criterion, which is in the last place, is effective against hacking and damage that may occur to works with blockchain technology.

4. CONCLUSION

The circular economy model, which keeps resources in the loop, ensures the use of resources as long as possible, enables energy savings and reduces waste, is a concept developed against the known linear model. On the other hand, developing technologies that contribute to businesses also support this economic model. Every business aiming at sustainable logistics also contributes to the circular economy model. This model, which makes resource management effective, reduces carbon emissions, and ensures recycling and recovery of waste, is possible with blockchain technology. In this study, the circular economy and blockchain technology integration, which are discussed in the light of these parameters, are shown with criteria.

At this stage, Entropy Method, one of the Multi-Criteria Decision Making methods, was used. As a result of the blockchain technology literature examined within the scope of sustainability, 11 criteria (Reducing carbon emissions, reducing logistics cost, ease of communication, hacking, increased performance, data immutability, effective information sharing, transparency, uncertain legal status, new technology, trust) were decided and evaluated. As a result of the evaluation, the most important criteria were Reducing carbon emissions and reducing logistics cost. It can be said that these criteria will contribute significantly to the "3R" rule of the circular economy.

Considering the sustainable logistics studies for businesses, the importance of blockchain technology, which has been shown to facilitate the transition to the circular economy, has been tried to be conveyed in this study. The importance of blockchain technology will increase gradually when uncertainty disappears in future studies. In this process, in addition to this study, criteria can be developed and solutions can be evaluated with new methods. At the same time, logistics activities of different sectors can be examined in detail and contribute to the literatüre.

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