

Blockchain Technology in Waste Management: Theoretical Evaluation for System Adoption

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Abstract

In recent years Blockchain technology has become increasingly important and accepted (i.e. business sector, supply chain, and other aspects of sustainability). The purpose of this study was to determine the potential of Brewer spent yeast and determine the possibility of blockchain adoption in Brewer Spent Yeast (BSY) waste management. This study uses primary data and literature studies in the preparation of blockchain-based waste management. The data obtained were analyzed using the Decision-Making Trial and Evaluation Laboratory (DEMATEL) method to extract the relationship between criteria within the blockchain framework. From the results of this study, it is known in the blockchain management aspect, it was found that the availability of technology and understanding of technology use insights were the most dominant cause criteria $(R_i - C_i) > 0.00$. While the impact criteria with a value $(R_i - C_i) < 0.00$ such as the criteria can be used for many sources of waste, cheaper transactions, and aspects of a culture of transparency in the implementation of waste treatment. The cause criteria will influence the effect criteria in the process of adopting the blockchain model in Brewer Spent Yeast (BSY) waste management.

Keywords

Blockchain, Waste Management, Adoption, Brewer Spent Yeast, DEMATEL

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1. INTRODUCTION

Waste can be defined very subjectively because it relates to different assessments between people. But if it is defined simply, then waste or garbage is any substance that is disposed of or has been disposed of by the thrower. These wasters or actors can be categorized as industries, groups, individuals, and society in general (Williams, 2005). Every waste has potential if it is combined with good waste management. Some of the managements that are mostly carried out are reuse, recycle, and reduce (Demirbas, 2011). The concept is a simple waste management which the majority have been implemented in the community.

Wastes in the current era are mostly produced by industries such as the food, beverage, property, health, medicine, and other industries. The waste is created because of 2 things, namely waste products (San Martin et al., 2020) or because production efficiency has not been maximized (Rocha et al., 2015). This research is designed to study waste management in the beer industry. This industry produces the main product in the form of beer. Then in the beer beverage processing industry, there are residual products from each process such as liquid waste (BSG)/husk waste,

yeast waste (BSY)/yeast waste, and a non-organic filter device called qishegur (Jaeger et al., 2020; San Martin et al., 2020). Brewer's spend grain (BSG) is a waste of wheat as the main raw material for brewing beer. Brewer's spend yeast (BSY) is a yeast waste left over from a fermenter in sewage treatment (Mathias et al., 2015). This waste consists of yeast with the most species, namely *Saccharomyces sp* (Jaeger et al., 2020). Then qishegur waste is a filter waste in the form of non-organic substances.

This study tries to manage Brewer spent yeast waste in terms of bio-sustainability management. Brewer spent yeast (BSY) is a waste from the production of beer beverage processing. This waste is in solid form with the main constituent, namely the yeast *Saccharomyces cereviceae* (Jacob et al., 2019). BSY has the main content, namely protein, nitrogen, and minerals (Jaeger et al., 2020). This shows that BSY can be utilized into something more valuable than just waste. It is known from the study of Jaeger et al. (2020) that BSY can be used as animal feed (Oliveira et al., 2016), functional food flavor (Vieira et al., 2016), fermentation agent (Radosavljević et al., 2020), and bio-absorbent (Ferraz et al., 2004; Riordan et al., 1997; Machado et al., 2008). However, it should be noted that in Indonesia, BSY waste,

which incidentally still contains alcohol, has become one of the special concerns regarding its halal status. So that the process of reviewing, processing, and flowing this waste needs to be given more attention.

It is known from one of the beer beverage processing industries that the production of BSY waste reaches 1400-4000 tons/year. This number is included in a large category and needs to be managed properly because it can affect social and environmental conditions (Das et al., 2019). It is known that in 2019, the production of waste or waste in people living in urban areas reached 1 million m³/day (BPS, 2022). But with a maximum waste carrying capacity of only 80-90% (BPS, 2022), so that waste management is needed to minimize waste in the environment or in the field. The process requires good waste and social management so that the waste management process can implement the SDGs concept. This concept requires management to pay attention to sustainability aspects such as economic, social, environmental, behavioral, and cultural (Yeheyis et al., 2013).

With the potential for BSY, waste management, and special cases of beer waste in the majority of Indonesians, a system or management is needed that can accommodate comprehensive BSY waste management. Then it was discovered that in recent decades there has been a management concept carried out to determine the number and flow of goods/objects within a certain period. One of these technologies or systems uses the blockchain concept. Blockchain is a model that emerged as a result of user agreements to facilitate the process of recording transactions and tracking assets in business networks. Assets can be in the form of houses, cars, cash, and land or intangible intellectual property, patents, copyrights, and brands (Janssen et al., 2020). Blockchain technology is used for management applications because it has features that can support activities. The features contained in blockchain technology are a decentralized system (Crosby et al., 2016), transparency (Hu et al., 2018), immutable (Zheng et al., 2018), and peer to peer (Agi and Jha, 2022; Tönmussen and Teuteberg, 2020). Across several factors, there are use cases of Blockchain technology showing high potential in achieving supply chain operations and management objectives (Hackius and Petersen, 2017; Kshetri, 2018; Queiroz and Wamba, 2019).

From several studies that have been carried out, it can be seen that the blockchain concept has the potential to be used in waste management, especially BSY waste. This is taken from one of the benefits of blockchain, namely traceability, transparency, and security of the data obtained. The simple concept is how to maximize the potential of BSY to be used as a waste supply chain model that has a direct impact on the community. In addition, the Blockchain model used can increase transparency, documentation, and waste tracking by companies.

2. EXPERIMENTAL SECTION

2.1 Materials

This research was conducted with a literature and survey approach to related respondents. The respondents used are respondents who know the blockchain system more deeply. This respondent focuses on providing an assessment and providing views related to the use of blockchain in waste management. The results of this assessment will be analyzed further. This type of respondent consists of engineers, IT developers, IT management, and researchers. For the number of respondents, this study was acquired from the modified study of Agi and Jha (2022). This study uses a purposive sampling technique with a target of 100 potential respondents.

2.2 Data Analysis

For the analysis of the assessment of the Blockchain model using the DEMATEL analysis method. This method was originally developed to solve complex real-world problems by: considering and analyzing multiple dimensions and factors involving multiple stakeholders. As a type of structural modeling method, DEMATEL is used to analyze and reveal causal relationships between system components. The DEMATEL method is applied to analyze variables that affect a particular system and utilize the knowledge of experts to create causal alternatives between variables.

This method not only converts the interdependence of factors into cause-and-effect relationships but also determines the system components assisted by impact relationship diagrams. To use the DEMATEL method, first a complex system must be defined, then the factors (variables in the DEMATEL method) that affect the system must be identified. This is achieved by reviewing the literature or by using expert opinion. In addition, a measurement scale should be developed to express the relationship and strength of the relationship between these factors. A typical scale range for this purpose is 0 to 4 indicating the following values: 0 = no priority, 1 = low priority, 2 = medium priority or equivalent, 3 = high priority, 4 = very high priority.

Respondents were asked to determine the impact of each predictor on each predictor (Agi and Jha, 2022). The categories and criteria used as assessment factors for blockchain technology to be compiled are presented in Table 1 below.

The DEMATEL method differs from similar survey-based studies for two reasons. First, respondents are individuals who have information about the phenomenon being investigated in addition to being an expert in their field (Bai et al., 2017; Li and Mathiyazhagan, 2018). Even a small number of respondents can provide detailed insights about the phenomenon being studied. Second, the method relies on respondents' critical evaluation of theoretically selected factors to help researchers establish the relative importance and mutual benefit of the interdependence of these factors. The steps used in the DEMATEL analysis in this study are: Collecting data from 100 expertises to fill in the direct

Table 1. Category and Criteria in Blockchain Model

Category	Code	Criteria	References
Company readiness	E1	Technology Availability	(Agi and Jha, 2022; Behnke and Janssen, 2020; Bumblauskas et al., 2020; Janssen et al., 2020)
	E2	Knowledge and ability to use technology	(Agi and Jha, 2022; Behnke and Janssen, 2020; Mendling et al., 2018)
Relative advantage	E3	Data integrity in Blockchain	(Agi and Jha, 2022; Babich and Hilary, 2020; Berneis et al., 2021)
	E4	Can be used for multiple sources/waste	(Agi and Jha, 2022; Babich and Hilary, 2020; van Hoek, 2019)
	E5	Lower transaction costs	(Agi and Jha, 2022; Schmidt and Wagner, 2019; Wamba et al., 2020)
System compatibility	E6	Ease of implementation	(Agi and Jha, 2022; Chang et al., 2019; Janssen et al., 2020; Mendling et al., 2018; Wang et al., 2019b)
	E7	Cultural aspects in the implementation of transparency in the amount and treatment of waste	(Agi and Jha, 2022; Behnke and Janssen, 2020; Janssen et al., 2020; Wang et al., 2019b; Zheng et al., 2018)
	E8	Cooperative in implementing regulations	(Behnke and Janssen, 2020; Kouhizadeh and Sarkis, 2018; Wang et al., 2019b; Zheng et al., 2018)
	E9	Cooperative in the process of adoption to waste management	(Agi and Jha, 2022; Babich and Hilary, 2020)
Complexity	E10	Harmonization of standards in Blockchain	(Agi and Jha, 2022; Janssen et al., 2020; Lacity, 2018; Wang et al., 2019b)
	E11	Interest of parties or subjects in the waste management transparency model	(Agi and Jha, 2022; Janssen et al., 2020)
External challenge	E12	The role of the government in implementing the Blockchain model for waste	(Agi and Jha, 2022; Lacity, 2018)
Category	E13	Development so that the system can be narrowed down for each prefecture/province	(Janssen et al., 2020; Mendling et al., 2018; Pournader et al., 2020)
Company readiness	E14	The system is designed to be flexible to environmental and social issues	(Barles, 2014; Dua et al., 2020; Gopalakrishnan et al., 2021)

relationship matrix (V_{ij}) between criteria as shown in Table 1. The matrix used is 14×14 in size with fields 0-4 by each expertise.

Compute the direct relationship matrix (B). This step uses the data in the first step to get the aggregate value (aij) using the following Equation:

$$A = \frac{1}{k} \sum_{k=1}^k Ak \quad (1)$$

Compute the normalized direct relationship matrix. This normalization is done by determining the maximum value for each row following the following Equation:

$$S = \max \sum_{j=1}^n aij \quad (2)$$

Then the normalization of the matrix is carried out according to the following Equation:

$$B = \frac{1}{S}A \quad (3)$$

Computing the total matrix of relationships. This matrix uses a normalized matrix by following the following Equation:

$$T = B(I - B)^{-1} \quad (4)$$

Computing the total factor of influence. The total effect of a factor (i) on other factors is calculated by adding up the elements in the corresponding row Ri in the total relation matrix (T), as in Equation (5). As for the influence that factor (j) receives from other factors in the system, it is equal to the number of elements in the corresponding column (Cj) in the same matrix (T). Equations (5) and (6) used in determining the variables Ri and Ci are:

$$Ri = \sum_{j=1}^n tij; i, j \in [1, n] \quad (5)$$

$$Cj = \sum_{i=1}^n tij; i, j \in [1, n] \quad (6)$$

Computational prominence (Pi) and net effect (Ei) of assessment factors. The equations used are:

$$Pi = Ri + Cj; i = j \quad (7)$$

$$Ei = Ri - Cj; i = j \quad (8)$$

3. RESULTS AND DISCUSSION

3.1 Blockchain Model

It is known that waste management is based on a waste management hierarchy consisting of reduce, reuse, and recycle processes as well as disposal. In the case of Brewery spent yeast (BSY) it is not possible to reduce the process because it is the core ingredient of the brewing process. Please note that BSY which has been used 5 times cannot be reused as a fermenter. So there is a choice between direct disposal or recycling. From these two managements, it is further developed related to the concept of recycling. Recycling of brewery spent yeast (BSY) can be interpreted from the meaning of recycling, namely using/returning it into other products. For this reason, the preparation of this research began by discovering the potential utilization and nutrients contained in BSY. Then it is integrated with sustainable management which of course uses technology. This is intended so that waste treatment can be tracked, there is documentation, and is transparent. So the concept of recycling using blockchain technology is compiled in this research.

The blockchain application model and the business model designed in this study are presented in Figure 1. The illustration contains a blockchain model, business logic, and management system that can be used. The three illustrations are mutually integrated with the designed blockchain model.

The development of this blockchain model focuses on implementing BSY waste management with a focus on trace and tracking processes, documentation, and tokenization. Trace and tracking are carried out so that information on waste distribution can be maintained in terms of information on the amount of waste, processing, and distribution that can be recorded in every transaction. This is done because the distribution of waste such as BSY needs to be tracked regularly so that it is utilized optimally without any potential disposal of the BSY. Then, the documentation process is used to record and store data on the system. This process will produce secure and unaltered data from the transaction side. This use will result in transparent data for participants who make transactions with this waste. Then tokenization is carried out to increase awareness in treating waste in each role. Independent waste treatment processes such as reuse, reduce, recycle, and so on can provide token value to each user.

These tokens are used for payment of waste requirements or exchange for rewards equivalent to the token's value. These processes require a large network, transparency, and strong data security so that this Blockchain is structured. This is done because blockchain has features that support peer-to-peer, transparency, decentralization, and immutable. It should be noted that because this is an initial concept, Blockchain is only used for transaction processing (Agi and Jha, 2022; Pournader et al., 2020; Zheng et al., 2018). Mean-

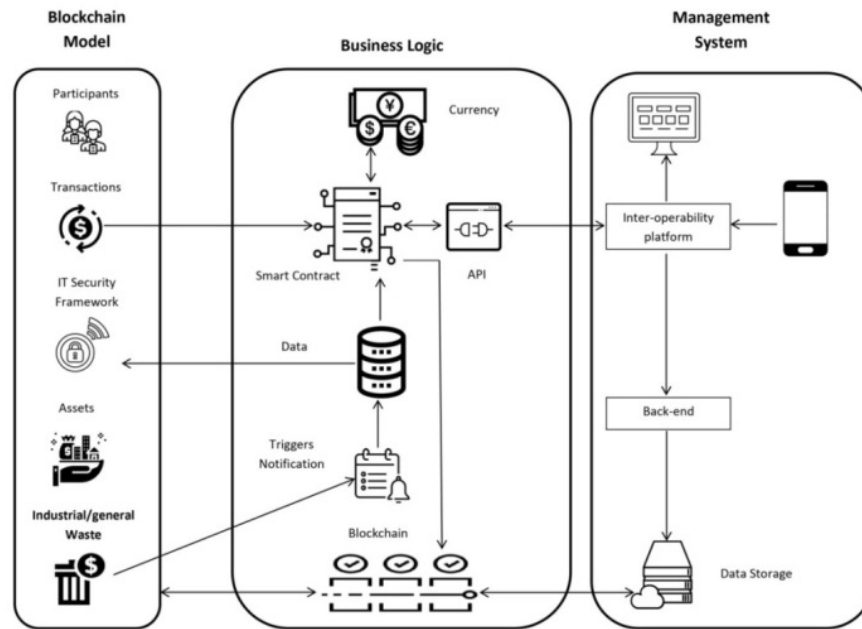


Figure 1. Blockchain Models, Business Logic and Management Systems in the Use of Blockchain

while, information, notifications, and changes to waste data can be adjusted periodically or this system still uses the SQL (Standard Query Language) basis. This is done to avoid changes in the condition of the waste within a certain time so that it can be renewed.

3.2 Evaluation for Blockchain Adoption Process to Companies

Then, because this Blockchain needs to be run by a company or developer, this technology requires an assessment so that it can be adopted. The assessment and analysis used in this study is the DEMATEL analysis. In this study, an assessment related to blockchain evaluation was carried out by inviting 100 potential respondents who have an understanding of blockchain management or information technology. This study follows a similar study based on the opinion of experts such as Agi and Jha (2022) which was modified. There are 2 steps in collecting answers from respondents. First, invite 100 potential respondents to give them a full explanation of the purpose of the study and ask if they are willing to fill out the matrix of mutual influence between the 14 factors as presented in Table 1. Then the file was sent to 24 respondents who stated their willingness to take part in the study. Data collection took place from mid-April to mid-June 2022. The profile of respondents who filled out the assessment is presented in Table 2 below.

The results of filling out the direct relationship matrix by 24 respondents who have been processed using Equation (1)

Table 2. Short Profile of Respondents

Business Sector	Frequency
Manufacture	6
Consultant	5
Service	13
Respondent Function	Frequency
IT Department and engineer	7
Consultant	5
Service	6
Logistic	6
Company Size of Employee	Frequency
Less than 1000	10
More than 1000	14

then normalize the data using Equation (2). The normalized matrix is then computed using Equation (4) to obtain a total relationship matrix (T). This computation is done to get the values of R_i and C_i . The total relationship matrix is presented in Table 3 below:

The value of the total relationship matrix (T) as presented in Table 3 is then continued with the determination of R_i using Equation (5) and C_i using Equation (6). Determination of the value of R_i and C_i is used to determine the

Table 3. Total Relation Matrix (T)

Criteria	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	E11	E12	E13	E14
E1	0.406	0.483	0.485	0.558	0.511	0.472	0.542	0.441	0.453	0.51	0.477	0.515	0.566	0.46
E2	0.441	0.389	0.466	0.544	0.487	0.452	0.502	0.429	0.433	0.485	0.462	0.496	0.543	0.449
E3	0.417	0.416	0.36	0.48	0.457	0.412	0.466	0.402	0.397	0.446	0.414	0.448	0.492	0.41
E4	0.373	0.362	0.366	0.361	0.39	0.35	0.405	0.336	0.347	0.375	0.365	0.406	0.449	0.352
E5	0.38	0.381	0.378	0.44	0.348	0.377	0.422	0.35	0.353	0.412	0.373	0.413	0.451	0.359
E6	0.457	0.454	0.453	0.519	0.491	0.377	0.511	0.416	0.421	0.492	0.455	0.488	0.542	0.453
E7	0.338	0.337	0.341	0.392	0.365	0.318	0.318	0.315	0.314	0.364	0.343	0.367	0.4	0.335
E8	0.43	0.432	0.437	0.509	0.473	0.429	0.479	0.346	0.42	0.477	0.437	0.474	0.52	0.432
E9	0.437	0.437	0.44	0.509	0.475	0.429	0.47	0.412	0.35	0.481	0.441	0.475	0.529	0.434
E10	0.388	0.39	0.399	0.456	0.409	0.371	0.427	0.348	0.349	0.352	0.396	0.419	0.474	0.374
E11	0.402	0.408	0.415	0.467	0.437	0.399	0.441	0.368	0.371	0.427	0.344	0.451	0.484	0.397
E12	0.366	0.367	0.369	0.428	0.404	0.354	0.408	0.341	0.344	0.401	0.357	0.341	0.441	0.359
E13	0.317	0.321	0.321	0.371	0.351	0.311	0.351	0.295	0.286	0.335	0.308	0.355	0.323	0.291
E14	0.418	0.414	0.416	0.478	0.448	0.41	0.454	0.393	0.394	0.452	0.424	0.454	0.507	0.347

Table 4. Prominence and Net effect from Evaluation

Category	Criteria	Ri	Ci	Prominence (Ri+Cj)	Net effect (Ri-Cj)
Company capability/Readiness	E1	6.878	5.567	12.446	1.311
	E2	6.578	5.591	12.169	0.987
Relative advantage	E3	6.016	5.646	11.663	0.37
	E4	5.239	6.512	11.751	-1.274
	E5	5.438	6.047	11.485	-0.609
System compatibility	E6	6.53	5.461	11.99	1.069
	E7	4.846	6.197	11.043	-1.351
	E8	6.295	5.192	11.487	1.103
	E9	6.319	5.231	11.55	1.089
Complexity	E10	5.551	6.008	11.559	-0.456
	E11	5.811	5.595	11.406	0.216
External challenge	E12	5.28	6.104	11.384	-0.824
Category	E13	4.534	6.722	11.256	-2.188
Company capability/Readiness	E14	6.01	5.451	11.461	0.558

value of excellence (prominence) and net effect (net effect). The values of Ri, Ci, prominence, and net effect are then presented in Table 4 below:

Table 4 shows the value of excellence and net effect. It should be noted that the superiority of a criterion indicates its overall importance in the system (Bai et al., 2017). If excellence shows the importance of the overall enabler, then the net effect indicates that this criterion must be categorized as a cause or an effect. Criteria that have a positive net effect value indicate that they have more impact on the enablers in the system. On the other hand, criteria with a negative net effect value indicate that they are more influenced by other criteria of the system.

Table 4 and Figure 2 show that the criteria for technology availability are criteria followed by the criteria for insight and understanding of technology, as well as ease of

implementation. These criteria are the 3 most prominent criteria followed by other criteria as presented in Figure 2 and Table 4. On the other hand, the criteria for the influence of aspects of corporate culture on Blockchain implementation, involvement of the government's role in the use of Blockchain, and the use of Blockchain can be used in any space. province or prefecture is a criterion with a low level of prominence.

The results presented in Figure 3 show the relationship between the dimensions of excellence and the net effect, indicating that 6 of the 14 criteria have a negative net effect value. Meanwhile, 8 of the 14 criteria have a positive net effect value. These results position that E1, E2, E3, E6, E8, E9, E11, and E14 become cause criteria or have an important role in the system. while the criteria with a negative net effect value, namely E4, E5, E7, E10, E12, and

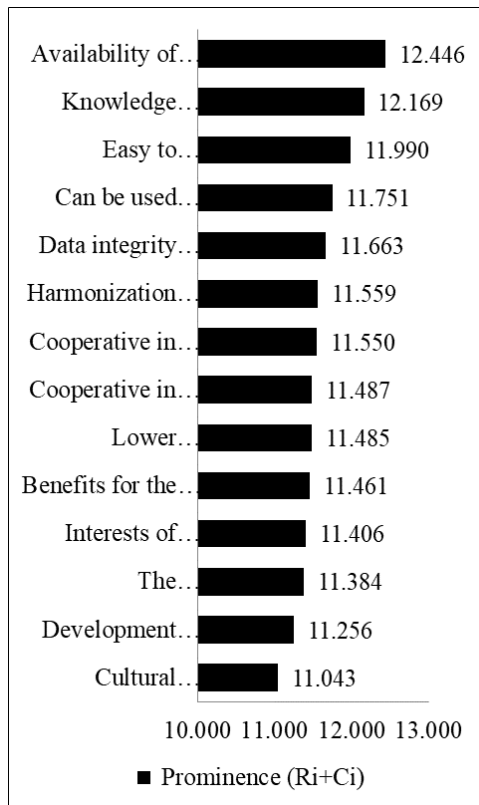


Figure 2. Prominence Level from each Criteria

E14 are the effect criteria. The effect criteria are criteria that will depend on the criteria because their nature will appear together with the cause criteria which are arranged in the blockchain framework. These cause and effect criteria will provide convenience in the preparation of blockchain technology models. This happens because the developer only needs to develop a cause criterion, so the effect value will follow. So that the compilation costs can be more efficient because the development of the blockchain framework can be simpler.

3.3 Management Implication

The results obtained in this study indicate that the availability of technology and understanding related to the system need to be the initial attention of the management sector. This needs to be done before gathering each participant and implementing it from a managerial perspective. Both of these resulted in some consensus being drawn regarding blockchain technology in waste management. First, to raise awareness among companies and participants that generate waste in a sustainable manner. Second, to develop and harmonize standard technologies with existing management. Third, to prepare regulations that support the adoption and use of technology. In addition, awareness of the sustainability aspects of bioproducts puts more pressure on obtaining detailed and accurate information from all

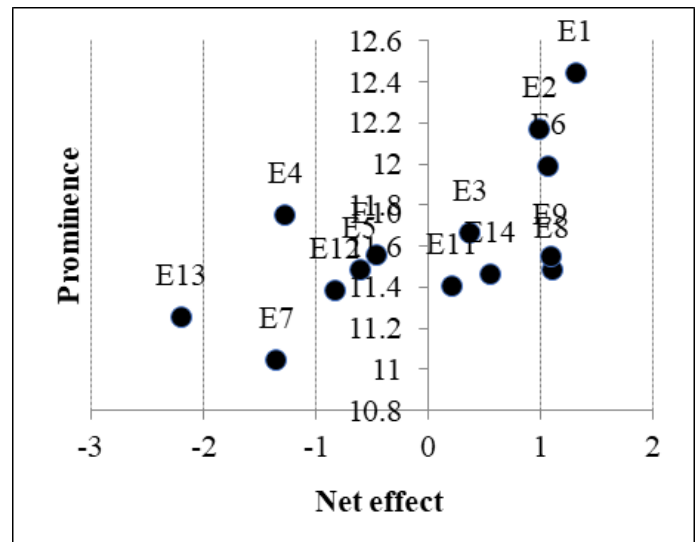


Figure 3. Relation between Prominence and Net Effect

members of this waste supply chain regarding social and environmental practices.

On the other hand, this information and system will encourage the validity of data and distribution of waste treatment such as BSY. So the possibility that shows that BSY's management is only limited to re-fermenting materials in collectors or waste in landfills can be reduced. Thus maximizing the potential of BSY waste can be increased. The actions of industry representative bodies, consulting firms, and technology solution promoters are crucial in this regard. For example they can host seminars, meetings and workshops where new blockchain-enabled business models need to be discussed. This activity is necessary because businesses with blockchain platforms have the advantage of sharing tamper-proof information and reducing transaction costs that can be demonstrated and clarified for managers. Consortiums or industry representative bodies may also undertake, or offer support for, proof-of-use blockchain models (Lacity, 2018), which can give credence to new technologies and are the first step towards implementing real solutions. Companies can also undertake industry-specific collective initiatives to develop and agree on best practices and governance structures for blockchain technology (Agi and Jha, 2022; Behnke and Janssen, 2020).

The results obtained in this study also show that the development of universal or general standards for blockchain technology is important to do. Thus, solution providers need to work to adopt universal standards for these technologies (Janssen et al., 2020) and improve interoperability between blockchain and enterprise information systems (Wang et al., 2019a). Solution providers can also work with legislators and communities communities such as NGOs or environmental communities to build appropriate governance structures for waste management so that decisions and the concept of

peer-to-peer can take place optimally (Babich and Hilary, 2020). It should be noted that regulations regarding data security and privacy have an impact on the potential use of blockchain (Lacity, 2018). This indicates that creating, changing, or adapting rules with the blockchain system will support the adoption of this technology (Agi and Jha, 2022).

Conclusions should only answer the objectives of the research. Tells how your work advances the field from the present state of knowledge. Without clear conclusions, reviewers and readers will find it difficult to judge the work, and whether or not it merits publication in the journal. Do not repeat the Abstract, or just list experimental results. Provide a clear scientific justification for your work, and indicate possible applications and extensions. This conclusion should be provided as a paragraph. You should also suggest future experiments and/or point out those that are underway.

3.4 Limitation

The limitations that arise in this study are the number of samples and the diversity used. Respondents used in this study exclusively consisted of engineers, IT management, and IT developers. This will probably introduce a bias in the results. So that the supporting factors for implementation such as government organizations, NGOs, and traditional community groups. Opinions from people in developed countries need to be added because they will provide new views related to the management of this Brewer Spent Yeast (BSY) waste. Because it is known that blockchain applications in waste management have been carried out in developed countries. In addition, this evaluation model is only limited to evaluation related to the adoption of blockchain technology in waste management. In an assessment, if it will be developed, it has the points contained in this research, but the application in the field is returned to the developer or company to assess it economically. Because making this model is a long-term investment, so it requires a high cost and commitment from the management.

4. CONCLUSIONS

This research reveals that for the emergence of blockchain adoption in waste management it is critical to develop technology standards, provide interoperability followed by insights between blockchain and enterprise systems, adapt laws and regulations to support blockchain-enabled business models, and conduct information exchange processes. The results of this study found that the availability of technology and understanding of technology use insights were the most dominant activating criteria that influenced other criteria. On the other hand, this study also found that there were clausal criteria or were affected by the activating criteria being implemented. The criteria for the clause (effect) are that it can be used for many sources of waste, cheaper transactions, aspects of corporate culture in the implementation of waste treatment, harmonization of processing standards

in blockchain, the role of the government in implementing the blockchain model, and system development so that it can be used in every province/prefecture.

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