An implementation framework of blockchain-based hazardous waste transfer management system

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Abstract

The rapid increase in volume and types of hazardous waste (HW) due to China's rapid economic development makes it significant to conduct HW safety management. However, due to the information asymmetry between the regulators and regulated institutions, problems such as illegal dumping and statistical fraud are common in hazardous waste transfer (HWT) activities. Moreover, there is a severe problem of information isolated island among waste production companies, transportation companies, and treatment companies in the HW market. Promoting the monitoring and information traceability of the whole process of HWT is the main challenge for HW management. Blockchain provides an ideal solution to overcome the above challenges. This study builds a framework of the blockchain-based HWT management system, enabling government regulators to obtain relevant information in HWT and improve HW's convenience. The system is introduced in detail from the infrastructure, blockchain-service, functions and users, emphasizing six information management functions. Finally, the positive impact and various challenges encountered in implementing blockchain in HWT management were discussed. This study applies blockchain to the research field of HWT management, which expands the application of blockchain in the field of solid waste management with great theoretical and practical significance.

1. Introduction

With China's rapid development, HW's generation is also increasing rapidly (Wang et al., 2017). The amount of HW generated in China increased by 6.4 times from 10.79 million tons in 2007 to 69.37 million tons in 2017 (NBSC, 2008; NBSC, 2019). Due to the insufficient capacity of hazardous waste treatment in China, the number of HW criminal cases is gradually increasing, such as illegal storage, illegal dumping. (Kang et al., 2020; Zhang et al., 2017). The root of the HW problem lies in the severe information asymmetry among enterprises and governments, which leads to significant uncertainty in the process of hazardous waste management (CNRRA, 2016). Some waste production companies, treatment companies take advantage of information superiority (mainly by hiding some information) to break the regulation or make illegal actions. There is no trading platform to inquire about the disposal price, waste production volume, and disposal volume, resulting in a relatively chaotic HWT market. The difficulty in defining HW property rights in waste production company has caused great confusion in the HW trading market. When HW is a positive-value resource commodity, the waste-producing company is the supplier, and the treatment company is the demand-side. However, when the HW is a negative-value commodity, the waste-producing company is the demander, and the waste treatment company becomes the supply side (Wang, 2014).

Most criminal cases of HW occurred during the transfer phase. The vast majority of HW in China is generated by economically developed provinces such as Shandong, Shanghai, Jiangsu, and Zhejiang. However, due to the unreasonable industrial layout and market factors, HW cannot be treated in the developed regions. A considerable part has been transferred to other regions, including trans-provincial and intra-provincial (Chen et al., 2017). Due to information management's imperfection and the lack of adequate supervision, more and more HW-related criminal cases occurred during HWT processes. One of

the top ten typical HW cases in 2018 showed that 4,820 tons of HW were illegally dumped during transportation from Zhejiang to Fujian. In the 2018 Yangtze River Basin waste removal action, 58 cases are related to HWT (Kang et al., 2020). Therefore, it is urgent to apply emerging technologies to improve the HWT process's supervision, reduce the information asymmetry between the company and the government, and combat illegal behaviors.

Some kinds of emerging information technology were applied continuously in the field of solid waste management. The combination of new technologies such as the internet of things(IoT), GPS, mobile terminals, and blockchain makes the intelligent supervision of solid waste possible (Fatimah et al., 2020; França et al., 2020). Many solid waste contents contain information management in the latest version of China's Solid Waste Management Law. The 78th legal provision requires the Ministry of Ecology and Environment to establish a national information supervision system (MEEPC, 2020). HW's digital management can complete change the traditional backward manual registration method and improve HW's information level in collecting, transportation, storage, and treatment stages. HW production company, weight, collection time, disposal time, treatment company, and other data are collected and counted by information technology, which can timely and accurately grasp the waste disposal situation and improve the management level.

Some cities across the country have established or are establishing HW supervision platforms (Wang et al., 2019). However, these platforms pay more attention to the supervision and management of waste production companies, and treatment companies without analyzing the enterprise management scenarios, which makes it difficult to form a closed-circuit evidence chain or to achieve a traceable monitoring model. HW's legal out-of-warehouse volume will be supervised using smart electronic scales, camera networking, and other equipment. However, it will be difficult for the environmental protection department to control the daily waste production by relying on the enterprise account. Combined with the comprehensive analysis of enterprise production process, scale, production status, waste production coefficient, and other factors, the regulatory department can better grasp the amount of HW. Some companies may underreport or change the types of HW statistics data to pursue economic benefits (Hu, 2018). Moreover, the existing supervision platform has not realized the organic combination of multiple single HW management systems. The mere digitalization of business management without some systematic design will bring difficulties to the operation of specific business scenarios. According to the Hazardous Waste Manifest System(HWMS), the applied transfer quantity (recorded in the transferred document), the out-of-warehouse quantity (provided by the waste production enterprise), and the entering-warehouse quantity (provided by the treatment company) must be consistent. However, due to the possible water loss of some HW (such as zinc-containing wastes), there will be data difference between delivery quality and out-of-warehouse quality (Pyssa, 2017). It is difficult for transport drivers to complete HW handover through the existing platform when these three types of figures are inconsistent.

Blockchain can completely change the way people manage environmental resources and help promote sustainable development(WEF, 2019). The so-called blockchain is a distributed accounting system implemented by computer technology. It provides an immutable accounting solution for multiple

distributed participants in the chain through distributed software architecture and advanced computing technology (Olinde & Johnson, 2015; Helo & Hao, 2019). Blockchain has the characteristics of data preservation, tamper resistance, and traceability of historical data. By saving information in the blockchain, it will effectively solve the problem of information asymmetry between participants and regulators, as well as reduce contract disputes and improve cooperation efficiency. The blockchain is characterized by decentralization, anonymity and traceability, which are helpful to its application in different fields such as supply chain, insurance and financial management, as well as HWT management that requires tracking information in the whole process.

It is helpful to form a closed-circuit chain of information in the entire process of HWT with “blockchain + IoT”. The management departments have the means to monitor the HWT process under the above technical combination support. The blockchain application will reduce the possibility of information asymmetry between regulators and participating companies and clearly define the responsibilities of relevant participants through a combination of transfer regulations and business content through several built-in smart contracts of blockchain. The purpose of this study is to develop a framework of the blockchain-based HWT management system.

The remainder of the study is organized as follows: The second section reviews the concept, characteristics of blockchain, and its application in solid waste management. The third section describes how to apply the blockchain to the whole process of HWT. The fourth section introduces a framework of the blockchain-based HWT management system. The fifth and sixth section discusses the positive impact and obstacles of applying blockchain in HWT management. The last section summarizes the full text and points out the future research direction.

2. Literature Review

Blockchain is a point-to-point distributed ledger technology based on the cryptographic algorithm, an integrated application of computer technologies such as distributed storage, point-to-point transmission, consensus mechanism, and encryption algorithm (Hong et al., 2020). The blockchain principle is to save the transaction data generated in the system in a period into blocks. Each block is connected by recording the previous block's hash value and the current block, forming a blockchain data structure (Yuan & Wang, 2016). The main technical features of blockchain include immutability, decentralized technology, enhanced security, distributed ledgers, consensus, and faster settlement (Gwyneth Iredale, 2020).

Swan pointed out that blockchain can be divided into three stages based on application scope and development stage (Swan, 2018). Nakamoto published his paper bitcoin, “a peer-to-peer electronic cash system,” in 2008, which marks the birth of bitcoin and represents the arrival of the era of blockchain 1.0. The underlying architecture of bitcoin adopts blockchain (Nakamoto, 2008; Crosby et al., 2016). The era of blockchain 2.0 began in 2014 when Vitalik Buterin integrated smart contracts with blockchain to launch the Ethereum project, in which smart contracts were deployed as transaction confirmation (Buterin, 2014). The core idea of blockchain 2.0 is to use the blockchain as a programmable distributed credit

infrastructure to support intelligent contract applications. The era of blockchain 3.0 began with the exploration of blockchain in various fields. With the development of artificial intelligence, IoT, and quantum technology, blockchain will have more and more extensive application scenarios (Ma, 2019).

The smart contract is a computable transaction protocol that implements contract terms, which has the characteristics of visibility, enforceability, verifiability, and privacy (Szabo, 1997). In the early stage of blockchain development, bitcoin did not introduce smart contract technology. Smart contract was introduced in the blockchain 2.0 stage (Li et al., 2020). Although smart contracts can only be used with assets in the digital ecosystem, many applications are actively exploring areas outside of digital currency, such as transactions and fair exchanges (Bognera, 2018), identity management (Yasin & Liu, 2016), medical record privacy (Xia et al., 2017), contract management (Yuan & Wang, 2016; Zou et al., 2019).

2.1 Blockchain in supply chain

One of the most promising blockchain applications is relationship management in global supply chains (Casey & Wong, 2017). The traditional supply chain's main challenge is the lack of an open and credible information resource in the whole supply chain (Wang et al., 2017).

Blockchain has the characteristics of information transparency, traceability, which will redefine the traditional trust system and address the challenges on traditional supply chain (Underwood, 2016). The application of blockchain in supply chain management is gradually becoming an academic hotspot (Liu & Li, 2020). There have been many studies focused on the specific application of blockchain in the supply chain, including diamond industry (Choi, 2019), food industry (Susanne & Massimo, 2020; Feng et al., 2020; Stranieri et al., 2021; Bumblauskas et al., 2019), prefabricated buildings (Zhang et al., 2020; Wang et al., 2020) and so on.

Blockchain will positively impact the rate of return on investment in the food supply chain. Moreover, blockchain makes it easy for consumers to access information about food transactions and track sources due to the increased accessibility, availability, and sharing of information (Feng et al., 2020; Stranieri et al., 2021). A prefabricated supply chain management system based on blockchain was developed, which helps solve the current challenges, such as information fragmentation, poor traceability, and lack of real-time information (Wang et al., 2020).

Many researchers also explored the combination of blockchain and new-generation information technology, such as IoT, radio frequency identification (RFID), computer vision, and building information model (BIM) (Christidis & Devetsikiotis, 2016; Kshetri, 2018; Xue & Lu, 2020). The blockchains will strengthen supply chain activities, leading to automated payments, source tracking, contract management, disintermediation, data ownership control, and redefinition of trust (Li et al., 2019).

2.2 Blockchain integration with solid waste management

Blockchain has the great potential to promote sustainable development (França et al., 2020). As game-changers, blockchain will completely change the current management paradigm (WEF, 2019). There are

many explorations on applying blockchains in environmental protection, such as improving solid waste management, classification of garbage, and mitigating climate change (Howson, 2019; Bierbaum et al., 2020). Lamichhane tried to develop a smart waste management system by combining the IoT with blockchain, which required residents to use cryptocurrency controlled by smart contracts to pay for waste disposals (Lamichhane, 2017). This program will effectively reduce service costs, especially for developing countries with insufficient government resources (Lamichhane, 2017). Another case of applying blockchain to urban waste management comes from São Paulo State, Brazil. The local government uses blockchain-based cryptocurrency to replace the management mode of urban waste green coins, effectively preventing fraud, loss, and mistakes in receiving/exchanging/paying for green coins (França et al., 2020). The "Plastic Bank" established in 2013, also applied blockchain to encourage waste plastic collections and reduce marine pollutions. Plastic Bank's principle is that scavengers can exchange waste plastics for blockchain-based encrypted tokens in the recycling center, which can be used to buy necessities (Plastic Bank, 2019). Blockchain is especially suitable for tracing high-value and high-hazard wastes such as e-waste. Applying blockchain to e-waste management could effectively reduce the information imbalance in the process of e-waste recycling, improve the recovery rate, and combat the illegal trade (Gupta & Bedi, 2018). In general, blockchain has great application potential in solid waste management, especially for HW and construction waste, which are paid special attention by the government departments.

China takes the leading position in blockchain research, which becomes more famous after "1024" President Xi Jinping's speech (Wang et al., 2020). China's blockchain policy tends to apply leading technologies to various fields of society, including public welfare, medical care, transportation, environmental protection, but adopts a restrained attitude towards cryptocurrency such as bitcoin (Wang et al., 2020). Many Chinese companies and scholars are exploring blockchain in solid waste management, including waste classification, rural waste, etc. However, these studies are still in concept discussion or small-scale application (Zhang 2019; Zhao, 2019). There is still a lack of relevant research on some specific wastes, such as HW.

3. Blockchain Usage To Hwt Management

As shown in Fig. 1, this study proposes applying blockchain to the whole process of managing HWT, aims at solving the problem of information asymmetry between the regulators and regulated institutions in HWT, improves the efficiency of the whole business process. HWT business includes five stages: preparation, application, loading, transportation, acceptance, and settlement. The following paragraphs explain how the blockchain usage to HWT management.

The preparation stage of the HWT business is to find a suitable cooperative partner, negotiate costs and reach an agreement. The current HWT market lacks a business platform that can win the trust of all parties. The HWT market based on blockchain will be a decentralized and trusted information platform. Waste production companies publish output/input requirements through the blockchain. Potential partners obtain corresponding information on the platform. The occurrence of document fraud will be

eliminated with the information platform. When the HW treatment companies register on the platform, the platform will store the data about the HW business license, treatment process, treatment scale on the chain, etc. The environmental protection department acts as an authoritative agency to review qualification information. Only the companies that have passed the review can conduct HW trading business. The trust of qualification information is also reflected in HW transportation companies and production companies. Besides, multi-channel technology will achieve differentiated information protection. The transfer requirements are only open to nodes that have obtained individual permissions, which will prevent the disclosure of quotation information between competitors and lead to malicious competition.

Through the blockchain, the contract signing and transfer application stage will be simplified. In the traditional inter-provincial mode, the HW production company, transportation company, and treatment company could only apply for HWT through local departments after signing the contract on HWT business offline. It has to re-find suitable partners, re-sign the contract and apply again when the transfer application is not approved by the government. The blockchain could effectively combine the transfer application and the business contract. Only those who pass the application can generate a smart contract for the HWT business. Relevant information such as HW information (name, number, weight, color, container), expense information (processing fees, transportation fees, etc.), transportation company information (license plate number, driver information, vehicle information), and treatment company information (type and scale of HW processing qualification, proposed processing technology) would be directly filled in or imported by calling the registration office to complete the filling of the HWT business application form; Then, the environmental protection department conducts the application review and makes a decision. If the HWT business is approved, the blockchain will generate an e-contract and transfer business code exclusively to this transaction and simultaneously freeze processing and transportation fees. The above information will be broadcasted in the form of "transaction." All nodes will receive, verify and store the above information. This information will be recorded on the blockchain in the form of a timestamp.

The HW loading stage can be divided into information check, loading, and signature confirmation. The combination of blockchain and other IoT technologies will overcome the limitations of the traditional model. The HW production company and drivers of transportation company complete the information check of this transfer business through the blockchain. Only drivers registered on the blockchain and obtained the key of this transfer business can pass the information verification. HW loading can only be carried out after the identity information verification is completed. The loading process data will be automatically collected without human participation, including the front photo, electronic weighing, packaging type, single-piece quality, and so on, by using cameras, smart electronic scales, sensors, and other electronic equipment related software. Afterwards, the blockchain is used to record the data, which ensures the data's mutual confirmation and integrity. Signature confirmation is an essential link. Compared with the possibility of forgery in the traditional business, only the person who obtains the business key can complete the electronic signature in the blockchain, eliminating the possibility of information forgery.

In the traditional mode, the lack of real time supervision in HW transportation is a big challenge for regulatory authorities, which could be addressed by the blockchain. The status and location during HW transportation will be recorded in real-time through the IoTs and GIS/GPS/BeiDou Navigation Satellite System (BDS). The management system will upload these HW statuses and location data to the blockchain at a particular time interval. HW transportation information will be used as the judgment condition for transfer business execution. If the operation violates the management regulations is executed, the corresponding procedures written in smart contract will be triggered. For example, opening the warehouse of trucks without reaching the destination will trigger the alarm program and related punishment measures (such as fines).

Blockchain could also be applied to standardize the HW receiving and payment stage. When the transportation company transports the HW to the treatment company, the treatment company employees will check the identity information with the transportation driver and start receiving activities. The transportation driver and the workers in the treatment company jointly check the type, quality, packaging materials, and other hazardous waste contents and upload the weighing quality, truck photos, and other information to the blockchain. After the driver and employees check the HW-related information and reach an agreement, they will perform an electronic signature and confirm the waste receipt. The contract settlement procedure and invoice issuing procedure will automatically trigger when HW is accepted. Furthermore, the corresponding built-in smart contract will be triggered according to different scenarios when HW is not accepted commonly.

The application of blockchain will change the existing mode of management and operation of HWT. The original intention of formulating HWMS is to supervise the cross-regional management of HW. However, it is difficult to track the whole process of HWT without the assistance of information system, and it is also difficult to accurately define the responsibility of each stakeholder. With the blockchain, the entire HWT process will be standardized through the built-in smart contract and the stakeholder responsibilities will be precisely defined. For example, overloading trucks is a long-standing problem in China's transportation industry, and overloading HW trucks can easily lead to major environmental accidents (Xu et al., 2018). When the hazardous waste transport truck is overloaded, it will directly trigger the built-in smart contract in the blockchain, which will eliminate the overload phenomenon from the source. The blockchain-based HWT business will also completely change the current operating mode, including contract signing and fee payment methods. The transfer business e-contract will be automatically generated when the hazardous waste transfer application is approved. The related fees and insurance fees will be frozen simultaneously, directly replacing traditional models such as business contract signing and deposit payment.

4. The Framework Of The Blockchain-based Hwt Management System

According to the blockchain application in HWT management proposed in the previous section, a framework of the blockchain-based HWT management system is proposed, as shown in Fig. 2. This system will be divided into four layers: infrastructure layer, blockchain- services layer, functions layer, and

users layer. The infrastructure layer collects data of the whole process of HWT, including HW materials, application, transportation, and acceptance. The service layer uses blockchain to process and analyze data. The function layer is responsible for information management in different stages of the HWT process. The direct participants of HWT business, regulatory authority, auxiliary departments, and others will operate or query relevant business information through the users' layer.

4.1 Infrastructure layer

The infrastructure layer's hardware layer mainly includes various devices for collecting data in the whole process of waste transfer business, including mobile terminals, GPS/GIS/BDS, bar codes, RFID, electronic fences, two-dimensional codes surveillance videos, and other sensors. The IoT technology has revolutionized the way of information collection. All the HWT business information can be collected manually through the IoT technology, which reduces the statistical errors of information caused by manual errors or unintentional errors. However, the data collection through the IoT technology could not avoid the intentional data fraud. Fortunately, blockchain could eliminate this intentional fraud by tracing the sources of all HW information. The electronic devices are used in various stages of the HWT business. For example, in the loading stage, the HW information is scanned by RFID. The smart electronic scale obtains the weight information. The monitoring video photographs the truck head information and the weighing process information. The mobile terminal confirms the loading information. The HWT data collected by the hardware layer is transmitted through the gateway system. The gateway system will also control that interval and data transmission type (Zhang et al., 2020).

4.2 Service layer

The blockchain service layer is responsible for processing the data uploaded from the infrastructure layer. The uploaded data can be divided into HW characteristic data such as hazard type, weight and packaging mode, and business data uploaded by participants at the blockchain node. The HW characteristic data, transfer application, loading, transportation, and acceptance data will be transmitted to the HWT blockchain according to the preset interval and format requirements. The blockchain-based HWT system will provide users with several data services, including data processing, data analysis, and service management. The data processing includes data screening, cleaning, and review. The data that has been filtered and cleaned based on the requirements and specifications can be stored on the chain. Data analysis through statistical techniques or machine learning methods would help the regulatory authorities to improve the efficiency of HW supervision and standardize the HWT market. The historical data is used to analyze the out-of-warehouse volume of HW from waste-producing company. If the data fluctuates greatly, the regulatory authorities need to pay attention and investigate the cause to avoid illegal activities. The blockchain is updated and maintained through service management. The nodes that have obtained individual permissions will apply this service to modify the blockchain's built-in smart contract rules when the management regulations for HWT are changed.

4.3 Functions layer

There are six critical applications in the functions layer. The first four functions are mainly for different stages of HWT business: contract management, warehousing management, transportation status management, and payment management, while the other two functions run through all stages of HWT: identity management and statistical inquiry

(1)Contract management

Contract management is used to register the information of the HWT business contract. It is essential in the form of data items or parameters as the information storage medium. It replaces the function of traditional paper contracts with e-contracts. The information that needs to exist in the e-contract for HWT business includes contract number, participant information, transfer of HW information, contract status, contract creation time, business expenses, insurance expenses. In the traditional model, the critical premise of HW trans-provincial transfer is approved by the destination provincial environmental protection department. After the application of blockchain, this procedure will be the core step of contract creation. The participant applies for the transfer business through the client, and the environmental protection department reviews the content of the transfer business and gives decision-making opinions. When the transfer application is accepted, the e-contract will generate the HWT business contract number. When the contract is generated, the business expenses will be deducted from the producer's account and assigned to the smart contract. The traditional model is necessary to sign the transfer contract and the transportation contract separately after the transfer application is approved. In contrast, the transfer application and transfer contract can be combined through the blockchain, which will improve the entire business's efficiency.

(2)Warehousing management

Warehousing management is an essential part of the daily management of production companies and treatment companies. It is also the focus of the regulatory authorities. However, managing the entering-warehouse and out-of-warehouse records of departmental enterprises is not perfect. There are even missing or lost entering-warehouse and out-of-warehouse information. With the blockchain, it is possible to set up a complete HWT information chain, including basic information management, entering-warehouse management, inventory management, out-of-warehouse management, statistical analysis, etc. When hazardous wastes are weighed and tested after reaching destination, the weighing and test data are entered into the blockchain and compared with the information in the transfer e-contract. The illegal dumping during HW transportation could be detected if the comparison results differentiate. Furthermore, the regulatory authorities could use blockchain to monitor the status of HW management, and reduce the environmental and safety risks of companies.

(3)Transportation management

The application of transportation management aims to manage the whole process of hazardous waste transfer. One of the main drawbacks of traditional HWT is the lack of process supervision, which leads to potential illegal dumping and other illegal events. It is difficult to trace back information and define

related responsibilities. A series of smart contracts set up through the blockchain will effectively improve the entire HWT and clearly define the appropriate liability boundaries. With transportation management, receiving and transporting vehicles can be timely tracked by the IoT and the GPS. Information such as the HW transportation route, location, driving speed, working driver status, and other information can be dynamically displayed. Furthermore, the dynamic information is updated through a system to the contract state in the blockchain. The blockchain contract status will be synchronized with the transportation status. The blockchain is the form of status change to realize the integration of "logistics" and "information flow." Moreover, these data are traceable and cannot be tampered with. When an accident occurs during transportation, it will automatically trigger the relevant preset program: inform the environmental, traffic and public security departments at the first time, and start the relevant emergency plan at the same time.

(4)Payment management

Payment management aims to manage the treatment expenses, insurance, and invoices of HWT business. The treatment and transportation fees are transferred to the third-party account identified by the relevant regulatory authorities. Then the business amount is frozen through the blockchain. After the HWT business is automatically settled through the smart contract, the fees frozen in the third places will be settled into the treatment company's accounts and the transportation company, respectively. Furthermore, issue the relevant invoice at the same time. In case of illegal dumping and treatment, certain punishment and insurance procedures will be triggered. Each HW transportation contract can only be settled once in the blockchain. The settlement information will be saved to the state database in the hash value, which will effectively combat cheating such as multiple settlements or false settlements.

(5)Identity management

The role of identity management is to authenticate and manage the identity information of HWT participants. Problems such as fraud and affiliation of participants' identity information in the HWT business have plagued the regulatory authorities. The above phenomenon will be effectively cracked down through the built-in smart contract of blockchain. The identity verification mechanism mainly runs through the entire process of HWT. This function is used for identity verification of production company, transportation company, and treatment company, requiring them to have verified authenticity on the relevant business network. Participants are required to register information during the HWT application and transfer contract generation stage. Besides, the identity of the participants needs to be verified in the contract generation process. If there is unregistered information of either party, the verification fails, and the corresponding contract cannot be generated. In the HW transportation stage, the transportation company uploads the location and transportation progress information through the registered identity to update the contract status. When the built-in smart contract of blockchain receives the status change request from the transportation company, it also needs to verify the identity information. It is necessary to verify both parties' identity information after the HW is transported to the destination in the acceptance

and settlement stage. Moreover, the acceptance and settlement operations can only be carried out after passing the verification.

(6) Statistical inquiry

Statistical inquiry is mainly used for statistics and analysis of related data such as HW production, transportation, and treatment. The regulatory authorities can apply this function to realize real-time data analysis and grasp HW treatment status. Statistical information includes waste production companies, producing areas, waste types, treatment methods, industry types, transfer time, the average charge amount of HW, and so on. Blockchain ensures the authenticity and traceability of the above data, which helps avoid data errors caused by statistical data errors. The above statistical data is not entirely disclosed outside the regulatory system. Blockchain's channel encryption technology will make some sensitive information only open to authorized persons with a certain level. This function is helpful to break the current chaotic situation of the HW trading market. Relevant companies can find HW treatment price and qualification through this function. At the same time, competitors cannot obtain sensitive information such as company treatment technology.

4.4 User layer

The main users at the user layer include government supervision departments, participating enterprises, non-governmental organizations and so on. Among them, government supervision departments include the environmental protection department, transportation administration bureau, city administration bureau, and public security bureau. These departments make decisions and manage the whole process of HWT through blockchain. For example, in case of HW accidents, the blockchain can quickly track the historical data and determine the relevant responsible person. The blockchain is a decentralized information platform that can obtain information from all parties, including business partners, e-contracts, and cross-regional transfers. Other organizations or individuals, including Non-Governmental Organizations (NGOs) and some scholars concerned about HW, could make statistics, analysis, and supervision of hazardous waste transfer business data through the blockchain.

5. Influence Of Blockchain In Hwt

Blockchain will completely change the supply chain management model of HWT management. The application of blockchain to HWT management will have some positive effects. Some of these positive effects can be directly attributed to blockchain factors. However, some of them are based on blockchain, not only due to blockchain factors but indirectly due to the interaction of other factors (Köhler & Pizzol, 2020). The following content discusses the direct and indirect effects of blockchain.

5.1 Direct impact

The direct impact of blockchain on HWT includes increasing participants' trust, providing information traceability, and effectively defining and executing relevant responsibilities.

(1) Information platforms supported by blockchain are easy to gain the trust of participants. The asymmetric cryptography and multi-channel blockchain will form a differentiated information-sharing platform for HWT management. The hybrid chain will effectively protect related companies' private data (Ma et al., 2019). Any company or individual concerned with HW's transfer can query the public supervision data through the public chain. Some core information of related companies are all managed through private chain, which are only open to certain participants. This differentiated information protection can effectively meet the regulatory authorities' information management needs for the regulated departments. It can provide participants with a trusted information platform without worrying about participating enterprises' commercial leakage.

(2) The blockchain's chain structure will ensure that the on-chain data can be effectively tracked and then track the relevant responsible person for the HWT accident. The blockchain's data is stored in a chain structure and cannot be changed once chained (Sabeti et al., 2019). It will be easy to trace the relevant responsible persons and the illegal behavior information of HWT with blockchain, which ensures the safe operation of the entire process of HWT. At the same time, it will also eliminate information fraud and illegal registration during the transfer of HW.

(3) The built-in smart contract of blockchain will more clearly define the boundaries of participants' responsibilities and help automate the implementation of regulations and management practices related to HWT. The blockchain encapsulates laws and regulations, relevant rules, and contract requirements related to HWT through built-in smart contracts. It defines each participating unit's liability boundary through programmed code. Once relevant management requirements in the HWT are violated, the corresponding smart contract will be automatically triggered. In HW-related accidents, the blockchain will clearly define the relevant responsibilities and provide relevant evidence to avoid various disputes effectively.

5.2 Indirect impact

The blockchain's indirect impact is to change the information management mode of the HWT and improve operating efficiency. Traditional HWT business is full of information preparation and verification, which wastes much time, human resources, and capital cost, and its operational efficiency is relatively low. The regular information technology will make the transfer of HW more digitalized and automated, while it will not ensure the trust between participants and cause information asymmetry between regulators and regulated institution. However, the blockchain-based HWT could will increase participants' trust while achieving digitization and automation, which will lead to the improvement of the operational efficiency and supervision efficiency of HWT.

(1) Blockchain will help regulators improve their regulatory efficiency. The blockchain records all the information in the whole process of HWT, including real-name authentication, e-contract, business, logistics, payment, and invoice, etc., which can be verified with each other. Blockchain helps regulators monitor the flow of HWT contracts, funds, logistics, and bills in the process and discover relevant management problems in a timely and efficient manner. Besides, HW treatment companies have

preferential policies on corporate income tax. The blockchain will form a complete chain of evidence, effectively combat tax evasion such as false invoices (Long et al., 2020).

(2) Blockchain will improve management efficiency for a participating company. In the traditional HWT business, information verification and material preparation requires a lot of human resources and time, which leads to the low efficiency of business operation. The digitalization and automation level of the whole process will be improved through information means such as IoT. However, it is difficult to solve the problem of data trust. Furthermore, blockchain will ensure the authenticity and immutability of the data on the chain. The combination of IoT and blockchain can improve business management's informatization level and solve the problems of lack of information trust and information asymmetry (ZJPDEE, 2020).

6. Challenges And Suggestions

From the laboratory to the field application, an innovative technology needs to consider technical factors and consider policy, economic, social, legal, and other factors, which may support or hinder the application of related technologies (Pólvara et al., 2020). Mori found that 20% of the barriers to the application of blockchains are due to technical reasons. In comparison, another 80% are due to current business processes, modes, and management systems (Mori, 2016). For the application of blockchain in HWT management, the biggest obstacle may not be technology itself, but the need for institutional adjustment and innovation. The following section discusses the above non-technical factors. It should be emphasized that there is still a myriad of challenges to be solved with the blockchain's technical level (Frizzo-Barker et al., 2020). Therefore, instead of discussing the common technical challenges, this study focuses on the non-technical obstacles that are unique and significant in order to apply blockchain.

The application of blockchain will facilitate the implementation of the HWMS. However, It also puts forward requirements for the improvement of the current system. there are critical problems, such as data ownership, uplink data quality, etc. that restricted block chain application in HWT. They are also the problems that must be solved to promote the application of blockchain. Besides, to realize the application of blockchain in the HWT management at the national level, it needs the government's direct promotion, professional talents training, and the revision of relevant laws and regulations.

(1) Ensuring the quality of uplink data is the premise of blockchain applications in HWT management. Blockchain can solve the trust problem on the chain. However, it is challenging to prevent wrong data input, recorded and protected forever (Harwick 2016). If the source data under the chain is "polluted," the data input into the blockchain is garbage, called "Garbage in, Garbage out." Each node should adopt business data standards and business technical standards to regulate the uplink data. Data standards include unified data definition, classification, record format, coding, coding structure, classification specifications, data model, and attribute description. Also, there are incorrect data in a transaction on the blockchain, which may trigger related smart contracts and lead to unnecessary losses or penalties (Filipova, 2018). These data and subsequent triggered programs will be difficult to withdraw or recover. In

other words, the immutability feature of the blockchain conflicts with the right of deletion (Right to be forgotten) and the right to correction of the data subject. Based on the above phenomenon, it is necessary to foresee various data quality problems and formulate intervention mechanisms for such problems as incorrect data input in the alliance chain.

(2) It is the core problem of blockchain application in HWT to build a reasonable and adequate data sharing model and determine the data sharing boundary. HWT business involves a large amount of data. Data ownership will confuse the application of blockchain, especially the unclear definition of power and responsibility related to data ownership. A critical competitive advantage for companies is the availability of private data and opportunistic actions. However, blockchain will make relevant information and processes transparent and unchangeable, which will bring challenges to the data use between partners and various existing privacy policies (Papathanasiou, 2020; Leng, 2020). It is technically feasible to realize differentiated information sharing through blockchain multi-channel technology. The main problem is establishing a data-sharing mechanism, such as determining the scope and objects of data sharing. It is urgent to carry out more in-depth research. Each participant (peer) should sort out their data according to their actual situation, including identifying unclassified data, confidential and sensitive. the identification of unclassified data, confidential data and sensitive data. Attackers' behavior impersonating legitimate users to obtain data will affect data sharing sustainability (Xu et al., 2019). It is only an effective way to solve this problem by formulating access control measures such as identity authentication and critical usage and management rules. Moreover, to maximize the effective sharing of data, it is a potential scheme to use part of the data with compensation through the market mechanism.

(3) The direct support of relevant government departments is an essential driving force for the successful deployment of blockchain in HWT management. The latest version of the solid waste law requires establishing a national-level information platform for HW prevention and control to promote process monitoring and information traceability. The monitoring system for the whole HW process can be constructed based on IoT and other technologies. However, at present, there is a lack of a reliable management ecosystem for HW data. The need for a credible and efficient ecosystem can be met by using blockchain. The blockchain's characteristics make the blockchain particularly suitable for social supervision projects involving public ownership, such as HW management (Huckle, 2016). The application of blockchain in the management of HWT will improve government departments' supervision efficiency and combat the occurrence of illegal transfers and dumping incidents. The above capability will discourage some companies' enthusiasm to use blockchain for HWT, so the government needs to promote the construction of a four-level (national-provincial-city-country) blockchain management system and deploy government public critical infrastructure.

(4) Information management and professional talent support are essential guarantees to ensure blockchain in HWT management. At present, there is no specific regulation for the application of blockchain in China except to strictly control the "token" (Zhao, 2019; Xia et al., 2020). It is necessary to revise relevant laws and policies to provide legal support for the application of blockchain and smart contracts. The HWT involves many management regulations. How to combine blockchain with these

management regulations is also urgent research. The blockchain-based HWT system requires strong technical personnel support, and the lack of blockchain expertise will hinder its application. HW business stakeholders must learn how to use blockchain, in which intensive technical training is a reference approach.

7. Conclusion

A framework of blockchain-based information management system for HWT was proposed in this study to solve the information asymmetry problems, such as qualification and application review, transportation supervision, and payment. This study fills the research gap of blockchain application in HW management. This study firstly reviewed the development context of blockchain and its application research; Then, a framework of HWT management system based on blockchain was developed, and the related application functions of the system were discussed in detail. Finally, Impacts and obstacles of blockchain application in the field of HWT management were summarized. The system can strengthen the management of HWT information from the following three perspectives:

(1) Differentiated information sharing among participants. HW related information of production companies, transportation companies and treatment companies, For example, treatment companies' shared information, including processing type, processing scale and processing technology, will be stored in the shared ledger, and participants can access this information with different permissions.

(2) Tracing information related to HWT. The whole process information of HWT, including business occurrence time, participating companies and personnel, business information, etc., will be automatically stored in the form of the hash value. The above information can be traced back to the information source and cannot be modified. Accident disputes during the HW transfer can be somewhat resolved by tracing the relevant responsible information through the blockchain.

(3) Real-time supervision of the whole process of HWT. The whole process of HWT is managed in real-time through the blockchain, including application, review, delivery, transportation, receipt, payment, and invoicing. Through the blockchain, the real-time integration of "logistics" and "information flow" can be realized. Any participant can query the operation status. Moreover, this model improves business efficiency and regulatory efficiency.

Although a new system based on blockchain for HWT management was proposed, it lacks a specific evaluation of its effectiveness, providing future research opportunities. Future research is necessary to refine the entire HWT system and focus on a series of issues such as data quality, information security storage, and information sharing rules. The existing national HW management information system can partially solve the problem of the lack of supervision on HW-related information, it is difficult to improve the supervision efficiency and end the current situation of information fraud such as underreporting of production data. In future research, blockchain's application should be expanded from the transportation stage to HW's whole life cycle, including production, transportation, and treatment. Future research should also consider how to use blockchain to solve other waste management problems. The application of

blockchain to solid waste management, such as construction waste, electronic waste, and municipal solid waste, also becomes a popular research area.

Declarations

Authors' contributions

Conceptualization:Yujie Lu; Methodology: Guanghan Song; Writing-original draft preparation: Guanghan Song; Writing-review and editing:Guanghan Song, Yujie Lu, Haibo Feng, Han Lin and Yang Zheng.All authors have read and approved the final manuscript.

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Figures

Figure 1

Blockchain usage to HWT management

Figure 2

The overall framework of the blockchain-based HWT management system