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Research paper

Blockchain application in circular marine plastic debris management

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ABSTRACT

The threat to the environment and humanity caused by marine plastic debris has aroused global attention. This research aims to explore the feasibility of applying blockchain technology (BCT) in marine plastic debris management. A case study on three pioneer recycling organizations is conducted based on secondary data. The study found that BCT can be applied to solve some of the existing challenges of marine plastic debris management. A digital token system and identity recognition mechanism based on BCT can increase the public awareness for marine plastic debris governance. The derived digital wallets and distributed ledgers can effectively replace paper documents and cash transactions in the traditional recycling chain, and minimize global impact on local economies, thus improve efficiency and safety. Also, the traceability and high transparency of blockchain and the application of smart contracts can effectively build a global recycling network. In addition, the application of BCT can greatly improve the transparency of recycling value chains, and make them more accepting of supervision from society and consumers. This research is one of the first studies on BCT in marine plastic debris management and explores worldwide pioneering companies. In practice, this study can help companies analyse the defects in their own waste disposal models and help practitioners make decisions to adopt BCT. In academia, as one of the early exploratory studies on the application of BCT to the treatment of marine plastic debris, this study provides further empirical reference on BCT based business models and recycling chains, and can guide future research in this field.

1. Introduction

Marine debris has become a global environmental pollution problem. The United Nations Environment Programme (UNEP) highlighted the problem of marine pollution in its 2018 annual report (UNEP, 2018). Entanglement and ingestion of marine debris lead to a large number of fish, mammals, and birds losing their lives (Kühn, Rebolledo, & van Franeker, 2015). Reports on this phenomenon are still increasing and show a trend of globalization (De Stephanis, Giménez, Carpinelli, Gutierrez-Exposito, & Cañadas, 2013; Hong et al., 2013; Naidoo & Rajkaran, 2020; WWF, 2015), which means that the impact of marine debris on marine life is expanding. Moreover, the massive increase of marine debris also has a negative impact on humans. Marine plastics polluting aquaculture, fisheries, coastal beauty, and tourism services have caused inestimable economic losses (Hagen, 1989). In addition, the microplastics found in fish containing toxic chemical components have hidden dangers affecting human health via food supply chain (Gallo et al., 2018). Therefore, taking action to control marine debris (especially on marine plastics) is urgent worldwide.

Marine debris treatment has attracted the attention of the media, countries, and international organizations (Carlini & Kleine, 2018). Haward (2018) stated that marine debris control needs to be solved through a combination of global and local actions. Many coastal developing countries are the main source of the marine debris (Jambeck et al., 2015) because of their basic economic conditions (Gabrys, Hawkins, & Michael, 2013), lack of sufficient incentives (Carrington, 2018) and marine debris recycling systems (Marcelin & Cela, 2020). Some developed countries have the ability to take specific local actions (e.g. the floating debris collection device in South Korea (Jung, Sung, Chun, & Keel, 2010)), but such actions have not radiated to the world. Therefore, there is an urgent need to establish a global recycling marine debris collaboration to achieve global and local actions.

Circular economy (CE) is a supply chain recycling strategy to eliminate the large amount of waste generated in production and consumption by transforming the traditional linear production system into a closed-loop system (Kirchherr, Reike, & Hekkert, 2017; Nandi, Hervani,

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& Helms, 2020). The CE business model will benefit enterprises from economic, environmental, and social aspects (van Loon & Van Wassenhove, 2020). Cases from the construction industry (Lederer, Gassner, Kleemann, & Fellner, 2020), the textile industry (Koszewska, 2018), and medical industry (Kane, Bakker, & Balkenende, 2018), proving that the CE model is an effective method to eliminate environmental pollution caused by waste generation. However, Sikdar (2019) pointed out there is a need for more specific technologies to support the CE model to solve the current global plastic packaging recycling failures which cause marine plastic pollution. New technologies including the Internet of Things (IOT), blockchain technology (BCT), artificial intelligence (Lasi, Fettke, Kemper, Feld, & Hoffmann, 2014), may be useful to implement CE and sustainable supply chains (Bai & Sarkis, 2020; Kouhizadeh, Zhu, & Sarkis, 2020).

BCT is increasingly explored in academia and industry (Wang, Han, & Beynon-Davies, 2019). In academia, current research has spread the application of blockchain from finance to other industries including supply chains (Chang & Chen, 2020). Research from agriculture (Kamath, 2018), fishery (De Sousa, 2020; Probst, 2020), retail industry (Chakrabarti & Chaudhuri, 2017) and other industries has confirmed that BCT can improve the operational efficiency of supply chains and reduce risk. In addition, BCT shows excellent potential to support CE. Kouhizadeh et al. (2020) showed impact of BCT on economical, society and environment aspects by empirical studies of BCT on CE in different industries. In practice, however, some leading organizations have started the BCT based project to combat the marine debris. For example, Plastic Bank and IBM developed a BCT based platform for plastic waste management (Katz, 2019); Waste2Wear's BCT-based platform improves the physical flow in the recycling chain through the transparency brought by distributed ledgers and consensus mechanism (Waste2Wear, 2021b).

The development of these innovative recycling concepts shows that practices are leading research, and the phenomenon deserves more academic attention. Because of characteristics of effective and efficient traceability and high transparency, BCT has the potentials to avoid the disadvantages of the traditional marine debris treatment system. This will be significant if BCT can be introduced to manage the exponential increasing marine plastic debris worldwide (Hagen, 1989). But there is scant research to explore how to apply BCT to manage the marine plastic debris. To fill the research gap, this research aims to analyse the feasibility of applying BCT in marine debris management and answer the following three research questions:

(1) What are the challenges of current marine plastic debris management?
(2) How can blockchain technology be applied in marine plastic debris management?
(3) What are the advantages of applying blockchain technology in marine plastic debris management?

To answer the above research questions, this research employs a qualitative case study to conduct the research and contributes to the following different aspects. First, as one pioneer work exploring BCT in marine plastic debris management, this study enriches the marine waste management literatures, specifically from the perspective of CE. This research investigates the challenges in the current marine debris treatment and explores the role of BCT as a strategic tool in the marine debris treatment business model through three case organizations. The advantages brought by the application of BCT can be summarized as: formalization of the recycling profession, creation of economic benefits, global cooperation, digital currency system, transaction security, and a transparent and efficient recycling chain. Second, this research has valuable practical implications. BCT can respond to the challenges in the management of marine debris recycling, awakening public awareness of recycling, the formation of a global recycling network, and increasing supervision from society and consumers. It provides a useful guidance to relevant stakeholders to improve marine plastic debris management.

The outline of this article is as follows: In Section 2, the concepts of marine plastic debris and BCT are described in detail, and the status of marine plastic debris treatment is critically reviewed. Section 3 presents the detailed research methodology. Section 4 analyses three pioneer case companies, including their business models, and describes their applications of BCT in their recycling chains. Section 5 conducts a cross-case analysis and discussion. Finally, Section 6 provides the conclusion and limitations of the research.

2. Literature review

This section reviews the existing literature on marine plastic debris, CE and the treatment of marine plastic debris, and BCT applied to CE.

2.1. Marine plastic debris

Marine debris is one of the most serious environmental problems worldwide. In particular, plastic is regarded as one of the most serious pollutants and has triggered political and scientific attention over the last decade worldwide (UNEP, 2016; 2017). Due to their longevity, plastics are the main component of marine debris and travel far from the source.

The largest source of marine plastic is land-based (Li, Tse, & Fok, 2016). Onshore marine pollution sources will generate 4.8 million to 12.7 million tons of marine debris annually (Jambeck et al., 2015) from beach tourists as well as coastal industrial and living areas (Hidalgo-Ruz et al., 2018; UNEP, 2016, 2017). Table 1 provides a summary on the proportion and sources of plastic waste in marine debris. Most marine debris come from coastal human activities, which verifies the views of Li et al. (2016) and Hidalgo-Ruz et al. (2018). Research also found that marine plastic debris waste also comes from global rivers flows into the ocean every year, especially from developing countries (Lebreton et al., 2017; Purba et al., 2019; Schmidt, Krauth, & Wagner, 2017). With the increase of marine debris, the risk of its harm to organisms has increased (van Truong & Chu, 2019), causing a negative impact on human activities (Newman, Watkins, Farmer, Ten Brink, & Schweitzer, 2015).

Table 1
The proportion and source of plastic waste in marine debris.

Research	Location	Proportion of plastics waste	Sources
Zhou et al. (2011)	China	44.9% (floating marine debris) 47.0% (seafloor marine debris) 42.0% (beached marine debris)	Coastal/ recreational activity
Hong et al. (2013)	South Korea	66.7	Fishing activities
Syakti et al. (2017)	Coastal area of Indonesia	75%	Beach tourism
Ambrose et al. (2019)	Bahamas	93%	Ocean
Pelamatti et al. (2019)	Mexico	57%	Not reported
Cavalcante et al. (2020)	Northeastern Brazil	82.6%	Human recreational activities and fishing activities
Gaibor et al. (2020)	Ecuador	65%	Beach tourism and living area (consumer items)
Hayati, Adrianto, Krisanti, Pranowo, and Kurniawan (2020)	Tidung Island, Jakarta, Indonesia	83.86%	Tourism

Plastic has become an indispensable material and is widely used for packaging, construction, and other purposes (MacInnes Jr., 2020). However, in 2015, about 79% of plastic products were discarded or accumulated in landfills, 12% were incinerated, and only 9% of plastic products were recycled and reused (Geyer, Jambeck, & Law, 2017). Over 90% of the plastics widely used in current society are virgin products (Ellen MacArthur Foundation, 2015). Establishing effective recycling and reuse mechanisms will greatly reduce the possibility of plastic flowing into the ocean and slow down the generation of marine debris from the source.

2.2. CE and the treatment of marine plastic debris

CE can be referred to the economic system replacing the 'end-of-life' concept with reducing, alternatively reusing, recycling and recovering materials in production/distribution and consumption processes (Kirchherr et al., 2017). It can minimize the consumption of finite resources (Ellen MacArthur Foundation, 2015). CE implies that resource inputs, waste, emissions and energy leaks are minimized by the slowing, closing and narrowing of material and energy loops. It can be achieved through sustainable design, maintenance, repair, reuse, remanufacturing, renovation and recycling (Geissdoerfer, Savaget, Bocken, & Hultink, 2017) by transforming the traditional linear production system into a closed-loop system (Nandi et al., 2020; Rhodes, 2019). However, Sikdar (2019) pointed out there is a need for more specific technologies to improve the CE model so that a "plastic recycle and reuse system" can be achieved to control the spread of marine debris.

Although some countries have formulated specific actions or policies for the treatment of marine litter, according to Haward (2018), the solution to marine litter should consider global-level policies and local-level actions. However, the existing marine debris treatment programs have not yet reached this standard.

2.2.1. Status of marine plastic debris management in developing countries

Most studies take developing countries or regions as case studies on marine debris and discuss the impact of raising public awareness on reducing the discharge of marine litter (Ambrose et al., 2019; Chen et al., 2019). Many developing countries receive large quantities of plastic waste from developed nations, but they do not have adequate facilities to treat them (Gunarathne, Tennakoon, & Weragoda, 2019) because of lack of government supervision and management (Moh, 2017), leading to social security issues such as fraudulent transactions in the recycling value system (Chen, Geng, & Fujita, 2010). The legitimate rights and interests of the collectors (usually women or children) are endangered by risks of fraudulent transactions or robbery. Schaaf (2016) pointed out that the transaction security is of paramount importance for collectors as the bottom layer of the recycling supply chain. The developing countries must deal with the challenges including:

1) How to effectively encourage the public to collect waste in developing countries, avoiding that the materials become marine debris?
2) How to effectively protect the legitimate rights and interests of collectors in developing countries?
3) How to ensure the development of appropriate waste management and recycling facilities?

2.2.2. Status of marine plastic debris management in developed countries

According to the 3R (reusing, recycling and recovering) principle of CE proposed by Cheng and Chou (2018), it is more economical and feasible to recycle marine plastic at the source before it is decomposed into microplastics. Some developed countries have established relatively complete national recycling and reusing systems. The Sustainable Packaging Coalition (SPC) in the United States has developed a "how2recycle" label for packaging to inform consumers of what can be recycled in order to increase the recycling rate (How2Recycle, 2020). The Netherlands have established a recycling chain (raw material producers, retailers, waste collectors, etc.) for PET (Polyethylene terephthalate, preferred plastic container for beverages) bottles as an attempt to close the loop. These actions follow the principles of CE and have produced certain effects, which may be helpful to the construction of recycling systems worldwide. However, there are no studies and reports confirming that such pilot programmes of developed countries have radiated to developing countries. In summary, the main challenges for developed countries are:

1) How to ensure that plastic waste that is meant for recycling does not get exported to developing countries without credible proof that those countries have appropriate infrastructure for recycling the materials, and that it actually happens?
2) How to scale up successful pilot recycling schemes?
3) How to effectively connect enterprises and individuals in developed countries with recycling systems in developing countries and form a global system?

2.3. BCT and CE

Developed as a transaction processing system, BCT is distinguished from previous transaction processing systems through its unique technologies: block propagation and synchronization, consensus mechanism, and smart contract (Li, Jiang, Chen, Luo, & Wen, 2020). Block propagation and synchronization can also be called a distributed database or distributed ledger (Iansiti & Lakhani, 2017). Different from the traditional trading systems, the distributed ledger is not owned or controlled by a single entity (Mondal et al., 2019). Through distributed accounting and storage, each single entity realizes information self-verification, transmission, and management without additional third-party control (Swan, 2015), which is a process of decentralization. Each node can also query blockchain data through the distributed ledger to realize data transparency and openness (Cole, Stevenson, & Aitken, 2019). Consensus algorithm is a method used by blockchain to ensure the reliability and consistency of data and transactions. The reliable consensus algorithm improves data security through preventing the data stored in the blockchain from being artificially tampered and also protects the identification of each block node (Tönnissen & Teuteberg, 2020). The essence of smart contract is to verify, secure and enact transactions or agreements between consenting parties in a decentralized network (Saberi, Kouhizadeh, Sarkis, & Shen, 2019) and smart contract is a way of automating the implementation of agreements on the network program to achieve high independence in BCT (Kouhizadeh et al., 2020). Therefore, the strengths of BCT are summarized as decentralization, openness, independence, security and anonymity (Hastig & Sodhi, 2020).

BCT experienced continuous evolutions and has expanded from its initial application in the financial field to other sectors and one of the most promising application is for CE (Kouhizadeh et al., 2020). Esmaeilian, Sarkis, Lewis, and Behdad (2020) summarized four potential advantages of blockchain applications in CE, including: incentive mechanism, improving visibility, improving system efficiency and cross-network performance. Specifically, incentive mechanism refers to using tokens to reward the green behaviour by participants and the traceability and transparent characteristics of BCT can enable manufactures to monitor the whole product life cycle. The system efficiency of BCT application can reflect in the cost reduction of verification and networking and these capabilities can provide better corporate performance reporting and monitor sustainability actions among actors (Esmaeilian et al., 2020).

Through a case study of 10 typical case companies in different industries, Kouhizadeh et al. (2020) proved that the characteristics of blockchain provide a transparent, decentralized, and secure transaction process and may regenerate resources, reduce costs, and improve efficiency and responsiveness for the construction of CE. However, these ten cases are still not sufficient to provide detailed evidence for BCT benefits and the long-term performance are still not clear. Staub (2019) further explained that the transparency of the blockchain plays an important role in building an accountability system for waste management in a CE to solve the problem of unclear responsibilities for recycling in the existing linear production system, which can response to the Extended Producer Responsibility (EPR) to promote recycling performance. Narayan and Tidström (2020) constructed a framework for a blockchain-based reward token mechanism to support the transition to a CE model of value creation and highlighted the coopetition strategy for applying CE resources. In practice, Koscina, Lombard-Platet, and Cluchet (2019) introduced the case of Plastic Coin as an incentive mechanism for recycling and França, Neto, Gonçalves, and Almeida (2020) further explained that the blockchain based reward mechanism will significantly improve the reliability and credibility of transactions in the CE compared with traditional approaches. However, when discussing the feasibility of applying blockchain in waste management, organizations need to understand the changes and impacts on the business and its stakeholders (Catalini & Michelman, 2017). In addition, considering the early stage of BCT adoption in CE, the real benefit and application obstacles need further exploration.

3. Research methodology

3.1. Research design

At present, there are few references for the application of BCT in the field of marine debris management. Therefore, the inductive analysis method guided by interpretivism is suitable for achieving the research objectives (Collis & Hussey, 2014). This research uses qualitative research strategies and exploratory thinking to discuss the feasibility and practicality of applying BCT in marine plastic debris management.

As a commonly used qualitative research method, case study is suitable for exploratory research (Yin, 2014). It is a strategy capable of gaining insights into phenomena in the real world from in-depth research (Eisenhardt, 1989). The case study method is suitable for inductive work to perfect, expand or generate theory (Ridder, Hoon, & McCandless Baluch, 2014), especially with flexibility in developing creative theory development (Voss, Tsikriktsis, & Frohlich, 2002). In addition, it can gain insight into real phenomena (Yin, 2014). Case studies require the selection of sufficiently representative cases (Kathleen, 1989). A single case study is likely to cause the lack of application properties and lead to research incomprehensive. Therefore, this study uses multiple case studies based on secondary data.

3.2. Case selection

The chosen cases are pioneer companies in the use of BCT in marine plastic debris management. Six pioneer companies applying blockchain were selected initially: Plastic Bank, Bounties Network, Dell, HP, Waste2Wear, and Zumo. According to the selection criteria of representative cases, the application characteristics of BCT are used to screen cases. Plastic Bank, Bounties Network, and Zumo mainly apply the reward token mechanism of BCT. Plastic Bank is currently the most widely used company with the longest establishment time, whereas Bounties Network's blockchain project is still in the pilot phase. Zumo is only a token issuing company, so the representativeness is lower than Plastic Bank. HP, Waste2Wear, and Dell focus on the transparency and traceability of BCT. Waste2Wear is a supplier of recycled materials. Both Dell and HP are final product manufacturers, with Dell, as the initiator of the NEXTWAVE consortium (manufacturers alliance for the treatment of marine plastic debris), being more representative than HP. Finally, we selected the three most representative cases for analysis: Plastic Bank, Waste2Wear, and Dell. Table 2 presents the basic information of the three organizations.

Table 2
Background of the three case organizations.

Company	Scale	Position in the recycling chain	Specific application stage	Geographic coverage
Plastic Bank	19 staff in the management team and operating in 5 countries	Social Enterprise	Collection stage and transportation processing stage	Haiti, Brazil, Indonesia, the Philippines, Egypt
Waste2Wear	26 people in 15 countries	Seller of secondary plastic materials	Transportation processing stage	China, India
Dell	Global enterprise	Buyer or user of secondary plastics	Collection stage and transportation processing stage	Asian Area

(Note: data as of November 2021).

3.3. Data collection and analysis

Secondary data is most often used as part of a case study or survey research strategy (Saunders, Lewis, & Thornhill, 2016). Multiple-source secondary data collected in this research include document and survey-based data, such as archive data, company annual reports, blogs and news. Secondary data can support effective and reliable quality dimensions (Eisenhardt & Graebner, 2007). Triangulation of data and information from multiple sources can ensure data validity and minimize data bias (Bryman & Bell, 2015). For each case, this research identified multiple sources to verify the collected data. Section 4 provides the details of each case organization supported by a wide coverage of sources.

This research adopts the "thematic analysis" to identify themes or patterns that appear in secondary data (Bryman & Bell, 2015; Guest & McLellan, 2003). Before data analysis, all secondary transcripts were grouped into documents. According to Miles and Huberman (1994), thematic analysis consists of conducting "intra-case analysis" and then "cross-case analysis" to compare the three cases. In intra-case analysis, the first step is to understand the company's history and BCT application. The second step is to have a broader understanding of the benefits of BCT applications by exploring the business model of the enterprise and forming the codes. Finally, followed by case study processes by Voss et al. (2002), this paper forms code clusters by sorting and inducing similar codes, and transform them into sub-topics and finally forming the final themes. Cross-case analysis compared the three cases to identify different BCT applications and solutions and tabulated the main findings and conclusions. We validated the results by performing validity and reliability tests as shown in Table 3 (Yin, 2014).

4. Within case analysis

4.1. Case 1: Plastic Bank

Plastic Bank is a social enterprise established in Vancouver, Canada in May 2013 which committed to solving ocean plastic waste and global poverty (Plastic Bank, 2020a). Through cooperation with IBM and Cognition Foundry, Plastic Bank developed the "IBM-Plastic Bank" blockchain platform to redefine the value of plastic waste, interrupt the flow of plastic to the ocean, and sell social plastic as a new product to achieve CE (Katz, 2020).

4.1.1. The business model of Plastic Bank

Plastic Bank encourages residents in developing regions to collect plastic waste and transport it to local processing centres and use its specially developed mobile phone application as a trading platform to

Table 3
Reliability and validity in this research.

Validity and reliability criteria	Case study tactics
Construct validity	• Multiple sources of evidence were applied to triangulate the data (including webpages describing the BCT systems, companies, and governmental and semigovernmental organizations, in addition to catalogues and magazines articles. • The draft report was reviewed by all co-authors.
Internal validity	• A clear research framework on blockchain functions to deal with the challenges of marine plastic debris management. • Discussing the findings among the researchers. • Triangulating to confirm the emerging findings. • Refining the theoretical orientation of the research.
External validity	• Rationale for the case selection. • Details of the case study context. • Cross-case analysis and discussion.
Reliability	• The development of the case study database serves to enhance the reliability of the research findings.

exchange digital tokens. Digital tokens usually have two functions. They are pegged to the US dollar, which can be exchanged for cash in specialized non-profit stores. In addition to cash exchange, Plastic Bank encourages citizens to use the token to exchange daily necessities in the branch, such as groceries, cooking fuels, school tuition, and health insurance (Barnett, 2018). From the collection point, the collected plastics will be transported to the processing centre and ground into pellets, which is called "social plastic" and distinguished from virgin plastic (Holland, 2020). Once sold to manufacturers, social plastics can be reused in packaging or new products to replace virgin plastics.

Platic Bank cooperated with several famous manufactures. Although the price of social plastic is about three times higher than virgin plastic, international enterprises such as Henkel, Shell and Marks and Spencer still purchase and use the social plastics to produce more environmentally friendly and socially ethical products to offset their plastic footprint (Field, 2017). This provides an advantage over competitors, because conscious consumers are using their purchasing power to reward products which use social plastics. For manufacturers which use less than 250 tons of plastics per year, Plastic Bank has launched the "Social Plastic Collection Credits" (SPCC) function, which is similar to carbon credits, 1 SPCC is equal to recycled 1 kg of plastic waste, which is valued at approximately US$0.44 (Plastic Bank, 2020b). SPCC is the core of all plastic neutral programs, enabling individuals and organizations to become part of the social plastic ecosystem by investing in SPCC to offset their plastic footprint. SPCC is also a buffer fund to help Plastic Bank maintain the operation of the collection stage in the marine plastic recycling value chain. SPCC are used to provide goods for social plastic collectors, build more recycling centres, expand the business of plastic banks, and strengthen the stability of the social plastics supply chain (Holland, 2020). Plastic Bank's business model is summarized in Fig. 1. Socially conscious consumers (including businesses and individuals) offset their plastic footprint by purchasing SPCCs.

4.1.2. *The application of blockchain in the case of Plastic Bank*

The IBM-Plastic Bank blockchain platform is a token reward system based on the circulation of the entire value chain of recycled plastics by Plastic Bank (from collection, credit and compensation to delivery to manufacturers for reuse) (IBM, 2020). The blockchain system mainly functions as a digital token to provide people involved in plastic waste recycling with valuable commodity compensation and record transactions at the micro level. The Plastic Bank banking application can run on mobile phones of plastic collectors as a digital wallet, when plastic is traded to different locations around the world to buy digital tokens. This mobile application uses BCT on IBM's LinuxONE server to track trade data and store digital tokens to ensure the security of the transaction (Mok, 2018). The introduction of digital tokens and digital wallet creates secure asset-backed rewards to support the exchange of plastic waste and commodities for these collectors who potentially cannot read or write and do not have their own bank accounts. This business model combined with BCT monetize plastic waste and serve low-income earners to reduce many of the risks associated with handling cash and help Plastic Bank build trust with collector community and corporate partners by using digital tokens (Katz, 2020).

4.2. *Case 2: Waste2Wear*

Headquartered in Shanghai, China, Waste2Wear is a company that produces textiles from recycled plastic bottles collected from the ocean.

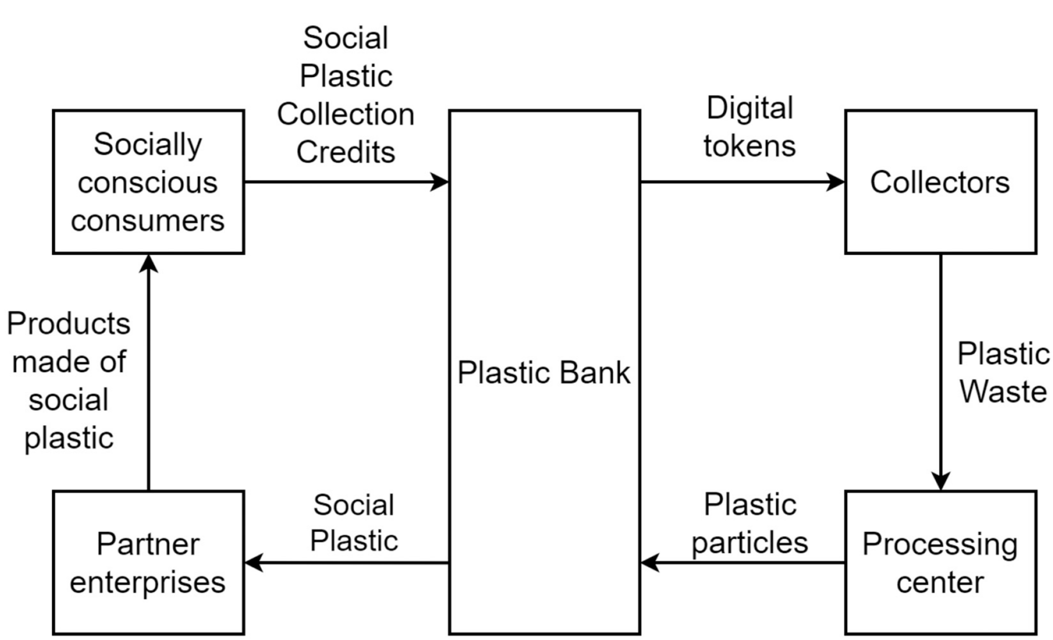

Fig. 1. The business model of Plastic Bank.
(Source: created by authors).

Waste2wear applies BCT to provide customers with conclusive evidence on the journey of plastic waste, from the ocean to final clothing and accessories, making the sustainable value chain of recycled plastic fabrics completely transparent (Fisher, 2019). At the international textile fair Premiere Vision, Waste2Wear demonstrated the world's first batch of recycled marine plastic fabric fully tracked by BCT (Waste2Wear, 2019a). As a leader in using recycled plastic waste to create innovative fabrics, Waste2Wear has become one of the few companies that can prove its operation is truly sustainable through BCT.

4.2.1. The business model of Waste2Wear

Similar to Plastic Bank, the business model of Waste2Wear (Fig. 2) also starts with the collection of plastic waste. Marine plastics are not only collected from coastal areas such as beaches and ports by collectors, but also from the ocean. By cooperating with local governments and NGOs, Waste2Wear encourages former fishermen to make up for lost income due to environmental regulations (such as fishing moratoriums) by fishing plastic from the ocean (Waste2Wear, 2019a). The plastic used for Waste2Wear textile products came from the ocean and coastal areas of Chongming Island, an island near Shanghai, and more than three tons of waste were collected every week from this area alone in 2019 (Première Vision, 2019).

The collected marine waste plastics are weighed and delivered to Waste2Wear collection centre, and collectors are rewarded per kilogram or bag in the form of cash or coupons (Rich, 2017). The weighed and packaged marine plastics are sent to the processing centre, which also provides income for local disadvantaged groups (Kim, 2016). When finished textiles are produced, they need to go through three steps to verify the "Waste2Wear® RA-3 Standard", including chemical analysis, microscopic assessment, and document validation (Waste2Wear, 2019a). A corresponding certificate will be provided for customers to access online. The processed products include uniforms for workers, hotels, hospitals, schools and household items such as curtains, bed sheets and pillows (Waste2Wear, 2019b). They have also partnered with fashion and sportswear brands such as Oilily, Fabienne Chapot (Waste2Wear, 2021a). In addition, Waste2Wear encourages consumers to return their purchased products from Waste2Wear when they are no longer used, especially disposable or semi-disposable products, to be used as a feedstock for the next generation of products.

4.2.2. The application of Blockchain in the case of Waste2Wear

Waste2wear establishes a reliable supplier network through a blockchain platform called WE-CO system, closely connecting waste collectors, NGOs, governments and other participants in the value chain (Waste2Wear, 2021b). BCT provides high transparency and traceability, as Waste2Wear is required to ensure that its supply chain is as sustainable as it advertises (Chilcott, 2020). For each production order, the WE-CO system carries the collected information from the collection centre and the environmental impact reports from the processing centre, including OEKO-TEX, BSCI, Global Recycling Standards, and the Waste2Wear® RA-3 Standard certificate (Waste2Wear, 2021b). International brand customers can log in to their secure accounts in WE-CO, access all documents online to monitor their orders at every step of the value chain, and track the source of recycled materials. The final consumer can also scan the QR code on the clothes to enquire about the content of recycled plastic in the product or even the place of collection (Waste2Wear, 2019a).

4.3. Case 3: Dell

Dell is a multinational technology company headquartered in Round Rock, Texas. Dell's products include personal computers, servers, smartphones, TVs, computer software, and others. Dell Technologies collaborated with cloud and virtualization software company VMware to develop a blockchain-based technology platform to track their recycled packaging and products. Dell's product supply chain is mainly located in Southeast Asia (Katariya, Çetinkaya, & Tekin, 2014), where contributed 60% of the global ocean plastic content in 2019 (Suzuki & Kishimoto, 2019). VMware, a subsidiary of Dell Technologies, is currently committed to the VMware 2020 plan to develop virtualization technology to enable customers to operate in a more sustainable manner (VMware, 2020). The blockchain solution created by VMware and Dell

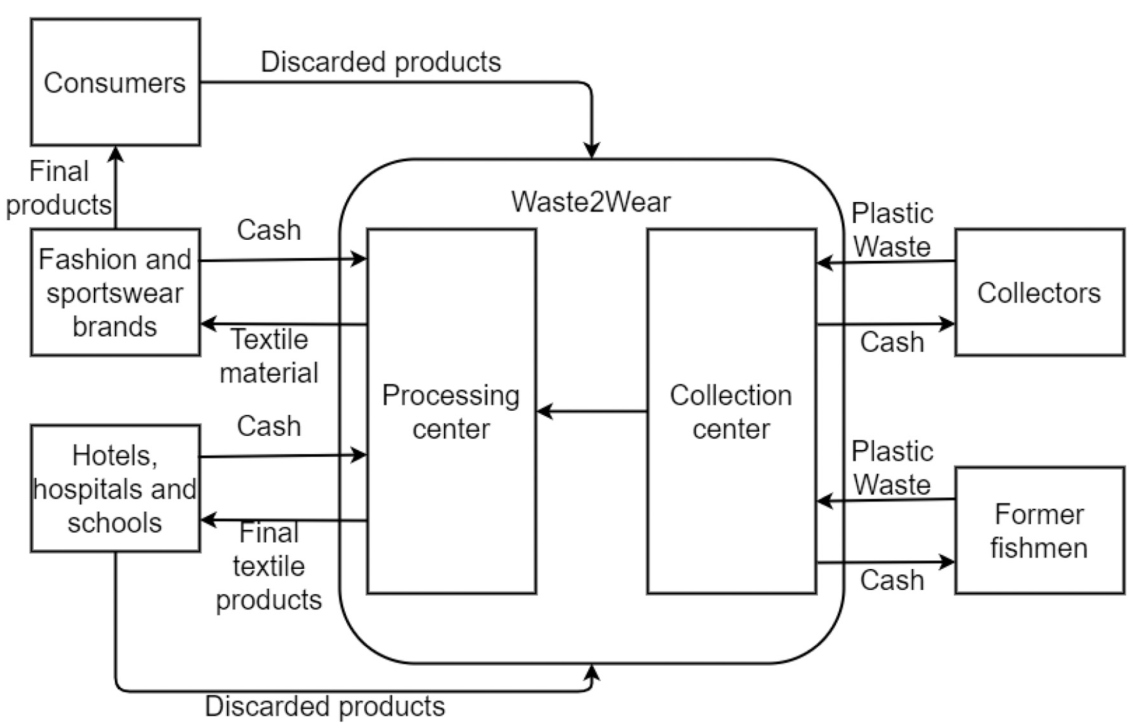

Fig. 2. The business model of Waste2Wear.
(Source: created by authors).

technologies tracks the plastics used by Dell in its packaging and products and allow end consumers to view where the plastic originally came from and other information.

4.3.1. The business model of Dell

In 2014, Dell established a complete supply chain of recycled materials, including collectors, processors, recyclers and package manufacturers for Dell laptops (Dell Technologies, 2020a), as shown in Fig. 3. In 2017, Dell and the Lonely Whale Foundation, a non-profit organization, established The NextWave Plastics consortium, which is composed of multinational technologies and consumer brands, to ensure that waste materials stay in the economy and prevent them from entering the ocean (Murray, 2020). Dell not only recycles marine waste including metals and plastics, but also collects usable materials when electronic products are returned to Dell through recycling, return, or other means. As a member of NextWave, the recycled materials will not only be used in their own products and packaging but can also be sold to other NextWave partners for their reuse (Dell Technologies, 2020a). After disassembling the parts which can be reused after repairing, recyclable materials and the collected marine plastic are shredded, melted, and then mixed with other plastics to be used in new parts or packaging (Dell Technologies, 2020b). In 2017, Dell took the lead in using marine plastics in packaging. The packaging trays of its XPS 13 products consist of 25% marine plastics and 75% recycled PET, and do not contain any virgin plastics (Dell Technologies, 2020c). The remaining materials that have no recycling value for new Dell products, will be sent to the commodity market to be responsibly purchased, recycled and used by other NextWave partners (Dell Technologies, 2020b). Through cross-industry and internal collaboration, member companies develop commercially viable and operable supply chains and integrate non-primitive plastic materials into products and packaging (NexyWave, 2020), to develop the world's first ocean-going plastic supply chain network (Murray, 2020).

4.3.2. The application of Blockchain in the case of Dell

Through the "VMWare blockchain" platform, Dell supports transactions between collectors, recyclers and manufacturers. The information about each transaction is stored in the blockchain. Through the platform, consumers can verify the source of the recycled materials used in the products that they purchase, such as which type of plastic is recycled and where the collected items came from (Gluckman & Secon, 2019). In addition, Dell's after-sales department can also strengthen the recycling and reuse of waste products by tracking products (TRUCOST, 2015). While Dell's blockchain platform tracks the recycling of marine plastics, it also strengthens the protection of waste plastic collectors. The company uses the blockchain solution to verify whether individuals collecting plastic suffer forced labour or receive substandard income (Otieno, 2019). The essence of BCT in the Dell recycling supply chain is to provide authenticity of information flow in the supply chain through high transparency and traceability. Through BCT, Dell has responded to society's requirements for sustainability and increased its social influence.

5. Cross-case analysis and discussion

A cross-case analysis and discussion is conducted to compare BCT solutions in marine plastic debris recycling value chains; identify how BCT address the challenges of marine plastic debris treatment; and the benefits of BCT in the recycling value chains.

5.1. Analysis based on the stage of plastic waste recycling

Section 4 suggests that BCT can, for instance, be adopted by social enterprises (Plastic Bank), materials suppliers (Waste2wear), or final product manufacturer (Dell). With the support of BCT, stages of plastic waste management were discussed: the collection stage (Plastic Bank and Dell) as well as the transportation and processing stage (Dell and Waste2wear). Table 4 summarizes the blockchain-based plastic recycling management schemes involved in the three cases according to different stages.

BCT has been applied in different stages of marine plastic debris management, representing the application of BCT to different business models, including B2B [Waste2Wear], B2C [Plastic Bank] and both [Dell]. In B2B, the case companies carry out transactions with other business stakeholders, while the B2C model includes recycling incentive solutions for individual users (informal waste collectors or residents). Social enterprises represented by Plastic Bank are mainly involved in the collection stage of marine debris management, aiming to recycle marine plastic debris into a CE model. As a provider of secondary materials, Waste2Wear focuses on how to ensure the authenticity of marine plastic

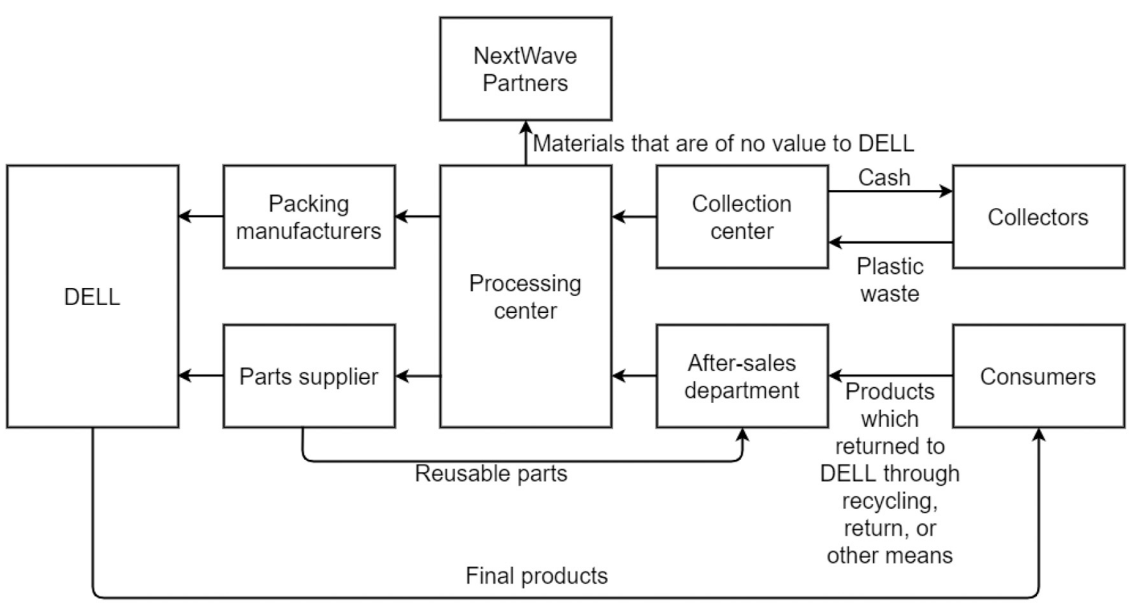

Fig. 3. The business model of Dell.
(Source: created by authors).

Table 4
The blockchain-based schemes involved in the three cases based on the recycling value chain stages.

Company	The role of case company in the recycling value chain	The stage of blockchain application	Stakeholders	Blockchain features	Benefits
Plastic Bank	Social enterprise	Collection	Full time collectors, Medium collectors, Collection centres.	Blockchain-based reward tokens encourage collectors to collect marine plastics in exchange for rewards (e.g. groceries, health care)	(1) Improves the social awareness of people in developing countries. (2) Prevents fraudulent transactions targeting vulnerable collectors during the collection phase.
			Local entrepreneurs and communities, collection centres, enterprises or individuals who have purchased social plastic credit.	The credit mechanism ensures that there are sufficient buffer funds at the collection stage to ensure the integrity of the recycling chain. BCT guarantees the safety and traceability of funds.	(1) Constructs the capital flow of the global plastic waste recycling value chain. (2) Protects the recycling value chain from being affected by the local economy and prevents corruption and fraud in the collection stage.
			All stakeholders.	Blockchain-based digital wallets record the transaction information and protect transaction rewards of collectors and downstream enterprises in the distributed ledger.	(1) Protects the income of basic workers (collectors and downstream companies) in the recycling value chain and improves the security of capital flow in the recycling value chain.
Dell	Final product manufacturer	Collection stage	Collectors, collection centres	The blockchain-based personal identification system establishes an exclusive identity for the staff on the recycling chain and protects their personal contract in the recycling value chain.	(1) Prevents fraudulent transactions targeting vulnerable collectors during the collection phase, and improves the security of capital flow in the recycling value chain.
		Transportation and processing	Dell, Nextwave partners and processing centres	Through smart contracts based on BCT, the auto supervision and management of material classification during processing can be realized.	(1) Improves the efficiency of classification to strengthen the waste flow in the plastics recycling value chain.
			Dell, consumers, and processing centres	BCT combined with Internet of Things (IoT) and RFID can automatically supervise physical flow during logistics processes and record the logistics data on the blockchain platform.	(1) Monitors the recycling value chain with enhanced transparency and traceability. (2) Reduces the risk of data loss or damage and improves the security of waste flow in the recycling value chain.
Waste2Wear	Raw material provider	Transportation and processing	Waste2Wear, consumers, and processing centres, collectors, collection centres	(As above)	(As above)

debris. Therefore, BCT is applied to its B2B model to build a visible waste flow so that downstream companies can be integrated into the value chain. Dell, as the manufacturer of the final product and the initiator of the global recycling network, needs to pay attention to the protection of the rights and interests of marine garbage collectors in developing countries, responding to pressure from consumers. Therefore, BCT is applied to two business models. The unique advantage of BCT solutions is that they can integrate various stakeholders to form a recycling network, which is difficult to be achieved in traditional recycling chains.

5.2. BCT and the challenges of marine plastic debris treatment

5.2.1. Risks and safety of the recycling chain

Risks can be reduced by an electronic record platform based on distributed ledgers replacing paper documents, which are prone to human errors, damage and loss during transactions (Harris, 2016). In the case of Waste2Wear, BCT allows the digitization of paper documents, by uploading transaction information and order information to the distributed ledger of the blockchain system (Baumung & Fomin, 2019). Every stakeholder in the transportation process will store all the data under the action of the distributed ledger. Therefore, the risk of loss and damage in multi-segment transactions and the long-distance transportation can be avoided (Albrecht, 2018). Also, due to the consensus mechanism of BCT, malicious modification of transaction contract data (fraud) is essentially impossible (Ye, Li, Cai, Gu, & Fukuda, 2018).

Avoiding cash payments is another aspect of reducing the risk. The digital wallet based on BCT will effectively guarantee the transaction security of poor collectors in developing countries. Especially the countries with poor domestic social order such as Haiti, crimes such as robbery seriously threaten the transaction security of collectors and collection centres. Criminals wander around collection centres to rob cash from vulnerable collectors (Brown, 2018). Due to the lack of basic reading and writing ability and identity information (Zanotti, Stephenson, & McGehee, 2016), most collectors are not eligible to have bank accounts, which increases their risk of being robbed. As demonstrated in the case of Plastic Bank, the social environment of Haiti urgently requires safe transactions. Digital wallet technology based on BCT serves as a fund protection mechanism similar to a bank account. With the help of BCT, collectors protect the assets of the digital wallet by setting up their own private keys. In addition, the digital token system that works with digital wallets can be used as a digital currency to support local fund operations. Additionally, in extremely poor countries, the rapid devaluation of currencies threatens the legitimate rights and interests of collectors (The World Bank, 2020). Demand for recycled plastics has also dropped sharply due to the decrease of international crude oil price (Depersio, 2020), which means recyclers have to lower the price of recycled plastics. This means that the most marginalized members of society, such as waste collectors, may be in the riskiest position in the recycling chain (Plastics For Change, 2017). Therefore, the digital token which is issued by the Plastic Bank and under supervision from international organizations can play a role as a supplement to the local currency to stabilize prices. Commodities traded through digital tokens will reduce the impact of national currency depreciation. In addition, digital wallet technology can also be used as a personal identification mechanism for collectors to obtain microloans to achieve financial inclusion (Holland, 2020).

5.2.2. Awakening public awareness of recycling

Reward token mechanisms have increased the public's enthusiasm for recycling. Plastic Bank is not the only case where the reward mechanism of the blockchain is applied to waste collection. The "Green coin" of Brazil (França et al., 2020) and the "Swachh Tokens" of India (Gopalakrishnan & Ramaguru, 2019) use the same mechanism, allowing people to participate through reward mechanism. The blockchain system can release the financial value of plastic waste.

Dell's recycling chain mainly uses BCT to establish a personal identification mechanism to establish a social identity for collectors and regulate their employment. As a new self-managed identity verification method, the characteristics of distributed ledger can enhance personal privacy, security, and control (Simons, 2018). In a decentralized identity system (DID), through asymmetric key-based point-to-point authentication and secure information exchange of the blockchain, which can only be updated after verification by both parties and users, identity verification is performed through a primary key (Zoltán, Dirk, Sebastian, & Felix, 2020). Therefore, BCT makes information tampering more difficult and increases protected information security. Through the establishment of identity and hence status for collectors, collecting plastic waste becomes a profession.

5.2.3. Supervision from society and consumers

Society and consumers can supervise recycling chain activities more efficiently through blockchain platforms. For Waste2Wear and Dell, BCT collects, stores, and manages the key product information of each batch of materials in its entire life cycle. Each batch receives an information label, which is a unique digital encrypted identifier that links the physical product to the virtual identity. The application of distributed ledger reduces the material supplier's monopoly on key information. Through the information tag and uploading information to the distributed information block, a shared transaction record of each batch of materials is created (Abeyratne & Monfared, 2016).

The BCT-based mobile banking application developed by Plastic Bank and IBM can help socially conscious organizations and individuals track transaction records of their investment. For the social recycling value chain, how to gain the trust of investors is always a key issue (Rogers, Leuschner, & Choi, 2020). Chow (2018) pointed out that traditional paper documents will bring potential fraudulent transactions and counterfeiting problems to the supply chain, which in turn challenges a company's sustainable development performance (Hastig & Sodhi, 2020). Traceable chains based on BCT will protect the funds of investors and accept their supervision. In addition, BCT provides a visual flow of funds for cooperative companies so that the rapid trust of partners can be strengthened (Dubey, Gunasekaran, Bryde, Dwivedi, & Papadopoulos, 2020).

5.2.4. The formation of a global recycling network

The application of BCT can contribute to the formation of global recycling networks. The credit mechanism established under the traceability feature of the blockchain can form a global flow of funds for plastics recycling. With the help of blockchain platforms, through a model similar to carbon credits, social plastic credits allow partners to offset the plastic consumed by their products in the form of investment. The funds they invest will provide flexibility of recycle value chain as buffer. BCT records all transactions through a distributed database and shares them with partners on the blockchain network and the historical records will always have a permanent footprint. By creating an auditable real-time impact tracking for funds (Plastic Bank, 2020c), Plastic Banks can construct a visual process of capital flow. For socially conscious companies and individuals, their influence can be more intuitively manifested. Therefore, they may be more willing to invest in Plastic Bank to offset their plastic pollution on the environment. As a result, this mechanism could construct a global recycling value chain funding network and strengthen cooperation and exchanges between enterprises in developed and developing countries.

Dell use BCT to establish a global physical flow for plastics recycling value chains. As a member of the NextWave Alliance, Dell's recycling value chain is obliged to supply recycled materials to partners in different regions of the world. This process usually involves many stakeholders worldwide. The application of smart contracts can automatically monitor and correct errors at the transportation and processing stage (such as incorrect material allocation), thereby alleviating pressure on the physical flow.

Based on the above analysis, Table 5 summarizes the blockchain functions to deal with the challenges of plastic waste management.

5.3. Benefits of BCT in plastic recycling value chains

Analysis has shown that BCT has the potential to solve some of the traditional plastic recycling problems in both B2B and B2C models. The benefits of applying BCT include formalization of recycling professions, creation of economic benefits, global cooperation, creating digital currency systems, transaction security, and a transparent and efficient recycling chain.

5.3.1. Formalization of the recycling profession

The formalization of the recycling profession is a prerequisite for the formation of a circular economy. The BCT-based system for plastic waste management professionalizes waste collection. The identity system based on digital wallets or professional contracts provides collectors with identities and also establishes the responsible subject for the basic recycling stage. The BCT-based decentralized identifier will match the user's identity on the chain through digital verification to establish the protection of the rights and interests of collectors and provides accountability when accidents happened. In addition, a waste classification management system based on smart contracts is also one of the expandable applications of BCT. The case of Dell's global cooperative waste stream network shows that the automatic material classification system can coordinate the resource acquisition of different stakeholders. In other words, the system has the potential to provide guidance on the classification of different materials of plastic waste in the early stages of collection (e.g. collectors or collection centres), including automatic monitoring and correction of errors, to restore the maximum value of different materials wastes. Thus, the chaos caused by the unclear classification of plastic wastes and the selection of potentially wrong processing methods can be mitigated.

5.3.2. Creation of economic benefits

The BCT based CE approach to plastics recycling can bring economic benefits. Processing and collection centres can provide a large number of jobs for marginalized groups, yielding a basic income and reducing poverty. BCT assigns standard prices to plastic waste, turning waste into resources (Katz, 2019). All transactions in the recycling value chain are based on this price standard, which provides the world with an opportunity to collect and trade plastic waste as currency.

5.3.3. Global cooperation

The BCT-based recycling system promotes the construction of a global recycling value network. From a social perspective, the auditable real-time impact tracking brought by the BCT application can attract a wide range of investments from companies or individuals at the global level, thereby establishing a more stable fund flow to provide more financial services such as loans, local franchises, which may attract more potential global stakeholders to participate. From the perspective of waste, BCT can improve the physical flow of the existing recycling value chain and make global resources sharing possible through clearer processes. For instance, Dell's BCT provides a one-to-many mode for making recycled materials accessible to its global partners, facilitating cross-

Table 5
Blockchain functions dealing with plastic waste treatment challenges.

Challenges	Blockchain functions	Cases involved
Risks in the management of plastics recycling	Electronic records based on BCT (elimination of paper-based documents)	Uploading, updating, and confirming orders and material information can all run on the blockchain to prevent the risks due to loss of paper materials [Waste2Wear, Dell]. Under the supervision of the consensus mechanism, all transaction information including contract information for collectors will be stored in the blockchain and arbitrary modification is prohibited [Dell, Plastic Bank].
	Token reward system based on BCT	The exclusive digital token system can replace local currency for transactions, which can protect collectors from the impact of local currency depreciation and global crude oil price fluctuations and improve the stability of the recycling value chain [Plastic Bank].
	Digital account based on BCT (elimination of cash transactions)	Establishing a digital account system for collectors through the blockchain system to help them manage and protect their assets through private keys. The personal identification can additionally provide access to small loans and more financial services [Plastic Bank].
Awakening public awareness of recycling	Token reward system based on BCT	Plastic Bank establishes a reward mechanism protected by BCT to issue digital tokens and release the financial value of plastic waste. This can inspire people to adopt ecologically sensible behaviours [Plastic Bank].
	Identification mechanism based on BCT	The DID mechanism based on the blockchain system enhances the collectors' personal privacy, security and control. It protects the collectors' labour contract and improves the collectors' status in the recycling chain and in society [Dell].
The formation of a global recycling network	Plastic credit mechanism based on BCT	The social plastic credit mechanism integrates socially conscious small businesses and individuals in developed countries into the recycling value chain to contribute funds and offset their plastic footprint, thus provides buffer funds for the recycling value chain. The auditable real-time impact tracking will increase the attractiveness to buyers [Plastic Bank].
	Automatic material classification system based on BCT	Smart contracts can automatically monitor and correct errors at the transportation and processing stages, ensuring that each batch of recycled materials is sent to the correct location [Dell].

Table 5 (*continued*)

Challenges	Blockchain functions	Cases involved
Supervision from the society and consumers	Traceability system based on BCT	BCT collects, stores and manages the key product information of each batch of materials throughout its life cycle. By combining RFID and other technologies, BCT links materials information on the physical flow to virtual identities on the network and ensures that end consumers or social organizations can track each batch of materials and its transaction records [Waste2Wear, Dell]. The fund tracking mechanism ensures that social plastic credit which comes from individuals or organizations in developed countries can be supervised by the providers, increasing trust of international partners in the system [Plastic Bank].

industry cooperation and communication.

5.3.4. *Digital currency system*

The BCT-based digital currency system is a transformative innovation. From an environmental perspective, the reward mechanism based on this system is essentially a public trading platform that enables people to participate in the recycling of plastic waste to gain revenue. With more companies and regions joining the platform, uncooperative behaviour and improper processing can be sanctioned, forming an accountability system to supplement the positive incentives of tokens. From a social perspective, building this system in a fragile developing country can potentially protect the country's economy. Digital tokens which are strictly regulated by international organizations and countries will potentially reduce the impact of inflation on the domestic market and prevent currency devaluation.

5.3.5. *Transaction security*

The application of BCT improves the security of the recycling value chain. The digital account system based on the distributed ledger and the consensus mechanism effectively protect the vulnerable downstream stakeholders in the recycling chain. Collectors or collection aggregators can only transfer or use the assets stored in digital accounts through personal private keys (Aydar, Cetin, Ayvaz, & Aygun, 2019), which reduces the possibility of assets in the value chain being damaged by external factors. Furthermore, transparent and traceable transaction data ensures that stakeholders will not be harmed by internal corruption. The application of BCT reduces the probability of recycled materials losing value due to damage or loss of transaction data.

5.3.6. *A transparent and efficient recycling chain*

BCT helps the recycling system collects, stores and manages the key product information of each batch of materials throughout its life cycle. The ultimate consumer or social regulator can check the blockchain platform to verify the authenticity of each batch of materials. In addition, through smart contracts on BCT, the operation of the recycling value chain is automatically supervised. The transaction recording system based on the distributed ledger reduce potential fraudulent transactions and forgery problems in the traditional paper document recording system. Thus, BCT can improve the transparency of physical, information and capital flows and enhance trust of cooperative companies (Dubey et al., 2020).

6. Conclusion

6.1. Theoretical and managerial contributions

This research explores the application of blockchain in marine plastic debris management. The research aims to summarize the challenges in the current marine plastics debris collection and treatment; to analyse how BCT applications can solve the challenges of plastic recycling; and discussing the advantages to implementing BCT in this context. Marine debris has become a global pollution problem, affecting both the environment and human activities. Therefore, marine debris has caused widespread concern in society. Plastic waste management and recycling faces different challenges in developing and developed countries. Four overarching challenges were identified: the risks in plastic recycling chains, public awareness of the marine debris problem, building a global collaborative recycling network, and supervision from society and end consumers.

This study selected three pioneer companies for within-case analysis and cross-case analysis. The case background and business models of the three case companies were explored, and the specific applications of BCT were analysed. The analysis revealed that each of the above-mentioned challenges was addressed by two or more case companies through blockchain applications. The findings indicate that BCT applications can run smoothly in different business models including B2B and B2C. The benefits of BCT application include the formalization of the recycling profession, the creation of economic benefits, global cooperation, the introduction of digital currency systems, increased transaction security, and a transparent and efficient recycling chain.

This research is one of the first studies on blockchain in marine plastic debris management and explore worldwide pioneering companies. It further supports the application of BCT in recycling and CE, responding to Sikdar (2019). The business model combined with BCT complies with the marine debris governance framework standard proposed by Haward (2018). This study identifies existing BCT functions and lists benefits. In practice, it may help companies analyse the defects in their own plastic waste treatment model and assist practitioners in adopting BCT. In academia, as one of the early exploratory studies on the application of BCT to the treatment of marine plastic debris, this study highlights the business model of the pioneers and provides further empirical reference and may direct future research in this area.

6.2. Limitation and future research

The limitations of this research include that BCT application in marine plastic debris management is mostly in the pilot stage, case selections are pioneer companies, and other cases may provide extra functions, benefits, which may not be covered in this research, thus leads to the generalization issue. Our analysis offers solutions with a focus on developing countries, rather than developed countries. How BCT offers solutions to marine plastic debris management in developed countries need further research. In addition, the secondary data collection may not be in-depth enough to study the implementation process, in particular the implementation decision marking processes, implementation barriers, which needs more detailed and intensive research perhaps via interviews. Although the current study provides interesting findings, there are still many concepts to explore in this area along with the rapid development of BCT. At this stage, research on applying BCT in circular economy and sustainable supply chain management is still limited, and hence this research calls for more research to explore the full potential of BCT.

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