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Blockchain Technology for Governance of Plastic Waste Management: Where Are We?

Katrien Steenmans [1,2,*], Phillip Taylor [3,4] and Ine Steenmans [5]

1 Centre for Business in Society, Coventry University, Coventry CV1 5FB, UK
2 Coventry Law School, Coventry University, Coventry CV1 5FB, UK
3 Trilateral Research, London SW1X 7QA, UK; phillip.taylor@trilateralresearch.com
4 Department of Computer Science, University of Warwick, Coventry CV4 7AL, UK
5 Department of Science, Technology Engineering and Public Policy, University College London, London WC1E 6BT, UK; ine.steenmans@ucl.ac.uk
* Correspondence: katrien.steenmans@coventry.ac.uk

Abstract: Blockchain technology is emerging as a plausible disruptor of waste management practices that influence the governance of plastics. The interest among the waste management community in the potential and fundamental changes to complex resource management associated with blockchain adoption parallels recent research in other sectors, such as finance, health, public administration, etc. During any comparable period characterized by a step-change in positive coverage of an early-stage technology, it can be challenging for actors to access a grounded, evidence-based oversight of the current state of practice and make informed decisions about whether or how to adopt blockchain technology. The current absence of such a systematic overview of recent experiences with blockchain initiatives disrupting waste practices not only limits the visibility of these experimental efforts, but also limits the learning that can be shared across waste plastics researcher and practitioner communities. This paper contributes with a current overview of blockchain technology adoption in the waste management sector, giving particular attention to implications for the governance of plastics. Our study draws on both primary interview data and secondary documentation data to map the landscape of current blockchain initiatives in the global waste sector. We identify four areas of blockchain use that are beginning to change waste management practices (payment, recycling and reuse rewards, monitoring and tracking of waste, and smart contracts). We conclude by outlining five areas of significant blockchain uses, implications, and influences of relevance to the development of circular plastic waste governance in both research and practice.

Keywords: blockchain technology; waste; plastics; circular economy; emerging technology; disruptive innovation; scoping review

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1. Introduction

Budding technological advancements and innovations are continually explored as instruments for supporting more effective and efficient management of resources and waste. Examples in recent years include applications of wireless sensor networks to improve on-site handling and transfer of solid wastes (Longhi et al. 2012); Geographic Information Systems (GIS) to optimize siting of municipal solid waste landfills (Chang et al. 1997; Sumathi et al. 2008); Internet of Things technology to enhance urban waste and resource management (Zheng et al. 2011; Gubbi et al. 2013; Zanella et al. 2014); and machine learning and artificial intelligence to better aid decisions in waste management (Król et al. 2016; Gupta et al. 2019; Abdallah et al. 2020). Blockchain technology is another such disruptive technology that has been heralded over the past decade as a possible remedy to some of the world's prominent environmental problems. These include, for example, resources, conservation, and recycling management (Saberi et al. 2018); supporting Emission Trading Schemes (Khaqqi et al. 2018); governing the waste–water–energy–food resource nexus

(Steenmans et al. 2018a, 2018b); the energy sector (Andoni et al. 2017; Pinson et al. 2017); and nature conservation (Baynham-Herd 2017). Arguably, blockchain has been the subject of more enthusiasm than previous technologies—owed in part to its applications in finance and currency (Andreessen 2014; Tapscott and Tapscott 2017; Treleaven et al. 2017) and the public sector (Ølnes 2015; Berryhill et al. 2019).

The touted appeal and significance of blockchain technology derives from both its design structure and functions. Blockchain is a virtual distributed ledger on which data can be permanently stored, usually without the need for a central database or authority. In essence, blockchains comprise a series of 'blocks' where each block contains the record of a set of transactions (e.g., a sale of goods or transfer of payments) and a cryptographic hash of the previous block. These hashes provide a link between the blocks, and are central to its immutability. Data written to a block cannot be changed without affecting its hash. Therefore, changing data in a block on the blockchain breaks the link to the hash in the subsequent block. It can thus provide secure information with origins that can be verified, produce records of transactions that can be publicly accessible, and enable transparency and accountability.

Different design choices can provide different benefits. For example, blockchains can be private (i.e., owned and stored by a single entity) or public (i.e., stored by users on nodes in a network). Blockchains can be permissioned (only authorized users are allowed to read or write data to them) or permissionless (i.e., accessible to anyone). Moreover, blockchain technology facilitates smart contracts, which can automate transactions and their recordings, without the need for intermediaries. It is these characteristics that have resulted in extant academic literature highlighting the benefits of blockchain technology for resource and waste management. These benefits have been described generally (Chapron 2017; Ongena et al. 2018; Saberi et al. 2018; Steenmans and Taylor 2018; Taylor et al. 2020) as well as in more targeted application contexts, such as circular economy transitions (Kouhizadeh et al. 2019; Vogel et al. 2019; Shojaei et al. 2021). Circular economies have been identified as strategic policy instruments critical to addressing the concomitant crises of constrained natural resources and unsustainable waste management (e.g., with circular economy laws adopted in China, France, Japan, Spain, and South Korea, and proposed in Mexico and Uruguay). In a circular economy, resource and waste streams are reused, recycled, and recovered instead of sent to landfills or incinerated (Kirchherr et al. 2017). In the context of emerging practices in the governance of plastics, some studies have investigated the use of blockchain in enhancing plastic product recyclability across product manufacturing and life-cycle management (Chidepatil et al. 2020; Sandhiya and Ramakrishna 2020; Khadke Swikriti et al. 2021; Liu et al. 2021).

While recent academic literature considers some of blockchain's distinctive attributes and activities relevant to waste and resource management sector development, more systematic and holistic overviews of blockchain's existing and emerging disruptions to those sectors in practice are lacking (Ongena et al. 2018). Little extant literature reports on experiences with blockchain across the waste sector. This literature gap is arguably unsurprising given that both researcher and practitioner communities are still within the relatively early stages of understanding the long-term impacts of blockchain technology for the governance of wastes. The absence of such reporting, however, not only limits the visibility of these experimental efforts, but also limits the learning and support that can be shared across waste and plastics researcher and practitioner communities.

Two questions, therefore, face the waste and plastics sectors:

1. What blockchain initiatives are representative of current waste and plastics sector activity?
2. What are common or distinctive experiences across these initiatives that could provide insights about likely future disruptions and development lessons for both the waste and plastics sectors?

This paper contributes to the above questions with a review of recent global applications of blockchain technology in waste management practices. This review specifically explores the extent to which their intended benefits align with circular economy and plastic waste system transitions. It aims to increase visibility of the range of ongoing blockchain experiences within the waste and plastics sectors, as well as identify areas that would benefit from further research and development. The following section, Section 2, provides an overview of the research design and methods adopted for the objectives of this paper. Section 3 presents our findings with an overview of blockchain initiatives. The subsequent section, Section 4, discusses five summary observations on blockchain technology for circular plastic waste governance. The final section, Section 5, concludes with recommended areas for further work.

2. Research Design and Methods

The research question framing this paper is: *how can blockchain technology support the governance of circular plastic waste management?* For this purpose, a three-step process was adopted: (1) a scoping review identified reported blockchain technology-based initiatives within the waste management sector; (2) semi-structured interview data were used to triangulate and validate scoping review data about the initiatives, as well as provide anecdotal contextualizing evidence; and (3) categorization through qualitative coding of initiatives according to their attributes was used to explore and identify implications for plastic waste management and governance discussions. This three-step process is summarized in Figure 1.

2.1. Scoping Reviews

Scoping reviews generate suitable and appropriate data outputs when exploring emerging fields about which there is little direct extant literature (Mays et al. 2001; Arksey and O'Malley 2005). They take a structured approach to mapping concepts, sources, and types of evidence available within a research area (Mays et al. 2001; Levac et al. 2010; Munn et al. 2018), but are less constrained by the need for clearly bounded and precise searching questions used in a more focused systematic review (Mays et al. 2001; Arksey and O'Malley 2005). This study followed the five methodological scoping review stages articulated by Arksey and O'Malley (2005) and advanced by Levac et al. (2010) (see Figure 1). A scoping review was selected as the data collection and reduction method for its suitability to this study's purpose of mapping the landscape of blockchain technology-based waste initiatives in the absence of significant volumes of other peer-reviewed case literature.

The scoping review was conducted through a Google search, with the search string revised after an initial scoping round to ensure websites with relevant information were captured. It was organized with two search components for mapping initiatives: (1) "what" (blockchain technology), and (2) "where" (waste management sector). The string was: ("blockchain technology" OR "blockchain") AND ("waste" OR "recycling" OR "recycle"). Search results considered for inclusion were either of the websites of the initiative themselves, in which case they were then screened to ensure they met the inclusion criteria (see below), or of articles and reports on such initiatives, in which case the homepage of the initiative was found where possible. Where no homepage was found and the initiative was only reported on by third-party sources, the information provided by these were used to check whether the initiative met the inclusion criteria. The data sources for initiatives are set out in Table A1 in Appendix A. The search was undertaken in 2018 and repeated in 2021 to verify details and include recent initiatives.

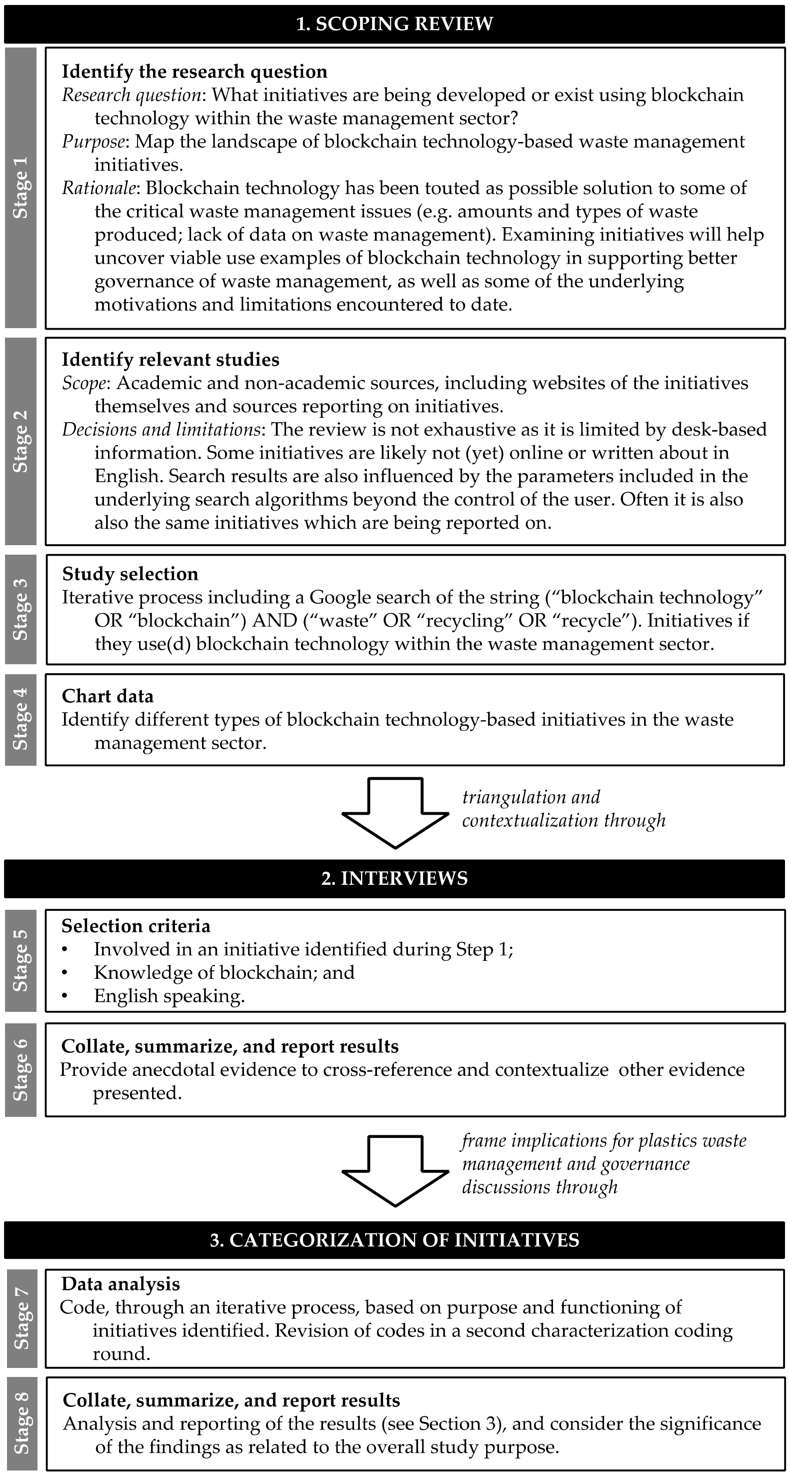

Figure 1. Overview of the three-step process: (**1**) scoping review methodology adapted from Arksey and O'Malley (2005) and Levac et al. (2010); (**2**) interviews; and (**3**) categorization of initiatives.

Each initiative had to meet the following inclusion criteria:

- *Eligible technology*: only initiatives using blockchain technology were included; and
- *Eligible sector*: only initiatives within the waste management sector were included.

The latter inclusion criterion was not limited to plastics, as (1) the scoping exercise identified very few plastic waste projects, and (2) wider lessons learnt from other waste management projects are believed by authors to be useful to plastic waste management.

Table A2 in Appendix A provides a list of the excluded initiatives with reasons for their exclusion.

For each of the 21 initiatives identified, the following information was identified: the year the initiative was initiated; the stage it is at (pilot; development; operational; discontinued); type of waste; geographic focus; and an understanding of the initiative to facilitate categorization of the initiative.

Limitations of the search include that the search was only performed in English and that there are likely relevant initiatives that are not yet publicized, or for other reasons less likely to be returned in the search results. This paper therefore likely does not provide an exhaustive overview of all blockchain technology-based initiatives for waste management.

2.2. Interviews

Following the scoping reviews, interviews were conducted in 2019 for triangulation and validation of data collected through the scoping review. Interviews were semi-structured and virtual. As a consequence of limited participant availability, five interviews were conducted. Interviewees were individuals with first-hand knowledge of initiatives mapped in the scoping review—either the founders with technical expertise or another technical expert. Open-ended interview questions included questions on the history of initiatives, the rationale for using blockchain technology, challenges of using blockchain technology, and insights into perceived regulatory and governance opportunities and challenges. The interview guide is included in Table A3 and an overview of the interview participants is included in Table A4, both in Appendix B. This research received ethical approval from Coventry University (project P85816).

These interviews provide anecdotal and contextualizing evidence, not generalizable observations. Low-frequency evidence has been criticized for being used in research analysis without assessing truthfulness, or typicality, and using it as a foundation to form generalizations without adequate justification (Saks 1992; Hyman 1998; Heise 1999). Generalization is, however, not the purpose here. Instead, the interviews provide evidence with which to cross-reference and contextualize other research evidence collected (Enkin and Jadad 1998) and identify potential emerging themes and patterns of early experience.

2.3. Categorization of Initiatives

The third and final step was to characterize and categorize the blockchain technology initiatives with a particular view of exploring patterns of significance and commonality in the ways that they influence plastics and waste governance. This used an iterative process based on coding the purpose, design, and developmental experience of the mapped initiatives. Coding facilitates the organization, sorting, and analysis of data (Charmaz 2006), with a code a word or short phrase that "assigns a summative, salient, essence-capturing, and/or evocative attribute for a portion of ... data" (Saldaña 2012, p. 3). An inductive coding round generated an initial coding scheme, which was revised and extended in a second characterization coding round.

The findings of the three-step process have been collated and are presented in the next section.

3. Blockchain Technology Initiatives within the Waste Management Sector

There is variable reporting on the level of detail provided on existing initiatives applying blockchain technology to waste management. Table 1 provides a synthesis overview of the identified projects using blockchain from the scoping review. Noticeably, most initiatives are still in development, though some have reached piloting and operational stages, while some others are discontinued.

Table 1. Overview of 21 existing blockchain technology applications to waste management. Italicized text indicates that the date is based on when the initiative was first reported rather than necessarily when it was founded; an asterisk (*) indicates there is no recently updated information since the initiative was first reported on.

Initiative	Focus Area	Usage Type	Intended Users	Geographic Focus	Initiated	Stage
Agora Tech Lab	household waste	cryptocurrency-based reuse and recycling rewards	civil society	cities	2017	pilot
Arep	waste collected at train stations	monitoring and tracking of waste	train station managers	France	2017[1]	project discontinued after completed pilot
Bounties Network	plastic waste	cryptocurrency-based payments	civil society, social entrepreneurs, non-profit organizations	global–so far in Canada Philippines, U.K., USA, Venezuela	2018	pilot
Citizen Involved & Technology Assisted Governance (CITAG)	waste	monitoring and tracking of waste	civil society, municipal authorities and waste industry	Bruhat Bengaluru Mahanagara (India)	2019	pilot*
Dutch Ministry for Infrastructure	company waste	monitoring and tracking of waste from producers to landfills	public authorities and waste management organizations transporting between the Netherlands and Belgium	The Netherlands and Flanders (Belgium)	2018	Development *
Jay Phillips Partnership	waste being shipped	cryptocurrency payments	Jay Phillips Partnership //private corporation //international	U.K., Far East, Indian subcontinent, and Europe	2018[2]	Pilot *
JellyCoin	Plastics, metals, and organic waste	cryptocurrency-based reuse and recycling reward	civil society	Argentine province of Misiones	2019	Development * *(no website anymore so likely discontinued)*
Lidbot (previously Two)	waste	cryptocurrency payments monitoring and tracking of waste	no specified focus–waste management sector generally	global—piloted in Singapore and Taiwan	2018	pilot

Table 1. *Cont.*

Initiative	Focus Area	Usage Type	Intended Users	Geographic Focus	Initiated	Stage
Oil & Gas Supply Chain (OGSC, formerly OILSC)	oil and gas waste	smart contract implementation	oil and gas waste disposal companies, organizations, and government agencies	global—no specified area	2016	development
Parry & Evans	company waste	cryptocurrency payments monitoring and tracking of waste	Parry & Evans	U.K.	2017[3]	Pilot *
Plastic Bank	plastic waste	cryptocurrency-based reuse and recycling reward	civil society	Brazil, Haiti, Indonesia, Philippines[4]	2013	operational
Prismm Environmental	factory waste	cryptocurrency payments	Prismm Environmental	U.K.	2018[5]	Operational *
Recereum	household waste	cryptocurrency-based reuse and recycling reward	civil society and waste management organizations	global—no specified area	2017	project discontinued (predecessor for W2V Eco Solutions)
Recyclebot	solid waste	monitoring and tracking of waste cryptocurrency payments	civil society and waste management organizations	Zambia, Tanzania, South Africa, Nigeria, Kenya	2018	development
RecycleGO	recyclable waste (including a specific focus on plastics recycling)	monitoring and tracking of waste	waste management organizations (to be expanded to civil society, private sector)	global—no specified area	2018	operational
RecycleToCoin	single-use plastic bottles and aluminum cans	cryptocurrency-based reuse and recycling reward	civil society	U.K.	2017	Development * *(no website anymore so likely discontinued)*

Table 1. *Cont.*

Initiative	Focus Area	Usage Type	Intended Users	Geographic Focus	Initiated	Stage
Save Environment Tokens (SET)	solid waste	cryptocurrency-based recycling reward	local authorities	global—no specified area	2018	development *(no website anymore so likely discontinued)*
Save Planet Earth	metal, plastics, municipal solid waste	unclear	unclear	global—no specified area	2021	planned for 2022
Swachhcoin	household waste	cryptocurrency-based reuse and recycling reward	civil society	global—no specified area	2014	project discontinued (predecessor Swachh 2.0)[6]
Vastum	waste	monitoring and tracking of waste	government, regulators, waste producers, waste industry, municipal authorities	U.K.	2019	development
W2V Eco Solutions	waste	cryptocurrency-based reuse and recycling rewards	civil society	global—no specified area	2019	pilot

The primary contribution area of blockchain technology-based initiatives was categorized into four non-discrete types based on their usage type: (1) cryptocurrency payments, (2) cryptocurrency-based reuse and recycling rewards, (3) monitoring and tracking of waste, and (4) smart contract implementation. Each of these categories is described in the next section, including how they can link to circular economy approaches (or not). Where collected, anecdotal evidence on some of the regulatory and governance opportunities and challenges encountered by mapped initiatives is included. In the subsequent section, Section 4, we then synthesize and transpose the experiences and reflections shared in these discussions and scoping results content to observations for informing the ongoing development of the governance of circular plastic waste.

3.1. Cryptocurrency Payments

Initiatives by Bounties for the Oceans, Jay Phillips Partnership, and Prismm Environmental make use of the commonly recognized blockchain technology function of facilitating payments. The Bounties for the Oceans initiative rewards citizens for picking up plastic waste with Dai (a stablecoin cryptocurrency linked to the value of the USD). Participants have to share a picture on Twitter of themselves with the waste picked up at a cleanup site (e.g., park, beach, street, riverbank), with the day's newspaper or a camera date stamp, and use specified tags and hashtags. If the submission is verified and accepted, the participant receives 10 Dai. The Jay Phillips Partnership and Prismm Environmental initiatives similarly accept and make payments with cryptocurrency—this time Bitcoin—but within the context of commercial transactions involving waste material and recycling. The adoption of cryptocurrency payments for transactions in these latter two initiatives is economically motivated to remove transaction fees for payments, as well as enable instant and secure payment (Sanderson 2017). Such incentives need to be counterbalanced, however, with questions surrounding the volatility and subsequent risks of Bitcoin and other cryptocurrencies in comparison to traditional currencies (Kim et al. 2021; Sigalos 2021).

The scoping review data identify benefits of adopting cryptocurrency payments for incentivizing circular approaches, but these are not specific only to circular plastics practices, nor necessarily exclusive of benefiting opposing practices. Bounties for the Oceans use the cryptocurrency payment function to reduce the amount of plastic waste that has escaped into the environment, whereas Prismm Environmental and Parry & Evans have used it to trade recyclable paper. The application could equally be used, however, to facilitate payments of any waste that is, for example, being sent to landfill.

3.2. Cryptocurrency-Based Reuse and Recycling Rewards

The cryptocurrency-based reuse and recycling rewards category is a distinct application case of the cryptocurrency payments usage type. Blockchain technology can facilitate rewards-based systems in which people receive money or other blockchain-secured items as a reward for bringing in waste items, which may then be reused or recycled (which is how it differs from the previous discussed type, which is limited to cryptocurrency transactions and the purpose of the waste transaction is unspecified). The Plastic Bank (2018), for example, rewards people in developing countries without access to banks. Rewards are given for bringing plastic waste to recycling centers with a bespoke type of token as a financial incentive for recycling. Companies then buy the recovered plastic from the Plastic Bank and recycle it to produce new consumables. This initiative creates a financial recycling reward mechanism accessible to those excluded from conventional banking systems. In contrast to the cryptocurrency payments used by the Plastic Bank, Agora Tech Lab (2018) looks beyond traditional rewards for purchasing goods and additionally allows tokens to be pooled together by neighborhoods to redeem them for public services to strengthen community ties. SwachhCoin is a comparable recycling reward system, though it differs in its further inclusion of data from Internet of Things-enabled smart waste and resource use devices, such as household bins. These data are used to improve the efficiency of waste management once waste has left individual consumers.[7]

These varying blockchain technology applications engage a range of economic, environmental, and social motivations, aligning with the espoused benefits of circular economies (Kirchherr et al. 2017). The focus on recycling and recovery within this type of usage of blockchain also demonstrates how these applications may embody or at least support circular economy principles. There are, however, also challenges with such approaches. The underlying driver of change developed in these initiatives is in increasing the perceived value of waste—to make it seem as a "valuable" rather than "waste". Swachhcoin, for example, emphasizes that its aim is to turn waste into products of high economic value for both households and waste management companies. They explicitly state that their aims include increasing profits and operational efficiency gains for waste management companies. Increasing the value of waste risks commodifying waste, which does not actually discourage its generation. Therefore, there is a risk of such blockchain uses counteracting the very purpose of the circular economy agenda, which has as its primary objective the prevention of total waste. Arguably, if what-would-be-waste is earmarked for subsequent use and meets certain other requirements, then it may not be considered waste at all, but a by-product. This is the case in the European Union (EU) as a consequence of the Waste Framework Directive (WFD 2008). In this context, blockchain usage may divert potential waste into use as by-products that would align with the circular economy paradigm. In legal terms, no waste would be produced, despite not changing consumer behavior or discouraging overconsumption (Prendeville et al. 2014; Lofthouse and Prendeville 2017).

As with the more general use for cryptocurrency payments for plastics and waste management, blockchain technology is not strictly necessary for reuse and recycling reward applications. Rewards could be secured in different ways, such as non-digital community loyalty scheme credits. One justification for blockchain adoption still made for some initiatives is that it provides "the foundation for how do we safely put millions of dollars into [countries] and not have it just go into the wrong hands" (Interview Participant A). Additionally, the use of blockchain technology in these initiatives has also appeared to provide a mechanism for raising interest in and attention to initiative impacts, where: "out of everything we do, the fact that blockchain is there is quite often one of the biggest talking points" (Interview Participant A).

3.3. Monitoring and Tracking of Waste

Some initiatives use blockchain technology for the purpose of capturing longitudinal data on waste transactions. One of the inherent characteristics of blockchain as a data ledger means that events and transactions are recorded on blocks, enabling the provenance of resources and wastes to be made available. These data can be used to optimize effectiveness and efficiency of waste management. For example, Arep, a subsidiary of SNCF (the French national railway company), used a system where sensors on each station waste bin collected data and put them on the blockchain. These data were used to optimize waste management in stations (Arep 2017). Another initiative by Parry & Evans uses blockchain data on waste shipments to expedite administrative reporting requirements (Recycling Today 2017). In addition to use for improving municipal waste management, the Citizen Involved & Technology Assisted Governance (CITAG) initiative on waste management is piloting use of blockchain as a permanent record of Bangalore citizen grievance filings about (non-)collection of waste. These data are then further used to hold relevant entities accountable for collector neglect.

This type of blockchain technology use can be supportive of non-circular approaches (see the Parry & Evans case), though there are multiple observed and reported benefits of this type to better support the governance of circular resource practices, including those for plastics. Blockchain technology can help trace responsibility, which may be used to support enforcement and compliance with regulations and standards. For example, if resources are tagged in some way (using, for example, a barcode or Quick Response (QR) code) and linked to a blockchain listing the producer and subsequent owners, then, if they are illegally dumped in the natural environment, the data on the blockchain can be used to identify who was responsible (Steenmans and Taylor 2018). A comparable application is currently being explored in the construction sector, linking the concept of material passports for buildings with blockchain technology to encourage circular economies (e.g., Honic et al. 2018; Kovacic et al. 2018). Several challenges and uncertainties remain to be addressed to realize such benefits in practice. This includes the breakdown of materials (i.e., where tags are placed in case of material breakdown. In the case of plastics and microbeads, there is a need to identifying appropriate options for tag removals). There are also regulatory uncertainties around, for example, gray areas in relation to who has responsibility for resources and materials, as well as issues related to dealing with fraudulent information entered on the blockchain, which cannot easily be changed as a result of the immutability characteristic of blockchain technology (Steenmans and Taylor 2018; Taylor et al. 2020).

As with the previous two blockchain primary use categories, these benefits can be achieved either with or without the use of blockchain technologies.

3.4. Smart Contract Implementation

This type is not distinct from the previous types, but is instead an implementation choice. Cryptocurrency payments, cryptocurrency reuse and recycling rewards, and monitoring and tracking of waste functions are all typically implemented using smart contracts. A smart contract is, in its essence, a computer program and data that can be used to digitally monitor, execute, or enforce agreements. They support automation of transactions, thereby minimizing certain administrative burdens, as well as improve cost effectiveness. These features help explain why smart contracts provide one of the key motivations for using blockchain technology to enable the other initiative types as described by interviewees:

> "other than the security aspect, the biggest thing that blockchain enables is a system set-up using smart contracts ... which just gives us really full control over putting all the rules and conditions into the system, to ensure that it always works the way it's supposed to. So for us the biggest thing–blockchain is mostly just even an open-sourced digital ledger, but it's a smart contract". (Interview Participant A)

> "putting your smart contract online, customizing it and having it working, it's like a breeze, really super easy and this is why this was a really good technology to use at the time". (Interview Participant E)

The OGSC initiative listed in Table 1 reports the use of blockchain technology for this purpose in moving contracts between oil and gas companies and drill management and waste disposal service providers onto the blockchain. This is, however, not yet operational (OGSC 2021). This initiative faces a challenge that extends beyond the resource and waste management sectors. Though a form of smart contracts has been created (Mell et al. 2017), smart contracts for legal transactions and purposes do not yet exist, and may never exist as a result of the limitations of code to deal with ambiguity, sub-text, and misunderstanding (Freshfields Bruckhaus Deringer 2018; Song 2018). Therefore, this is a theoretical use type for which there is no reported application case in practice to date.

4. Observations on Blockchain Technology for Circular Plastic Waste Governance

Across both mapped initiative and interview data, multiple, repeated and mutually supportive beliefs are articulated about the ways that experiences from blockchain technology-based initiatives can inform the development of future governance of circular economies. We present these under five themes: good governance characteristics; role of law; multiplicity and decentralization; solution-based approaches; and blockchain design choices. Examples of plastic waste management are included where relevant. This overview of observations is summarized in Figure 2.

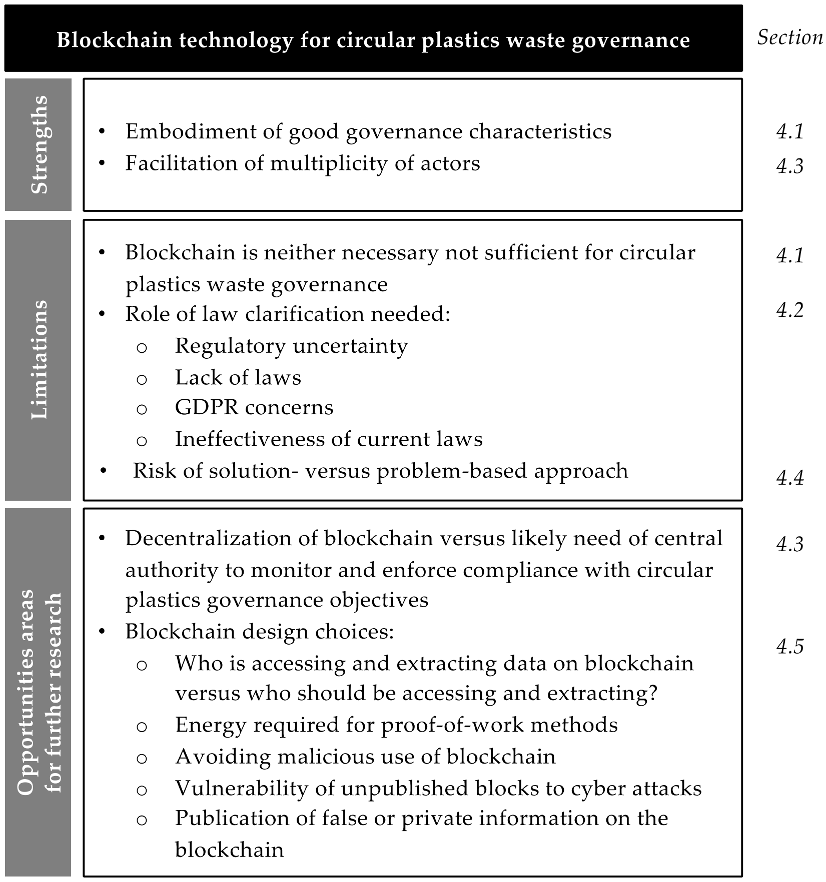

Figure 2. Overview of observations on blockchain uses for, implications for, and influences on circular plastic waste governance. This is based on online initiative and interview data evidence.

4.1. Embodiment of Good Governance Characteristics

A number of the waste and resource initiatives mapped in this study adopted blockchain technology for its capacity to operationalize some of the dimensions identified as contributing to good governance: participation (e.g., CITAG, Plastic Bank), transparency (e.g., Arep, Plastic Bank, OGSC), responsiveness (e.g., Jay Phillips Partnership, Prismm Environmental), effectiveness and efficiency (e.g., Arep, Swachhcoin), and accountability (e.g., CITAG).[8] Many of these dimensions, characteristic of good governance systems, arise from blockchain technology being a permanent data ledger with smart contracts with inherent characteristics of immutability, decentralization, transparency, and being consensus driven, as well as their resulting benefits for enhanced provenance, auditing, corroboration, trustworthiness, and incentivization (Steenmans et al. 2021). These potential benefits are not yet trusted in practice, however, as raised in the interviews: “two years ago all you heard about blockchain on the news was ICO scams and crashing tokens, which then ironically put a mistrust onto a trust technology” (Interview Participant A).

Crucially, the use of blockchain technology does not ensure good governance of neither the identified resource and waste management initiatives, nor other plastic waste management activities. It is capable of operationally enabling characteristics, such as accountability and transparency, if complemented by other measures. Moreover, even when characteristics of good governance systems are present, environmentally sound management of plastic waste is not necessarily guaranteed. There could, for example, be good governance of waste being sent to landfill and incineration. Blockchain technology can thus provide a facilitative tool or mechanism for the governance of circular plastic waste management, but it does not provide a “silver bullet” for its good governance.

4.2. Role of Law

The relationships between the role of law and use of blockchain technologies for more circular waste management lack clarity in experiences to date. None of the initiatives identified in this study were mandated by laws. Only one initiative was developed with an explicit claim to support the implementation of existing laws: JellyCoin. JellyCoin described an intention to reward citizens for compliance with environmental regulations in the Argentine province of Misiones with a blockchain technology-based token called JellyCoin. Users of the JellyCoin platform would have been required to register as a waste producer (residents throwing items away), collector (individuals responsible for sorting specific wastes, such as plastics, metals, and organic waste), or generator (entities processing waste at designated locations), and upload information on the waste they held. The platform would then connect producers with collectors, and collectors to generators, who process the waste at designated locations. The JellyCoin initiative appears to never have been fully developed and to have been discontinued.[9] It is unclear, however, exactly how blockchain technology was intended to support regulatory compliance. Moreover, the initiative has been criticized for being a tax exemption "dressed in new crypto clothes" (Lanz 2019), highlighting the challenges in validating sustainability cases used to justify blockchain technology use.

An interviewee provided similar reflections that current perceptions are that the role of law in relation to blockchain technology-based initiatives is weak. This cautions others looking to translate experiences into new uses such as, for example, plastics governance. They noted laws often focus on areas that are not the dominant foci of waste reuse or recycling initiatives:

> "most legalities around waste have to do with literally shipping garbage ... That's where you get a lot of regulation ... I've found a lot of the waste laws are about what you can do with unsorted garbage; not necessarily with recycled and sorted materials". (Interview Participant A)

There are, however, opportunities for strengthening linkages between the combined influences of law and blockchain technology use for plastic waste management. Cryptocurrency-based reuse and recycling rewards initiatives may contribute to meeting littered waste reduction targets and increasing reuse and recycling targets of other wastes (as was possibly the rationale for JellyCoin). They could also contribute to monitoring and tracking for general reporting requirements (as in the case of the Dutch Ministry for Infrastructure initiative, which uses blockchain technology in part to help automate the checks of necessary permits required under articles 23 to 27 of the EU Waste Framework Directive), or to support the implementation and enforcement of laws. For example, the California State Legislature rejected two bills, SB 54 and AB 1080 (solid waste: packaging and products), in 2020, which would have required manufacturers and retailers of single-use packaging or products to reduce by 75% the waste generated from single-use packaging and products offered for sale or sold in the state through reduction, recycling, or composting, in addition to other commitments. Blockchain technology use could support such measures by providing permanent, immutable ledgers onto which to record such information. Similarly, extended producer responsibility, a legal concept in which responsibilities for waste management are shifted from consumers and authorities to the producer of the product identified as part of an integrated regulatory approach for circular economies (Steenmans 2019), could also benefit from having data on product producers and holders on a virtual distributed ledger (Akbarieh et al. 2020; Sandhiya and Ramakrishna 2020).

Conversely, laws could also present barriers to blockchain technology adoption for better resource management. Interviewees highlighted multiple legal and regulatory barriers encountered throughout the development of their blockchain for waste initiatives: a general lack of laws; legal uncertainty; the General Data Protection Regulation (GDPR 2016); ineffectiveness of current waste laws; and high cost of licenses for a small technology business in their specific geographic area of operation.

In relation to the lack of laws, one interview participant stated that a key barrier of law "is by not being there" (Interview Participant B), with another interview participant describing the uncertainty around regulatory and legal requirements as "the biggest headache" in using blockchain for waste and resource management:

> "That actually probably would be ... the biggest headache. Not necessarily the laws around it, but the lack of laws. So even when I talked to the authorities of [X] government, their statement was most countries have a–no one's in charge of digital banking or blockchain-based token systems, and different countries sometimes it falls into digital banking, sometimes it falls into security ... quite often countries don't have anyone in charge of this and it's really a wait and see. So they'll see how it gets used, put out, then make a decision on what you can and can't do. So one of the harder things is most countries there's not a definitive rule of here's what you can do. So the ambiguity on that can be a bit tricky". (Interview Participant A)

Furthermore, a lack of laws and regulation increases perceived risk around the likelihood of sudden, significant regulatory changes. This discourages potential investors and other stakeholders in blockchain technology:

> "you can have different countries where all of a sudden you now follow banking rules or digital payment rules or security's rules, just because you're using blockchain, not because you fall into those categories. So that's the big risk of–if someone really wants to put legal pressure on something they could, so the more ambiguous it is, [the more problematic] ... Partners might not like the fact that there's ambiguity". (Interview Participant A)

Further uncertainty and perceptions of risk surround GDPR. Interview participants reflected: "GDPR and blockchain aren't particularly best friends" (Interview Participant D). This has also been discussed in the literature (e.g., Berberich and Steiner 2016; Van Humbeeck 2019), with Tatar et al. (2020) highlighting three contradictions between GDPR and blockchain technology: (1) right to be forgotten versus irreversibility/immutability of records, (2) data protection by design versus tamper-proofness and transparency of blockchain, and (3) data controller versus decentralized nodes. These mismatches could affect blockchain technology applications for circular plastics economies in affected regulatory contexts.

In the above examples of using blockchain technology to support measures, such as those proposed and later rejected by the California State Legislature and extended producer responsibility, there would need to be a record of the manufacturers and producers—but how does this align with the identified GDPR issues? Tatar et al. (2020) recognize that these are not insurmountable obstacles. Similarly, Interview Participant D shared how the initiative in which they are involved has adopted a process of putting data on private blockchains to which a password is added (in addition to the cryptographic hashes used in blockchain). That way, the data can be taken from the blockchain during the process, but once everything is finished, then the data are removed from the private chain, yet the list of processes and actions in which the data were used is still available.

The final legal barrier concerned, the ineffectiveness of existing laws:

> "For example, legislation just got passed this year on plastics, but it's only for a certain type of plastic, and it's a type of plastic that is very easy to make. But it's also very easy to replace with another plastic. So the regulation doesn't really make so much of a change, except make people pay for plastic. It doesn't really solve the problems, it just pushes the cost to the consumer. The new plastics are still being dumped the same old way". (Interview Participant B)

Interview Participant B clarified that in such situations, one option for better governance of plastics is not to be against the implementation of laws, but instead to advocate for extended producer responsibility and measures to ensure greater responsibility on the consumer. Other interview participants echoed this perspective on the future role for law, with some of the desired future regulatory options identified as tax ("If anything, the more governments can actually regulate taxes on using new plastic as compared to recycled plastic I think would be a great thing"–Interview Participant A), and "a global standardized waste and recycling labelling system ... to make it extremely simple for people to know what they can throw in the garbage and what they can put in recycling" (Interview Participant C), as a key issue is contaminated bags of recycling ending up in landfill as a result of contamination.

No unassailable legal barriers were thus identified for adopting blockchain technology for circular plastics governance. Instead, there was general consensus across the anecdotal evidence that there is a role for law in providing further prevention, reuse, recycling, and recovery incentives. Importantly, blockchain technology may support such regulatory incentives, but is neither necessary nor sufficient for them.

4.3. Multiplicity of Actors and Decentralization

Current blockchain technology-based initiatives for waste management demonstrate that a range of actors across the public, private, and third sectors are pursuing blockchain technology for the benefit of government authorities, private sector organizations, and civil society. This is in part a product of the way by which such initiatives are typically initiated. There are examples of both top-down (CITAG; Dutch Ministry for Infrastructure; JellyCoin), where there has been governmental driver for the development of the initiative, and bottom-up (all other identified initiatives) approaches to governing waste, where private or third sector actors initiated the initiatives. Each of the examined initiatives notably also involves a multiplicity of stakeholders.

Multiple stakeholder interaction may be facilitated by characteristic features of blockchain technology. This importantly includes decentralization of control of information and power. With blockchain technologies, decentralization denotes either (1) multiple copies of the database (i.e., ledger) exist, or (2) the codebase is public and multiple agents can contribute. The former enables multiple stakeholders—anyone if public, or authorized stakeholders if private—to participate either by extracting data from or putting data on the blockchain, including writing and executing new smart contracts. This aligns with calls by some that decentralized or distributed approaches with high levels of local participation, starting from plastic production to plastic waste generation, are what is needed for circular plastic waste economies (Joshi et al. 2019; Ayeleru et al. 2020). The second form of decentralization means the community behind a blockchain project and its codebase are typically democratic in nature.

Even though decentralization is a touted benefit of blockchain technology, there remain issues with its implementation. For example, a central authority is likely still needed in practice to fulfil more circular plastics practices; "probably the whole decentralization is very, true utopian" (Interview Participant C). A central authority—whether a government or other type of entity—should be involved to monitor and enforce compliance with circularity objectives in plastics governance.

4.4. Problem- vs. Solution-Based Approaches

The focus of available initiative descriptors is often on the use of blockchain technology and how it can be used to address certain challenges (i.e., solution-oriented), rather than beginning with the identification and unpacking of challenges (i.e., problem-oriented). An interviewee summarized this with:

> "I find a lot of blockchain projects are case studies, prototypes, proof of concepts and people starting with, 'I want a blockchain business, let's see how I can build a blockchain business,' which can be very different than 'I have a real business with a real business model and blockchain helps this part of my solution'". (Interview Participant A)

This role for shifting from solution- to problem-based approaches is also echoed in blockchain technology practice more generally. Recently, the US National Institute of Standards and Technology emphasized the need to ask, "*How can blockchain technology potentially benefit us?*" rather than "*How can we make our problem fit into the blockchain technology paradigm?*" (Yaga et al. 2018). Some of the initiatives included in the scoping review have adopted this approach, which is reflected in their published rationale for using blockchain—they first established the purpose of their initiative, and then identified the relevant technology rather than the other way around; "we're a business that uses blockchain, not a blockchain business" (Interview Participant A).

In the context of governance of plastic waste, too, the starting point needs to be questions such as the ones this Special Issue aims to address: What are the regulatory opportunities and challenges for fostering and enhancing circular plastics economies? What are some of the justice and equity issues related to the governance of plastics? What are property issues and liability for harm from plastics? Clarity of beliefs held in response to these questions are needed before possible solutions should be considered—which includes, but is not limited to, consideration of the potential role of blockchain technology.

4.5. Blockchain Design Choices

Even in cases where blockchain technology is identified as helpful following a problem-based approach to framing circular plastics governance, practical decisions still need to be made before envisioned benefits can materialize.

Within ideal circular plastics economies, plastic waste should not even be created, though some plastic waste is likely inevitable (at the very least in the short-term). Current initiatives, however, are designed to focus on the end-of-life stage when waste has already been created, rather than a life-cycle approach that expands perspectives beyond waste management to issues of overconsumption and resource inefficiencies (Ekvall et al. 2007). If the life-cycles of plastic products are monitored—which could be facilitated by blockchain technology—then data-driven tools can be generated to promote transitions to circular economies (Tseng et al. 2018). Using blockchain technology to track life-cycles requires most or all involved stakeholders to engage with blockchain and publish a block for every transaction, so that a comprehensive and holistic overview of the life-cycle is generated.

In practice, there are multiple challenges to realizing this opportunity for engaging blockchain for a fundamental redesign of the plastics life-cycle itself: all those involved would need the relevant technical skills. There are also practical difficulties as discussed in Section 3.3 concerning the breakdown of materials. Such approaches will also likely require coopetition, where common standards need to be established between actors that are actually in competition. These issues remain unresolved. Current blockchain technology applications in plastic waste management are therefore not yet pushing boundaries far enough to truly disrupt environmental governance and catalyze a more systemic overhaul of current plastics management approaches.

Aside from the EU context-specific GDPR issues, there are further blockchain design questions related to who is accessing and extracting the data on the blockchain (whether focused on end-of-life or full life-cycles), compared to who should be accessing and extracting the data in order to inform law- and policymaking and enforcement and governance generally. There would need to be capacity for dealing with the data and, depending on the data available, there are then questions and challenges relating to how to turn the available data into useful and actionable insights.

Additional issues relate to the limitations of blockchain technology itself, including the amount of energy used for proof-of-work methods to verify blockchains. Alternatives exist such as proof-of-stake or proof-of-work and depend on the particular application:

> "you do get . . . people say[ing], 'Oh, I thought blockchain was terrible for the environment,' and Bitcoin is technically terrible for the environment. Doing a system that requires mining is terrible for the environment, but I actually got my

> guys to do the math, and a transaction on our system is one tenth the [energy] cost of sending an email". (Interview Participant A)

Finally, design choices would need to engage with the potential of malicious use of blockchain, vulnerability of unpublished blocks to cyber-attacks, and publication of false or private information on the blockchain (Yaga et al. 2018).

5. Conclusions

Governance of plastic waste involves a variety of activities, legislature, cooperation mechanisms, and other policy instruments (Vince and Hardesty 2018). To continue to improve the future of sustainable plastics governance, many of these instruments employed will experience change—some of these changes more disruptive than others. This paper examined the changes introduced by emerging technology believed by some to have the potential to transform plastics governance: blockchain technology.

To reduce current challenges faced by plastics and waste management researchers and practitioners in accessing evidence about the current state of blockchain use in plastic waste governance, this paper contributed a global scoping review of recent experiences with blockchain technology in plastics and waste management initiatives.

Of the 21 initiatives identified and investigated, we found that the considerable majority remains in early concept development and pilot project stage. Several initiatives were recently discontinued. We recommend further investigation of the underlying causes for these trends in blockchain experimentation and uptake in the plastics sector, and whether these reflect more general early technology adoption challenges, or reflect specific challenges to the use of blockchain for better plastics governance.

The mapped landscape of current blockchain for plastics and waste initiatives identified four connected areas of blockchain technology use beginning to change waste management practices: (1) cryptocurrency payments, (2) cryptocurrency-based reuse and recycling rewards, (3) monitoring and tracking of waste, and (4) smart contract implementation. Descriptions of some of the different approaches by which initiatives are realizing these in practice were used to explore their differential value assumptions and benefits achieved. These benefits of blockchain use range from operational gains from the reduction of transaction fees and administration costs, as well as increasing the security of payment, to more multi-dimensional changes in opening plastics "markets" to actors without previous access to traditional banks or credit. Other benefits include the wider interest blockchain adoption attracts, raising awareness and visibility of waste sector and plastics recycling practices, and increased confidence in efficacy of accountability and enforcement mechanisms. The research suggests that while blockchain technology does not appear to provide the "silver bullet" capacities for resolving extant waste and plastics challenges as sometimes claimed, its use can nonetheless make valuable contributions across a range of plastics resource management activities.

In exploring project documentation and experiences, several areas of strength and weakness of the fit of blockchain technology application and influence in plastics governance recurred. We summarize these in five themes with implications for continued development of circular plastic waste governance in both research and practice.

First, blockchain technology can facilitate the incorporation of the good governance characteristics: participation, transparency, responsiveness, effectiveness and efficiency, and accountability. Second, closely related to these enhanced plastics management capacities, blockchain technology has a potential role in supporting the operationalization of regulations. Third, mapped initiatives also demonstrate that this role extends to supporting greater transparency and accountability in resource exchanges between a multiplicity of stakeholders, with related contributions to new approaches to monitoring, compliance, and enforcement of plastics related activity. Fourth, we observe a current pattern where solution-based approaches presume in favor of using blockchain technology, at the potential expense of sufficient analysis and framing of the plastics governance issues that need to be urgently addressed. The fifth and final area of development identifies the need for better understanding the implications of the blockchain design choices made for these early-stage initiatives. For each of these areas, we recommend further investigation of the underlying assumptions of distinctive value and benefit of blockchain use within the plastics sector, as well as forward-looking analysis of consequences and impacts on sustainable resource management and stakeholder inclusion and equality.

Overall, our mapping of the current state of practice gives cause to believe that initiatives using blockchain technology will support the effective attainment of circular plastics development. Its use has the potential to disrupt some of the major economic and social mechanisms driving plastics use, reuse, recycling, and recovery. Given the early period in this technology's adoption, we hope others will contribute further mapping and analysis of distinctive impacts. Finally, we believe there to be major value in developing this knowledge with collaborative efforts between developers and researchers to simultaneously explore the practical feasibilities of putting data on the blockchain, develop useful and actionable outputs from it, and create knowledge that is shareable with a wider research and practice community.

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Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The interview data presented in this study are not publicly available due to confidentiality.

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Appendix A

Table A1. Source material for blockchain technology-based waste management initiatives.

Initiative	Source
Agora Tech Lab	Agora Tech Lab. 2018. Waste management fueled by blockchain. Available online: www.agoratechlab.com (accessed on 13 September 2021).
Arep	Digital SNCF. 2017. Data-tritus–Comment la blockchain simplifie le tri des déchets. Available online: www.digital.sncf.com/actualites/data-tritus-comment-la-blockchain-simplifie-le-tri-des-dechets (accessed on 13 September 2021).
Bounties Network	Beylin, Mark. 2018. Bounties for the Oceans: Incentives to change the world. Available online: https://medium.com/bounties-network/bounties-for-the-oceans-incentives-to-change-the-world-8f3429fd01e9 (accessed on 6 September 2021). Calderon, Justin. 2019. Poorer communities in the developing world bear the brunt of plastic pollution. Could a new digital payment system spark a clean-up revolution? Available online: www.bbc.com/future/article/20190613-a-simple-online-system-that-could-end-plastic-pollution (accessed on 8 September 2021). Pop, Simona. 2018. Bounties for the Oceans: Philippines pilot., Available online: https://medium.com/bounties-network/bounties-for-the-oceans-philippines-pilot-db4319b0012 (accessed on 6 September 2021). The Bounties Network. N.d. Bounties for the Oceans: Manila. Available online: https://bounties.network/manila.html (accessed on 6 September 2021).

Table A1. *Cont.*

Initiative	Source
Citizen Involved & Technology Assisted Governance (CITAG)	CITAG. N.d. Society for Citizen Involved Technology Assisted Governance. Available online: https://citag.home.blog (accessed on 8 September 2021). Mallow, Chris. 2021. Even garbage is using blockchain now. Available online: www.bloomberg.com/news/articles/2021-03-18/even-garbage-is-using-blockchain-now (accessed on 8 September 2021).
Dutch Ministry for Infrastructure	LTO Network. 2021. Waste transport on blockchain. Available online: www.ltonetwork.com/use-cases/waste-transport-on-blockchain/ (accessed on 13 September 2021). Stolk, John. 2018. Dutch and Belgian authorities to streamline European waste transportation on blockchain. Available online: https://medium.com/capptions/dutch-and-belgian-authorities-to-streamline-european-waste-transportation-on-blockchain-5e44522d3eb (accessed on 13 September 2021).
Jay Phillips Partnership	Jackson, Mike. 2018. How Bitcoin and blockchain technology can benefit the waste management industry. Available online: www.recyclingwasteworld.co.uk/in-depth-article/how-bitcoin-and-blockchain-technology-can-be-put-to-good-use-in-the-waste-management-industry/168216 (accessed on 6 September 2021).
JellyCoin	Lanz, Jose Antonio. 2019. Argentina to reward waste management with new "wastecoin" called JellyCoin. Available online: https://decrypt.co/8695/argentina-reward-waste-management-with-new-wastecoin-called-jellycoin (accessed on 13 September 2021). *[When research was undertaken in 2018, there was a website: www.jellycoin.org that is no longer attached to initiative.]*
Lidbot	IOTA Foundation. 2020. Ldbot—building the future of waste management. Available online: https://blog.iota.org/lidbot-and-iota-building-the-future-of-waste-management-680504f4e303/ (accessed on 6 September 2021). Lidbot. N.d. Lidbot. Available online: https://lidbot.com (accessed on 6 September 2021).
Oil & Gas Supply Chain (OGSC, formerly OILSC)	OGSC. 2021. Oil & Gas Supply Chain. Available online: https://oilsc.io (accessed on 13 September 2021).
Parry & Evans	Sanderson, Paul. 2017. Prismm Environmental and Parry & Evans become first companies to trade recyclable paper using Bitcoin in UK. Available online: https://www.rebnews.com/prismm-environmental-and-parry-evans-become-first-companies-to-trade-recyclable-paper-using-bitcoin-in-uk/ (accessed on 6 September 2021).
Plastic Bank	Plastic Bank. 2020. Plastic Bank. Available online: https://plasticbank.com (accessed on 6 September 2021).
Prismm Environmental	Jackson, Mike. 2018. How Bitcoin and blockchain technology can benefit the waste management industry. Available online: https://www.recyclingwasteworld.co.uk/in-depth-article/how-bitcoin-and-blockchain-technology-can-be-put-to-good-use-in-the-waste-management-industry/168216 (accessed on 6 September 2021). Sanderson, Paul. 2017. Prismm Environmental and Parry & Evans become first companies to trade recyclable paper using Bitcoin in UK. Available online: www.rebnews.com/prismm-environmental-and-parry-evans-become-first-companies-to-trade-recyclable-paper-using-bitcoin-in-uk/ (accessed on 6 September 2021).
Recereum	Recereum. 2017. Recereum. Available online: https://recereum.com (accessed on 13 September 2021).
Recyclebot	Recyclebot. N.d. Recyclebot. Fastest way to recycle solid waste. Available online: http://recyclebot.launchrock.com (accessed on 15 September 2021).
RecycleGO	RecycleGo. 2020. RecycleGo. Available online: https://recyclego.com (accessed on 13 September 2021).
RecycleToCoin	The Blockchain Development Company. 2017. First recycling initiative from blockchain. Available online: www.recycling-magazine.com/2017/11/11/first-recycling-initiative-blockchain/ (accessed on 13 September 2021). *[When research was undertaken in 2018, there was a website: www.recycletocoin.com that is no longer attached to initiative.]*

Table A1. *Cont.*

Initiative	Source
Save Environment Tokens (SET)	Save Environment Token (SET). What is Save Environmnet Token (SET) and how does it work? Available online: https://medium.com/save-environment-token/what-is-save-environment-token-set-and-how-does-it-work-4b8388d9860f (accessed on 16 September 2021). *[When research was undertaken in 2018, there was a website: www.set4earth.com that is no longer active.]*
Save Planet Earth	Save Planet Earth. 2021. The official home of $SPE. Available online: https://saveplanetearth.io (accessed on 16 September 2021).
Swachhcoin	Swachhcoin. 2018. All you need to know about Swachhcoin. Available online: https://medium.com/@swachhcoin/all-you-need-to-know-about-swachhcoin-53bb58e12c3d (accessed on 6 September 2021). Swachhcoin. 2021. Swachhcoin. Available online: http://swachhcoin.com (accessed on 6 September 2021).
Vastum	Anthesis. 2019. Anthesis waste tracking system wins development funding from GovTechCatalyst Challenge. Available online: www.anthesisgroup.com/smart-waste-tracking-system-govtech-catalyst-defra/ (accessed on 7 September 2021).
W2V Eco Solutions	W2V Eco Solutions. 2021. W2V Eco Solutions. Available online: https://w2v.io (accessed on 13 September 2021).

Table A2. Excluded project.

Initiative	Reasons for Exclusion
4New	Reports exist questioning its veracity.

Appendix B

Table A3. Interview guide.

Purpose of Question	Main Question	Possible Follow-Up Questions and Prompts If Needed
Ice-breaker	Please tell me about [the initiative].	What is its purpose? What is the waste [or resource/being used? Can you describe the life-cycle of this particular resource? How are you getting people involved? When? Why? What are users getting out of it?
Description of initiative	For what purpose is blockchain being used in [name of initiative]? How is blockchain technology used in [name of initiative]: please talk me through the process of how the waste [or resource/and its related data comes to be on the blockchain. Please included in your explanation the users involved at different stages.	What issues are faced? What rationale suggested the fit with blockchain? Clarification if have data privacy concerns: We do not need specific identifiers, but are interested in a general, high-level description. For example, an individual person brings waste to a company, and it is that company that puts data on the blockchain about what the resource is and who has brought it in.
Technology	What blockchain technology has been used? I.e., have you made your own or are you using, e.g., Ethereum? What is the size of the user base? Do users actively engage with blockchain or is it all 'behind the scenes?	
Incentives	What were your incentives for adopting blockchain for the purpose of [the initiative]? Were there any particular legal incentives? That is, is there anything in the law or particular law or policy that motivated you?	Questions focused on eliciting additional detail. E.g., if answer "environmental", then followed-up with identifying the particular environmental elements (e.g., reduce waste, incentivize recycling, etc.).
Barriers	What were your main challenges or difficulties for adopting blockchain for the purpose of [the initiative]? Were there any particular legal barriers?	Were these overcome? How were these overcome? How were they avoided?
Laws and policies	Are you aware of your initiative helping meet requirements set out in any laws or policies?	For example, how is blockchain technology supporting waste laws and policies?
Future looking	What knowledge gaps do you face? What practical design issues do you face? What practical implementation issues do you face?	What questions would you like answered? What trends do you expect in future blockchain for waste action?

Table A4. Interview participant overview.

Interview Participant	Type	Role
A	cryptocurrency-based reuse and recycling reward	co-founder
B	cryptocurrency payments monitoring and tracking of waste	founder
C	monitoring and tracking of waste cryptocurrency payments	technical expert
D	monitoring and tracking of waste	technical expert
E	monitoring and tracking of waste	technical expert

Notes

1. Date when Arep (2017) first reported this initiative.
2. Date when Jackson (2018) first reported this initiative.
3. Date when Recycling Recycling Today (2017) first reported initiative.
4. Expansion is planned into Ethiopia, India, and South Africa (Sustainable Brands 2018).
5. Date when Jackson (2018) first reported initiative.
6. No information is available on this, so it is not included in the table.
7. Further information about the details of this initiative is currently unavailable as the homepage is being updated in preparation for Swachh 2.0. It is therefore unclear how this initiative intends to expand and whether these intentions have been operationalized yet.
8. A discussion of "good governance" is beyond the scope of this paper but see, for example, Graham et al. (2003) and UNESCAP (2019) for discussions on characteristics of good governance.
9. JellyCoin appears to have been discontinued. Its website is no longer online (nor is its "parent" network website) and its Twitter account has also not been updated in recent months (whereas previously it was active).

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