Regulatory Opportunities and Challenges for Blockchain Adoption for Circular Economies

1st Katrien Steenmans
Coventry Law School and
Centre for Business in Society
Coventry University
Coventry, UK
katrien.steenmans@coventry.ac.uk

2nd Phillip Taylor
Trilateral Research
London, UK
University of Warwick
Coventry, UK
phillip.taylor@trilateralresearch.com

3rd Ine Steenmans
Department of Science, Technology,
Engineering and Public Policy
University College London
London, UK
ine.steenmans@ucl.ac.uk

***Abstract*—The literature on blockchain technology and circular economy is at a nascent stage, with only initial limited and superficial recognition of the possible role blockchain may have in supporting circular economy laws and policies. This paper contributes to this emerging area by exploring the regulatory opportunities and challenges for adoption of blockchain for circular waste management. In particular, through a mixed methods approach combining empirical and doctrinal research, this paper presents initial findings on: (1) the current role of blockchain within the legal landscape on circular economies; (2) the regulatory barriers of blockchain application to circular economies; and (3) opportunities of blockchain in supporting regulatory mechanisms promoting circularity.**

***Index Terms*—circular economy, blockchain, law, waste, extended producer responsibility, right to repair**

I. Introduction

As a result of its promise to concomitantly address resource and waste crises, the circular economy concept has been gaining prominence in academia, the private sector, and policies [1]. There is no single agreed definition of the concept, but there is general consensus that the circular economy moves away from a linear take-make-dispose model of resource use towards the prevention of wastes, or alternatively the reuse, recycling, or other recovery of resources and wastes [2]. Consequently, the concept is lauded for its anticipated economic, environmental, and social benefits, such as a predicted USD3.7 trillion annual economic benefit as a result of resource efficiency gains [3], job creation (e.g. an estimated 700,000 net additional jobs within Europe [4]), and contributions to mitigating certain resource-related climate change impacts given that more than two thirds of global greenhouse gas emissions are related to material management [5]. Moreover, these benefits have caused the circular economy concept to receive additional attention during the coronavirus pandemic with, for example, Naidoo and Fisher [6] and Ibn-Mohammed et al. [7] arguing that the circular economy presents a viable solution in a world where economic growth is no longer sufficient to achieve sustainable development.

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Laws and policies are being implemented globally to accelerate circular economy realizations. Examples include China's Circular Economy Promotion Law 2008, European Union's (EU) 2020 Circular Economy Action Plan, France's Anti-Waste and Circular Economy Law 2020, and South Korea's Framework Act on Resources Circulation 2018, with other states going through the legislative process to enact such laws, such as the proposed General Circular Economy Law in Mexico and Sustainable Circular Economy Law in Uruguay (see [8] and [9] for further examples). Despite these advancements within the legal landscape, circular economy implementations are still limited and isolated [10], [11], especially given the needed scale to counter the waste and resource crises. There are also increasing questions surrounding the actual 'circularity' and its effectiveness; Laurenti et al. [12] and Friant et al. [13] warn that the concept is at risk of becoming a greenwashing tool as a result of perpetuating business-as-usual; Prendeville et al. [14] and Lofthouse and Prendeville [15] emphasize the need to strengthen focus on changing consumer behavior or discouraging overconsumption; and Murray, Skene and Haynes [16] warns of unintended detrimental environmental or social consequences.

Blockchain has been identified as a potential tool in addressing and overcoming some of these challenges in relation to resource management generally [17], [18], as well as waste and circular economies specifically [19]–[21]. This paper aims to contribute to this developing area of literature [22] by exploring the regulatory opportunities and challenges for adoption of blockchain for circular waste management.

The remainder of this paper is structured as follows. Section II outlines the research design adopted for the purposes of this aim. The current status quo of explicit links between circular economies, laws, and blockchain is then set out in Section III. Section IV then considers the legal challenges that exist. Section V then discusses opportunities where blockchain may contribute to the governance of circular economies in law through the use of examples. The final Section VI concludes.

II. Research Design

The research question framing this paper is: *What are the regulatory opportunities and challenges for adopting*

blockchain for circular economy implementations? For this purpose, a mixed methods approach was adopted. Doctrinal research was combined with empirical research — specifically interviews — to (1) triangulate data from the law, literature, and interviews for validation purposes, (2) facilitate explanations and enhance understanding, and (3) complement each other and offset weaknesses of each of the methods.

This paper uses the doctrinal research method rather than can be labelled as a doctrinal paper as interviews are also used. Doctrinal analysis in its purest has been described as "not subscrib[ing] to any overarching theoretical perspective, nor does it concern itself with policy interests. Instead, the black letter method focuses almost entirely on law's own language of statutes and case law to make sense of the legal world" [23]. It thus comprises identifying, analyzing, and synthesizing the content of law, including the identification of ambiguities and inconsistencies [24], [25]. This process was used to identify the current legal context in Section III and to provide examples of legal requirements that may benefit from the use of blockchain in Section V.

Interviews were employed to deepen understanding of stakeholders' perspectives of regulatory barriers and opportunities in using blockchain in the resource and waste management sector for facilitating circular approaches. The interviews were semi-structured, facilitated by open-ended questions, to allow interview participants to choose the most relevant issues to them. The open-ended interview questions included questions on perceived regulatory and governance opportunities and challenges, e.g. Were there any particular legal incentives for adopting blockchain for the purpose of [the initiative]? Were there any particular legal barriers to adopting blockchain for the purpose of [the initiative]? Follow-up questions focused on eliciting additional detail (for example, if answered 'environmental', then followed-up to identify the particular environmental elements, such as reduce waste, incentivize recycling, etc.) and also included: Were the legal barriers overcome? How were legal barriers overcome?

Interview subjects were selected using the following criteria:

- Involved in an initiative using blockchain for incentivizing the prevention of wastes or the reuse, recycling, and other recovery of resources and wastes;
- Knowledge of blockchain; and
- English speaking.

In as far as possible, participants were selected of similar capacity and levels — either the founders with technical expertise or the lead technical expert. An overview of interview participants is provided in Table I. Five participants were interviewed in total in 2019. The number of participants was limited by practical obstacles, including low response rates to emails and limited availability, but thoroughness rather than quantity is key as it is qualitative research [26]. Low numbers have been criticized for often being used without assessing their truthfulness, or typicality, and using it as a foundation to form generalizations without adequate justification [27]–[29]. Generalization is, however, not the purpose of this paper, but instead the anecdotal evidence from the interviews is used to draw out issues also identified in literature and complement other evidence presented [30].

III. Current Contributions of Blockchain to the Legal Landscape of Circular Economies

This section examines the links between blockchain, circular economies, and law in practice by exploring: (1) the benefits of blockchain for circular economies, particularly in relation to regulatory requirements, (2) whether any circular economy laws identify a role for (blockchain) technology, and (3) whether existing applications of blockchain within the waste and resource sector link to the law.

A. Benefits of Blockchain for Circular Economy Transitions

The literature on blockchain and circular economy is still at a nascent stage, with Kouhizadeh et al. recently observing "blockchain's application in the circular economy is still neglected in both research and practice" [31]. Initial emerging observations on the links between blockchain and circular economies recognize possible advantages. Through a review of 57 research and practice items in 2020, Böckel et al. identify the following benefits (in order of frequency) of blockchain for circular economies: (1) traceability, (2) security and privacy, (3) multiple, (4) transparency, (5) immutability, (6) efficiency, (7) cost reduction/profitability, (8) decentralization, (9) new business models, (10) trust/verification, (11) streamlining/automatization, (12) increased sustainability, (12) no intermediary, and (13) other [22]. For example, in order to identify materials available for recycling and reuse to support transitions towards circular economies, stakeholders require shared and transparent information on such available material and resource flows [22], [31]. Further particulars of this and other advantages are elaborated on in Böckel et al. [22], as well as more recent research published in 2021 (see for example [20], [21]).

The focus of this paper is on the benefits specifically useful for regulatory purposes. This necessitates an understanding of the requirements within the legal landscape on circular economy implementations. The circular economy and the law is of a sprawling nature as a result of the concept transgressing multiple sectors and governance levels, and engaging a broad spectrum of stakeholders. Lesniewska and Steenmans outline relevant and overlapping areas of law to circular economies, which include, inter alia, competition, consumer, contract, human rights, property, intellectual property, and tax law [9]. Due to this vast nature, this paper focuses on environmental — and in particular waste — laws. Such laws generally cover: measures to incentivize prevention, reuse, recycling, and other recovery of wastes and resources (e.g. a waste hierarchy setting out a priority order for waste and resource management, targets, standards, labelling, tax, etc.); reporting requirements, often to facilitate monitoring, accountability, and transparency; and enforcement and compliance mechanisms (e.g. penalties).

The primary benefit of blockchain for circular economies identified — traceability — links to a number of these legal components. Traceability means that blockchain can

TABLE I
INTERVIEW PARTICIPANT OVERVIEW.

Interview participant	Initiative summary	Role
A	Uses cryptocurrency tokens to reward citizens for bringing in plastic wastes to then be reused, recycled, or recovered	Co-founder
B	Uses cryptocurrency payments for transactions between citizens and/or waste management organizations; and monitors and tracks solid waste	Founder
C	Monitors and tracks waste to optimize waste management	Technical expert lead
D	Monitors and tracks waste for reporting requirements	Technical expert lead
E	Monitors and tracks waste to optimize waste management	Technical expert lead

provide provenance information, as it is at its essence a data ledger, which can facilitate auditing. This benefit linked with blockchain being able to provide information transparency and reliability [31] result in it supporting measures that incentivize circular economies. This is the focus of Section V. Moreover, tracking and monitoring is critical to enforcement and compliance.

There are also benefits identified that are not universally agreed. For example, even though the need for an intermediary is highlighted as a benefit, Taylor et al. [20] and Steenmans et al. [19] recognize that within the legal context intermediaries may still be needed for compliance and enforcement.

While these are key benefits, blockchain is not a silver bullet for supporting regulatory mandates on circular economies. Blockchain only overcomes some challenges that the circular economy faces. Blockchain will need to be combined both with other technological advances, such as the Internet of Things, sensors, and artificial intelligence, as well as with other measures effecting systemic and behavioral changes [19], [22], [32].

B. Blockchain and Circular Economy Laws

There is a growing (though still limited) number of laws and policies on circular economies (see Section I). Even though some of these are relatively new and have been adopted within social and political contexts in which the role of innovative technologies are being promoted, there is only limited and superficial acknowledgment of technology in them as discussed below.

Only the EU's Circular Economy Action Plan, which is not a binding law but a policy document introducing legislative and non-legislative measures, mentions blockchain specifically: "Innovative models based on a closer relationship with customers, mass customisation, the sharing and collaborative economy, and powered by technologies, such as the internet of things, big data, blockchain and artificial intelligence, will not only accelerate circularity but also the dematerialisation of our economy and make Europe less dependent on primary materials" [33]. The Plan, therefore, lends support to a focus on blockchain, but it lacks specificity. More detail is provided within other parts of the Plan on the particular role of such technologies. It is identified that there should be promotion of digital technologies for "tracking, tracing and mapping or resources" [33], which is again reiterated by stating that a cross-cutting action should be that "Digital technologies can track the journeys of products, components and materials and make the resulting data securely accessible" [33]. These identified potential contributions of technologies align with the dominant monitoring and tracking advantage discussed in the previous subsection III-A.

As demonstrated by Table II, circular economy laws generally identify a role for technology, but do not provide any specific examples. For example, three provisions within China's Circular Economy Promotion Law address technology, but lacks detail; e.g. Article 6 neither elaborates on what such plans should entail or the type of technologies (e.g. to assist with so-called administrative dimensions, such as blockchain technologies, or technologies to improving, for example, the efficiency of recycling and other recovery).

C. Blockchain-based Waste Management Initiatives and Law

There is similarly limited linking by blockchain-based initiatives to laws. Steenmans et al. review adoption of blockchain within the waste and resource management sector for the purpose of evaluating their contributions to the governance of the sector [19]. None of the initiatives identified were explicitly mandated by laws, though a couple identified links to waste laws, likely as a result as being initiated by governmental authorities. JellyCoin, for example, was initiated in the Argentine province of Misiones primarily to support existing laws [19], [34]. The JellyCoin platform aimed to have users register as a waste producer, collector, or generator, 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 initiative, however, appears to have been discontinued, as neither its website nor its 'parent' network's website are still online, and its Twitter account has not been updated recently. It is therefore unclear exactly how blockchain was intended to support regulatory compliance.

Other existing initiatives have been initiated by governments, with the aim in part to support certain waste regulations or at the very least policies, despite no explicit link being made as with JellyCoin. For example, the Dutch Ministry for Infrastructure Initiative uses blockchain in part to help automate the checks of necessary permits required under Articles 23 to 27 of the EU Waste Framework Directive 2008/98/EC [35]. In Bruhat Bengaluru Mahanagara in India, the Citizen Involved and Technology Assisted Governance (CITAG) initiative is piloting using blockchain as a permanent record of Bangalore

TABLE II
PROVISIONS RELEVANT TO BLOCKCHAIN WITHIN A SAMPLE OF ENACTED CIRCULAR ECONOMY LAWS.

Circular economy law	**Provisions on technologies**
China's Circular Economy Promotion Law 2008	*Article 6:* "technological development plans" may form part of the industrial policies to develop a circular economy. *Article 7:* "The state encourages and supports the research, development and promotion of science and technology relating to circular economy". *Article 42:* funds to be set up "specially for the development of circular economy so as to support the research and development of the science and technology relating to circular economy, the demonstration and promotion of technologies and products of circular economy, the implementation of important circular economy projects and information services for the development of circular economy".
Japan's Basic Act for Establishing a Sound Material-Cycle Society	*Article 30:* "(1) The State shall promote the development of science and technology towards the establishment of a Sound Material-Cycle Society, including methods for evaluating the degree of environmental load resulting from the cyclical use and disposal of circulative resources and technologies for preventing or restraining the generation of wastes, etc. from products, etc. or for appropriate cyclical use and disposal of circulative resources. (2) The State shall take necessary measures, including improvement of research systems, promotion of research and development activities, dissemination of its results, and training of researchers, to promote the development of science and technology towards the establishment of a Sound Material-Cycle Society".
South Korea's Framework Act on Resources Circulation 2018	*Article 2(6):* 'resource-circulating industry' is defined as " an industry in the types of business prescribed by Ordinance of the Ministry of Environment, which makes wastes circularly utilizable to the maximum extent possible, or researches and develops technology and systems necessary for promoting a transition to a resource-circulating society". *Article 26(1):* "the State and a local government may provide necessary financial and technical assistance of extend loans, etc ... which implement any of the following projects: ... 2. A project for research and technology development relating to a resource-circulating society". *Article 26(2):* "The Government may subsidize a business entity ... with funds necessary for ... establishing ... research and technology development funds".

citizen grievance filings and (non-)collection of waste to hold relevant entities accountability for collector neglect [36].

These and the lack of further examples demonstrate that there are potential missed and further opportunities, as discussed in Section III-A and revisited in Section V. Moreover, explicit linking to laws may further incentivize or underpin blockchain-based initiatives within the waste sector.

IV. REGULATORY CHALLENGES

Barriers and challenges exist both in relation to laws on waste management that need to be addressed before the application of blockchain can be considered (e.g. definitional issues [20], and to laws and blockchain. This section focuses on the latter. It should also be noted that the barriers experienced are not universal. Interview Participant E, for example, stated about their blockchain-based initiative that there "never [was] any kind of legal issue ... it was too small scale of an experiment ... I think, for a while, we could have gone without hearing about legal issue at all". Their respective initiative was discontinued for other reasons.

A. Lack of Laws and Resultant Regulatory Uncertainty

Interview Participant B stated that a key barrier of the law "is by not being there", with Interview Participant A also having identified this barrier: "That actually probably would be ... the biggest headache. Not necessarily the laws around it, but the lack of laws". This barrier is echoed in the literature with "lacking regulation" identified as one of the challenges to blockchain for circular economy transitions in Böckel et al.'s review of 57 research and practice items [22].

The lack of laws results in uncertainty and perceived risk, as it leads to reactive (rather than proactive) legislating. Interview Participant A observed "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". There is thus a risk of sudden changes, which generates perceived risk: "the more ambiguous it is, [the more problematic] ... Partners might not like the fact that there's ambiguity" (Interview Participant A). A recent example of such a sudden (but not necessarily unexpected) change was China's recent announcement to ban cryptocurrencies [37]. Even though this ban is not on blockchain, most reported existing blockchain-based initiatives promoting circular waste practices rely on cryptocurrency payments [19], including initiatives by Agora Tech Lab [38], the Bounties Network [39], Plastic Bank [40], and Recyclebot [41].

Several factors may contribute to the rationale for a lack of laws, including the challenges of regulating "fast-moving vocabulary" and the resultant "unstable verbal terrain" (e.g. blockchain is also referred to as distributed ledger, shared ledger, consensus ledger; public blockchains may be called permissionless or open blockchains; and the names of different parties involved in operating the databases or ledgers include miners, nodes, and validators) [42]. The changing language also indicates that blockchain is still an evolving technology, which also poses challenges. This is an area that warrants further research; theories of anticipatory regulation [43] or responsive regulation [44], for example, may contribute to resolving some of the uncertainty challenges.

B. General Data Protection Rules

Interview participants also identified risks and uncertainties surrounding General Data Protection Rules (GDPR): e.g.

"GDPR ad blockchain aren't particular best friends" (Interview Participant D). Tensions between GDPR and blockchain have been identified in the literature, including between: (1) the right to be forgotten versus the irreversibility/immutability of records, (2) data protection by design versus tamper-proofness and transparency of blockchain, and (3) data controller versus decentralized nodes [45] (see also [46], [47] as well as [20] for privacy issues in relation to waste management specifically).

The contradictions between blockchain and GDPR are, however, not unassailable [45], with Interview Participant D discussing their initiative's hybrid solution: "So what we do is we not only hash the data, but we allow for adding a password to that data, meaning that even with quantum computing, the password still needs to be there to calculate back the hash. So that package, that envelope, that's what we store on the blockchain".

V. Regulatory Opportunities

As mentioned throughout this paper, there are opportunities for blockchain-based approaches to support circular economy laws. This section describes two such examples — extended producer responsibility and the right to repair — by setting out the legal requirement, the possible role of blockchain, and any uncertainties in relation to blockchain that remain.

A. Extended Producer Responsibility

Extended producer responsibility is a measure where responsibility for waste management remains with the product producer instead of transferring to consumers with ownership. Such responsibility may be physical responsibility, economic responsibility, liability, or informative responsibility [48]. There are global examples of extended producer responsibility, including within the EU under Article 8 of the Waste Framework Directive 2008/98/EC. This states that that such measures "may include an acceptance of returned products and of waste that remains after those products have been used" by "any natural or legal person who professionally develops, manufactures, processes, treats, sells or imports products" (Article 8(1)). This requires the final waste holder to have knowledge of the natural or legal person identified as responsible (which will depend on the particular implementation of the extended producer responsibility). This is where blockchain may contribute: its ability to provide provenance information.

There are, however, obstacles with such application. For example, how would this information be available to the waste producer? If it is through the use of, for example, a barcode or Quick Response (QR) code linked to a blockchain listing the producer or other relevant natural or legal person, there are challenges such as the possible breakdown of materials (where to place this tag in case of material breakdown, e.g. consider plastics and microbeads; how to tackle removals of codes) [20], [49]. Comparable blockchain applications are being considered within the building and construction sector in relation to material passports, which will also have to consider similar issues [50], [51].

B. Right to Repair

There are some recent developments in relation to the right to repair in law. These generally all seem to do with requirements to provide information that needs to be accessible to specified users.

As part of France's Anti-Waste and Circular Economy Law 2020, there is a requirement for producers, importers, distributors, and other sellers to provide a repairability index of electrical and electronic equipment free of charge to inform the consumer about the ability to repair the product. This index aims to: inform consumers about those products that are easier to fix; extend lifecycles (including through encouraging consumers to repair damaged products); provide an economic benefit to consumers; and create competition among producers to design products in the interests of the environment and consumer. Currently the index covers smartphones, laptops, televisions, washing machines, and electric lawnmowers, but expected that more products are to be added to the list. From 1 January 2024, these entities should also provide a durability index to complement the repairability criteria.

Blockchain could be helpful for similar reasons to extended producer responsibility, as well as similar challenges, discussed in the previous Subsection V-A. This again underlines that traceability offered by blockchain (with its critical contribution of being able to provide provenance information) is a key contribution of blockchain to the legal landscape of circular economies (see Section III-A).

VI. Conclusion / Concluding Remarks

The paper highlights may be summarized as follows:

- There is only limited recognition of the contributions blockchain can make to regulating circular economies both within practice and research.
- Anecdotal evidence suggests that two key regulatory challenges to blockchain applications for circularity are the lack of laws and resultant regulatory uncertainty and perceived risks, as well as GDPR concerns. Neither of these challenges have been identified as insurmountable.
- Opportunities for blockchain application to support regulatory measures incentivizing circular economies — generally to support monitoring and tracking of provenance —- need to be further explored.

Further research is warranted in each of these areas, such as: How can emerging and evolving technology be integrated more effectively within circular economy laws? Can theories of anticipatory or responsive regulation help inform regulatory approaches to blockchain to overcome and avoid some of the challenges related to the lack of laws? Throughout such investigations, it is critical to remember that blockchain application should not be the driver of circular economy laws; approaches need to be problem- rather than solution-based. Even where blockchain is identified as part of the solution, it is only one part of a much bigger puzzle of different mechanisms and technologies.

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