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BLOCKCHAIN BASED WASTE MANAGEMENT

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Purpose: The reason for writing the paper is the fact that there is a global waste and resource crises that necessitate more sustainable waste management practices, comprising redirecting waste streams once sent to landfill or incinerated to be reused, recycled, or recovered instead. Blockchain waste management platform could be used by the waste management (WM) authorities to achieve sustainable sanitation.
Design/methodology/approach: There are some fundamental issues that need to be resolved before Blockchain technology applications within the waste sector can have the desired effects for supporting sustainable waste management (e.g. lowering electricity consumption, increasing scalability of Blockchain).
Findings: The focus tends to be on economic and often environmental benefits, but social benefits, and resultant equity and justice issues, are often overlooked.
Practical implications: The application of Blockchain technology within the waste management sector is a particular example of supply chain management. Within the context of waste management, current applications of Blockchain typically focus on (1) payment or rewards facilitation and/or (2) monitoring and tracking of waste.
Social implications: Compliance with the Directive 2008/98/EC of the European Parliament and of the Council on waste by reducing overall impacts of resource use and improving the efficiency of such use.
Originality/value: For efficient results, it is crucial to introduce a modern waste management system to notice a full cycle of waste management, from how they were collected to when and where they were thrown away. Review of recent papers on these issues may be a valuable source of knowledge for interested parties.

Keywords: waste, management, Blockchain, circular economy.

Category of the paper: Literature review.

1. Introduction

As the world's population size has grown, waste generation has increased rapidly. This has had a significant effect on humanity, wildlife and the environment. As a result, governments have tried to replace traditional disposal methods, which result in pollution, with sustainable alternatives.

In the previous century, the world population grew substantially. At the same time, the world was changed by urbanisation, industrialisation and increased levels of affluence. According to D. Hoornweg et al., waste production has increased tenfold (oornweg, et al., 2013). Rubbish is being generated faster than other environmental pollutants, including greenhouse gases. Plastic clogs the world's oceans and rivers, causing flooding in developing world cities. Solid waste management is one of the greatest costs to municipal budgets. Solid waste is mostly an urban phenomenon. In rural communities there are fewer packaged products, less food waste and less manufacturing. A city resident generates twice as much waste as their rural counterpart of the same affluence. As a country becomes richer, the composition of its waste changes. With more money comes more packaging, imports, electronic waste and broken toys and appliances. The wealth of a country can readily be measured, for example, by how many mobile phones it discards. Solid waste can thus be used as a proxy for the environmental impact of urbanization. Most of a material's impact is through production and use. Less than 5% stems from waste management, which includes emissions from collection trucks, landfills and incinerators. The rate at which solid-waste generation will rise depends on expected urban population and living standards growth and human responses (Hoornweg et al., 2013).

In the opinion of Ph. Taylor (Taylor et al., 2020) global waste and resource crises necessitate more sustainable waste management practices, comprising redirecting waste streams once sent to landfill or incinerated to be reused, recycled, or recovered instead (e.g. Velenturf, Purnell, 2017; Lag-Brotons et al., 2020). To support such practices, principles and aims such as "zero waste" (e.g., Silva et al., 2016) , "circular economy" (in which wastes and resources are prevented, reused, recycled, or recovered) (e.g., Kirchherr et al., 2017; Jensen, 2022) and "resource efficiency" (e.g., Wilts et al., 2016; Resource efficiency, 2020) have been introduced.

Exploration of the suitability of Blockchain technology in overcoming these challenges is of high importance. In particular, the opportunities and challenges for Blockchain in (1)offering clarity in property rights of products and wastes, (2)supporting law and policy goals by incentivizing sustainable waste management, and (3)maintaining anonymity and privacy for institutions and individuals should be considered.

This review paper contains a short introduction to the EU Directive on waste, the issue of how digitalization can help build a circular economy ecosystem, short description of the Blockchain technology, the way how Blockchain could transform the waste management

industry and a presentation of main results of the EU research project entitled ‘Innovative training based on Blockchain technology applied to waste management – BlockWASTE’.

2. Methods and Results

2.1. Waste Directive of the EU

The relevant parts of the Directive (EU Waste Directive, 2008) are presented below. “This Directive lays down measures to protect the environment and human health by preventing or reducing the adverse impacts of the generation and management of waste and by reducing overall impacts of resource use and improving the efficiency of such use. It establishes the legislative framework for the handling of waste in the Community. It defines key concepts such as waste, recovery and disposal and puts in place the essential requirements for the management of waste, notably an obligation for an establishment or undertaking carrying out waste management operations to have a permit or to be registered and an obligation for the Member States to draw up waste management plans. It also establishes major principles such as an obligation to handle waste in a way that does not have a negative impact on the environment or human health, an encouragement to apply the waste hierarchy and, in accordance with the polluter pays principle, a requirement that the costs of disposing of waste must be borne by the holder of waste, by previous holders or by the producers of the product from which the waste came.

Waste hierarchy

The following waste hierarchy shall apply as a priority order in waste prevention and management legislation and policy: prevention; preparing for re-use; recycling; other recovery, e.g. energy recovery; and disposal”.

2.2. Circular Economy

After analysing a set of 114 definitions of the circular economy J. Kirchherr et al. (Kirchherr et al., 2017) defined it as an economic system that replaces the ‘end-of-life’ concept with reducing, alternatively reusing, recycling and recovering materials in production/distribution and consumption processes. It operates at the micro level (products, companies, consumers), meso level (eco-industrial parks) and macro level (city, region, nation and beyond), with the aim to accomplish sustainable development, thus simultaneously creating environmental quality, economic prosperity and social equity, to the benefit of current and future generations. It is enabled by novel business models and responsible consumers.

In the frames of World Economic Forum – Strategic Intelligence Division, H.H. Jensen (Jensen, 2022) most recently (Aug 25, 2022) published an essay entitled: 'How digitalization can help build a circular economy ecosystem' with a subtitle: 'Ending our reliance on finite natural resources'. The main part of the essay is as follows:

"The circular economy decouples economic growth and development from the consumption of finite natural resources. It deploys principles and strategies to achieve global climate and environmental goals while increasing competitiveness and profitability. It changes the way we produce and consume to become more resilient, more innovative and more resource efficient and it increases our supply chain flexibility. The global circular economy ensures that the concept of waste is just a comma in history. Before the industrial revolution and mass production, waste almost didn't exist; everything was reused, repaired, and regenerated. In our modern society, we see materials and products that no longer perform their original function as unusable. This practice must be eradicated. If we are to reach global climate goals, while continuing to increase global wealth, we must ensure that the concept of waste is not an integral part of our modern society. Materials and products must maintain their economic value and never become unusable; instead, they should be continuously on a journey towards their next-use." Next, H. Jensen considers the topic of circular economy as being ecosystem-centric. "The most interesting opportunities to innovate and differentiate in a circular economy rest with organizations. Companies that use the circular economy's competitive advantages collaborate with their ecosystem partners to create, capture and deliver sustainable value. By extending the lifespan of products and parts and benefitting from all usage cycles, companies improve resource efficiency, increase resilience and customer intimacy and create new income sources. The competitive circular business model operates across organizations and is ecosystem centric. This is compared to the traditional company-centric linear model, where companies primarily focus on up-front product sales to the next in line, do not consider how to create benefits throughout a product's full usage cycle and do not have a business model that incentivises them to extend the lifespan of products… It's worth noting that an outcome of improved circularity across the business ecosystems is the increased visibility afforded by digitalisation and ecosystem transparency. This is especially true in the current era of supply chain fragility."

According to H. Burdett et al. (Burdett, et al., 2021), authors of a White paper 'Circular Trailblazers: Scale-ups Leading the Way Towards a More Circular Economy', the potential of the circular economy is clear, yet the truly innovative business models and solutions that have the possibility to delink economic progress from environmental impacts have yet to scale up and achieve system-wide transformation (see the Figure 1 - visualisation of approaches to circular economy).

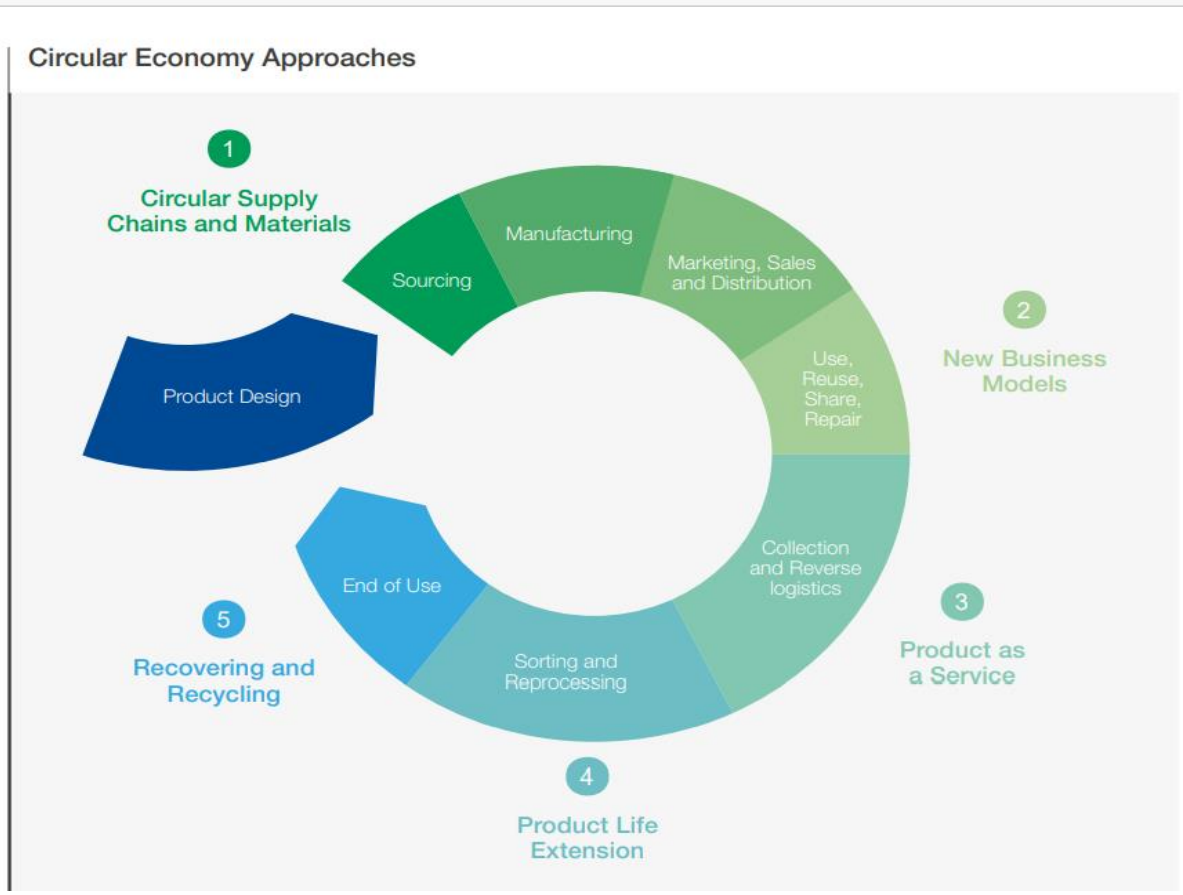

Figure 1. Circular economy approaches.

Source: World Economic Forum - Circular economy (Burdett et al., 2021), p. 6.

2.3. Blockchain Technology

There are many publications on the Blockchain technology. The book *The Real Business of Blockchain* is outstanding and one of the first books on this transformative technology written for business leaders (Furlonger, Uzureau, 2019). In this paper a following, recently published, short explanation of the Blockchain technology is presented (Ni Chulain, 2022): "Blockchains have become popular over the past few years because they allow us to secure and verify all kinds of data in a decentralised network that cannot be altered. A Blockchain is a database in the form of a distributed ledger that uses cryptography to secure any kind of information. This ledger takes the form of a series of records or "blocks" that are each added onto the previous block in the chain, hence the name "Blockchain". Each block contains a timestamp, data, and a hash. This is a unique identifier for all the contents of the block, sort of like a digital fingerprint. Crucially, once data has been recorded and verified in a block, it cannot be altered. Instead, if a change has to be made, this is recorded and verified in a new block which is then added to the chain. Each new block reinforces the verification of the previous block and hence the entire Blockchain. The block also contains the hash of the previous block in the chain. These are the backbone of a *public* Blockchain. It's important to remember that the word blockchain doesn't describe any single database or network. Rather, it's a type of technology

and there are different kinds of Blockchains that work in different ways. A *public* Blockchain like Bitcoin, allows anyone to join the network and access the distributed ledger. A *private* Blockchain is a closed network. It still uses some decentralisation and a peer to peer system, but overall this kind is controlled by a single entity and access is restricted to a defined network. A *hybrid* Blockchain is a combination of a *public* and *private* Blockchain. This kind of Blockchain allows an entity to distribute a ledger with some publicly accessible data but also restrict access to more sensitive data within the network. A *consortium* Blockchain has similarities with a *private* Blockchain only. This type of ledger is controlled by multiple entities rather than a single one".

Applications of newest developments of the Blockchain technology within the Ethereum Ecosystem – the 'Merge' (Watson, Andreoli, 2022) creates an excellent chance for numerous new implementations of this technology due to substantial lowering of electricity consumption and increasing scalability of Blockchain.

2.4. Potential transformation of the Waste Management Industry

LeewayHertz - a software development company declares that it can deliver tailor-made digital solutions to businesses worldwide (LeewayHertz, 2022). The growing waste generation rates, the issues of finding new disposal sites, depletion of landfill space, waste disposal and management methods are hampering adequate waste management. For efficient results, it is crucial to introduce a modern waste management (WM) system to notice a full cycle of waste management, from how they were collected to when and where they were thrown away. The LeewayHertz company developed a Blockchain waste management platform as a reinvention of the traditional waste management program. Blockchain waste management platform could be used by the WM authorities to achieve sustainable sanitation. Also, connecting Internet of Things (IoT) weighing sensors and Radio Frequency Identification (RFID) sensors with the decentralized network can help to generate the data and offer real-time tracking facility of the garbage trucks throughout their journey. Stakeholders involved in the Blockchain waste management system are: 1.Customers – use the platform to place the waste collection request. 2.Municipality employee or customer service officer – who places waste collection requests on customer's behalf. 3.Inspector – who is responsible for visiting the assigned sites to perform the inspection. 4.Contractors – who are responsible for waste collection and management operations. 5.Police – who can perform the legal formalities assigned to them. 6.Admin – who manages waste management system.

The company claims that the Blockchain waste management platform can provide the stakeholders with a traceable and transparent way to regulate waste management activities. Underpinning all the above elements, the waste management industry can be transformed with better tracking, storing, collecting and interrogating of the data facility – ensuring trust and fairness to the system.

3. EU research project 'BlockWASTE'

In the period of 24 months (01-10-2020 to 30-09-2022) a Consortium of five European Universities representing Estonia, Germany, Greece, Netherlands and Spain conducted a research project entitled 'Innovative training based on Blockchain technology applied to waste management – BLOCKWASTE' in the field of Cooperation for innovation and the exchange of good practices and Strategic Partnerships for higher education (EU research project BlockWASTE, 2022). The brief project description is as follows: "The BlockWASTE project aims to address the interoperability between waste management and Blockchain technology and to promote its proper treatment through educational training, so that the data collected is shared within a safe environment, i.e. a room of certainty and trust between all parties involved. For this purpose, the objectives of the BlockWASTE project were: To conduct research on solid waste generated in cities and the way it is managed, so that it can be used to create an information base of good practices that allows waste management units to reintroduce waste into the value chain, promoting the idea of Intelligent Circular Cities. To identify the benefits of the Blockchain Technology within the municipal waste management process. To create a study plan that allows the training of teachers and professionals of organizations and companies of the sector in the overlap of the fields of Waste Management, Circular Economy and Blockchain Technology. To develop an interactive tool based on Blockchain Technology which will make it possible to put into practice the management of data obtained from urban waste, thus visualizing the way in which the data is implemented in the Blockchain and enabling users to evaluate different forms of management". The results of the project are addressed to:

- Enterprises and SMEs, IT professionals, urbanisms and waste management professionals.
- Universities (professors, students and researchers).
- Public bodies.

In this project following technical documents were published (Technical documents – BlockWaste, 2022): Handbooks of Circular Economy strategies applied to Municipal Waste Management using Blockchain technologies. 1. Handbook 1: Waste management and Circular Economy. This document presents the main definitions and characteristics of Municipal Solid Waste (MSW), management practices, as well as policies and instruments in MSW management towards Circular Economy (CE). 2. Handbook 2: Blockchain. This document describes and explains the basic principles of Blockchain. It describes what Blockchain is, when you can use it, what components a Blockchain is made up of, what Blockchain technologies are used and it gives a description of various successful Blockchain applications. 3. Handbook 3: Blockchain-based Municipal Waste Management. The aim of this Handbook 3 is to guide professionals in the waste management sector on how they should implement IoT and Blockchain technology as strategies of Circular Economy. Therefore, it is addressed to

practitioners knowing about the advantages of using the Blockchain technology as well as having a sufficient understanding of the Circular Economy and its goals. 4. Guideline notes and functional specifications. This report sets out the guidance notes and functional specifications of the interactive tool. These functional specifications and user guidance serve as an ongoing reference point for the lead developer of the task to write the programming code. This document shows the visual appearance of the user interface and the description of each of the possible user input actions. 5. Municipal waste management curriculum using blockchain technology. 6. Building the Collaborative Platform. This document presents the results of the Activity "Building the Collaborative Platform." (Collaborative Platform – BlockWaste, 2022). The first stage of this Intellectual Output builds on the creation of a Collaborative Platform based on previous Erasmus+ projects related to waste management and Blockchain, in order to:

- Establish synergies with those previous experiences.
- Take advantage of the training materials, curriculum and reports that have been carried out.
- Enhance the impact of these previous Erasmus+ projects.

All the collection developed has been compiled in the report 'Open educational resource' (Oer, 2022), where one can find projects related to the topics of the project.

Discussion

The Blockchain technology is a new branch of study that has not yet been widely implemented in curricula. That is why results of the EU Project 'BlockWASTE' may serve as a base for the beginning of the training in Blockchain technology, demonstrating, through its implementation in the solid waste management, its applicability in the Circular Economy.

Summary

The world is gradually moving towards the concept of Circular Economy where the consumption of raw materials and energy is reduced by re-using waste and inserting them in the production cycle, by producing energy from waste and by increasing the rate of recycling. This transition requires a reform in higher education curricula that deal with these subjects. The Blockchain technology was born to support any sector if it applies this technology properly, such as the insurance sector, health, transport and logistics, industry (waste management, product quality, process verification, etc.) and many others, because it can help them to improve the management of the company, and to discover and exploit new business models. To identify

the benefits of the Blockchain technology within the municipal waste management (MSW) process research on solid waste generated in cities and how it is being managed is continued, so that it can be used to create an information base of good practices, to reintroduce waste into the value chain, promoting the idea of Intelligent Circular Cities. An interactive tool based on Blockchain technology was developed, which will make it possible to put into practice how the data obtained from urban waste would be managed, thus visualizing the way in which the data is implemented in the Blockchain and being able to evaluate different forms of management. In order to address the interoperability between waste management and Blockchain technology and to promote its proper treatment an educational training should be organized, so that the data collected is shared within a safe environment, i.e. a room of certainty and trust between all parties involved.

Applications of newest developments of the Blockchain technology within the Ethereum Ecosystem – the 'Merge' (Watson, Andreoli, 2022) creates an excellent chance for numerous new implementations of this technology due to substantial lowering of electricity consumption and increasing scalability of Blockchain.

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