Blockchain Applications for Waste Management

Analysis of Blockchain use cases in waste management and general guidance for starting Blockchain projects

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BlockWaste

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1 Introduction

1.1 Description of the BlockWASTE project

This comparative study is part of the BlockWASTE project, which is an EU-funded Erasmus Plus project. The 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, where there is no room for uncertainty and mistrust between all parties involved in waste chains or cycles.

For this purpose, the objectives of the BlockWASTE project are as follows:

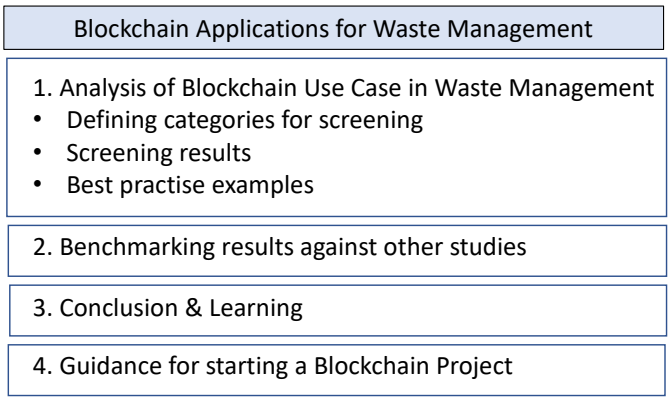
- To conduct research on solid waste generated in cities and how it is managed, so that an information base of good practices can be created that helps reintroduce waste into the value chain, promoting the idea of Intelligent Circular Cities.
- To identify the benefits of the Blockchain Technology within the municipal waste management (MSW) process.
- To create a study plan that supports 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

Further information is available from the BlockWASTE project website https://blockwasteproject.eu.

1.2 Objective of this study

The aim of this study is to learn from the analysis of best practice examples in waste management for future application in the municipal sector. The focus is on the problems that the blockchain technology can primarily solve. Blockchain is a cross-sectional technology and can be used for a wide variety of purposes. Secondly, the structural characteristics of the use cases can also be of interest, for example whether a case is a pure business solution for companies, i.e. B2B, or a business-to-consumer (B2C) or C2C solution, or whether a municipality or public administration is involved, i.e. P2C or P2B. The analysis should also reveal in which segment, or for which type of waste (municipal or industrial waste, or only one specific waste category like glass, plastics or paper) most use cases could be found.

Figure 1: Structure of the study



source: the author

The study begins with a description of the general characteristics of the blockchain applications found in waste management. Based on this, categories for screening are defined and screening results are presented and interpreted. Of course, it is questionable whether the results of a limited number of use cases (20 cases) are meaningful. Consequently, the results are compared with other studies on blockchain applications and analyzed for similarities and differences. Finally, core results are summarized, and the main findings are presented.

2 Analysis of Blockchain use cases in waste management

2.1 Characteristics of use cases

The search for Blockchain projects in waste management worldwide led to 20 use cases. The cases were identified by internet search. The results show that most Blockchain-based projects in waste management originate in the US. Surprisingly, there are only six projects from Europe, three of which are in the Netherlands. Only one project was found outside America or Europe, which was in India. While most projects were initiated by individuals or start-ups founded by individuals, there are only a few which were set up by major corporations such as Dell, BASF or Nestlé. There is only one project initiated by an NGO and one initiated by a public institution. These findings show that there is a bigger demand for sustainable blockchain waste management solutions in industry. Projects initiated by individuals highlight that one driving force of a project often defines its success, while projects set up by already established corporations provide sufficient funding for research and expertise. Use cases are listed with a brief description and internet sources in the appendix.

The relatively small number of projects documents that Blockchain applications in this area are still very new and that the knowledge about the application options of Blockchain has not yet fully reached the waste sector. Due to the mostly small scope of the projects in terms of the number of participants or the narrow spatial restriction to small test regions, it can be assumed that most of the projects are proof-of-concept applications. Usually, a prototype is developed for testing and learning, and a process simulation is carried out.

None of the listed projects had already been introduced to the market as a business case with real customers.

2.2 Predefining a set of categories for screening

For screening the use cases found (and answering question 1) it is important to predefine application categories. Projects are clustered based on five application categories:

1. "Product Documentation" includes those projects that use blockchain technology as a more or less static database for documentation. For example, producers could store material passports or repair instructions, etc. of their products in the blockchain.
2. "Certification and registration" contains cases where the Blockchain technology is used as a tool for the public registration of producers or products and the certification of public institutions. It is also conceivable that private or civil society organizations use the Blockchain for issuing product labels (eco labels etc.) and certificates.
3. "Trace and tracking of flows" within the supply and waste chain includes all projects that use blockchain technology as a database for recording transactions in chronological order with a timestamp and for recording material and payment flows. This is the documentation of a dynamic process with transactions over time. So here the focus is on the benefits of the transaction database.
4. "Tokenization" includes projects that use the Blockchain technology to generate digital values to design an incentive system or to generate tokens that contain usage rights for the joint use of objects.
5. "Automation of processes by smart contracts, IoT and AI" includes projects that use blockchain technology to automate processes by smart contracts, Internet of Things devices and AI data analysis.

Since blockchain technology can perform multiple functions within a project, all projects can be assigned to multiple categories simultaneously.

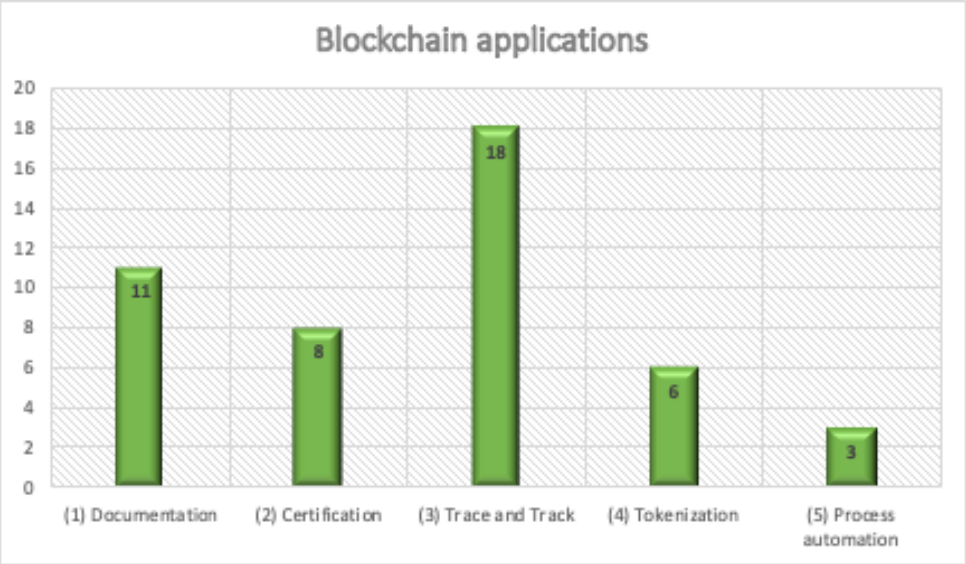
Further categories for the screening process of use cases were defined as

a. the stakeholder group, i.e. whether a project is an B2B, B2C, C2C, P2B or a P2C case and

b. the type of waste: municipal waste (solid waste), industrial waste, glass, plastics, food or prescription waste

2.3 Screening results

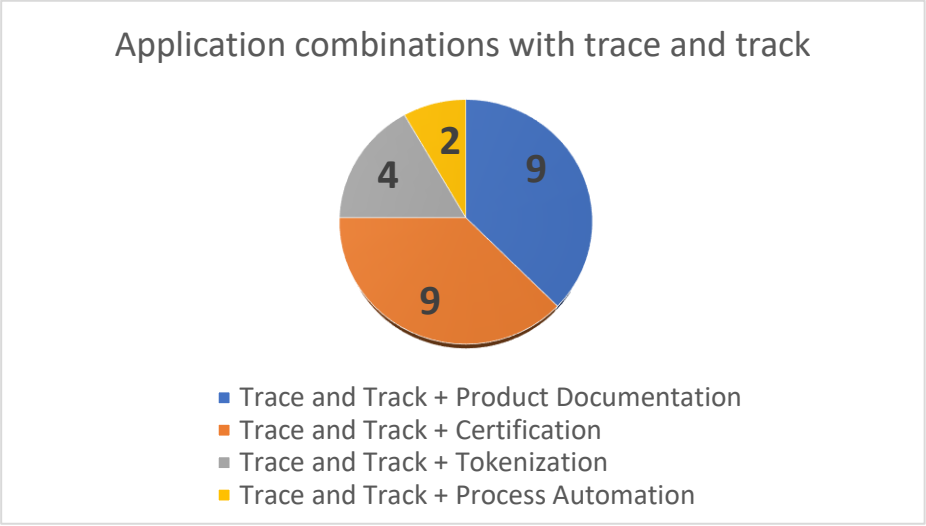
Figure 2: Screening results “Blockchain application”



Source: the author

Of the twenty projects that were assessed, eighteen can be categorized as used for tracing and tracking. Here it is important to say that when categorizing the projects, multiple answers were possible. Still, almost all projects make use of Blockchain as a technology that supports the tracking of material flows along the supply chain. The trace-and-track function of Blockchain technology appears most often in combination with certifying or documenting flows of material. This is most likely due to the fact that the process of tracking the movement of material along the supply/waste chain goes hand in hand with not only documenting said flow, but facilitates the issuing of certificates or labels verifying the place of origin etc.

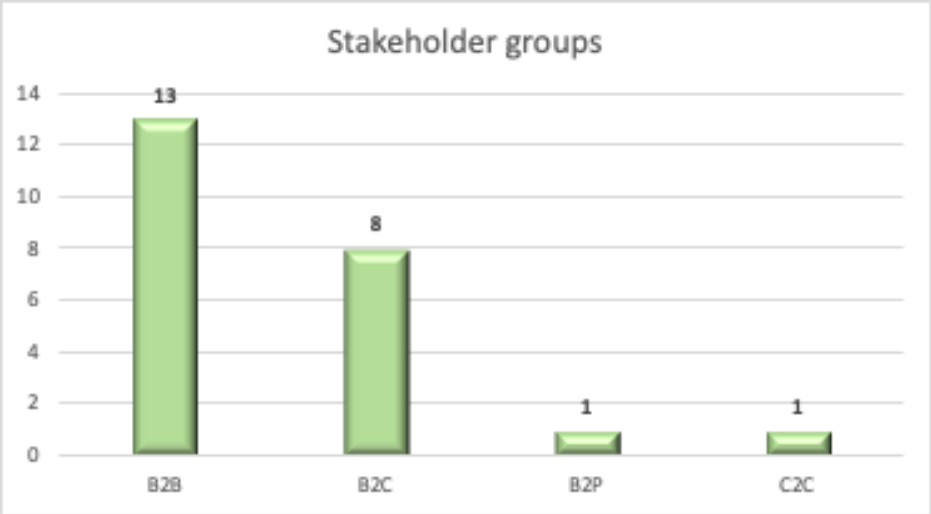
Figure 3: Using trace-and-track function for a second purpose



Source: the author

The usage of mainly these functions of Blockchain technologies can be explained by looking at the stakeholders involved in the different projects. The majority of projects are aimed at B2B relations. This, next to the fact that most projects were initiated by corporations or start-ups, leads to the conclusion that there is a strong interest on the part of certain industries to take advantage of Blockchain technologies to increase profitability. In transactions between businesses, the verification and documentation of material flows and movements along the supply chain is indispensable. By using Blockchain technology, the process of documenting, tracking and certifying can be run automatically without the need for manpower. Interestingly, all projects are focused either on B2B or B2C relations. Only two projects give attention to different business relations, namely B2P and C2C.

Figure 4: Stakeholder groups involved



Source: the author

The more unsorted and undifferentiated waste is, the more difficult it is to trace and track it using sensors, cameras or AI applications. The more specific waste is, such as plastics, glass or paper, the easier it is to set up a tracking system for monitoring the flow of material. A screening of the Blockchain use cases according to the types of waste resulted in the following picture:

Figure 5: Types of waste

Source: the author

Most projects deal with either municipal waste, industrial waste or plastic waste, given that those types are most damaging to the environment (plastics) or easiest to win resources from (industrial).

2.4 Three best practice examples

The following three best practice examples are standing out because of valuable partnerships with companies or organizations already working in the field of circular economy or blockchain that ensure funding and expertise. In addition, the selected best-practice examples are inspiring, as their blockchain applications, such as their trace-and-track approach or their tokenization, could possibly be transferable to other areas of waste management.

Excess Material Exchange (EME) is a B2B technology start-up which identifies, sorts and matches industry waste. The waste-matching does not only provide for more transparency of resource passports and tracing and tracking but also evaluates financial and environmental costs. This assures reliable information about the lower ecological footprint at lower costs. With their clear, transparent website it is easy to follow EME`s impact. The project is inspiring as it combines identifying and evaluating excess material with reusing the material in the most efficient way, using different blockchain features such as a resource passport and automated smart contracts for matchmaking.

RemediChain is a Blockchain project which aims at reducing prescription waste. Founded initially by a pharmacy and a university, its pool of supporters has grown rapidly in the past. RemediChain uses Blockchain technology to trace and track prescription drugs from individuals that are not needed or wanted anymore, collect them and redistribute them to people that are in need of them but cannot afford to buy them the regular way. If an individual is unsure of how to dispose of prescription waste, the project also offers to collect it and dispose of it in an environmentally friendly way. Even if the ways

in which Blockchain technology is used here are rather common, the impact the project creates is enormous. It found a sustainable solution to a very specific waste problem and by doing so, is helping people in need.

Plastic Bank is a B2C social startup headquartered in Canada that builds recycling ecosystems in developing countries. It establishes required collection points and offers a single price for plastic waste. Collectors of plastics receive rewards for the material they collect, which can be used for basic needs like food. Through Plastic Bank's blockchain, all transactions are stored so that collectors receive the exact value they are entitled to. Moreover, in addition to traceability, the blockchain enables transparency and rapid scalability. The project is inspiring because the Plastic Bank's incentive system might be transferable to the area of municipal waste.

3 Benchmarking results with findings of other studies

Both topics, blockchain technology and the circular economy, are relatively new, at least from an academic point of view, and thus there are few studies on the application of blockchain in the circular economy. The area of waste management within the circular economy is even more specific and limits the small number of studies even further.

3.1 PwC-Study 2018 - 65 Blockchain use cases for the environment

In 2018 PwC (2018) published a study titled "Building bock(chain)s for a better planet: Fourth Industrial Revolution for the Earth Series" based on the analysis of 65 blockchain use cases for the environment. "*Blockchain use-case solutions that are particularly relevant across environmental applications tend to cluster around the following cross-cutting themes: enabling the transition to cleaner and more efficient decentralized systems; peer-to-peer trading of resources or permits; supply-chain transparency and management; new financing models for environmental outcomes; and the realization of non-financial value and natural capital.*"

After analysing the 65 use cases, PwC identifies 8 main benefits of blockchain applications for the environment. The following table summarizes these in brief.

Figure 5: PwC results at a glance

1. 'See through' supply chains Transactional data throughout the supply chain can be recorded through the blockchain and an immutable record of provenance (i.e. origin) can be created, offering the potential of full traceability of products from source to store. Providing such transparency creates an opportunity to optimize supply-and-demand management, build resilience and ultimately enable more sustainable production, logistics and consumption.
2. Decentralized and sustainable resource management Blockchain could initiate a fundamental transition to global distributed utility systems. Platforms could collate distributed data on resources (e.g. household-level water and energy data from smart sensors) to end the current asymmetry of information that exists between stakeholders, enabling more informed – and even decentralized – decision-making with regard to system design and management of resources.
3. Raising the trillions: new sources of sustainable finance Employing blockchain-enabled finance platforms could potentially revolutionize access to

capital and unlock potential for new investors in projects that address environmental challenges – from retail-level investment in green infrastructure projects to charitable donations for developing countries.
4. Incentivizing circular economies If harnessed in the right way, blockchain could fundamentally change the way that materials and natural resources are valued, incentivizing individuals, companies and governments to unlock financial value from things that are currently wasted, discarded or treated as economically invaluable. This could drive widespread behaviour change and help to realize a truly circular economy.
5. Transforming carbon (and other environmental) markets Blockchain platforms could be harnessed to use cryptographic tokens with a tradable value to optimize existing credit management platforms for carbon (or other substances) and create new opportunities for carbon credit transactions.
6. Next-gen sustainability monitoring, reporting and verification Blockchain has the potential to transform both sustainability reporting and assurance, helping companies manage, demonstrate and improve their performance, while enabling consumers and investors to make better-informed decisions.
7. Automatic disaster preparedness and humanitarian relief Blockchain solutions could be transformational in terms of their ability to improve disaster preparedness and relief effectiveness
8. Earth management platforms New blockchain-enabled geospatial platforms are in the early stages of exploration and could monitor, manage and enable market mechanisms that protect the global environmental commons – from life on land to ocean health.

source: PwC (2018)

If PwC's results are reduced to the main advantages of blockchain applications, ignoring the sector-specific advantages mentioned such as new financing opportunities, transformation of the CO2 market, automatic disaster preparedness and earth management platform, then four main advantages remain: traceability of material flows in supply chains, decentralization, incentivizing and monitoring, reporting and verification. These results are largely consistent with the screening results and the results of the previous analysis on the potential of blockchain applications in waste management.

3.2 Climate-KIC – 2019 - 14 material-oriented Blockchain applications

In 2019 Climate-KIC (2019) analyzed 14 existing material-oriented blockchain applications based on the following set of categories:

Figure 6: Set of categories used by Climate KIC

Resource Efficiency enhancement To make sharing economy models attractive by removing middlemen and/or creating a blockchain-based identity system. To enable direct financing of sustainable projects
Resource Tracking To record transactions openly, indefinitely and immutably, enhancing the transparency and trust in the information provided. To empower consumers in their consumer decisions
Resource Pricing

To create more efficient credit management platforms. To create a cap-and-trade system considerably automated with smart contracts against politicians chasing their political agendas
Complementary Currency To create financial accounting and macroeconomic systems with rules different from the current monetary systems

source: Climate-KIC (2019)

Based on the Climate-KIC (2019, p. 15) report most use cases *"..concentrate in the use of complementary currency or 'coin' to reward stakeholders for participating in various stages of the waste recycling or recovery process. Besides, there are several blockchain applications designed to enhance resource efficiency and track resource along the value chains for increasing the recoverability of waste materials. Nonetheless, it is observed that only one blockchain application (Cycled, Norway) which is deemed close enough to waste resource pricing – supposedly the most cost- effective mechanism to achieve circular economy."*

Results of the analysis of 14 use cases in the area of waste management show that two motives are at the forefront of blockchain applications: reward and incentive systems via coins and tokens, and the tracking of resource flows. It is not surprising that these results coincide with the results of the screening, as half of the use cases considered are found in both studies (Climate-KIC 2019 and PwC 2018), even though the investigations were carried out independently and at different times.

3.3 Böckel/Nuzum/Weisbrod – 2020 - 12 Blockchain use cases in Circular Economy

In 2020 Böckel, Nuzum, and Weissbrod (2020) published an article entitled "Blockchain for the Circular Economy: Analysis of the Research-Practice Gap". The analysis revealed 12 different use cases. Ranked by frequency, the 12 use cases covered material passports, asset tracking, tokens, behavioural incentives, smart contracts, and trust mechanisms among others. This confirms the results of the screening of the use cases, even if the results are not directly comparable as the study of Böckel et al. (2020) refers to the circular economy in general and not specifically to waste management. However, the other results of the analysis of 30 academic research items (articles in journals etc.) and 27 practice items are as well interesting and are summarized in the table shown below.

Figure 7: Overview of structural dimensions and analytical categories

Table 6
Overview of structural dimensions and analytical categories.

Structural dimensions	Analytical coding categories ordered by frequency
Technical properties	1) permissions and data rights, 2) technical properties of specific use case, 3) combination with other technologies, 4) data processing, 5) brief information about blockchain type
Contexts	1) supply chain, 2) logistics, 3) plastics, 4) construction, 5) manufacturing, 6) waste management, 7) audit, certificates, 8) various, 9) agriculture, food, 10) smart cities, 11) mining, metals, 12) sharing economy, 13) small, medium companies, 14) electronics, 15) retail, 16) green marketing, 17) accounting, 18) life cycle analysis, 19) government, 20) energy, 21) clothing
Use Case	1) material passports, 2) smart contracts, 3) asset tracking, 4) incentivization, 5) cryptocurrency, 6) product deletion, 7) token, 8) credit rating, 9) trust mechanisms, 10) distributed ledger, 11) leasing, 12) escrow
Benefits	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, 13) other
Challenges	1) accessibility/ complexity, 2) energy use, 3) security/ privacy, 4) acceptance of the technology, 5) false initial information, 6) scalability, 7) reluctance of sharing information, 8) inefficiency, 9) lacking regulation, 10) lacking maturity of the technology, 11) high costs, 12) risk of centralization, 13) interoperability/ standardization, 14) other
R-Strategies	1) reduce, 2) reuse, 3) recycle, 4) recover

source: Böckel et al. (2020, p. 532)

It is striking that the blockchain applications were mostly examined in the context of supply chain and logistics and that the traceability of goods as well as data security and privacy were seen as the main advantages. These results are also largely in line with the previous analysis and the results of the screening.

3.4 Ahmad et al – 2021 – Blockchain for waste management in smart cities

In 2021 Ahmad, Salah, Jayaraman, Yaqoob, and Omar (2021) published a paper titled "Blockchain for Waste Management in Smart Cities: A Survey". It compares existing Blockchain-based solutions proposed for waste management in smart cities either as implemented use cases or as theoretical proposals in an academic paper. The table below summarizes results of the comparison.

Figure 8: Comparison of existing Blockchain-based solutions proposed for waste management in smart cities

TABLE I
COMPARISON OF THE EXISTING BLOCKCHAIN-BASED SOLUTIONS PROPOSED FOR WASTE MANAGEMENT IN SMART CITIES.

Article	Waste Type	Objectives	Services	Rewards/Penalties
[10]	Electronic Waste	To efficiently manage electronic waste using an Ethereum blockchain platform in 5G- enabled environment	Asset Tracking	Rewards
[38]	Electronic Waste	To investigate the role of blockchain for waste handling in compliance with rules stated in waste management act	Waste Shipment Tracking, Auditability	Both
[64]	General Waste	To track and monitor the flow of waste across the borders in a way that is transparent	Waste Shipment Tracking, Auditability	N/A
[66]	General Waste	To connect all participants and track the waste by assuring waste data reporting on a single platform	Waste Tracking, Auditability	N/A
[34]	Medical Waste	To assure that medical waste is handled in compliance with safety rules	Waste Shipment Tracking, Auditability, Transparency	Penalties
[67]	Solid Waste	Employing a blockchain-based system for life cycle assessment of solid materials	Waste Tracking, Policy Implications	N/A
[41]	Agricultural Waste	To transparently provide incentives to the farmers against agricultural waste in waste-to-energy project	Waste to Energy, Auditability	Rewards
[40]	Domestic Waste	To efficiently manage and monitor smart garbage through a blockchain-based system	Waste Frauds, Smart Bins Monitoring	Penalties
[42]	Solid Waste	To develop an Ethereum-based system to securely transfer tokens to users as a reward for participating in waste management activities	Waste Sorting, Transparency	Rewards
[37]	Electronic Waste	To implement a blockchain-based system that can trace the assets throughout their life cycle	Smartphone Tracking	Rewards
[45]	General Waste	To highlight the processes/participants involved in waste management activities using a blockchain based system	Waste Documentation, Waste Shipment Tracking	N/A
[65]	Industrial Waste	To present a conceptual architecture of a system employing blockchain technology for the industrial wastewater management	Water Waste Monitoring, Automation	N/A

source: Ahmad et al. (2021, p. 9)

The results of this survey also confirm that trace-and-track possibilities deriving by the interaction between IoT devices and Blockchain are of particular relevance for waste management and also for compliance with waste regulations. Tracking also seems to work independently of the underlying type of waste. This is because the waste types that the solutions presented here focus on are very heterogeneous. In addition to tracking, the possibility the Blockchain offers to use digital assets either as rewards or as punishments is again highlighted.

4 Conclusion & Learning

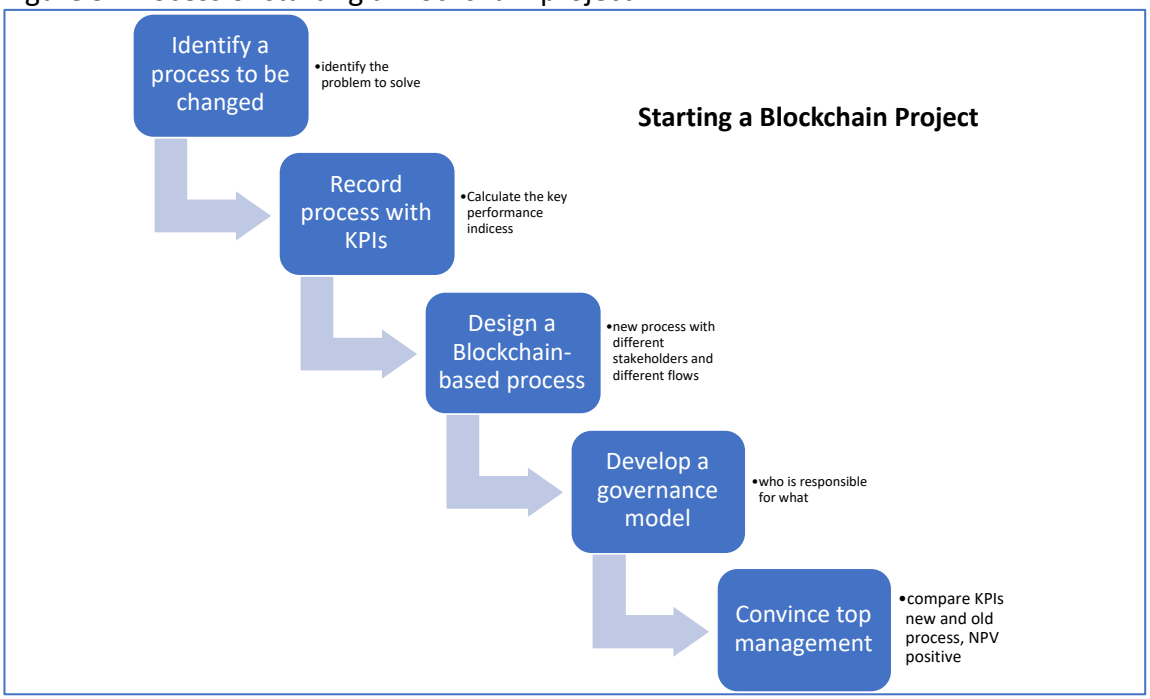
The low number of blockchain projects worldwide indicates that the diffusion process of Blockchain technology into the waste sector is still in its infancy. Most of the projects are small pilots that serve to test the possibilities and to learn. The projects have not matured into a business case but are still in proof-of-concept status. The exception is Plastic Bank, which has achieved a high degree of professionalism with the large number of supporters

on the entrepreneurial side. However, this is not a business case as it is a non-profit organisation.
Most use cases apply the blockchain as a transaction database that can, in an irrevocable and tamper-proof manner, record material flows in a value chain in a chronological order using time stamps. The advantage is that every network participant has the same information at the same time. Since the physical object must be digitally identified and replicated by a digital twin, this is easier with a specific type of waste (glass or paper, etc.) than with unsorted residual waste.
It is interesting that the trace-and-track option is primarily used for the documentation of a process, i.e. for auditing and certification. This probably reflects the high demand of consumers for transparency in the supply chain of products. On the other hand, the low number of token cases in connection with the trace-and-track function is surprising as the combination of both is promising. Tokens used as incentives and trace-and-track measuring changes in behaviour resulting from incentives are optimal processes. The Plastic Bank can serve as a best-practice example here which optimally interlocks both functions.
However, the other studies also show the high importance of token applications for designing incentive and reward systems. When it comes to peer-to-peer reward systems, the blockchain as a decentralized infrastructure for transferring digital values within a P2P-network combined with smart contracts to automate payment is ideally suited.
The majority of blockchain applications are business projects, mostly B2B applications, probably not using a public but a private blockchain with limited access rights and transparency. Some NGOs from the environmental sector have also designed projects, mostly locally, and use the token function to reward environmentally friendly behaviour. Unfortunately, no blockchain projects of municipal waste management companies are listed in any study. It seems that this sector, despite its central importance for the circular economy, has not yet reached the conceptual phase of testing blockchain technology. Or to put it differently, the diffusion of technological innovations seems to take longer in the public sector.
But the public as well as municipal waste managers should not leave the field to the Producer Responsibility Organisations working in the Extended Producer Responsibility scheme when it comes to blockchain. The blockchain enables transparency and is thus ideally suited to overcome the prevailing asymmetry of information between consumers, reusers, repairers, recyclers and producers. In the requirement for collaborative interaction between those network partners, the blockchain has more the character of a public infrastructure that works well when everyone benefits from using it.

5 Rough guidance for starting a Blockchain project

The development and implementation of a Blockchain project consists largely of change management and process management work. Contrary to expectations, the selection of the technical Blockchain solution plays a subordinate role. Intensive communication, understanding each other's interests, taking staff and stakeholders along and convincing them, explaining the technical possibilities of the Blockchain in simple terms - these are the components of the success of a project and for the selection of project team members. (Lenz, 2019)

Figure 9: Process of starting a Blockchain project



source: the author

Identification of suitable process

Blockchain projects are suitable for decentralized processes with a larger number of external participants, for whom it is absolutely essential to obtain reliable information about the status of a project or process at all times. Surely every manager in a company or its organization knows such processes of cooperation with a multitude of external partners. Usually these inter-organisational processes are characterized by a high number of failures, very long lead times, high costs of monitoring and a high dissatisfaction of those involved in this process. To identify a suitable process a shift of perspective is needed: From an intra-organizational view towards an inter-organisational perspective by understanding the interests of all stakeholders involved.

Recording the process with key performance indicators

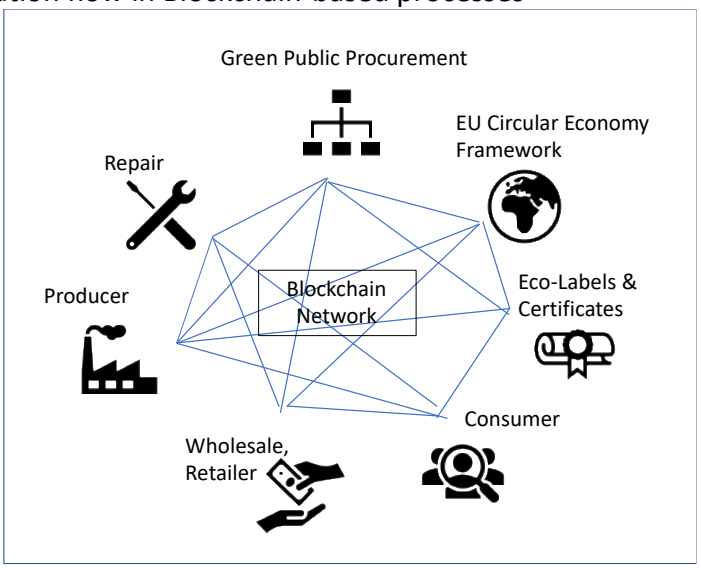
Once such a process has been identified, the next step is to record the workflow and the key performance indicators of the current process. One might assume that every company has already optimized its processes using Business Process Management software. This is often the case, but the related information is based solely on internal company data and only within the boundaries of an individual company. Most processes have never been optimized as a whole for everyone, including external partners.

The recording of the entire process with its key performance indicators can hardly be carried out by a single organization and requires the cooperation of all participants. It is recommended to record the process with simple software without a high degree of detail and to limit the selection of indicators to the most important ones, so that the coordination process and the amount of work remain manageable.

Design of a Blockchain-based process

This is the main challenge. Distributed Ledger Technology enables completely new problem solutions and therefore requires not only a deep understanding of the technological possibilities, but also the ability to think "out of the box". There are three flows to consider in process design: information flow, material flow and payment flow. The information flow will look completely different in a blockchain-based process, since the linearity of the information flow, which leads to many delays and inefficiencies, is overcome. All participants have the same information about the progress of the project at the same time. To the participants of a circular economy, the rough pattern could look like figure 10.

Figure 10: Information flow in Blockchain-based processes



source: the author

Development of a governance model

This is certainly the most important part of the collaborative process. A governance structure must be created that is shared by all stakeholders. Ultimately, it is about hierarchies and the distribution of power. Are all participating companies working together with the same rights as owners of a process, or are the rights centralized to a small circle of companies or distributed only inside one company?

In this respect, the following questions should be addressed primarily:

- Who determines participation in the business process?
- Who distributes the read and write rights to the participants in the Blockchain database?
- How is a new entry in the Blockchain validated, automatically via an algorithm, such as Proof of Work, or more centrally via Proof of Stake or Proof of Authority. The decision on the consensus mechanism determines both the scalability and the latency of such a process. As Wüst and Gervais (2018, p. 2) write: "*In centralized systems, the performance in terms of latency and throughput is generally much better than in Blockchain systems, as Blockchains add additional complexity through their consensus mechanism.*"

- Are changes in the process flow endorsed through a common, democratic agreement between the participants or via the hierarchy of the company with the highest capital?
- How is the process monitored? Are there any institutionalised solutions for disputes between participants?

It will be difficult for very hierarchical, centrally managed companies to engage in a governance model in which every participant has almost equal rights. But the economic advantages of the Blockchain solution can only be achieved if the high costs of centralized monitoring by one individual are replaced by a self-controlling, decentralized incentive system and transparency (Lenz, 2019).

Convincing top management

Ultimately, a decision to convert complex processes towards a Blockchain based transaction database with a large number of external interfaces will always be made by the company's executive board. The decisive argument in favour of testing the technology will ultimately be the prospect of considerable cost savings and higher profits. So the key performance indicators of the current process have to be compared with those of the new Blockchain-designed process.

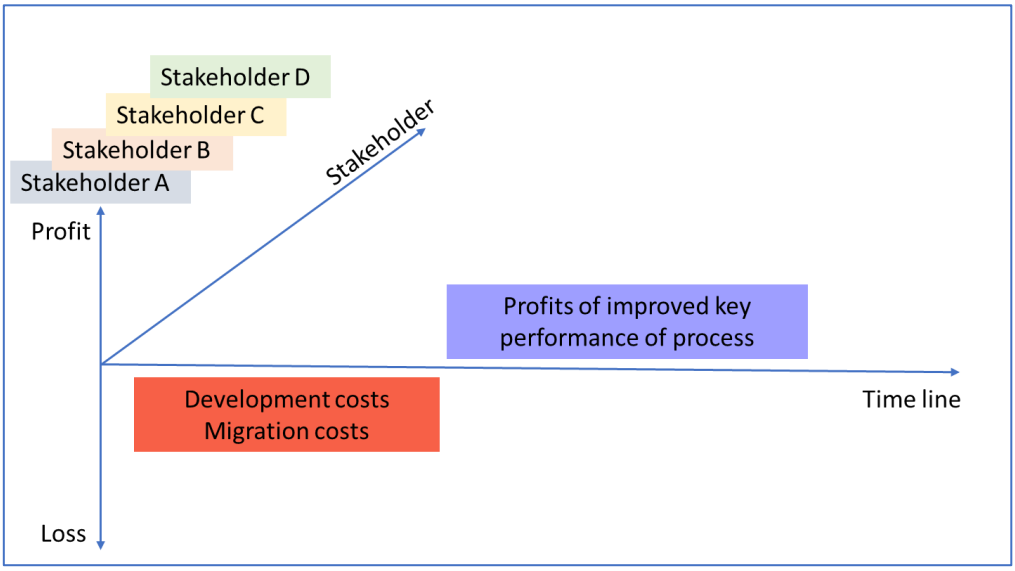
Figure 11: Convincing the management by KPIs

Key Performance Indicators	Current	Blockchain
no. of data interfaces, intermediaries, means of communication, persons involved		
Cycle time (planned, accuracy)		
Total inventory days of supply		
Cash-to-cash cycle time -> needed working capital		
Supplier fill rate -> actual delivery rate versus requested delivery rate		
On time departure from manufacturing subsidiaries to OEM		
Forecast accuracy, forecast volatility		
Monitoring and management costs		

Source: the authors

A Board would also like to have answers to the question of migration costs, i.e. the costs incurred by the conversion of the existing process. The future savings offered by a newly designed Blockchain process must clearly exceed the costs of the process conversion, otherwise such an investment would not be worthwhile. However, in a win-win-situation the net present value of such an investment must be positive for each stakeholder involved in the process.

Figure 12: Positive Net Present Value for all stakeholders?



Source: (Lenz, 2019)

If for each stakeholder involved the expected future profits exceed the initial costs of the process transformation, then the respective management can decide to carry out this investment or project. Of course, the Blockchain technology is relatively new and potential stakeholders lack experience. This naturally creates considerable uncertainty and a non-negligible risk of investment failure. Consequently, it is recommendable to start with a small simulation project that should be scalable. In the case of a successful test run, the project could be implemented on a wider scale.

References

Ahmad, R. W., Salah, K., Jayaraman, R., Yaqoob, I., & Omar, M. (2021). Blockchain for Waste Management in Smart Cities: A Survey.

Böckel, A., Nuzum, A.-K., & Weissbrod, I. (2020). Blockchain for the Circular Economy: Analysis of the Research-Practice Gap. *Sustainable Production and Consumption*.

Climate-KIC, e. (2019). *Market Analysis for Plastic waste recovery by regional blockchain networks*. Retrieved from https://ecircular.climate-kic.org/wp-content/uploads/sites/2/2019/02/Market-Analysis-for-Plastic-waste-recovery-by-regional-blockchain-networks.pdf

Lenz, R. (2019). Managing Distributed Ledgers: Blockchain and Beyond. Retrieved from https://ssrn.com/abstract=3360655

PwC. (2018). Building bock(chain)s for a better planet: Fourth Industrial Revolution for the Earth Series. Retrieved from https://www.pwc.com/gx/en/sustainability/assets/blockchain-for-a-better-planet.pdf

Wüst, K., & Gervais, A. (2018). *Do you need a Blockchain?* Paper presented at the 2018 Crypto Valley Conference on Blockchain Technology (CVCBT).

List of screened use cases of Blockchain application in waste management

No.	Projectname	Country	Blockchain-Category	Stake-holder	Type of Waste
1	Agora Tech Lab	NL	(3)Trace and Track (4)Tokenization	B2B	Municipal waste
2	Plastic Bank Recycling Corporation	CA	(3)Trace and Track (4)Tokenization	B2B, B2C	Plastic waste
3	Provenance	US	(1) Documentation (3)Trace and Track	B2C	/
4	Recereum	IN	(3)Trace and Track (4)Tokenization	B2B, B2C	Municipal waste
5	Swachhcoin	NL	(3)Trace and Track (5) Process automation	B2B	Municipal waste Industrial waste
6	EU Waste Transportation on Blockchain	NL	(3)Trace and Track	B2B	All types of waste
7	RecycleGO	US	(2) Certification (3) Trace and Track		Industrial waste
8	NVZN-token	US	(2) Certification (3) Trace and Track (4) Tokenization	B2B	Industrial waste
9	Naturipe	US	(1) Documentation (2) Certification (3) Trace and Track	B2C	Food waste
10	RemediChain	US	(1) Documentation (3) Trace and Track	B2C, C2C	Prescription waste
11	Recycling Traceability System (RTS by EOW	US	(2) Certification (3) Trace and Track	B2B	Glass waste
12	Recycling Traceability System (RTS by EOW	US	(1) Documentation (2) Certification (3) Trace and Track	B2B	Glass waste
13	Dell Technologies, VMware	US	(1) Documentation (3) Trace and Track	B2C	Plastic waste
14	Food Trust	US	(1) Documentation (2) Certification (3) Trace and Track (5) Process automation	B2B	Food waste
15	ReciChain	CA	(1) Documentation (2) Certification (3) Trace and Track	B2B, B2P	Municipal waste
16	Recycle-to-coin	UK	(1) Documentation (4) Tokenization	B2C	Municipal waste
17	Excess Material Ex-change	NL	(1) Documentation (2) Certification (3) Trace and Track	B2B	All types of waste
18	Circularise	NL	(1) Documentation (2) Certification (3) Trace and Track	B2B	Industrial waste (Plastics, Textiles, Metals, Automotive, Electronics & more)
19	Empower	NO	(1) Documentation (2) Certification (3) Trace and Track	B2B	Plastic waste
20	Naturecoin	CA	(4) Tokenization (5) Process automation	B2C	Plastic, Tins, Cans

1. Agora Tech Lab

Project	Initiator	Country	Blockchain	Stakeholder	Type of Waste
Agora Tech Lab	Tony Zhao	NL	(3) Trace and Track (4) Tokenization	B2B	Municipal waste

The start-up Agora Tech Lab based in Rotterdam aims to create participatory waste management frameworks in cities using blockchain technology. On the blockchain all waste management transactions are registered. Thus, the blockchain is used as a database tracking material flows in the waste chain. Based on the record of transactions, citizens can be rewarded for recycling waste through tokens that can be exchanged for local services (e.g. free public transport, tax breaks etc). Web pages: (1) (2)

2. The Plastic Bank Recycling Corp (DBA Plastic Bank)

Project	Initiator	Country	Blockchain	Stakeholder	Type of Waste
Plastic Bank Recycling Corp.	David Katz	CA	(3) Trace and Track (4) Tokenization	B2C	Plastic waste

The Plastic Bank, headquartered in Vancouver, British Columbia, Canada, builds recycling ecosystems in coastal communities. Collectors of plastics receive rewards for the material they collect, which can be used for basic needs like food. Through Plastic Bank's blockchain, all transactions are stored, allowing collectors to receive the exact value they are entitled to. Moreover, in addition to traceability, the blockchain enables transparency and rapid scalability. Web pages: (1)

3. Provenance

Project	Initiator	Country	Blockchain	Stakeholder	Type of Waste
Provenance	Jessi Baker	UK	(1) Documentation (3) Trace and Track	B2C	/

The company Provenance based in the UK aims to create transparent supply chains and enable people to make conscious purchasing decisions. Provenance's platform based on blockchain and open data makes it possible to collect product information on the one hand and to track the entire path of products on the other. Web pages: (1)

4. Recereum

Project	Initiator	Country	Blockchain	Stakeholder	Type of Waste
Recereum		IN	(3) Trace and Track (4) Tokenization	B2B, B2C	Municipal waste

Recerum is building a blockchain-based platform that allows organizations such as municipalities to reward proper waste separation through coins. These coins can be used for discounts on energy bills for example. In addition to rewarding proper waste separation, coins are also paid out in exchange for plastic and aluminum bottles as well as batteries and electronics. Web pages: (1), (2)

5. Swachhcoin

Project	Initiator	Country	Blockchain	Stakeholder	Type of Waste
Swachhcoin	NGO	NL	(3)Trace and Track (5) Process automation	B2B	Municipal waste Industrial waste

Swachhcoin is a non-profit organization. The project is a blockchain-based approach to the micromanagement of waste from households and industries. The waste is converted into usable products such as steel, glass or plastics in an environmentally friendly way. The Swachh ecosystem is a Decentralized Autonomous Organization (DAO) that is autonomously managed based on smart contracts. Web pages: (1), (2)

6. European Waste Transportation on Blockchain

Project	Initiator	Country	Blockchain	Stakeholder	Type of Waste
European Waste Transportation on Blockchain	Public	NL	(3)Trace and Track	B2B	All types of waste

The Netherlands infrastructure ministry's Human Environment and Transport Inspectorate (ILT) monitors many border crossings of waste transports. In these processes, several agencies have to exchange information in order to manage and control the process. Administration as well as control is currently mostly done manually. However, the manual handling of the processes is time-consuming and complex. ILT is working on a solution to this problem as part of the "European Waste Transportation on Blockchain" project in cooperation with the software companies LegalThings One and Safety Changer. With the use of blockchain and mobile

apps, manual interventions are to be removed from the processes and efficient cross-border waste transportation is to be made possible. Web pages: (1)

7. RecycleGO

Project	Initiator	Country	Blockchain	Stakeholder	Type of Waste
RecycleGO	Stan Chen	US	(2) Certification (3) Trace and Track		Industrial waste

RecycleGO provides recycling services and technologies. The aim is to use blockchain and other technologies to improve the recycling system by optimizing recycling operations and verifying supply chains and carbon offsets. For example, the company offers a software solution for customer and asset management, as well as billing and route planning for haulers. Through RecycleGO's blockchain-powered ledger, businesses and governments can verify their sustainability impacts. Web pages: (1)

8. INVIZION - NVZN-token

Project	Initiator	Country	Blockchain	Stakeholder	Type of Waste
NVZN-token	Corp.	US	(2) Certification (3) Trace and Track (4) Tokenization	B2B	Industrial waste

INVIZION is developing their own crypto-currency utility token, NVZN. The token is based on the Ethereum network and is supposed to revolutionize the waste tracking system. A token contains information like certification of origin and a batch number of waste produced. When the waste moves along the waste chain, it can easily be traced and tracked on a decentralized ledger with the help of IoT technology. The final destination of the waste will be CETS Mobile Hybrid Waste-to-Energy Stations, which can turn any waste into renewable energy, minimizing the carbon footprint of waste disposal by up to 30% and reducing the costs of waste disposal by up to 20%. Web pages: (1)

9. Naturipe

Project	Initiator	Country	Blockchain	Stakeholder	Type of Waste
Naturipe	Corp.	US	(1) Documentation (2) Certification (3) Trace and Track	B2C	Food waste

Partnering with SAP, Naturipe is planning to use blockchain technology to boost transparency in the food supply chain. Products produced by Naturipe will be equipped with a QR code on the packaging. When customers scan the code, they will be able to see the certification of origin of e.g. fruit along with information on where the fruit was grown, picked, packed and how it was stored at any point along the supply chain. Web pages: (1), (2)

10. RemediChain, Lipscomb University, Good Shepherd Pharmacy

Project	Initiator	Country	Blockchain	Stakeholder	Type of Waste
RemediChain	Corp.	US	(1) Documentation (3) Trace and Track	B2C, C2C	Prescription waste

The consortium aims to reduce prescription waste by using blockchain technology. The RemediChain ledger enables the gathering of surplus drugs and medications from individual donors and their redistribution to authorized patients in need. The blockchain aids in bypassing the pharmaceutical industry as a middleman and by doing so, making it possible to sell the medication at lower prices and even distribute donated medication for free. Individual donors can also donate expired medication, which will be collected, tracked and disposed of safely. Web pages: (1)

11. Rocky Mountain Bottle Company

Project	Initiator	Country	Blockchain	Stakeholder	Type of Waste
Recycling Traceability System (RTS by EOW	Corp.	US	(2) Certification (3) Trace and Track	B2B	Glass waste

The Rocky Mountain Bottle Company has partnered with the End of Waste Foundation (EOW) to create a circular economy in the glass industry. EOW's Recycling Traceability System (RTS, formerly known as Blockchain Waste Traceability Software (BWTS)) is used to track glass waste. It enables material recovery facilities (MRFs), glass processors and glass manufacturers to track glass waste along the recycling chain. MRFs determine the quantity of glass that is being delivered to processors, who then validate the quantities and report them to manufacturers, who will validate and report them to EOW. EOW issues a glass certificate

containing the data on how much glass has avoided landfills. Glass certificates can be purchased by businesses and individuals who want to become more sustainable and offset their carbon footprint. Web pages: (1), (2)

12. Ripple Glass

Project	Initiator	Country	Blockchain	Stakeholder	Type of Waste
Recycling Traceability System (RTS by EOW	Corp.	US	(1) Documentation (2) Certification (3) Trace and Track	B2B	Glass waste

Similar to case (10), Ripple Glass is also partnering with the End of Waste of Foundation (EOW) to be able to use their Recycling Traceability System (RTS, formerly known as Blockchain Waste Traceability Software (BWTS)). Ripple Glass plans to increase recycling rates with the help of RTS as it will provide immutable data on recycling rates. RTS is connecting material recovery facilities (MRFs), glass processors and glass manufacturers to better track glass waste along the recycling chain. MRFs determine the quantity of glass that is being delivered to the processors, who then validate the quantities and report them to the manufacturers, who will validate and report them to EOW. EOW issues a glass certificate containing the data on how much glass has avoided landfills. Glass certificates can be purchased by businesses and individuals who want to become more sustainable and offset their carbon footprint. Web pages: (1), (2)

13. Dell Technologies, VMware

Project	Initiator	Country	Blockchain	Stakeholder	Type of Waste
Dell Technologies, VMware	Corp.	US	(1) Documentation (3) Trace and Track	B2C	Plastic waste

Dell is partnering with VMware to track Dell's recycled packaging items. VMware is offering blockchain technologies that track recycled plastic. Customers will be able to see the origin of the recycled material, which type of plastics it is and where it has been recovered. Web pages: (1)

14. Nestlé, Grocer, IBM

Project	Initiator	Country	Blockchain	Stakeholder	Type of Waste
Food Trust	Corp.	US	(1) Documentation (2) Certification (3) Trace and Track (5) Process automation	B2B	Food waste

Nestlé and Grocer (Carrefour) are partnering with IBM to benefit from their food trust Blockchain technology. Food Trust is a network that aims for a more sustainable and smart food industry. The technology based on blockchain tracks individual food items, giving authorized users access to information on the whole food supply chain, data on the origin and current location of individual food items, as well as certifications, test data and temperature data. Nestlé and Grocer started testing the technology with only one product but have already expanded the range of products tracked with Food Trust. Web pages: (1)

15. reciChain BASF

Project	Initiator	Country	Blockchain	Stakeholder	Type of Waste
ReciChain	BASF	CA	(1) Documentation (2) Certification (3) Trace and Track	B2B, B2P	Solid waste

BASF launched the pilot project reciChain in Canada with the aim of a more competitive circular supply chain. By using a blockchain platform with a digital badge and loop count technology, sorting, tracing and monitoring plastics have improved. Data is shared transparently amongst market participants and the lifecycle of plastics is extended. Resulting from social inequality issues, the project was first launched in Brazil to help with concerns about the issuance of recycling certificates. Web pages: (1)

16. Recylce-to-coin

Project	Initiator	Country	Blockchain	Stakeholder	Type of Waste
Recycle-to-coin	Individual	UK	(1) Documentation (4) Tokenization	B2C	Solid waste

Recycle-to-coin is a reward system issued by Blockchain Development Company (BCDC) in 2017. Using an app-based system, recycling of plastic, aluminum and steel cans is rewarded in the form of tokens. ICO failed, Website is down. Web pages: (1)

17. Excess Materials Exchange (EME)

Project	Initiator	Country	Blockchain	Stakeholder	Type of Waste
Excess Material Exchange	Individual	NL	(1) Documentation (2) Certification (3) Trace and Track	B2B	All types of waste

EME is a digital matching platform to recycle non-used (waste) materials. Their four-step-model aims to increase financial value and decrease the ecological footprint. First, the raw materials passport provides an overview of origin and detachability of the product. The passport is provided with a QR code to be tracked and traced to follow the value chains of the raw materials. The potential added financial, ecological and social value is calculated to find realistic reuse options for materials and products. Partnering with innovative partners, circular economy ambitions may become reality. Web pages: (1)

18. Circularise

Project	Initiator	Country	Blockchain	Stakeholder	Type of Waste
Circularise	Individual	NL	(1) Documentation (2) Certification (3) Trace and Track	B2B	Industrial waste (Plastics, Textiles, Metals, Automotive, Electronics & more)

With supply chain integrity and compliance, Circularise helps stakeholders to trace raw materials. Their mission is to accelerate the transition to a circular economy and enable sustainable practices on a mass scale. Web pages: (1)

19. Empower

Project	Initiator	Country	Blockchain	Stakeholder	Type of Waste
Empower	Individual	NO	(1) Documentation (2) Certification (3) Trace and Track	B2B	Plastic waste

Based on the Norwegian bottle deposit system, Empower built a global plastic waste ecosystem. A variety of plastic collection points ensure a cost-efficient collection of waste. By tracking and making digital inventories they ensure that the majority of plastics is reused and recycled. The collected plastics is rewarded by a token. Transparency allows them to ensure that plastics ends up where they have the highest value and the lowest cost to society and environment. Web pages: (1)

20. Naturecoin

Project	Initiator	Country	Blockchain	Stakeholder	Type of Waste
Naturecoin	Individual	CA	(4) Tokenization (5) Process automation	B2C	Plastic, Tins, Cans

The decentralized peer-to-peer transaction model rewards individuals for recycling. Naturecoin uses smart bins for recycling in cities. The Naturecoin app will analyze waste and calculate a reward which is provided in form of the “Naturecoins” cryptocurrency. Tourists can then exchange the coins for goods or services, e.g. transport or souvenirs. Web pages: (1)