Handbook 3:
Blockchain-based Municipal Waste Management

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BlockWASTE project
https://blockwasteproject.eu/

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Foreword

This Handbook on "Blockchain-based Municipal Waste Management" was written within the BlockWASTE project, which is an EU-funded Erasmus Plus project run by a consortium of five partners from Estonia, Germany, Greece, Netherlands and Spain – for details cf the logos on the title page.

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 are as follows:

- 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 (MSW) 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.

This Handbook *Blockchain-based Municipal Waste Management* is based on the analysis of the previous comparative studies carried out within the BlockWASTE project:

- Comparative study of municipal solid waste (MSW) management regulations in each country, https://blockwasteproject.eu/wp-content/uploads/2021/12/O1.A1.-Comparative-study-of-Municipal-Solid-Waste.pdf
- State of Digitalization in European Municipal Waste Management, Comparative Study – five EU member countries, Estonia, Germany, Greece, the Netherlands, and Spain, https://blockwasteproject.eu/wp-content/uploads/2021/10/O1.A2.1-Comparative-State-of-Digitalization-in-Municipal-Waste-Management.pdf
- Blockchain Applications for Waste Management, Analysis of Blockchain use cases in waste management, https://blockwasteproject.eu/wp-content/uploads/2021/10/O1.A2.2-Blockchain-Applications-for-Waste-Management.pdf

For further information, please visit our BlockWASTE project website https://blockwasteproject.eu

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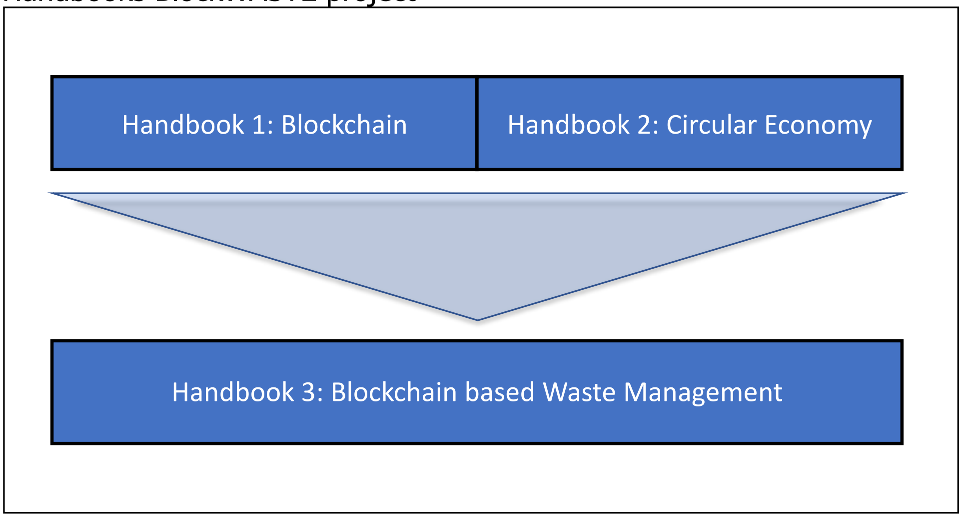
1. Introduction

The aim of this Handbook 3 "Blockchain-based Waste management" 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. For those readers with less knowledge in one of the aforementioned areas, we recommend reading either Handbook 1 (Blockchain) or Handbook 2 (Circular Economy). Manuals 1 and 2 are to be understood as a brief compendium and provide an overview of the essential content - cf fig 1.

Figure 1: Handbooks BlockWASTE project



Source: the authors

The structure of the handbook follows a deductive logic by presenting, in the first part, the changing role of municipal solid waste management within the transformation from the currently linear economic system to the Circular Economy. The focus is always on the use of Blockchain technology, which can make a substantial contribution to the transformation of municipal waste management. The three topics, the Circular Economy, the transformation of municipal waste management and the use of Blockchain technology, are interlinked and ways are shown how Blockchain technology can facilitate the needed role change of Municipal Waste Managers in various aspects. The second part of the handbook contains a clear guidance for waste managers on how to implement Blockchain Technology and to convert existing processes into Blockchain-based processes. This part provides guidance for the best use of Blockchain and smart contract technologies within the waste sector and supplies a coherent blueprint for implementation and application of these innovative technologies in municipal and local corporate organizations.

2. Transforming Municipal Waste Management within the Circular Economy

2.1. A role shift of Municipal Waste Management is needed

Municipal Waste Management's traditional role has been, ever since European cities expanded their services to citizens in the late middle ages, to collect and dispose of waste. In its operation, Municipal Waste Management (MWM) has relied on basic, mostly manual (even if automated) skills that allow the handling, treating and disposal of waste. Decision-making has mainly focused on 'What goes where' and 'How can we get it there'.

Over time, this 'linear' process has developed into a long chain most of which has disappeared from sight to the 'producers' of waste. The emerging Circular Economy breaks up and remodels this chain into a complex cycle of substance flows, data and stakeholder interventions that promises to combine sanitary, health, environmental and economic benefits. Kirchherr, Reike, and Hekkert (2017) have conducted a meta study on 114 definitions of the Circular Economy with the aim to create transparency regarding the current understanding of the Circular Economy concept. They adapted the 9R-strategies concept in original from Potting, Hekkert, Worrell, and Hanemaaijer (2017) and visualised them in the following table:

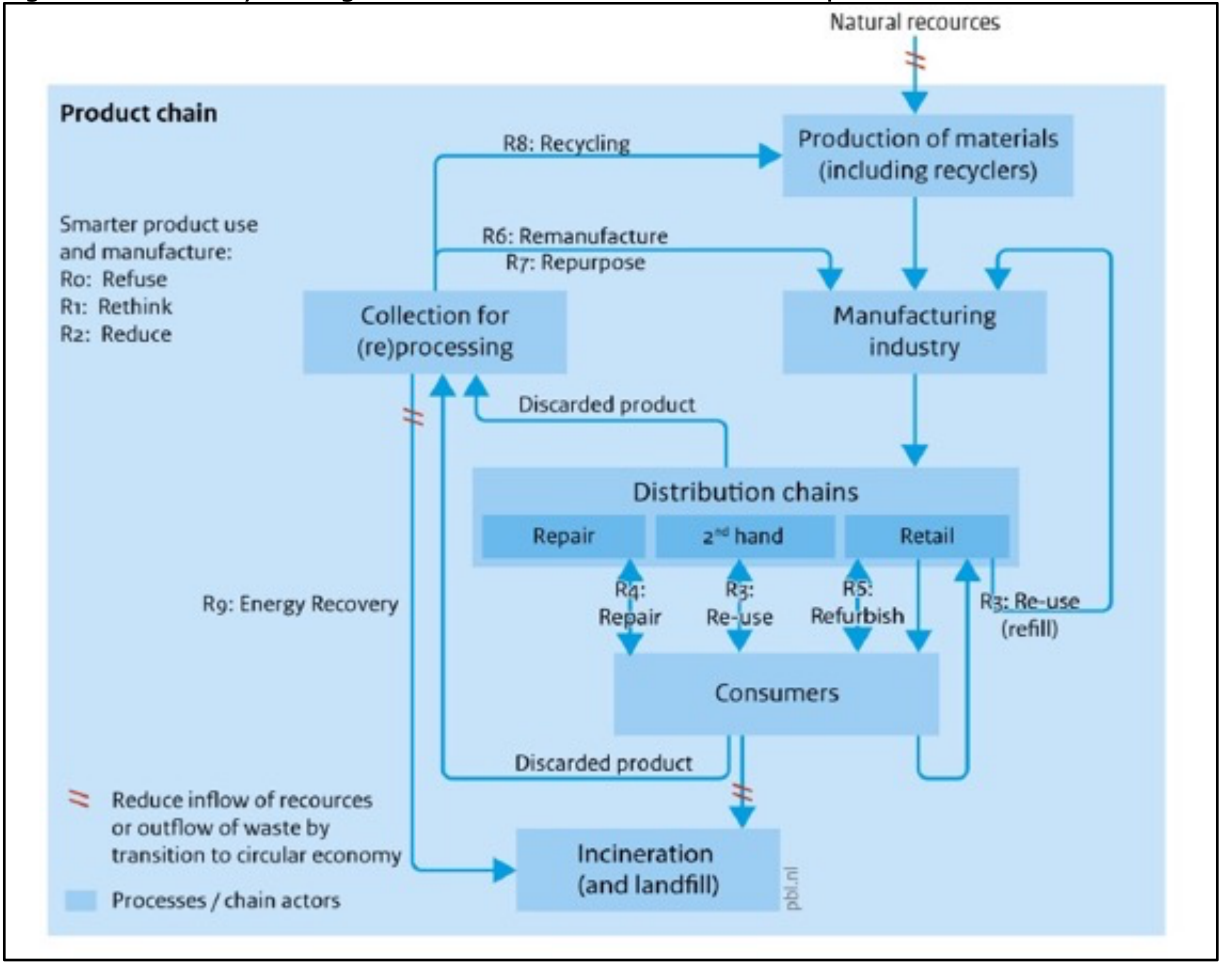
Figure 2: 9R-strategies of the Circular Economy

Circular economy ↑ Increasing circularity ↓ Linear economy		Strategies	
	Smarter product use and manu-facture	R0 Refuse	Make product redundant by abandoning its function or by offering the same function with a radically different product
		R1 Rethink	Make product use more intensive (e.g. by sharing product)
		R2 Reduce	Increase efficiency in product manufacture or use by consuming fewer natural resources and materials
	Extend lifespan of product and its parts	R3 Reuse	Reuse by another consumer of discarded product which is still in good condition and fulfils its original function
		R4 Repair	Repair and maintenance of defective product so it can be used with its original function
		R5 Refurbish	Restore an old product and bring it up to date
		R6 Remanufacture	Use parts of discarded product in a new product with the same function
		R7 Repurpose	Use discarded product or its parts in a new product with a different function
	Useful application of mate-rials	R8 Recycle	Process materials to obtain the same (high grade) or lower (low grade) quality
		R9 Recover	Incineration of material with energy recovery

Source: Kirchherr et al. (2017, p. 224)

According to Potting et al. (2017) the 9R' strategies can be visualized in a diagram documenting the collaboration of different stakeholders required in the value chain. Here it becomes clear once again how much the Circular Economy differs from the previous linear economic model of supply chains and how the complexity of material flows increases due to the multitude of connections between the actors.

Figure 3: Circularity strategies and the role of actors within the production chain

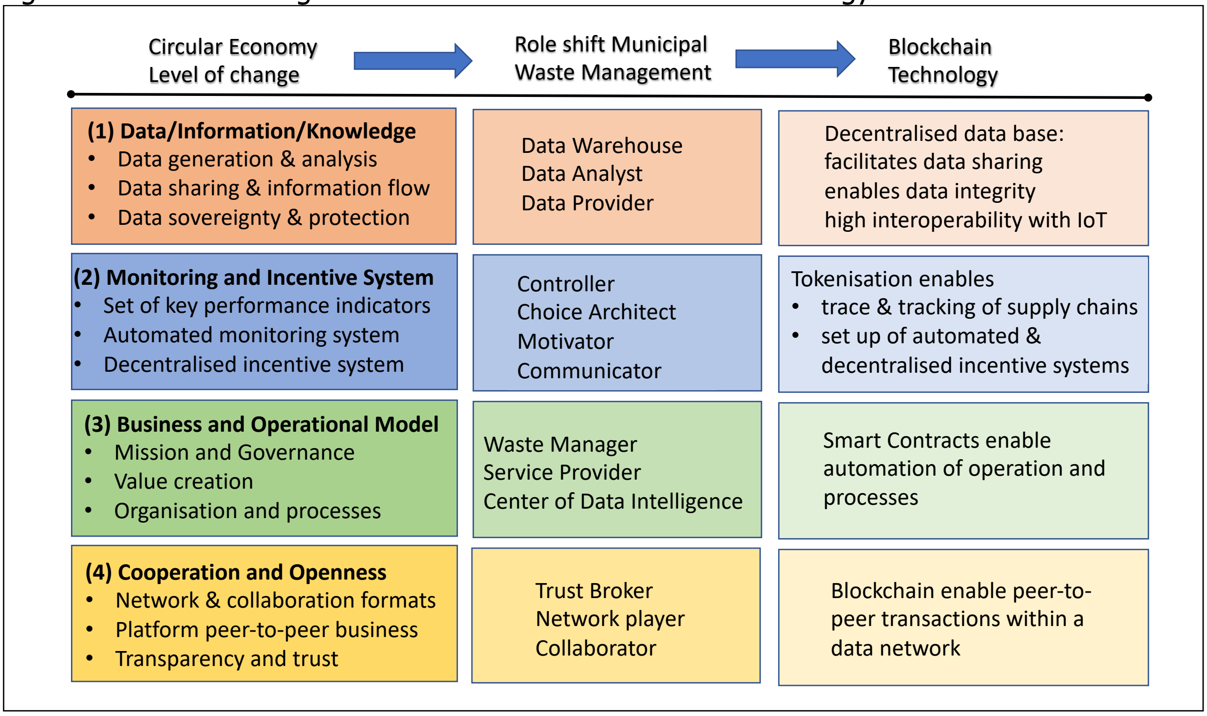


Source: Potting et al. (2017, p. 16)

This development has long been foreshadowed by recycling and reuse loops that were patched into linear waste chains. In the new world of waste, these 'loops' and especially their management are no longer to be one of several but will become the principal activity of municipal waste management organizations.

Under Circular Economy conditions, the focus of waste management organizations is no longer on disposal but on cycle management, modeling, control, and value creation. Municipal waste management finds itself at the heart of the Circular Economy as it harvests the waste streams produced by citizens and local businesses. These waste streams are to be significantly reduced, redirected, and processed in the future through prevention, reuse, repair and recycling. Municipal Waste Management's role in this is to decide whether a product or substance is to be reused, repaired, recycled as a whole, dismantled into its components in order to recycle valuable resources or processed into raw materials. Municipal waste services continue to collect the waste but will also and mainly act as distributors of raw materials and valuable objects to market participants for secondary use, for secondary recycling, for repair. This role of distribution hub that requires close interaction with service providers, product manufacturers, spare parts producers and energy producers is illustrated in figure 3. All reuse, recovery and recycling cycles pass through Municipal Waste Management organizations as waste collectors that form an entry gate to value chains that emerge in the Circular Economy. The success of the transformation of a linear into a Circular Economy is largely dependent on the performance of Municipal Waste Management.

Figure 4: Level of change - role shift MWM – Blockchain technology



Source: the authors

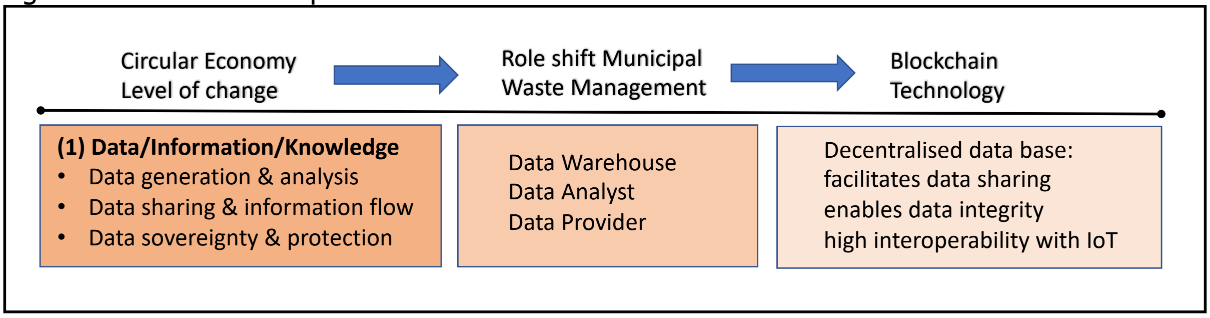
The transformation into a Circular Economy turns the current linear economic model upside down. This system change requires fundamental changes on different levels of the economy like shown in figure 4. For instance on level (1), data sharing, i.e. the information flow and knowledge about material and scarce resources inside of products between various stakeholders of the supply and waste chain becomes indispensable. But who collects, analyses and provides the data on waste for and to other stakeholders? This must be ensured by municipal waste management companies, which will act, in the future, as data warehouses, data analysts and data providers. Consequently, any level of change in the different categories of the Circular Economy implies a fundamental change in the roles and tasks of municipal waste management companies. The use of the Blockchain has a central role to play here as it facilitates the transformation from a linear to a circular economic model. For each of the necessary changes at the different levels, the use of Blockchain offers specific advantages. The decentralized concept of the Blockchain enables the necessary cooperation and collaboration between the many stakeholders in the Circular Economy.

In the following, each level of change is briefly described and the effects on the tasks of municipal waste management are outlined. The focus is always on the contribution that the use of Blockchain technology can make to achieving the goals of the Circular Economy.

2.2. Municipal Waste Data Management

In the following, the importance of the availability and sharing of data and information for the Circular Economy is highlighted and the role of the municipal waste management sector as a data provider is analysed. Finally, the function of the Blockchain as a decentralised database is highlighted. Figure 5 illustrates the pathway to a logical structuring of change actions.

Figure 5: MWM as data provider for CE

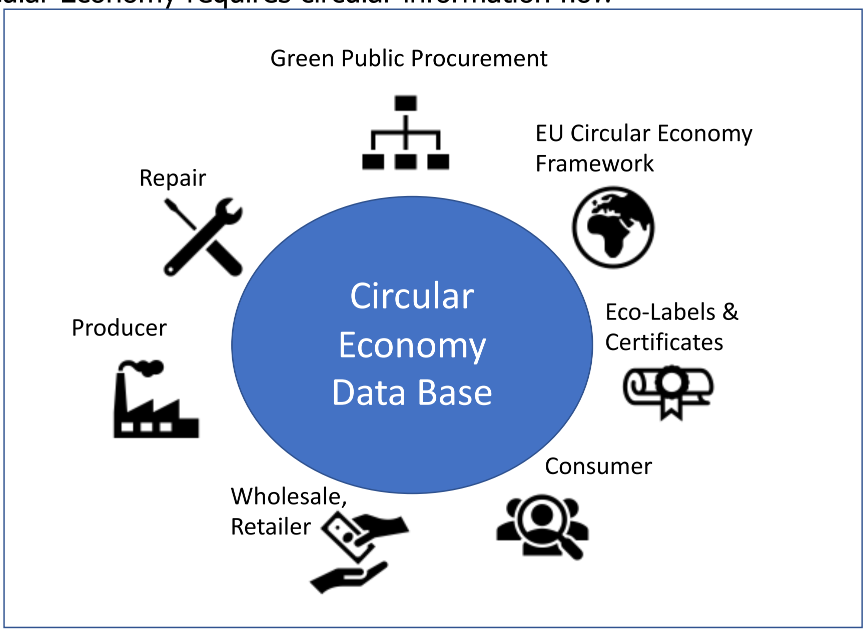


Source: the authors

2.2.1. Circular Economy requires circular information

Waste management can be effective if all stakeholders share data and information on the same platform, while each of them understands the multiple challenges posed inside each chain process. Each value chain process always consists of three flows: material flow, the opposite payment flow and information flow. The smooth and efficiently structured flow of information between the participants in the process chain is most important. If the information flow is obstructed because there are no automatic interfaces between the data silos of the companies or because media breaks slow down the information chain, then expensive delays and errors in the material flow and the payment flow will occur. In addition, monitoring costs will be enormous, because if there is no information security about the course of the process in long supply chains, permanent monitoring of the status quo will be necessary. If materials are to flow in the cycle in the future, then it is imperative that the flow of information also follows the cycle.

Figure 6: Circular Economy requires circular information flow



Source: the authors

Producers need to know when and how much of which recycled material flows back from Municipal Waste Management into their production in order to allow just-in-time planning. Wholesalers and retailers who will also offer recyclable products in the future will also wish to obtain information about the delivery and storage of these products. Consumers should be informed by producers about the longevity of the products and their environmental compatibility. In addition, consumers, producers and retailers should be informed in the future about how much waste and which categories they have put out so they can calculate fees on the

basis of actual waste output. The local repair shops would like to be informed by the producers about repair instructions and about the procurement of necessary spare parts.
The EU would like to set up a Circular Economy Reporting Framework to monitor processes so it will need relevant data and information.

The assessment of the environmental impact of products ensured by eco-labels and external "rating agencies" will also require a secure source of data. This also applies to green public procurement, which also needs reliable data.

2.2.2. No information disclosure without data integrity and data protection

However, transparency and data sharing comes along with the risks of privacy being violated or business secrets being stolen or the security of one's own database becoming endangered (cyber security), especially since the provision of data for the respective purpose and its transfer via automatic data interfaces is associated with considerable effort. Some current business models are based solely on information asymmetry between market participants and could have a hard time surviving in the future.

The effects of information asymmetry are also evident on the receiving side of the data. Can the recipient of the data, be it the consumer, the recycling company, etc., trust that the product data is genuine, credible and up-to-date, and comes from the producer as the source? How can proof of integrity and validity of data be provided? Data integrity must ensure the consistency, completeness, accuracy and validity of data over the entire retention period. All data changes would need to be documented in a traceable manner so that data cannot be changed or manipulated unnoticed or without authorization.

Interviews conducted with companies regarding the introduction of a material passport show that corporates request control over their data. In other words, they want to be the sovereign of their data and decide for themselves who has access to their data, at what time and to what extent. Furthermore, not every partner in the supply and waste chain should have full access to all the data, and especially access to sensitive corporate data should remain restricted. Here, again, the legal questions concerning liability for abuse / misuse of data and documenting who had access to which data records at what time (Rudolphi, 2018) arise.

Currently, the lack of trust in data sharing in the corporate sector is mostly addressed through legal contracts such as disclosure requirements, which hold the recipient of the data liable for the misuse or disclosure of the data to third parties. Or else, public or private institutions (supervisory and regulatory institutions, auditors) are interposed as trust-brokers who check the data, certify it, manage access rights and monitor its use (Verhulst, 2018). In most cases, web-based central cloud solutions from IT companies are used for the databases, shifting the trust burden with regard to the integrity and security of the data to the cloud provider. From the consumer's point of view, product labels and certificates from external, producer-independent public and private institutions are particularly important to increase trust in the validity of producer information. Ultimately, certification agencies also act as trust brokers between consumers and producers.

These solutions to the fundamental problem of information asymmetry have created an entire industry of auditors, testing companies, rating agencies, cloud database providers, whose central task is the registration, control, testing and management of data. On the public side, this bureaucratic burden is mirrored by a growing number of public institutions in charge of supervision and regulation based on a complex law system. Despite this considerable effort, it remains questionable whether such a system is up to the requirements of the information flows of a Circular Economy in view of the sheer number of participants, the wide ramification of supply and waste chains, the dynamic processes and the resulting variability of the data. The

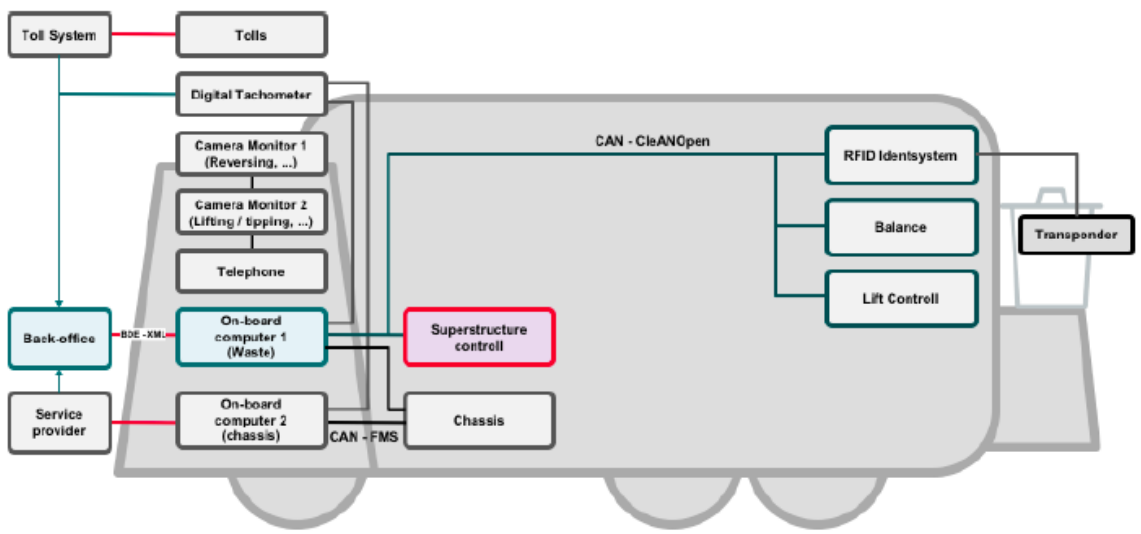
Blockchain as a decentralized database could function as a trust broker between stakeholders involved as will be demonstrated below.

2.2.3. Municipal Waste Data Management

The question is Who collects and records data in the Circular Economy. Ultimately, this can only be ensured by Municipal Waste Management. This is where the data accrues when waste is collected from businesses and consumers. Waste trucks and smart bins are to be equipped with a multitude of sensors and collect a multitude of data on waste quantity, quality, location, route and polluter during collection and store it directly in a database.

The illustration of a waste truck equipped with all options of using IoT solutions gives an excellent overview of the digitalization of the waste collection process.

Figure 7: IoT solutions to be integrated in waste trucks



Source: Adapted from a BDE/VKU publication (BDE - Bundesverband der deutschen Entsorgungs-, Wasser- und Rohstoffwirtschaft and VKU - Verband Kommunaler Unternehmen, 2015

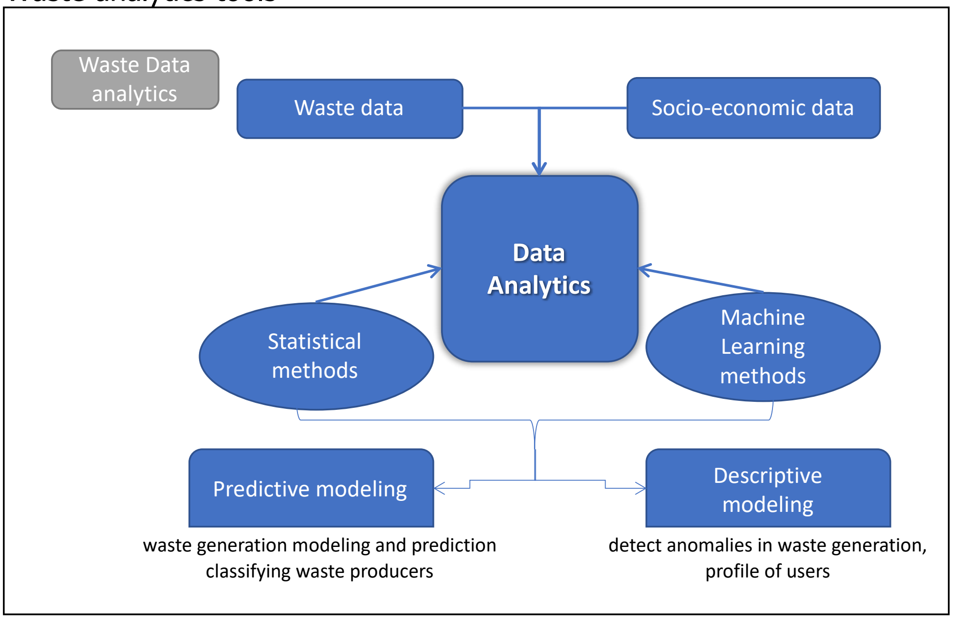
Source: Berg and Sebestyén (2020, p. 22)

For a successful implementation of a Blockchain-based waste management system it is required by the competent authorities that the system collects and analyzes data concerning a variety of aspects of waste management (operational, economic, environmental and social). These may include collection, transportation, treatment, material and energy recovery and disposal. By applying advanced digital technologies (Robotics, IoT, Data Analytics, Blockchain), a shift towards a sustainable materials management role could be achieved that influences each waste management sector. E.g. IoT will connect material and information flows that could be useful for manufacturers to track, monitor, control, optimize and eventually provide new products based on the concepts of Circular Economy. Increasing waste amounts, climate crisis, or extended producer responsibility are the main driving forces of such a shift. Operators need, however, to tackle issues concerning investment costs, the lack of digital literacy and a digital ecosystem, security concerns and the fear of job losses. The current trend in waste management practices that will dominate the near future involves the introduction of new business models such as waste trading platforms, waste-specific software suites and business analytics (Berg & Sebestyén, 2020).

Waste collection activities probably play the most significant role in the whole process since they may influence the subsequent operations of reuse, recycling and disposal (Bertanza, Ziliani, & Menoni, 2018). In all cases, each of the above activities must be addressed in accordance with the priorities agreed by the European Union (EU) Waste Framework Directive 2008/98/CE (European Union, 2008) and the goals set in the European Green Deal (European Commission, 2019).

For the assessment of municipal solid waste management strategies there is a need for large databases, systematic data collection and several processing procedures (Teixeira, Russo, Matos, & Bentes, 2014). Waste management data is considered as critical for implementing appropriate policy and planning for local contexts (Kaza, Yao, Bhada-Tata, & Van Woerden, 2018). In most cases, current waste management systems suppors manual data entry, which in turn has an increased probability of error and inaccurate information. In an advanced waste collection system, however, smart waste bins equipped with IoT sensoring technology that monitors bin waste levels and transmits data to a server via internet services, technologies like RFID and GPS sensors tracking the location of a waste collection vehicle will be the main source of data. Tons of data generated at collection points are, in most cases, unstructured. With appropriate data analytics tools, they will, however, be transformed into highly structured data available for processing. A waste bins' fill level, volatile organic compounds (VOC) level, temperature, and humidity are key waste generation data. This data will, along with data concerning population density, existing waste strategies and policies, number and characteristics of stakeholders and infrastructures and also the implementation of detailed waste compositional analysis, provide information to policy makers for determining their waste management strategies, awareness activities and motivation measures (Yoo, Rhim, & Park, 2019; Zorpas, 2020). According to the ETC/WMGE report (Berg & Sebestyén, 2020), "Data Analytics is the task of processing and analysing data in order to identify patterns, extract information, discover trends or calibrate models". Waste data analytics involve descriptive and predictive modeling using statistical and machine learning methods and techniques. To be precise, tree-based, neural-based and evolutionary algorithms along with the use of IoT may provide useful information concerning a multitude of factors: stakeholder profiles, anomalies in waste generation, classification of waste producers, improved logistics thanks to optimized waste collection routes that reduce unnecessary traffic, and subsequent air pollution as well as associated costs (Anh Khoa et al., 2020).

Figure 8: Waste analytics tools



Source: the authors

Overall, improvements in the waste collection and treatment process are expected thanks to optimized planning of resources and route planning, data analytics, and communication with citizens, consumers and customers. Recycling can be improved on the side of producers through facilitating the use of recyclates. On the side of consumers improvements can be made through enabling better purchasing and sorting decisions. On the recyclers' side waste sourcing will be improved. This evolution is in line with future waste management's focus changing from waste treatment to materials management.

Individualized waste data is sensitive data about individual consumer behaviour, which may only be passed on to third parties in strictly anonymized form, so that no conclusions can be drawn about the individual concerned. Citizens certainly will usually have more trust in local municipalities as public bodies than in commercial companies when it comes to data protection. For companies, too, data protection, including that of company-specific waste data, is of absolute importance in order to protect business secrecy. In this respect, it is clear that not every stakeholder can have full access to all data in the database. Limited access in line with data protection policies will be the norm. But from an efficiency point of view, it is much more cost-effective to set up a common public database than to create a separate database (silo) for the purposes mentioned above. For local communities and the local downstream authorities, i.e. the public sector, Municipal Waste Management ensures the analysis of local waste data and reporting. In return, private stakeholders use their own analytical tools via automated interfaces with the database.

2.2.4. Blockchain facilitates data sharing in the Circular Economy

One of the key questions of sustainable business is how to establish trust between unknown parties to enable transactions. This has so far been made possible by intermediaries which act as trust brokers, whose role, however, leads to an increase in transaction costs and makes markets less efficient. Blockchain technology can help minimize the necessary trust level and thus transaction costs incurred by the parties involved in the transaction, for example by reducing the dependence on intermediaries.

As Verhulst (2018) writes: *At their core, Blockchain technologies are a new type of disclosure mechanism that have the potential to address some of the information asymmetries listed above. By leveraging a shared and verified database of ledgers stored in a distributed manner, Blockchain seeks to redesign information ecosystems in a more transparent, immutable, and trusted manner. Solving information asymmetries may be the real potential of Blockchain, and this — much more than the current hype over virtual currencies — is the real reason to assess its potential.*

A Blockchain is a public, immutable, distributed ledger for storing data and recording transactions.

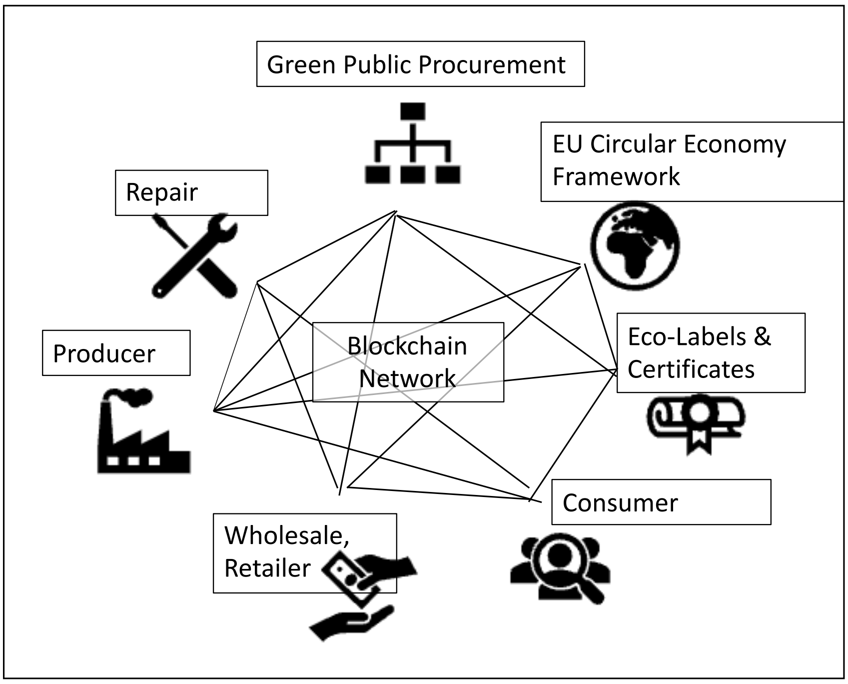
- In general, a "ledger" could be defined as a database that records transactions in a chronological order with the use of a time stamp. A bank customer sees the ledger of their bank account when checking transactions (cash in- and outflows) by using the online banking portal. However, this is a single private ledger as only the bank's accountant has the ability to change the ledger.
- A "public" ledger is accessible by all participants of a network and all have equal rights with no hierarchies existing. There is no single custodian who has the exclusive right to change the state of the ledger by recording new transactions. In a distributed ledger every network participant can download the full list of transactions (complete history) and has the right to read, to add data and to store the ledger.

- "Immutable" means that once the data of a Blockchain has been stored and encrypted, it is almost impossible to change or delete it afterwards. It is therefore only possible to add new data.
- "Distributed" means that a public Blockchain is not subject to the control of one participant or one organisation. Instead, the network (i.e. the totality of all participants) manages and secures the data, and each participant basically stores a complete copy of all data.

The core components of a Blockchain regularly consist of a combination of cryptography, peer-to-peer network technology, consensus mechanisms, ledger and a set of rules to determine valid transactions. A Blockchain is thus a distributed, state-of-the-art tamper-proof digital data structure that can be used to store all types of valuable data. One of the key characteristics of Blockchains is that there is no central authority that needs to be trusted (such as in cloud computing) and that each individual participant in a Blockchain network can check and validate each individual transaction themselves from the beginning of the records. This transparency is intended to have a deterrent effect on misconduct and to make it possible to carry out checks at any time without any reason. The Blockchain therefore does not require trust in an intermediary, as it allows the participants themselves to establish trust. (BaFin, 2018)

Blockchain technology is ideally suited to serve as a shared data network for storing and transferring data between a large number of network participants, thus overcoming information asymmetry and also establishing a decentralised incentive structure. The term "public infrastructure" fits best here for the incentive-based and controlled exchange of data that is the prerequisite for the functioning of the Circular Economy.

Figure 9: Blockchain based information flow



Source: the authors

Circular material flows need a decentralized information flow between stakeholders. The basic prerequisite of a circular flow of materials is the decentrally organised flow of information within a network of stakeholders. This is exactly what the Blockchain can do. The decentralised organisation of the network has two decisive advantages: In view of the sheer number of participants, it is an illusion to believe that a central database, with centralised management, can always be up-to-date or even efficiently process the mass of data that accumulates. In this respect, the decentralised nature of the network, in the sense that each individual stakeholder is responsible for entering the data and can also be held liable for it, is the most efficient form of organising the flow of information. It enables all actors in the supply and waste chain, regardless of their relationship, to exchange data easily, quickly and securely, optimising trade for all parties. Network paths are not predefined but develop dynamically, so that each participant can shape their information exchange in a self-determined way. The decentralised nature of Blockchain networks does not need a central authority to run a central account for the exchange of information and digital values. Peers are empowered to supply and exchange information and values by their own initiative.

2.2.5. Blockchain supports self-sovereignty of identity and data integrity

This decentralised concept comes along with the self-sovereignty of identity and private data. The proof of identity, the knowledge about who a stakeholder is, is essential for any contractual relation in our society. The proof of identity relies on personal information such as name, date of birth, fingerprints, passport number, bank account etc. The contracting parties must be 100% sure of the identity of the counterpart and their accountability in case of a breach of contract. Identity theft and misuse of personal information by hackers are high risks. In the current system, the proof of identity of individuals is provided by organisations, public administration and corporates. The Blockchain follows a decentralised concept of identification: Every network participant is the sovereign of their digital identification and his data.

The private data and its attributes are owned and controlled by individuals and stored by them in a digital safe and can be shared partly or fully, temporarily or permanently and for restricted or unrestricted use with other network peers via a public key. Each access of a third party to the private data base is registered, recorded and time-stamped. The self-sovereignty concept includes the right of data portability, i.e. of taking personal data away from one organisation and shifting it to another or to a private storage place (Lenz, 2019b, p. 22).

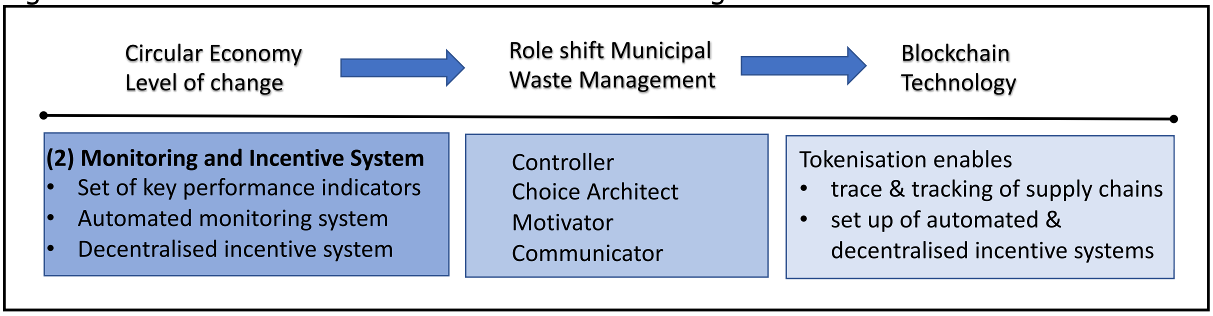
This aspect of control over one's own data seems to be of high importance especially for companies with regard to the provision of product information (Rudolphi, 2018). Narayan and Tidström (2020) suggest considering the supply of product information itself as a product. The recycling company has an economic advantage from the producer's exact information on the recyclable materials used in the product. The same applies to an external company that repairs the products, which derives an economic benefit from precise repair instructions. Consequently, product information represents a digital value and the rights to use the product information could be sold as tokens via the Blockchain.

By converting product information into openly available and accessible tokens in the Blockchain, the central issue for creating value would be not information and knowledge as such but the ability to use the information. Firms would easily identify the origin of information and suitable cooperation partners to foster value creation. (Narayan & Tidström, 2020)

2.3. Municipal Waste Manager - a choice architect for decision making

In the following, the importance of setting up a smart monitoring and incentive system tailored for each stakeholder of the Circular Economy is highlighted and municipal waste management's role in this is analyzed. As the Blockchain allows digital values to be transferred as tokens it could facilitate the setting-up of such a monitoring and incentive system. Figure 9 shows the pathway to the logical structure of the following analysis.

Figure 10: MWM as choice architect for decision making



Source: the authors

2.3.1. Circular Economy needs smart system of decentralized incentives

The economic model of the Circular Economy marks a clear breakaway from the current linear model. If it is well implemented, the lifespan of products will increase significantly and also encourage industry to produce durable and high-quality goods. Industry needs to draw away from short-term-focused upscaling of mass production as a source of profit. More revenue and profit is generated from sales of lower volumes of higher quality and a higher return on sales per product. Companies' marketing will change, accordingly, moving away from rewards or discounts granted to customers buying as much as possible ('buy four for the price of three'). The focus will be on highlighting customer benefits lying in the right match with customers' needs and preferences. Customers are not primarily encouraged to buy ten pairs of shoes but fewer pairs of high quality though. In the Circular Economy the purchase of brand-new products may become second best as it entails the consumption of new raw materials. A benefit is seen in saving resources, in buying second-hand products or having broken products repaired. If it has to be a new product, then it must be one containing a high percentage of recycled matter.

It is true that this brings back memories of stories heard from grandparents about post-WWII times when production capacities were destroyed and a lot of materials and products were not available or not affordable. People were forced to appreciate what was available and to make sparing use of it. Then, as now with the waste pyramid, the focus was on avoiding throwing things away, on reusing and repairing products. At that time though, it was not citizens' free decision but a pure necessity, due to supply shortage, to opt for second-hand products. This is different today. Citizens can make free choices and are constantly stimulated to buy new and more products. Most business models are based on the principle of achieving economies of scale by increasing sales item volume and bringing down unit costs.

The current economic system relies on the principle that more transactions lead to more profit. Turning this principle upside down so that eventually, less transactions lead to higher profit, requires a strong incentive system that motivates stakeholders at all levels involved in the supply and waste chain to change their behaviour. Of course, if this kind of system change was to be enacted in a top-down (supply-and-command) approach by an authoritarian government, it might seem easy to meet the goals of a Circular Economy, but it is doubtful that this process becomes sustainable in its results. In a market economy and a democratic environment, only a decentralized approach, with a strong incentive system combined with transparency, open information and knowledge flows, which guarantees each individual their economic freedom, will produce durable results. This approach does not exclusively target citizens' rationality but also allows for economic interests and incentives. The Circular Economy option needs to be chosen with conviction but also needs to address citizens' tangible interests so it is perceived to be worthwhile for everyone involved.

2.3.2. Municipal Waste Manager - a choice architect for behavioral change

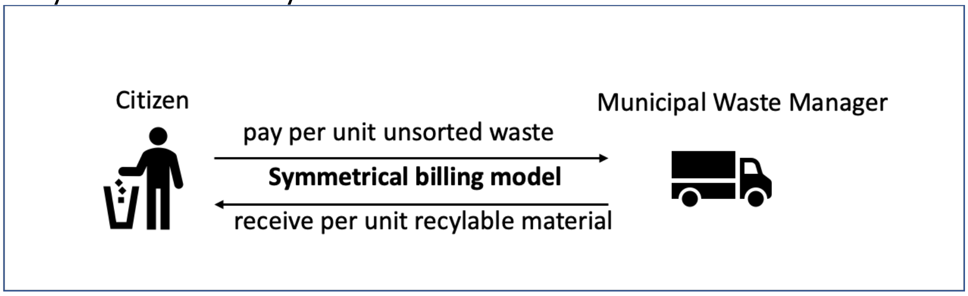
Nothing is more difficult than permanently changing a person's behaviour. In order to change behaviour, one needs to know why one should change the behaviour, in addition to assigning the responsibility for misbehaviour to an individual personally. The previous behaviour must become inconvenient and/or expensive as a decision option, while in return the decision to change a behaviour should be completely easy, free of inconvenience, as well as economically more favourable. To speak in Richard Thaler's words (Thaler, Sunstein, & Balz, 2013), the municipality is the architect of a citizen's decision-making situation with regard to buying a new product coming in heavy or light packaging or continuing to use the old product, repairing the old product, buying a re-used product ir throwing it away and separating recyclable material. Unfortunately, the decision situation is often not solely influenced by the local waste disposal company, but also by a number of other decision architects, which often turn out to be opponents (e.g. marketing).

However, a municipality's framing of a citizen's decision situation has some influence. In many EU countries, citizens still pay some kind of flat fee to their municipality for the collection and removal of waste. This fee often depends on the size of the house or flat and the number of residents. Since there is a negative social cost to littering, this fee means that the citizen pays zero marginal cost for an increasing volume of litter. As Messina and Tomasi (2020) state, this *"misalignment between individual and social costs determines/leads to an excessive production of waste and consequently an inefficient allocation of public resources".* In contrast the Pay-as-you throw (PAYT) fee model is designed to price each additional unit of waste and *"individual marginal costs are realigned with social ones, with the benefit of a reduction in the quantity of waste produced and a greater propensity to recycle."*

Based on empirical research conducted by Messina and Tomasi (2020) and Kinnaman (2006), the introduction of the PAYT-fee model significantly influences user behaviour: total waste decreases and unsorted waste almost halves. Overall costs incurred by municipalities adopting PAYT fall by roughly 10-20 per cent in capital terms, reflecting a reduction of one third in the cost of managing undifferentiated waste.

Two aspects in particular seem to be important in the introduction of the pay-as-you-throw system: Firstly, the amount of waste generated can be directly assigned to the individual household or the respective citizen by means of sensors in the waste bin and on the waste truck. This makes consumers responsible for their actions and reduces the danger of moral hazard or free-riding at the expense of the community. Secondly, the pay-as-you-throw system should be designed more symmetrically, in the sense that the citizen should also have a share in the profits of their waste management company through a deposit or refund system for recycling materials. This means that the PAYT system is completed by a pay-and-receive-as-you-throw system. Here, the Municipal Waste Manager should disclose their cost in the further processing of the unsorted residual waste on the one hand, and their revenue in the sale of the separated recyclable material on the other hand. Citizens should, in return, participate in the costs (pay) and revenues (receive) accordingly. Waste thus becomes a tradable resource and an object of business transaction between citizens and municipality, which might find, thanks to its symmetry, higher acceptance with citizens.

Figure 11: Pay-and-Receive-as-you-throw model



Source: the authors

Of course, there is a risk with this model that citizens will declare more residual waste as recyclable waste in order to improve their cost-benefit ratio. For poorly separated recyclable waste, especially organic waste, the municipality receives no or less revenue. Another risk of the polluter-pays fee model is that illegal dumping of waste in nature or waste 'tourism' may increase.

In this respect, the economic incentive system must be supported by targeted communication and behavioural economic elements. In order to understand citizens' decision-making situation, waste data needs to also carry personal data so that profile-based communication and nudging of citizens is possible. Addressing citizens with regular communication and information about possibilities of waste avoidance, correct separation of waste, prompt feedback about individually produced volume and separation quality via SMS or messengers after waste collection is important. By means of a waste scanner installed on a truck, separation quality can be measured when a waste bin is emptied. The same approach, incentive and communication concept will not be effective for all groups of citizens, but knowledge about citizens enables a municipality to segment groups. Some citizens can also be motivated by gamification or reward concepts such as free use of public services (theater, swimming pool, local transport etc.). Municipal Waste Managers thus become choice architects of citizens' decisions on waste, but in the spirit of Thaler et al. (2013), citizens are always to be openly informed about nudging efforts.

2.3.3. Blockchain enables incentivization by tokenization

The Distributed Ledger Technology empowers peers to exchange digital assets without intermediaries and without the use of platforms in a secured and trustful way. Within the new Internet of Value, an exchange of values, a legitimacy check of an authorisation of ownership, a proof of identity and a transaction consent to a change in ownership rely totally on peers' responsibility and are executed in a decentralised way within the network without using a central authority.

A token is the digital representation of a value that can be exchanged directly between stakeholders. Tokens can represent a right of use (utility token) or assets (asset token) or means of payment (payment token). Tokens can be ideally used as incentive mechanisms for rewarding behavioural change towards the Circular Economy.

For example, if a producer shares knowledge about their product as a material passport exchanged with a recycler or repairer, this has an economic benefit for the recipients of the knowledge. Consequently, in return for providing specific knowledge, the producer could be paid directly, peer-to-peer, via a payment token, without the intermediary of a bank.

A market economy is based on a multitude of decentralised economic decisions made based on incentives. The transition from the linear economic system to the Circular Economy cannot be organised top-down, but requires a smart design of economic incentives for market participants. With tokens, peer-to-peer based incentive systems for a network of Blockchain participants can be designed extremely efficiently and tailor-made for each application.

As PwC (2018) writes in its report: *"Incentivizing circular economies: Blockchain could fundamentally change the way in which materials and natural resources are valued and traded, 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."*

2.3.4. Use Blockchain to trace and track product life cycles

Blockchain Technology enhances transparency in the supply chain of products as every single part of a final product could be tracked in chronological order from the origin to the final point of sale. Even data such as the duration of use by a customer and the costs of waste could be recorded. The complete information of the product life cycle could be enriched with complementary data about the environmental costs of production by using sensors and cameras with their own network IDs. In this way, monetary values such as the price of a product or the profit of a company could be clearly linked to values of natural capital and environmental costs. Distributed Ledger Technology could be an enabler for sustainability-based accounting of value.

In some way Blockchain Technology enables the nominal sphere of accounting and value to reunite with the physical world of trading goods in the supply chain. The decentralisation of both systems will radically lower the complexity of accounting and thereby reduce the costs of monitoring and controlling.

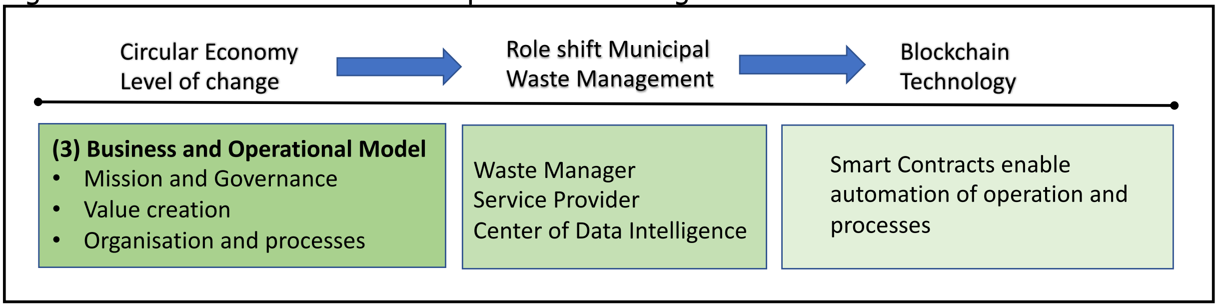
As IBM (2017, p. 5) writes about a "Message-based versus state-based communications":
"Today, organizations send messages back and forth to accomplish various tasks, with each organization maintaining its state of the task locally. On Blockchains, messages represent the shared state of the task, with each message moving the task to the next state in its lifecycle. Blockchains shift the paradigm from information held by a single owner to a shared lifetime history of an asset or transaction. Instead of message-based communications, the new paradigm is state-based."

The Extended Producer Responsibility (EPR) requires that producers pay for the end-of-life management of a product and the packaging they place on the market. The Blockchain application would make it possible, with less bureaucratic effort, to check whether a producers' fees really cover the costs incurred in waste processing and, in addition, an incentive mechanism could be combined with this: Less packaging, less waste, longer usage times, etc. should imply lower costs for a producer.

2.4. Transforming Municipal Waste Management

The transition towards a Circular Economy implies the end of mass production and business models which purely rely on unit cost degression. In a Circular Economy value creation and sustainability go hand in hand. Non-sustainable business models lose value and sustainable operations gain value. The realignment of the value system is mirrored by a change in corporates' missions, self-understanding and organization. The changed tasks and challenges (role shift) imply a new orientation both in the organisation and in the mission of municipal solid waste management. As with any digital transformation, it is not the software or IT that is decisive for success, but the realignment of an organisation, its processes and people. The Blockchain can make a substantial contribution here, on the one hand in automating processes using smart contracts, and on the other hand in interacting with existing IoT solutions. Figure 12 shows the pathway to the logical structure of the following analysis.

Figure 12: Transformation of Municipal Waste Management



Source: the authors

2.4.1. Value creation of MWM in the Circular Economy

On the one hand, MWMs' value proposition derives from supplying resources and tradables generated from data-harnessed substance flows circulating in a networked economy. This creates business opportunities for service providers, thus providing for 'trickling down' effects in terms of job and wealth creation. This proposition is mainly addressed to business clients. Depending on the distribution channel used, this proposition can be seen as a Manufacturer or a Merchant model in Michael Rappa's typology (Michael Rappa, 2010).

On the other hand, MWMs make a substantial contribution to citizens' needs for clearance of their containers and for accessing their waste data, and in a much more global sense, for a safe and clean environment resulting from lowering environmental impacts and for a high quality of goods supplied. The first aspect is characterized as a subscription model by Michael Rappa (Michael Rappa, 2010).

Until recently, MWMs' quality standards focused on substance quantities collected and disposed of or sold to recyclers/reusers or incinerating units. Income was, strictly speaking, mostly generated by activities resulting in a devaluation of assets, destruction of value and loss of resources.

If MWMs' success and performance standards are no longer indexed on amounts of waste collected and disposed of, what may replace the 'old world's' measuring benchmarks?

1. Standards and indicators that reflect the objectives of the wider Circular Economy such as circulation of materials, extension of product life cycles, upcycling and revaluation of recyclables and inclusion of citizens and stakeholders (for a more detailed view of KPIs cf ch 2.4 below)
2. Reduction of general waste and disposal volume
3. Citizens' recycling and waste avoidance behaviour and their use of MWMs' data services
4. Traceability and transparency of household waste and recycling flows
5. Value created from digitally classified waste streams
6. Business opportunities created by MWMOs for service providers

Needless to say, a number of these benchmarks may apply, depending on local contracting approaches, to activities performed by service providers and players other than MWMs.

2.4.2. Changes in operations and processes of MWM

The central role MWMs play for the Circular Economy lies in three factors:

1. MWMs are, among others, the entry gate of substance flows emanating from households.
2. They are also multi-stakeholder hubs connecting all users and service providers active in the waste and substance flow sector.
3. MWMs are the key collectors, producers and merchants of data mirroring waste /value streams and consumers' waste behaviour and of goods travelling along their life cycle.

This multilateral exposure to and interaction with multiple markets, cycles and stakeholders / target groups produces considerable complexities. It requires flexible and transparent processes that all parties involved can understand or engage in. Processes as diverse as nudging consumers into reducing waste volume, channeling substance flows towards recycling or upcycling, directing goods towards reuse or rehabilitation, analyzing streams by value content, generating or harvesting waste data etc all require specific technologies, communication, interaction and iteration patterns. This calls for a dismantling of old silo structures within MWM organisations so that typical old-time public administration routines can be overcome and changed into modern organizational layouts characterized by network organization, flat hierarchies, empowerment of staff, cross-disciplinary teams and agile leadership. This change also requires MWMs to open up their corporate boundaries to service providers, clients and other stakeholders and to become so-to-speak more 'osmotic'.

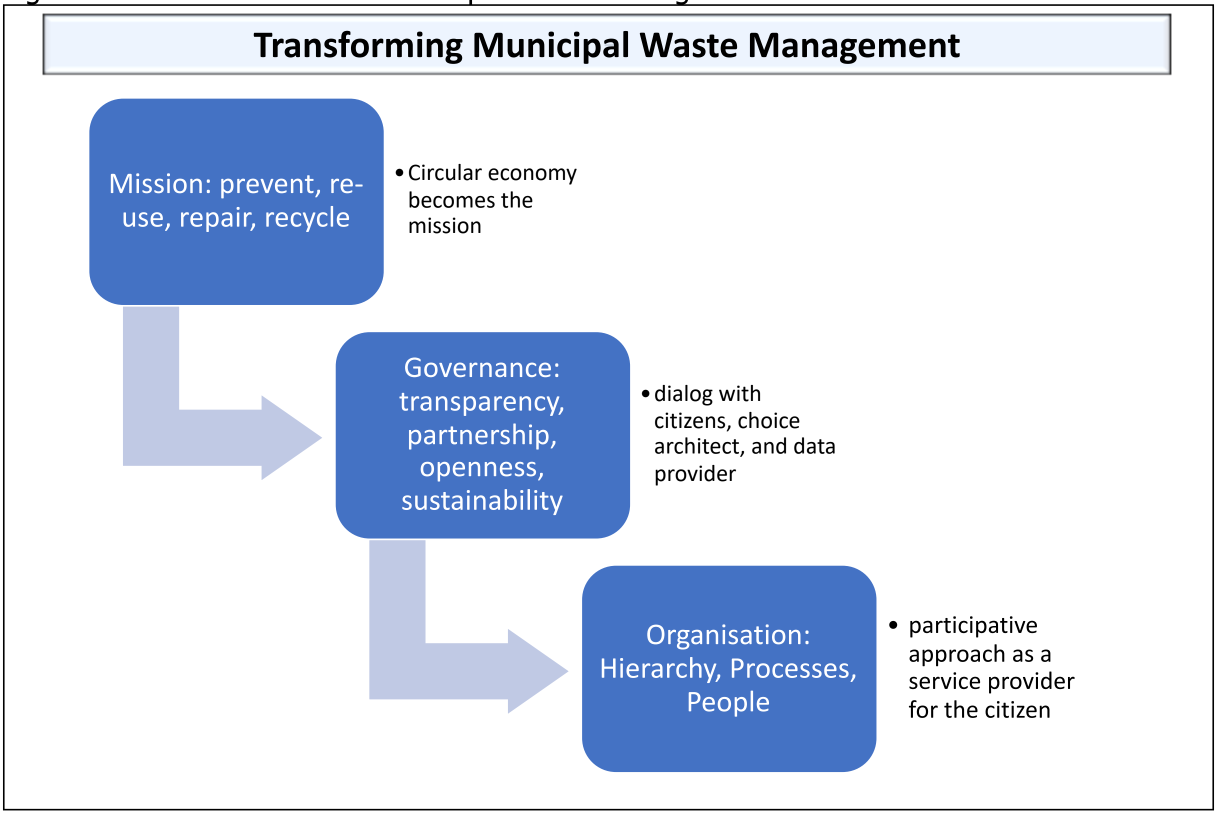
2.4.3. The pathway for transformation of MWM

Municipal waste management finds itself at the heart of the Circular Economy, motivating producers, consumers, retailers and wholesalers to create less waste, to use products longer, to give preference to second-hand products, etc. The Circular Economy is also a means of reducing waste. However, as with all other stakeholders in a market economy system, the question arises as to whether the incentive structures municipal waste management organizations offer are compatible with the above objectives or whether they support the goals of the Circular Economy in a sustainable manner. In the current system, the processes of MWMs are optimally organised if they collect and process or forward the waste generated by citizens as efficiently (at the lowest cost) as possible. In the Circular Economy, the existing key performance indicators applying to municipal waste management must be revised and expanded: Here, the quality of the organisation must also be assessed according to the extent to which MWM organisations succeed in reducing waste volume, in increasing the use of second-hand products, in supporting repair activities and in increasing recycling rates by

a. providing data and information
b. setting incentive structures for consumers and producers (pay-and-receive-as-you-throw model)
c. facilitating communication based on user profiles.

Waste prevention by citizens and local businesses must be embedded in the DNA of a Municipal Waste Management organisation. Waste prevention is the mission that the entire organisation, its staff structure and all processes must be aligned with. To put it simply: the less waste municipal waste management organizations need to collect from citizens, the more their efforts will be successful.

Figure 13: Transformation of Municipal Waste Management



Source: the authors

The mission and governance of municipal waste management organizations need to change regarding their view of citizens. The focus is no longer solely on the disposal of citizens' waste but on citizens as partners and customers of municipal waste organizations. To obtain the consent of households and citizens to their waste data being collected and analyzed, a high degree of trust in municipal service providers is necessary. In addition to trust in data protection, it is also necessary for citizens to have basic trust in a municipality as a public body and authority refraining from controlling citizens and from restricting them in their individual freedom and autonomy. Consequently, the provision of data and its use must create benefits for both municipalities and their citizens and the environment. Just as citizens are expected to change their behavior with regard to their waste, the role of public service providers will also have to change fundamentally:

- At a meso-level, a public organization needs to evolve towards being a partnership-based service provider for whom the interests of citizens are of first priority. Public credibility then also includes a high degree of transparency and an openness of organizations.
- Dialog-oriented communication with citizens implies a reform of organizational governance, aiming to establish a close partnership with the community and its citizens. Participation of local civil society organizations in the advisory boards of municipal waste management organizations might also be a trust-building measure.
- Credibility in terms of sustainability also requires public organizations to commit themselves to the goals of sustainability, to implement them in processes and to report on progress towards sustainability goals. In this process, every municipal waste management organization needs to define its sustainability strategy with indicators on organization and human resources, internal processes, and their contribution to value extraction from waste chains. Key performance indicators should be linked to sustainability and included in annual reporting.

The necessary transformation of municipal waste management with regard to the introduction of the Circular Economy is, as roughly outlined above, a cross-sectional task that entails the reform of the entire organization. This transformation process requires a clear strategy and costs a lot of investment and time. This is likely to be especially true for public organizations that are shielded from the dynamic competition of the market.

2.4.4. Implementing changes step by step

The developments described above will challenge MWMs that have a public administration and utility background to embark on a great leap ahead.

In a larger number of cases, the following steps might be useful:

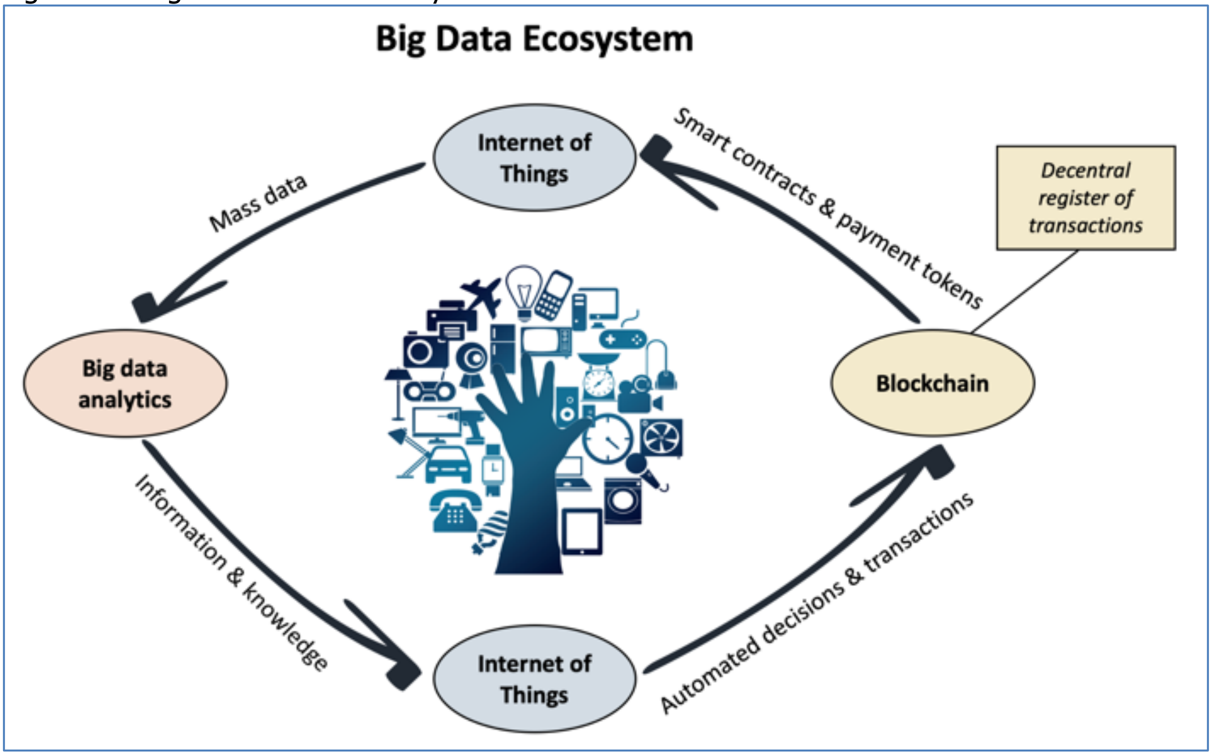
- Mapping internal processes
- Mapping existing partners / stakeholders and processes maintained with them
- Defining target areas / functions / capabilities that the specific MWMO needs to redesign for doing business in a Circular Economy (e.g. mission statement, skills profiles, digital infrastructure, hierarchies and corporate organization, new processes, corporate culture, change management, performance measurement etc)
- Deciding about eco-systems required for change (e.g. labs, satellite organizations or subsidiaries, consultative bodies, feedback or participation procedures, management approach, role of change activists and evangelists, IT infrastructure and data sharing etc)
- Including consumers, clients, partners and stakeholders early on
- Defining communication processes accompanying transformation all along
- Determining priorities (and non-priorities), fields of experimentation, scenarios and pilot projects
- Setting up timelines and outcomes
- Planning for alternative scenarios
- Defining incentives and encouragement actions for staff
- Launching pilot(s) and advocacy movements

As MWMs usually have strong local roots, transformation agendas vary considerably. It is therefore vital for MWMOs to define their own specific priorities rather than following a standard transformation agenda.

2.4.5. Enhancing automation by IoT & Smart Contracts and Blockchain

Progress in robotics and sensor technology, combined with big data analysis and self-learning algorithms, has produced networks of physical devices that can connect, collect and exchange data and take autonomous decisions. The emergence of Blockchain technology facilitates the overall trend of automated and speedy decision-making by providing a shared database for the recording and registration of decentralised transactions between P2Ps, P2Ms and machine-to-machine (M2M). Additionally, Blockchain technology enables the storage of software code with 'if-then' relationships within the database, which facilitates the use of so-called smart contracts in which Blockchain users store automated transactions, ready to be executed given a certain external event as trigger (Lenz, 2019a).

Figure 14: Big Data and IoT ecosystem



source: Lenz (2019a)

For the execution of autonomous decisions in the real physical world, machines with a variety of built-in sensors and a fast internet connection are needed. The development of the Internet of Things (IoT) provides the necessary link between the digital and the real world, without which Big Data analytics would lack both the mass of data generated by sensors for analysis and the executive power of machines for automated decision-making. Devices located in the IoT both feed algorithms with data and are to some extent controlled by those same algorithms.

Treleaven, Barnett, and Koshiyama (2019, p. 34) describe the close connection between Big Data, AI, IoT and Blockchain as four core algorithm technologies which *"…are intimately linked, i.e. AI provides the algorithms, Blockchain provides data storage and processing infrastructure, the IoT provides the data and Big Data (behavioural/predictive) provides the analysis."*

A comparative study about the "State of Digitalization in European Municipal Waste Management" in five EU member countries documents that municipal waste management organizations are currently running a wide range of innovative IoT projects, but most of the projects are isolated approaches and

"…also non-collaborative in nature with regard to sharing data with a large number of stakeholder groups and to generating synergy effects between the partners involved. But the Circular Economy, to be successful, requires collaboration between stakeholders, be it producers, consumers, supermarkets, municipalities or PROs, who need to share data in their collaboration. (Lenz et al., 2021, p. 27)"

"..The digitalization projects described in municipal waste management are very much driven by the use of new technology. The installation of telematics and IoT on waste trucks are typical tasks of mechanical engineers. The accomplishment of these tasks is of utmost importance for the smooth running of logistical processes within an organisation. But Blockchain is about

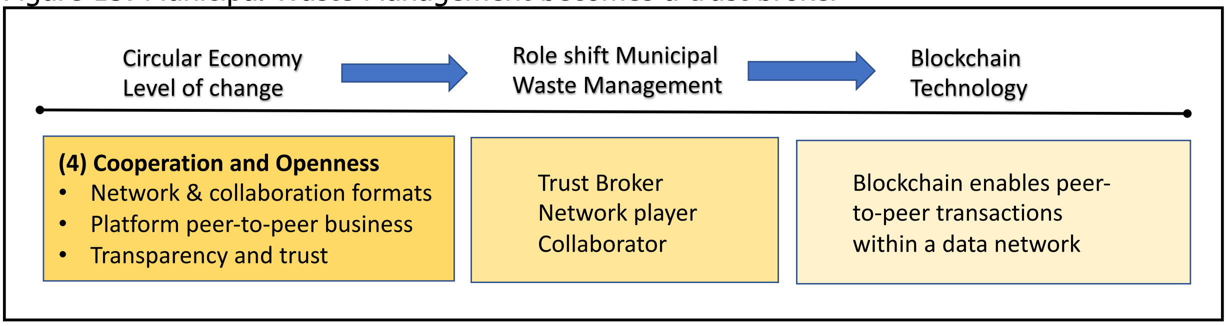
creating a win-win situation between stakeholders of a chain so that each of the partners involved ends up benefiting from the collaboration. (Lenz et al., 2021, p. 28).

When answering questions about the readiness of municipal waste management for the Blockchain, it is realized that solutions to technical problems are sometimes easier and quicker to deal with than changing an entire organizational model with a view to close cooperation in a network of partners. To finally answer the question about readiness for the application of Blockchain technology, it can be stated that, yes, from a purely technical point of view, most municipal waste management companies are up-to-date and use IoT extensively. What is missing is a clear data strategy which includes the analysis and the sharing of data with a variety of stakeholders. However, these are not technical problems but problems of the organisational development of municipal waste management companies (Lenz et al., 2021, p. 28).

2.5. Municipal Waste management becomes a trust broker

Data sharing and information flow between a multitude of stakeholders requires a collaborative approach which needs trust. Trust cannot be interpersonal trust between different actors due to the high number and heterogeneity of stakeholders and their geographical dispersion. It needs to be institutional trust, in this case in a local municipality and its waste management unit. This kind of trust can be enabled through technological trust created by the transparency of a decentralized Blockchain database. Figure 14 illustrates this enabling 'hinge' pattern.

Figure 15: Municipal Waste Management becomes a trust broker



Source: the authors

2.5.1. Municipal Waste Management – partnership-minded service providers

Municipal Waste Management organizations need to build trust with both citizens and market participants. Citizens become partners and both customers and suppliers of products and data. Market players become customers, value agents and creators. Citizens' double role lies in the fact that they ensure supply of materials and substances but also articulate demand for collection services.

This complex network of transactions requires, especially on the side of citizens, a high level of trust in municipal service providers. This trust 'capital' is necessary to gain the consent of households and citizens to MWMOs collecting and analyzing their waste data. This is why the mission and leadership of municipal waste management organizations needs to reshape its view of citizens who are to be treated as partners, valued suppliers and customers.

Municipal waste management organizations therefore need to evolve into partnership-minded service providers for whom the interests of citizens are paramount. The public credibility thus gained will also require a high degree of transparency, openness and accountability on the part of MWM organizations. Citizens need to be enabled to verify if MWM organizations comply with the goals and standards of sustainability and its implementation in processes and reporting.

This accountability requires new approaches to data storing, data access and data dissemination.

For MWM organizations to perform this role, it will not be good enough to reshape their task. Under Circular Economy conditions, the transformation of the municipal waste management sector entails reforms of MWMOs' entire organizational model.

One key activity that reflects this need is the provision and use made of (citizens' and substance flow) data and its use. It is only if this new cycle of transactions leads to mutual benefits for municipalities, service providers, citizens and the environment, that it meets with broad acceptance. This places considerable responsibilities on MWMs and requires new approaches to data storing, data access and data dissemination.

As sketched up above, the role of MWMOs as waste entry gates and transaction hubs is not a mere extension of a linear 'waste collection to sorting to forwarding to supplying or disposing' process but a 'synaptic' nexus operating in an environment of multiple transactions and dynamic landscapes of cycles and networks.

The interaction of 'waste' market participants shows a more and more complex picture and requires all stakeholders to engage in cluster-type of networking. This change needs a digital backbone in the form of platforms allowing for swift and transparent co-operation and data sharing.

As regards MWMs, the challenge might be to

- acquire new knowledge and skills
- remodel their entire organization and processes
- reinvent a corporate culture of openness, symmetry and accountability for themselves
- implement new accounting and control systems fit to measure circular and sustainable value creation
- adopt new co-operation and networking formats
- embrace digitalization with full determination
- build digital network infrastructure that can facilitate horizontal co-operation in a peer-to-peer logic

The emerging massive transformation process of MWMs that shines through these challenges requires a clear strategy and costs substantial investment in funding, time and transaction efforts.

2.5.2. Blockchain as facilitator of P2P-collaboration

Collaboration needs a high level of trust between partners as the desired result could only be achieved together. Everyone depends on each other, like participants of a rope party when climbing mountains. Trust can emerge if every participant has access to the same reliable information, at the same time, about activities and transactions. If only one shared database exists in the distributed network, recording all past transactions as a single source of truth for all participants, this is likely to be the case.

That is exactly what the Blockchain technology allows. It is a database technology for recording transactions within a network of peer-to-peer businesses. Blockchain has the advantage that data can be stored in individual "blocks" in a tamper-proof way, which means that participants in the Blockchain are able to check the authenticity, origin and integrity of the stored data. As a peer-to-peer network, combined with a distributed time-stamping server, Blockchain databases can be managed autonomously. There is no need for a single administrator as administrator rights are distributed to all network participants.

Blockchain is a very simple database technology that enables collaboration, but it is not a magic bullet for success. It is just a technology to solve certain information problems, but if the problem itself is not well defined (no. 1), if participants are reluctant to share information (no. 2), if decision-making processes are static and imbedded in a strong hierarchy (no. 3), if data interfaces are not automated and standardized (no. 4), and if the business process itself is not sustainable (no. 5), then a Blockchain application might be a waste of time and resources.

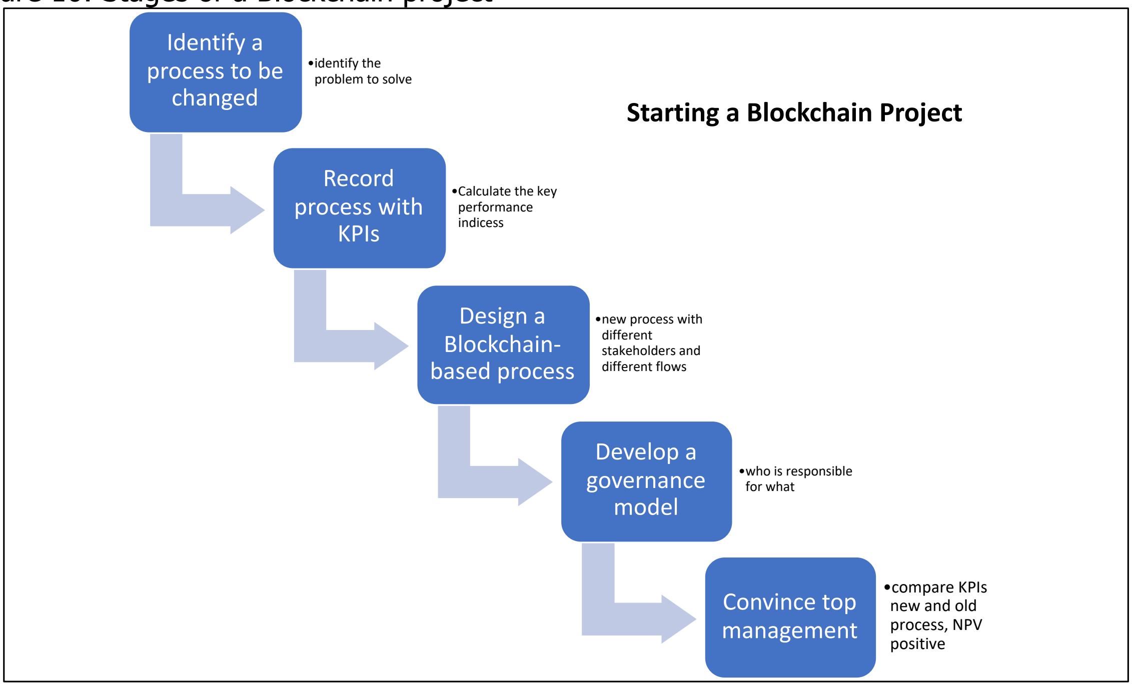
PwC (2016) put it well in their Q&A Blockchain FinTech
"Collaborative technology, such as Blockchain, promises the ability to improve the business processes that occur between companies, radically lowering the "cost of trust." For this reason, it may offer significantly higher returns for each investment dollar spent than traditional internal investments. So what's the catch? You cannot get the return by yourself; you must be willing and able to collaborate with customers, suppliers, and competitors in ways that you have never done before."

3. Guidance for starting Blockchain-based Waste Management Processes

3.1. Stages of 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 factors of a project's success and of a fortunate selection of project team members (Lenz, 2019).

Figure 16: Stages of a Blockchain project



Source: the authors

A typical Blockchain project is not really different from other projects. Mentally, the work can be divided into five stages: (1) Identification of a suitable process for the conversion to Blockchain, (2) Documentation of the existing key performance indicators so that the success can be measured later after the conversion. (3) Redesign of the new process flow. For the introduction of Blockchain technology, it may be possible to dispense with some intermediaries. (4) Introduction of the Blockchain implies setting up a collaborative business model that must offer benefits to each stakeholder. Consequently, a governance model for this process with binding rules of the game must be jointly agreed. (5) If this proof of concept for the Blockchain project is successful, the management needs to be convinced about the benefits of investing in a prototype. The five stages are described in detail below.

3.2. Identification of a suitable process for Blockchain conversion

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-organizational processes are characterized by a high number of failures, very long lead times, high costs of monitoring and 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-organizational perspective that enables to understand the interests of all stakeholders involved.

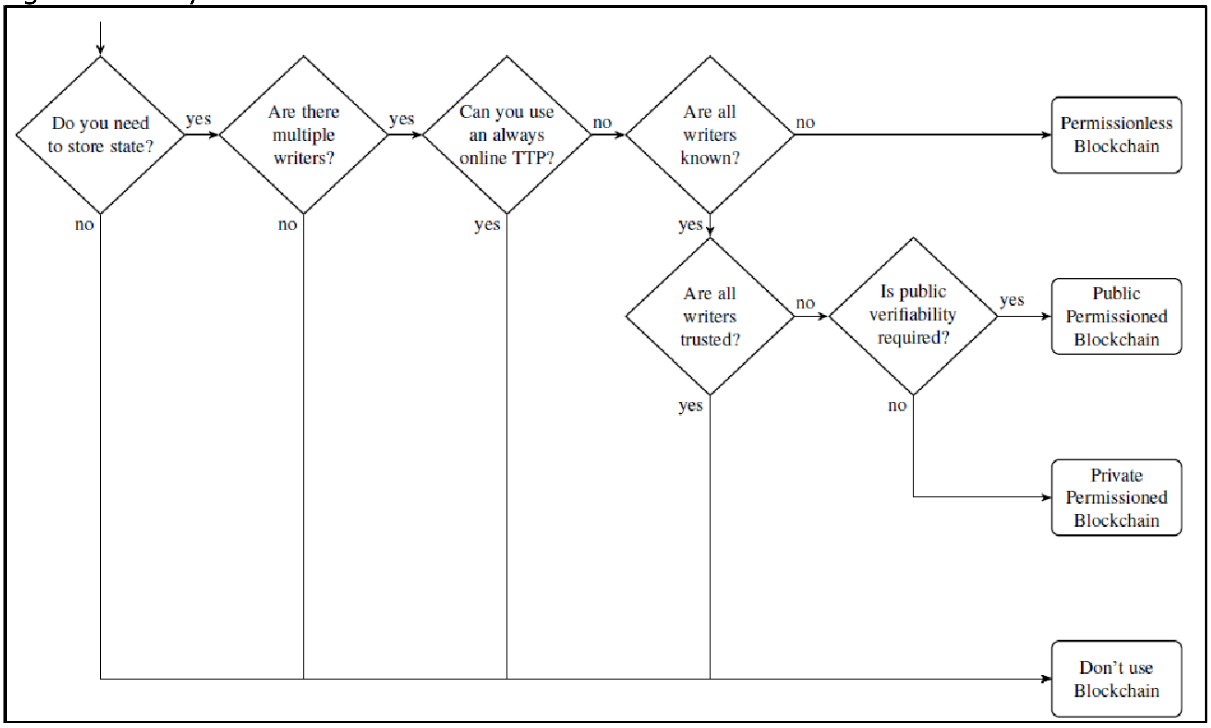
The substitution of trust in a central authority by transparency is exactly the advantage of a Blockchain. In a public Blockchain database accessible to everyone, each participant can verify at the same time who wrote what and how the state of a ledger has changed. Once stored, the information is irreversible and immutable, otherwise the logical consistency of the data stored in blocks would be destroyed. Thus, the two essential elements of the Blockchain complement each other: Public verifiability and integrity of data.

As Wüst and Gervais (2018, p. 2) point out: *The integrity of information is closely linked to public verifiability. If a system provides public verifiability, anyone can verify the integrity of the data."* Furthermore, the Blockchain data is kept redundantly as every writer within the network owns a replication of the data, which is permanently synchronized.

Blockchain solutions are therefore advantageous for processes in which a large number of participants are involved and in which it is of immanent importance for participants to obtain complete and reliable information about the current status of a process at all times. The reliable information about the current process status enables the participants to react to changes at any time so that the process does not run statically but remains dynamic.

Wüst and Gervais (2018) sketched this up in the following decision tree demonstrating for which case Blockchain solutions are most appropriate and for which case a central database might be the better solution.

Figure 17: Do you need a Blockchain?



Source: Wüst and Gervais (2018, p. 3)

Blockchain solutions are significantly less scalable than central databases. This is especially true for public Blockchain networks without access restrictions. The process of public validation within a permissionless network is time-consuming, so Blockchain applications are not suitable for storing and processing mass data at high speed.

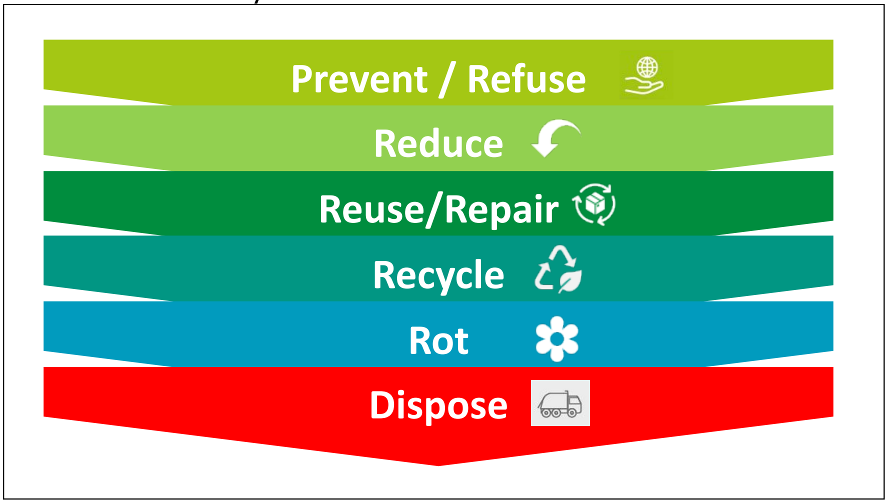
From the above comparison of the advantages and disadvantages of Blockchain applications with those of a central database, it can be derived that Blockchain technology has its greatest benefit in those applications where it is important for participants to document a certain state in a process or in a project in a reliable and tamper-proof way and where decentralized and autonomous data collection by a large number of participants is beneficial. Blockchain applications reach their limits when processing mass data at high speed. Here they have clear disadvantages compared to central database applications (Lenz, 2019b).

3.3. Recording the waste chain 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. Easily identifiable and measurable operational key performance indicators along with parameters that affect waste management policies are considered crucial elements of any waste management model. Authorities may use them so as to evaluate, in a quantitative manner, the progress and the improvement made by the developed model or the applied waste management strategy.

First and foremost it is the goals that are to be achieved. The development of KPIs serves to measure and quantify the degree to which objectives have been achieved. Here we can again refer to the previously mentioned 9Rs as goals of the Circular Economy (see figure 2), or the much-used representation of the waste pyramid can provide orientation.

Figure 18: Goals of the Waste Pyramid



Source: the authors based on EU waste hierarchy see article 4 of EU Waste Framework Directive

The overall target is to reduce waste as much as possible. The optimal opportunity to do this is simply to prevent / refuse waste by not using a material. If this is not possible the usage of a material might be reduced as much as possible e.g. by using a material-saving technology. If a material has to be used, reuse or repair should be intended with re-use meaning any operation by which products or components that are not waste are used again for the same purpose for which they were conceived. Repairing by user is possible if the technical design is not too complex and if spare parts are available – optimization of both is currently discussed in the EU. If this is not possible, recycling should be enabled, with recycling meaning any recovery operation by which waste materials are reprocessed into products, materials or substances whether for the original or other purposes. This includes the reprocessing of organic material but does not include energy recovery and the reprocessing into materials that are to be used as fuels or for backfilling operation (European Union, 2008 Art. 3 Waste Framework Directive 2008/98/EC). If this is not possible, natural (!) material should be rotted, otherwise disposal by incineration including energy extraction has to be done. Disposal in the form of landfill should be avoided at all. So, there is a variety of options forf reducing waste, which makes controlling more complex.

A literature review reveals the following list of the most appropriate operational KPIs that are widely used in waste management analysis and that could be assessed by municipal authorities: Waste Compositional Analysis, Municipal Solid Waste Production, Municipal Waste Recycling, Waste Production Rate, Waste Recovery Rate, Waste Generation Rate, Waste Infrastructure (AlHumid, Haider, AlSaleem, Shafiquzamman, & Sadiq, 2019; Pappas et al., 2022; Zorpas, 2020).

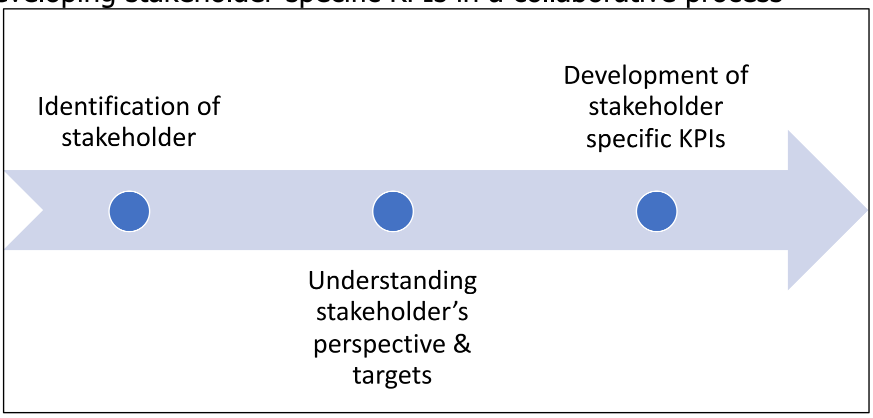
- Waste Compositional Analysis (WCA), could be thought of as the most important KPI, which is used to inform authorities about the type of waste materials that are generated within a specified area (plastics, aluminum, paper, glass, organic waste, and other materials), information that could be useful in forming a waste prevention and management strategy (Pappas et al., 2022; Vardopoulos et al., 2021). Raw data flow to the system via IoT devices installed on each waste bin, allowing the calculation of the percentage of each type of generated waste within a specific area at a specific time.
- Another important KPI, which largely depends on the city's extent and population, is Municipal Solid Waste Production, the ratio of average waste amount per capita (Loizia et al., 2021). It is calculated by dividing the total waste produced by the population of a specific area.
- Municipal Waste Recycling is also an important KPI for waste management, as it expresses the amount of waste material that has been recycled in comparison to total

solid waste produced, within a specific area at a specific time (Vardopoulos et al., 2021). Data of this kind and information derived from it is highly useful for municipal authorities as they can evaluate existing prevention activities and strategies but also operational aspects concerning collection systems (recycle bin type and capacity).

- Waste Production Rate, which expresses the change of the amount of waste generated annually, could be considered as a KPI that evaluates the performance of a waste management strategy pursued by authorities or could be used as metric in order to implement actions that would prevent an increase in quantity. (Loizia et al., 2021). The KPI is calculated by dividing the forecast of the total volume of waste generated each year by the total volume of waste generated the previous year.
- Waste Recovery Rate is a KPI that expresses the recovery of generated waste in a specific period. Waste Recovery Rate is calculated by dividing the amount of recovered waste by the amount of Municipal Solid Waste Production per type of waste, whereas available recovery options include recycling, reuse, waste-to-energy, refurbishing (Rhyner, Schwartz, Wenger, & Kohrell, 2017).
- Waste Generation Ratio estimates the generation of waste in the selected area in units of time, i.e. daily, weekly, monthly or annually and could serve as a metric of the effectiveness of a waste management strategy according to the increase or decrease of its value (Pappas et al., 2022).
- Waste Infrastructure is also a very important KPI since it could measure the environmental performance of the current waste management infrastructure. It involves the number and type of waste bins in a specific area. It provides useful information about the current infrastructure in relation to the residential density of that area. It is obvious that, as population density increases, the number of waste bins increases proportionally (Zorpas, Lasaridi, Voukkali, Loizia, & Chroni, 2015).

The key performance indicators listed above are important, but not sufficient for the conversion of an entire process to Blockchain technology. The goal of the Circular Economy is to achieve a reduction of waste, longer use of products, a higher repair rate, a higher recycling rate, etc. through behavioural changes of the stakeholders involved. Consequently, in order to achieve the overall goals, the KPIs must be tailored to the respective stakeholder group. Therefore, 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.

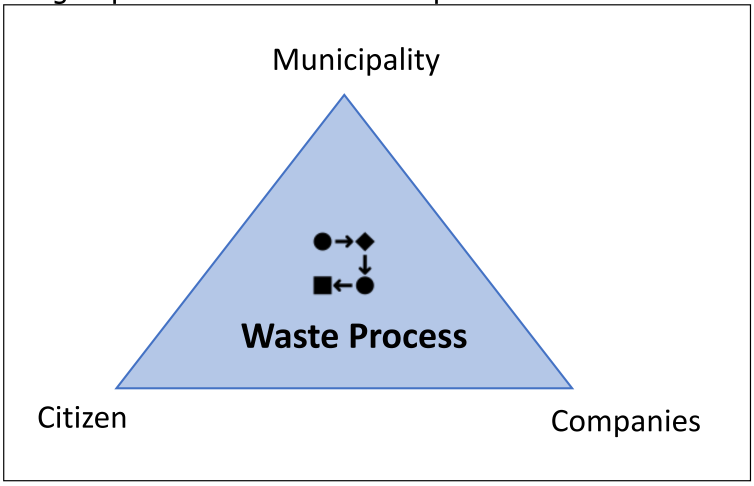
Figure 19: Developing stakeholder-specific KPIs in a collaborative process



Source: the authors

Stakeholders
All participants are stakeholders of the municipal waste management system while they (must) have an interest in an optimal system serving their targets. But as the perspectives or targets of the stakeholder groups might differ, KPIs for measuring the MSW system should be diversified and customized for each group. These stakeholders can be subdivided into Administration, Citizens and Businesses.

Figure 20: Stakeholder groups involved in the waste process



Source: the authors

- <u>Administrations / Municipalities</u>
  Administrations in this context should be defined as all governmental institutions which are directly or indirectly related to municipal waste management. These are first and foremost the municipal administrations directly responsible for the MSW management process. This covers process organization, waste logistics, garbage collection, operation of incineration and billing, accounting and settlement of services to citizens and companies. Secondly Administrations covers state government and political institutions as superordinated institutions which oversee and finance general networks and administrate legal frameworks.
  Since administrations are officially responsible for MSW management they have the highest need for efficient controlling and adequate KPIs. Administrations need transparency and rules, laws and incentive systems that are efficient concerning results and costs. The indicators might be the same for all administration levels but to a different degree of accuracy.
- <u>Citizens</u>
  Citizens are all inhabitants of municipalities which produce waste and are responsible for gathering and sorting waste. And they have to pay fees for MSW services to administrations. Some citizens might have, it is true, an additional interest in sustainable behavior and want to contribute to the world's future, but it is assumed that on average, all citizens as private individuals have the same interests and objectives. So citizens are interested in KPIs making their interests transparent.
- <u>Businesses</u>
  Companies are legal economic entities located in municipalities. They might be extremely diverse in general but have nearly the same interest concerning local MSW systems. Companies might be raw material producers, packaging producers, finished goods producers, traders/retailers as well as logistics or service companies. Even repair, preprocessing of waste and recycling companies are special companies which have responsibilities to assume in MSW processes. Another special case are publicly

owned companies operating in waste collection, preprocessing, incineration, and landfilling. These tasks might be outsourced to private companies.
Companies are even responsible for gathering and sorting waste. And they have to pay fees to administrations for MSW services. For companies there might be an additional interest in showing their results in "green behavior" through reporting and especially annual reports.

Stakeholder-specific objectives
Stakeholders pursue diverse objectives in waste management which could be described as follows: The general objective of all stakeholders seems to be to reduce waste of all types to save the world. Waste is a special type of pollution: air and water pollution are important too but, in this context, the specific kind of MSW should be discussed only taking into account that MSW may cause air pollution by burning in incinerations or water pollution in landfills or direct disposal.

Objectives and targets of Waste Management might be subdivided into direct targets which address major purposes and indirect targets which might be motivation drivers or outputs and measures that help reach direct targets.

Figure 21: Defining stakeholder-specific targets

Level	Interest / Target	Description
General	Direct: reducing overall waste per type	▶ Major target for all to save the world
Administrations (Municipalities)	Direct: processing cost reduction	▶ Municipalities to design cost-efficient MSW processes
	Indirect: pricing/invoicing waste	▶ Invoicing is necessary to balance costs against revenues. But pricing might integrate discounts.
	Indirect: incentivizing good collection and processing	▶ Incentives for citizens and companies might be helpful to fine-tune and reach targets quickly
	Indirect: punishing pollution	▶ In addition to incentives punishment might be necessary to suppress wrong actions.
	Indirect: increasing repair	▶ Increasing repair quota by supporting citizens and companies leads to a reduction of waste
Citizens	Direct: reducing costs	▶ It is assumed that all citizens have an interest in reducing
	Direct: incentives	▶ Receiving incentives
	Indirect: contributing to environment protection	▶ For some citizens saving the environment may be intrinsic motivation
	Indirect: optimizing collection	▶ If citizens optimize collection by sorting correctly, they increase the chance for optimal waste processes

	Indirect: increasing repair	▶ Repairing decreases waste and costs. Citizens might be supported by municipal institutions or companies which might be legally defined
Companies	Direct: reducing costs	▶ Reducing waste costs by optimizing waste processes leads to higher profits
	Direct: incentives	▶ Receive incentives
	Indirect: avoiding punishment	▶ Punishment leads to higher costs and image risks
	Indirect: reporting green activities	▶ Waste performance might become part of annual reporting and is a factor of image building
	Indirect: information about input	▶ If companies know quantities and prices of input materials obtained from reuse and recycling via Blockchain, production and logistics might be optimized. Consumer rights to return defective products by law e.g. for household appliances becomes transparent.
	Indirect: optimizing output	▶ Adequate waste reporting and transparency enabled by Blockchain usage might help to optimize production especially by reducing packaging. Consumer rights to return defective products might force a more sustainable development of products.
	Indirect: increasing repair (legal obligation)	▶ Repair might be required by law or offered as a service. Increased repair quota might generate revenues.

Source: the authors

Based on the beforehand defined stakeholders' interests on information about the material-, information- and payment-flows the key performance indicators could be derived. Focusing on the material flow within the process these targets could be converted into the following stakeholder-specific key performance indicators. Some of the KPIs listed below are already known from those previously presented and obtained from literature review. But in this case these KPIs are modified and tailored to the needs and targets of specific stakeholder groups.

Figure 22: Stakeholder-specific KPIs

Level	Interest / Target	KPI
General	Direct: reducing overall waste per type	▶ Quantity per type in t in total and per capita, change ▶ Recycling quota ▶ Reuse quota ▶ Reducing follow-up costs for future generations
Administrations (Municipalities)	Direct: processing cost reduction	▶ Process costs in total in EUR
	Indirect: pricing/invoicing waste	▶ Invoicing price per type

	Indirect: incentivizing good collection and processing	▶	(1- error rate) x incentive price per type
	Indirect: punishing pollution	▶	Price per t for material losses except processing
	Indirect: increasing repair	▶	Repair quota
Citizens	Direct: Reducing costs	▶	Waste cost per type and per capita in household
	Direct: incentives	▶	(1- error rate) x incentive price per type
	Indirect: contributing to environmental protection	▶	“environmental points” in %
	Indirect: optimizing collection	▶	Error rate per type
	Indirect: increasing repair	▶	Repair quota
Companies	Direct: reducing cost	▶	Total waste cost per type
	Direct: incentives	▶	(1- error rate) x incentive price per type
	Indirect: avoiding punishment	▶	Price per t for material losses except processing
	Indirect: reporting green activities	▶	Quantity per type in t in total, change
	Indirect: knowing input	▶	Quantity per type in t in total by supplier
	Indirect: optimizing output	▶	Quantity per type in t in total, change
	Indirect: increasing repair (legal obligation)	▶	Repair quota

Source: the authors

3.4. Design of a Blockchain-based process

This is where the main challenge lies. 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 be considered in process design: material flow, information flow and payment flow.

Material Flow

A prime focus is obviously on material flow, which needs to be measurable and quantifiable at every stage of the process. In an optimal solution, quantified tracing of a specific material along the entire material chain including reuse and recycling loops would be possible. The lifetime of a glass bottle may thus be described as follows: Glass is produced from silica and shaped as a bottle. The bottle is labeled and filled, transported to a trader, and used by a customer (citizen). After usage the bottle is collected, cleaned, refilled and so on. After 50 cycles the bottle must be recycled and therefore crushed and melted. The glass will reappear in new bottles and so on until the components cannot be used to produce new bottles due to material fatigue. Then the glass can be used as glass filler for highways. The problem of tracing is evident: while one specific bottle may hardly be ‘labeled’ (not as paper label) for tracing, at some stage the bottle must be destroyed and so the ‘label’ is destroyed. For correct tracing it is not the bottle but the glass material itself or even the silica as raw material that should be labeled. This can only be achieved by integrating a kind of ‘label’ (marker) into the chemical structure. As this appears far too complicated ‘labelling’ seems to be no solution for tracing.

So, although such labelling information can easily be stored in a Blockchain, a different solution is required for technical reasons. From a pragmatic angle, quantification of all material mentioned seems to possible in the form of weight (for some products like glass bottles maybe as the number of bottles multiplied by weight per bottle).

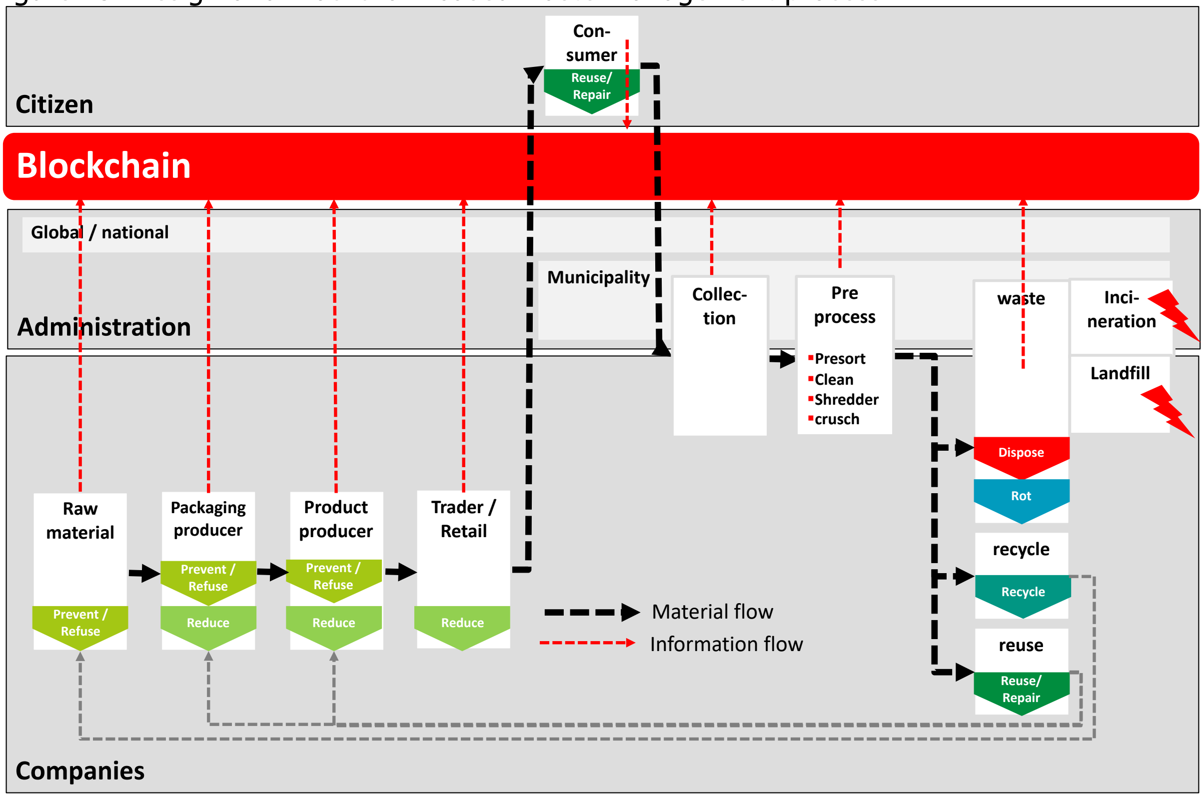
Consequently, each agent involved in the flow of this material should quantify input (incoming goods) and output (outgoing goods and waste) quantities of each mentioned type of material by weight. This is how material losses within a company or in a consumption process can be measured. As very often products consist of more than one or even composite material, material quantities of each product should be stored in the master dataset of a product. E.g. a sparkling water bottle consists of glass, a paper label and plastics used for the bottle cap. This information about material quantity can be recorded for each incoming or outgoing bottle. But even this simple example shows that there should be limits to tracking defined by law or rules: the quantification of the paper label does not seem to make sense. So overall, quantification at input and output stage should only be done for major categories of material that is, upon separation, weighed or volume-aggregated using the master data. This data should be stored daily in a Blockchain by type of material. Data on remaining material are to be stored in the company's IT system.

This approach seems to work in nearly every material flow except with private customers / citizens as here, there is no direct IT link. Quantification of citizens' output can be done by separation in different bins per material type (or later sorting) and weighing and/or scanning during the collection process. So, the aggregated output of a trader could be treated in the same way as input of private customers, if no losses occur in between. Once quantity measurement is executed, material flows are to be analyzed in a next step.

As material flows are the basis on which KPIs are developed, these material flows should be analyzed. One problem is that flows of materials may differ due to their special material properties. But as the principles applied are nearly identical, a generalized material flow which fits all types should be modelled. The standard process is linearized without loops:

A material flow starts with the production of raw material which is delivered to packaging and producers depending on the needs. Surely, packaging is itself a kind of product but is shown here separately because of its special importance in the waste chains. Producers may be producers of finished goods for end-customers or else producers of semi-finished goods supplied as pre-products to other producers. So there is actually a material loop in this step. It must be considered that producers of raw material and semi-finished goods are located in other municipalities than producers of finished goods. Once manufactured, finished goods are delivered to traders. Up to here all participating companies might have nearly the same interests concerning waste management. It should be mentioned that some companies actually produce MSW which has to be collected and invoiced by municipalities, but these steps are left out in the following graph for simplification reasons.

Figure 23: Design of a Blockchain-based waste management process



Source: the authors

Then products "leave" the process layer covered by businesses when sold to customers having another perspective on the process. Household customers sort waste e.g. in separate bins and waste is collected. Then waste is preprocessed and recycled, reused/repaired or treated through rotting, incineration or landfill.

Information Flow

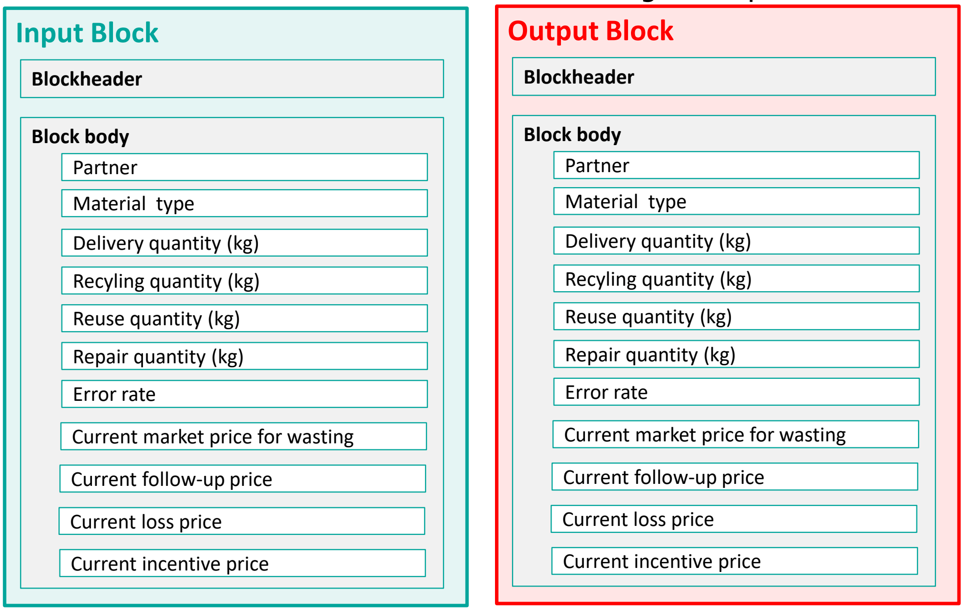
Information flow in a Blockchain-based process looks completely different from conventional process control, since conventional linear information flow which may create long delays and inefficiencies is overcome. All participants can simultaneously access the same (almost) real-time information about the progress of a project. There is only one single source of 'truth' within the network. The permanent synchronization of data and the existence of multiple copies also makes the database resilient against hacker attacks.

IBM (2017, p. 5) put it, in "Message-based versus state-based communications", as follows: *"Today, organizations send messages back and forth to accomplish various tasks, with each organization maintaining its state of the task locally. On Blockchains, messages represent the shared state of the task, with each message moving the task to the next state in its lifecycle. Blockchains shift the paradigm from information held by a single owner to a shared lifetime history of an asset or transaction. Instead of message-based communications, the new paradigm is state-based."*

Each basic piece of information relevant to the generation of KPIs has to be stored in the MSW-Blockchain. Therefore each participant (except citizens) has to generate one block per type so that aggregation will be possible. Quantities are measured as described above.

Current prices have to be uploaded via remote function call from a municipal server. This redundancy of price information (municipal server and each block) is suboptimal from the perspective of information theory but it leads to much higher performance when it comes to generating KPIs on demand. So overall the block structure should be as depicted in figure 24.

Figure 24: Block structure of Blockchain-based waste management process



Source: the authors

KPIs can be produced on demand from this information if the Blockchain is performant enough.

Collaboration needs a high level of trust between partners as the desired result can only be reached together. Everyone depends on each other, like participants of a rope party when climbing mountains. Trust can be created if every participant has access, at the same time, to the same reliable information about activities and transactions. This condition is fulfilled if there is only a single shared database in a distributed network that records all past transactions as a single source of truth for all participants.

Payment Flow

With the Blockchain, payment transactions can be organized peer-to-peer without an additional financial intermediary and can even be automated with the help of smart contracts. So-called payment tokens, i.e. digital values that assume monetary functions, can be used as money.

According to the Bank for International Settlements (2018, p. 97), "…*cryptocurrencies combine three key features. First, they are digital, aspiring to be a convenient means of payment and relying on cryptography to prevent counterfeiting and fraudulent transactions. Second, although created privately, they are no one's liability, ie they cannot be redeemed, and their value derives only from the expectation that they will continue to be accepted by others. This makes them akin to a commodity money (although without any intrinsic value in use). And, last, they allow for digital peer to-peer exchange".*

The most important point in this BIS statement is the last one: "Payment tokens allow for digital peer-to-peer exchange". The current means of payment circulating in the financial system do not allow for digital peer-to-peer exchange as they are issued by central authorities within the two-tier systems of commercial banks and central banks. Therefore, if the Distributed Ledger Technology is to gain acceptance in the real economy by trading directly peer-to-peer, payment tokens will need to become the natural complement for exchanging value on a digital basis.

As the BIS states, payment tokens are created privately, and their value derives only from the expectation that they will be accepted by others. They do not serve as a legal tender recognized by a legal system such as coins and notes. However, following the current discussion, some central banks might issue digital forms of value-based cash in the future. Currently, it is stable coins whose private issuers guarantee a 1-to-1 exchange rate of the payment token into all major currencies (US-Dollar, Euro, Yen or Swiss Franc), that appear to be most suited for peer-to-peer use. This is how stable coins represent a bridge between the existing fiat money of the banks and the crypto world.

3.5. Development of a governance model for Blockchain applications

The governance of the Blockchain is a stakeholder agreement which is jointly developed and adopted by all stakeholders involved. The core element of the Blockchain is its decentralisation, which delegates decisions and supervision to the network of stakeholders and not to a central institution or authority. Consequently, the stakeholders must first agree on the essential elements of cooperation in the governance of the data network. The establishment of a token-based incentive system makes it possible to create a win-win situation for all participants, thus motivating them to participate in this collaborative database. In the following, an overview of the essential elements of governance for Blockchain-based waste management is given.

Blockchain governance as a collaborative process

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 participants or via the hierarchy of the company with the highest capital share?
- How is the process monitored? Are there any institutionalized 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).

On-chain and off-chain Blockchain governance

Governance for Blockchain consortia consist of "on-chain" and "off-chain" agreements. The on-chain agreements are a number of agreements that deal with the operational part of the technology: node hosting, consensus mechanisms, access and permissions, and tokenization if applicable. Hence, the choice of protocol forms the basis of these on-chain agreements. In a Blockchain consortium, the off-chain agreements include the fundamental rules of the business part. The actors need to design a governance structure that is acceptable to all participants. There must also be agreement on how data will be shared, how much input/control each participant will have, and how issues related to the overall performance of the consortium and its participants will be handled.

Blockchains can contribute to better cooperation by discouraging or making impossible opportunistic behavior. It can also contribute to better coordination by facilitating communication and information sharing. Trust is inherent in Blockchain technology. Blockchains do not rely directly on legal systems to enforce agreements, as contracts normally do, and Blockchains do not require personal trust or direct connections between collaborators. However, Actors need, however, to gain confidence in the technology and build technological trust in order to develop the consortium in a Blockchain ecosystem.

Blockchain enables a tokenized incentive system
As previously mentioned, an important element of Blockchain governance is the development of a tokenized incentive system to motivate the different actors in the waste chain. Such a token system may be of particular interest for motivating citizens. Depending on the adopted policies, fungible or non-fungible tokens can be provided to the Blockchain addresses of each user in quantities and kinds responding to the user's behavior. Typically, a mobile app allows the user to manage tokens in the Blockchain addresses by means of a Blockchain wallet where the private keys for token ownership are stored. Other ad-hoc solutions can be designed for particular categories of citizens. A set of Smart Contracts automatically enforces the earning of tokens by users who properly split and reduce waste and help improve the recycling rate. The set of Token Smart Contracts can directly interact with the set of Smart Contracts managing the waste tracking chain where proper behavior of households has been recorded by separation quality, waste reduction and other criteria, so that the corresponding reward in tokens is automatically earned by a household and deposited into its Blockchain wallet. The household can check the token reward earned in its wallet and verify the correspondence to the data recorded in the waste tracking chain, thanks to the transparency and immutability of the Blockchain. A Blockchain browser can be provided to the users, together with the wallet, in a mobile app. Tokens belong to the user and can, in principle, be accumulated, exchanged, gifted, sold, burned according to the policies adopted in the Smart Contract for each kind of token.

Municipalities or other main actors can adopt rewarding strategies (such as free use of public services) relying on tokens, since these are granted to be tamper-proof thanks to the Blockchain technology. The entire lifecycle of each token can be monitored by Blockchain transactions from the creation to the burning. Tokens cannot be falsified, double-spent or reproduced.

3.6. Convincing top management

Blockchain technologies potentially have a disruptive impact on value chains and the way in which value is created and distributed. One of the effects is a large degree of disintermediation. Through an industry-by-industry analysis Carson, Romanelli, Walsh, and Zhumaev (2018) revealed more than 90 discrete use cases of varying maturity for Blockchain across major industries and presented the following key insights on the strategic value of Blockchain:

1. Blockchain does not have to be a disintermediator to generate value, a fact that encourages permissioned commercial applications.
2. Blockchain's short-term value will be predominantly in reducing cost before creating transformative business models, and

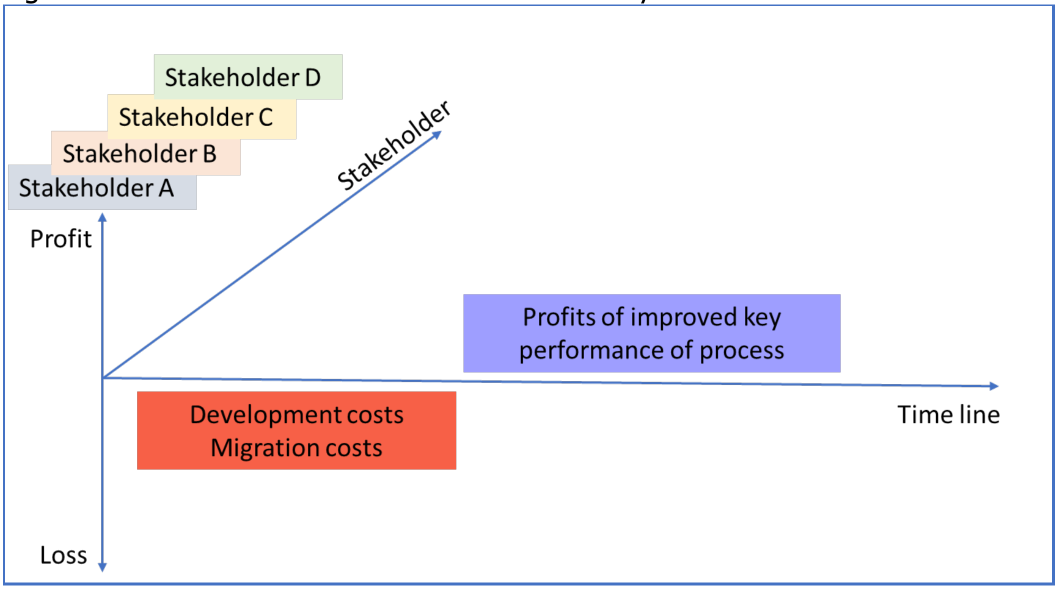
3. Blockchain is still in its infancy and has to grow to be feasible at scale, primarily because of the difficulty of resolving the "coopetition" paradox to establish common standards. What is actually meant by "coopetition paradox"?

At the end of the day it has to pay off ...

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 a 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. In municipal waste management, with a municipality being a public institution, however, the non-monetary KPIs such as reduced waste, better quality of waste separation, higher recycling and repair rates etc. must be taken into account in addition to the business-relevant key performance indicators (profit and cost).

A Board would also like to have answers to the question of migration costs, i.e. the costs incurred by the conversion of existing processes. 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 25: Positive Return of Investment for every stakeholder?



Source: Lenz (2019)

If for each stakeholder involved the expected future profit exceeds the initial cost of the process transformation, then the respective management can decide to carry out this investment or project. Realistically, the switch to a Blockchain-based waste management process will not result in a net benefit for everyone involved. For some stakeholders, the cost of migrating the existing process to a Blockchain-based process may also outweigh the potential benefits, especially as these occur with some uncertainty and the estimation of migration costs is relatively certain. This is where the decentralized incentive system outlined above in "3.5 Governance" comes into play. How important is it for those stakeholders with a manifest benefit to support the migration to the Blockchain undertaken by those participants with fewer advantages? In other words, how much of the advantage the former can only generate by switching to the Blockchain are they willing to give away via a token-based incentive system, so that in the end a win-win situation or, more precisely, a positive return on investment arises for each participant?

An ecosystem perspective is needed
In today's interconnected world companies inhabit ecosystems that extend beyond the boundaries of their own industries. This also applies to municipal solid waste management. This is an ecosystem with many players, including producers, consumers, municipalities, legislators and regulators, waste collectors, waste processors, recycling companies and so on. They are all actors in the ecosystem of municipal solid waste management. An ecosystem is an entity consisting of a heterogeneous set of actors that are linked to each other. These actors have their own autonomy and simultaneously cooperate and also compete. In the MWM ecosystem, the various actors work together to generate and capture value from processing municipal waste streams (in the most sustainable way possible). But at the same time, they have conflicting interests. For example, producers want the cheapest possible packaging, with a recognizable marketing story. Consumers want convenience in separating and offering their waste. Municipalities want to stay within their budgets and at the same time organize their (waste) processes more circularly, and so on. Additionally, in an ecosystem, certain actors are in direct competition with each other, for example the various waste collectors. Or parties in ecosystems implementing Blockchain innovations risk being minimized or eliminated, due to the disintermediary nature of Blockchain.

Choosing the appropriate Blockchain
Blockchains come in many forms, though one of the key concepts of Blockchain is the existence of a network of nodes in the networking process. Blockchains can roughly be divided into three types of Blockchain: Private, public and consortium. These types have many similarities, and the difference lies in who is allowed to participate in the network, how 'truth agreement', referred to as 'consensus', is created, and how the ledger is maintained. Blockchain initiatives in MWM are likely to start with consortium Blockchains, in which two or more parties will participate in the ecosystem, for example consumers using a smart container and waste collectors using smart contracts to execute invoicing per waste collection per household. Several parties can then join this Blockchain ecosystem. This is also necessary to make the chain (more) circular. Consortium Blockchains are made up of several entities and are partly decentralized as the consensus power and reading permissions are restricted to a set of people or nodes. In practice, consortium Blockchains can be applied to many business applications, have different sizes and may differ in their governance models and strategic goals.

Be aware that Blockchain is more than a technology
Blockchain is not just a technology but offers opportunities to create and distribute value in other ways. Ecosystem design requires a systems perspective. In addition to value creation and a delivery model, ecosystem design must take into account the distribution of value in an ecosystem. This requires deliberate ecosystem alignment and governance. It requires a paradigm shift, and to make this shift possible, involvement and advocacy from the organization's top management is needed.

Start small but make it scalable
A pitfall in the adoption process of Blockchain innovations is that, although the disruptive nature of Blockchain is potentially great, actors immediately think very big, whereas the chances of success are greater if they start small. 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 ("Proof of Concept"), the project could be implemented on a wider scale.

A start could for example be made with one activity in the MWM chain or an activity shared between two links or parties in an ecosystem. Gaining experience and sharing knowledge is vital to convince other actors in the MWM ecosystem to participate. Circularity can only be achieved if the whole chain is closed, which requires broad adoption and participation.

Educate management
A number of key performance indicators are mentioned above that could convince management. But before that, management must be educated about the fundamentals of Blockchain. 'Unknown' makes Blockchain 'unloved'. In addition, there are many misconceptions about Blockchain, e.g. the idea that it only has something to do with cryptocurrency, or that Blockchain is purely an ICT technology. A lack of Blockchain knowledge within the organization or waiting for other players in the ecosystem to go ahead with developing initiatives are also delaying factors in the adoption of Blockchain.

4. Final Recommendations

This handbook is intended to encourage European municipal waste management companies to take a different and innovative approach to implementing Blockchain solutions. Below are some final recommendations for taking such a path.

Learning from failed Blockchain projects
In conclusion, Blockchain has a potentially disruptive impact on ecosystems and the existing business models of the actors participating in these ecosystems. It is therefore vital that top management is involved in the decision-making process for adopting Blockchain innovations. Although Blockchain is an emerging popular technology, many Blockchain projects do fail. Trujillo, Fromhart, and Srinivas (2017) investigated that only 8% of all Blockchain projects in Github are active 1.2 years after their activation. An important reason for this high failure rate is the lack of a (financially) sustainable business case. Most Blockchain projects are focused on understanding and exploring the technology (by Proof-of-Concept, POC) but are not sufficiently disruptive in terms of recreating value and fail to understand that a re-design of the ecosystem is imperative for successful Blockchain adoption.

According to Trujillo et al. (2017, p. 11), the following conclusions can be drawn from the GitHub data:

- *Projects done by organisations have a higher survival rate than those of individuals*
- *Projects that survive tend to have multiple committers with less concentration of activities attributed to one particular committer*
- *Projects that are often copied are more prone to survive*
- *Projects that are "forks" of other projects tend to have high mortality rates*

The message deriving from this seems to be clear: Blockchain projects need a lot of resources (money and manpower), a project should be set up and operated in a collaborative manner, and it is not advisable to copy other projects instead of setting up one's own project that is individually designed to solve a specific problem.

Set up the right project team
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 people along and convincing them, explaining the technical possibilities of the Blockchain in simple terms - these are the components for the success of a project and for the selection of project team members. Besides IT experts, business controllers

and process designers, the team should include change managers with distinctive communication skills.

Municipal Waste Management as local and citizen-centred solution provider
From game theory it is known that collaborative approaches lead to better solutions than non-collaborative approaches in terms of increasing welfare. The transformation to a Circular Economy requires fundamental behavioural changes from all stakeholders, be it in consumption behaviour, waste disposal or business model chosen. Collaboration is to be understood in this sense that the common goal can only be achieved through the cooperation of all parties. A desired collaborative solution to a given problem would certainly be quicker to obtain in an authoritarian state exerting complete control over citizens. Whether this solution would also be sustainable, however, is questionable. In any case, such a top-down approach would deprive every individual of their economic freedom and fundamental rights. In democracies and market economies, such collaborative solutions are to be negotiated with all stakeholder groups and citizens make their free decision.

Municipal waste management has a decisive advantage in such a process of negotiation: the problem can be solved locally. People know each other, a relationship of trust can be built between a municipality and its citizens, and local solutions can be found. This makes it all the more important to emphasize the participative involvement of citizens in local solutions within cities and municipalities. Therefore, the role of municipalities as public waste managers must be emphasized. This role is neither driven by a commercial interest in complete data collection from citizens nor by the will to act as a local authority. Municipalities should rather sees themselves as agents acting on behalf of citizens. Such local agents, whose actions are geared solely to the interest of municipalities and controlled by citizens, would certainly be more willing to hand over their waste data than global players.

These local solutions of municipal waste management may be completely diverse across Europe, but they must finally lead to the goal of sustainable use of scarce resources. There will be no "one-size-fits-all" approach in matters of waste due to cultural differences but also differences in national waste treatment. What should rather be stimulated is mutual learning from innovative local approaches.

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