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BARRIERS TO CLOSING WASTE LOOPS IN THE EUROPEAN UNION

Implications for circular economy platforms in waste management

Master's Thesis
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Abstract of master's thesis

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Abstract

The idea of a circular economy (CE) has long been discussed in the European Union (EU) as a solution to environmental unsustainability. Implementation of CE has been limited however. Our research objectives can be summarized as investigating the barriers in the EU waste management supply chain to closing waste loops using digital waste exchange platforms. During the review of literature, two sets of barriers were found to exemplify the current challenges in the waste industry to close waste loops and the obstacles to adopting a digital waste exchange platform.

The empirical part of the research consisted of 31 semi-structured interviews with respondents from industry, waste management, end users of waste, platform providers and experts on waste management or CE. The respondents were from across the EU. During the interview process an interview guide was used to steer discussion and obtain qualitative data which were interpreted using the two groups of previously identified barriers. Subsequently a cross analysis was performed between the two sets of barriers to reveal which aspects of the industry had to change to enable the closing of waste loops using a waste exchange platform.

It was found that financial barriers were most prominent in the analysis of challenges related to developing circular economies. The current market structure was also seen as having an impact on the pace of industry development. Regarding the adoption of platform, the most significant barriers was the lack of accurate information for waste related materials (standardisation & classification). Furthermore, respondents saw imbalances in the market structure which seemed to favour downstream companies. Lastly, a framework for improved classification of waste was created and emerged as the theoretical contribution of the research. The study emerges as a stepping stone towards future research into operational challenges of adopting industry platforms to coordinate information and materials between ecosystem participants.

Keywords barriers, circular economy, closed loops, platforms, recovery, recycling, reuse, technology, waste markets, waste management, waste-to-energy

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Ideaa kiertotaloudesta on pitkään esitetty Euroopan unionissa (EU) ratkaisuksi ympäristön kuormituksen vähentämiselle. Kiertotalouden implementaatio on kuitenkin ollut heikkoa. Tutkimustavoitteenamme oli tutkia kiertotalouden esteitä EU:n jätehuollon toimitusketjuissa ja jätevirtojen sulkemisessa digitaalisten alustojen avulla. Kirjallisuuskatsauksen aikana löysimme kaksi pääasiallista esteryhmää, jotka kuvaavat tämänhetkisiä haasteita jätehuollossa. Jätevirtojen sulkeminen on kuitenkin vaikeaa ja digitaalisen jätevaihtoalustan käyttöönottamiselle on olemassa esteitä.

Tutkimuksen empiirinen osa koostui 31 teemahaastattelusta. Haastateltavat toimivat teollisuudessa, jätehuollossa, jätteen loppukäyttäjinä, digitaalisten alustojen toimittajina sekä jätehuoltoalan tai kiertotalouden asiantuntijoina eri puolilla EU:ta. Haastattelujen aikana käytimme haastatteluopasta keskustelujen ohjaamiseen ja kvalitatiivisen datan saamiseen, jotta saatoimme vertailla hankittua tietoa aikaisemmin tunnistettuihin esteryhmiin. Tämän jälkeen suoritimme poikittaisvertailun kahden esteryhmän välillä. Tällä haluttiin osoittaa, minkä aspektien pitäisi alalla muuttua, jotta jätevirtojen sulkeminen olisi mahdollista.

Tutkimuksessamme kävi ilmi, että suurimmat kiertotalouden kehityksen esteet olivat taloudellisia. Nykyisen markkinarakenteen nähtiin myös vaikuttavan alan kehitysvauhtiin. Merkittävin este digitaalisten alustojen käyttöönottamiselle oli tarkan informaation puute liittyen jätemateriaaleihin (standardointi ja luokitus). Tämän lisäksi haastateltavat näkivät epätasapainoa markkinarakenteessa, joka vaikutti suosivan toimitusketjun loppupäässä olevia yrityksiä. Tämän perustella loimme viitekehyksen jäteluokituksen parantamiseksi, joka toimii työn teoreettisena lisäyksenä. Toivomme, että tutkimuksemme voi toimia lähtökohtana tuleville tutkimuksille liittyen operatiivisiin haasteisiin teollisten alustojen informaation ja materiaalien koordinoimisessa.

Avainsanat digitaaliset alustat, energiakäyttö, esteet, jätehuolto, jätemarkkinat, kierrätys, kiertotalous, suljettu kierto, teknologia, uudelleenkäyttö

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List of Abbreviations

CBM	Circular business model
CE	Circular economy
DWE	Digital waste exchange
EI	Eco-innovation
EU	European Union
IE	Industrial ecology
IS	Industrial symbiosis
MRF	Materials recovery facility
MSP	Multi-sided platform
MSW	Municipal solid waste
OECD	Organisation for Economic Co-Operation and Development
PPP	Public private partnership
RDF	Refuse-derived fuel
SRF	Solid recovered fuel
WMT	Waste management theory
WTE	Waste-to-energy

1 Introduction

The thesis researches the role of waste management in a circular economy (CE) and the closing of waste loops to utilize waste. The motivation was the current pressure on waste management due to the needs of CE. The research explores the state of technological development and impact of platforms on the waste industry in enabling waste management activities to close waste loops. Research questions of the thesis investigated barriers to CE and platforms and the question of how to overcome these.

1.1 Background and Motivation

The unsustainability of linear economies

There is an inherent unsustainability to traditional linear economic models, where economic growth comes at the cost of negative environmental consequences. This has contributed to unsustainable environmental impacts like climate change, biodiversity and natural resource depletion, land degradation, and ocean pollution. Furthermore, governments, companies and organisations have come to realize that the traditional economic systems lead to underutilized resources, unnecessary volatility in resource prices and supply disruptions. (Ellen Macarthur Foundation, 2015[1]).

Since 2012 goods and services have annually consumed natural resources at a rate that takes 1.6 years for the earth to renew (WWF, 2016, p. 75), growing to 1.7 in 2018 (Global Footprint Network, 2018). In 2012, the 28-member States of the EU, used up five billion tonnes of material: four billion of which came from virgin materials (EPRS, 2017, pp. 16-17). Such consumption using a linear economic model is not viable in a world of finite resources. Materials and components have been estimated to make up between 40-60 percent of European manufacturers' total cost bases, due to high levels of importing. Which has led the EU to list the security of supply for 20 materials as critical (Ellen MacArthur Foundation, 2015[2]). In addition to the challenge of unsustainable consumption, significant amounts of waste are produced with negative environmental impacts.

The consumption of natural resources and the generation of waste are currently tied to economic growth. The unsustainability of current consumption and waste generation is exacerbated by projections of 3 billion people entering the middle class by 2030, an unprecedented increase in demand for consumer goods. Meanwhile whilst the lesser economically developed countries present rapidly increasing disposable income for consumption, the more affluent consumers of OECD (Organisation for Economic Cooperation and Development) economies have a resource footprint multiple times larger. (World Economic Forum, 2014). As noted by the European Parliamentary Research Service, EU members with higher GDPs tend to have higher levels of municipal waste generation, though they also have higher shares of recycling, composting and digestion compared to lower GDP members who rely more on landfilling (EPRS 2017, pp. 11, 31). This makes the decoupling of waste generation and the impacts of waste disposal from economic growth critical to improving sustainability.

The circular economy as a solution to linear waste

CE can allow for better balancing between the geographical locations of consumption and production, compared to linear models that are tied to the location of virgin materials. This could both reduce risks related to material availability, as well as logistics costs (EUR-Lex, 2015, p.2). The damaging environmental impacts of waste, unsustainable consumption of natural resources when waste goes unutilized, increases the importance of waste management and finding new CE solutions for waste recovery. Additionally, increasing legislative pressure coming from outside and originating within the EU, means that unsustainable waste management will not be viable in the future.

Exports of waste to Asia, particularly China, have been used to dispose of for instance low value plastics due to low labour costs required for high labour-intensive activities in recycling (EPRS, 2017, pp. 42-43). However, China has been increasing regulation on recyclable materials, banning 24 categories January 1st, 2018. In addition increasing quality standards on all scrap imports March 1st, bans on steel slag, post-industrial plastics, compressed auto pieces, small electric motors, insulated wires, as well as vessels by the end of 2018. Prohibiting wood pellets, stainless steel scrap, and nonferrous scrap excluding aluminium and copper by the end of 2019 (Moore, 2018). The ban is particularly problematic for plastics. In 2014, it was estimated that 87% (by weight) of plastic waste exports from the EU-27 at the time, went to China (Velis, 2014). A study at the New Materials Institute, University of Georgia has calculated that since 1992 China has cumulatively received more than 45 percent of the world's plastics waste. The study predicts that globally the waste ban, will lead to 111 million metric tons of plastic without an outlet by 2030 (Brooks et al., 2018). This places greater pressure on the waste management industry to find ways to utilize waste through closing waste loops.

Emergence of digital platforms to close waste loops

The purpose of this research was to understand how waste management needs to develop in the context of CE, both as an activity and as an industry. Waste management has a key role in managing waste prevention and creating a supply of high-quality secondary raw materials, and as a partner to enable new CE business models (EPRS 2017, pp. 15-17). This requires increased collaboration in the supply chain of waste, from waste creation to waste reuse, recycling or recovery to avoid landfilling.

New technologies such as digital platforms have enabled the faster exchange of information between parties and the creation of more complex relationships. Platforms act as a mechanism that enable digital interaction that serve a specific business objective (Altman & Tushman, 2017). Well-established platforms contain large volumes of interactional data and can be seen as the digital manifestation of the industry relationship structure. Understandably, there has been a rise in interest regarding utilizing platforms and their role in creation of digital ecosystems. However, relying solely on platforms to improve supply chain interaction necessary for CE is not enough. While platforms can facilitate information transfer, they have a limited capacity to improve the actual exchange of goods between partners. The aim of this study from a platform perspective is to explore how the physical limitations of waste exchange prevents the utilization of a platform to drive the ambitions of CE.

1.2 Research Questions

The research questions were planned in cooperation with Tana Oy, a Finnish supplier of landfill compactors, shredders, drum and mobile disc screens for waste management. After preliminary discussions with experts on the waste management industry from Tana, and the reviewing of literature on CE, we sought to investigate barriers to the closing of waste loops and enabling waste exchange platforms.

The research questions were:

Q1. What are the barriers to closing waste loops and to waste utilization in the EU waste management supply chain?

Q2. What are the barriers for utilizing a digital waste exchange platform to enable circular business models?

Q3. How can the challenges to closing waste loops and utilizing digital waste exchange platforms be overcome?

2 Literature Review

The literature review provides a summary of sources explored in relation to the research questions. First, an analysis of the EU waste industry sets the scene of the research. Second, the principles of CE establish a theoretical foundation of the subject. Then an overview of waste management theory explains the role of waste management within the context of CE. Next, a system view explores the waste industry as group of interdependent actors operating within the same system, whose collective actions shape the industry. Subsequently, the role of innovation in the waste industry is explored, including the impact of digital platforms. Lastly, industry related barriers to transitioning towards CE are presented and supplemented with platform related barriers.

2.1 Analysis of the EU Waste Industry

Over the past several decades, the EU waste industry has evolved from fragmented waste solution strategies of individual nations to a more uniform approach bound together by EU legislation. Although much work has been done to unify the asymmetric strategies of individual members states, some notable differences remain (Bourguignon, 2015). Considering regional disparities, it is still possible to talk about an EU waste sector as a whole and dwell deeper into the industry characteristics.

2.1.1 Overview of EU Waste Industry Structure

The European waste management industry can be understood by viewing the organisations that collect, process, dispose and monitor solid waste materials. Waste management requires a holistic perspective looking at the complicated network of stakeholders affecting the capturing of value in the waste ecosystem. Typical stakeholders include: policymakers, users, private companies, the government, customers, suppliers, regulators and local municipalities (Peltola et al., 2016). Which can be seen in Peltola and Mäkinen’s (2015) mapping of the waste flow ecosystem (Figure 1). In the figure the flow of waste materals originates from households and muncipalties and on the left, and is then handled and processed by various actors ending up as: incinerated, landfilled, recycled or sold to downstream customers.

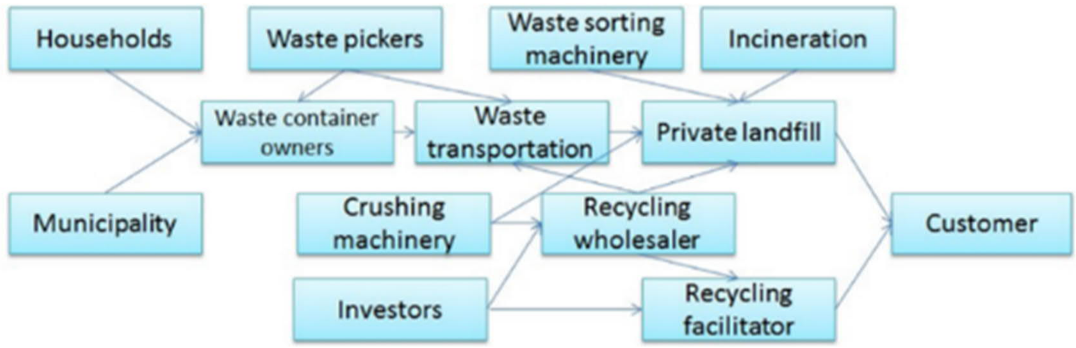

Figure 1: Waste flow ecosystem by Peltola & Mäkinen (2015)

The organisations that operate in the industry can be grouped into publicly funded waste management firms and privately-owned entities. Private companies operate by entering into agreements with local municipalities through long-term contracts **(**Hall & Nguyen, 2012). Public Private Partnerships (PPP) are seen by local governments as a way to procure public services from outside partners and in some cases financing for infrastructure projects. Although PPP projects promise increased efficiency and lower operation costs for waste management services, in practice, the results of such relationships have been mixed (Hall & Nguyen, 2012; European Commission, 2016[1]). While in some regions (such as the UK) PPP arrangement are popular, in other countries like Germany, the trend has been re-municipalisation in waste management (Weghmann, 2017). Clearly, there is not a one-size-fit all configuration for a suitable public-private split in the waste industry.

Another way to understand the industry is by analysing the waste flows to get a sense of the connection between regional, national and EU level waste management strategies The EU-28 produced around 2.6 billion tonnes of waste in 2014. The highest share of this waste was disposed through landfilling (41%), whilst non-energetic recovery and recycling made up 36% (EPRS 2017, pp. 31). Because EU household data is often bundled with waste generated by economic activity, it may be difficult to get an adequate understanding of waste contribution by the industrial sector alone. Therefore, in this research, municipal solid waste (MSW) and industrial waste were viewed as the single concept, comprising two sides of the "same coin". Following such an approach allowed researchers to consider a broader range of literature and focus on understanding how waste streams helped to shape the industry. Figure 2 takes a broader view of the waste streams generated in the EU industry and provides an interesting snapshot of the economy. Surprisingly, the figure shows that household waste is responsible for a relatively small part of total waste volumes, while mining and construction sectors generate the lion's share by mass.

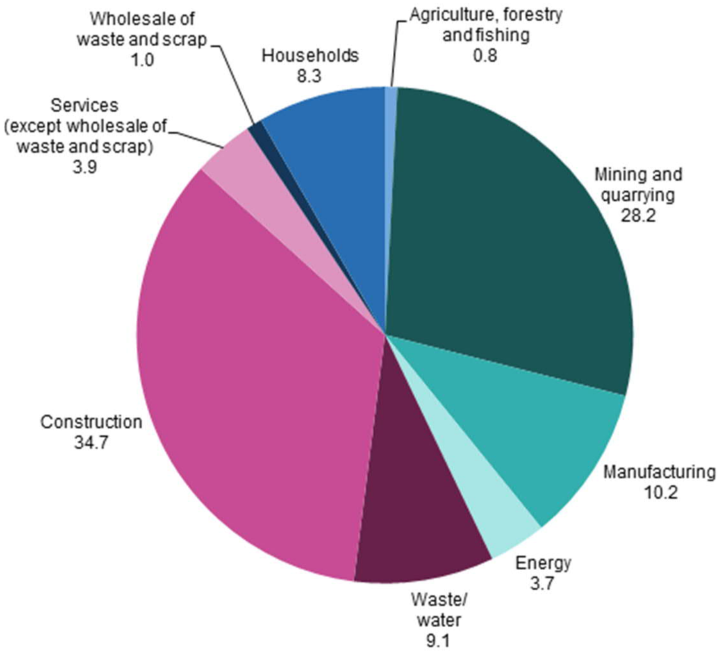

Figure 2: Waste volumes by origin in the EU-28 in 2014 (European Commission, 2017[1])

While representing a relatively small amount of total waste generated, MSW has a significant negative impact on the environment. In fact, *"…municipal solid waste (MSW), i.e. household waste and similar commercial, industrial and institutional waste is one of the most polluting categories of waste…"* (European Commission, 2016[2], pp.21). One of the reason could be the composition of MSW compared to other types of generated waste. For instance, in the mining sector, non-hazardous by-products such as rocks could be simply transported away. Similarly, in the construction industry, discarded building materials with large volumes such as wood, metal and cement can be easily disposed, as composition is often known. Since such materials are often inert, they are less harmful to the environment and can be reused as building aggregates (Velzeboer & van Zomeren, 2017). Other waste types are more problematic to dispose of, while adhering to environmental laws.

Analysing the waste industry by composition in connection with disposal methods may give more insight into the EU waste industry. In the EU, waste legislation was strengthened with the introduction of the Council Directive 1999/31/EC, which encompassed categories of waste and established the legal methods for disposal or long-term storage (EUR-Lex, 1999). The directive was later updated to expand its scope of operation. The current Landfill Directive 2008/98/EC establishes four waste categories (municipal waste, hazardous waste, non-hazardous waste and inert waste) and mandates that disposal be performed at the corresponding landfill type (European Commission, 2016[3]). Both the origin and composition of waste material is considered when determining the waste category. *"In total, about 4 % of the waste generated is estimated as hazardous."* (European

Commission, pp.19, 2016[2])· The List of Waste provides common classification terminology for all EU member states, used to determine how hazardous the waste material is for the environment. Waste originating from industrial production is tested to assess its environmental impact and a corresponding classification is derived using the list (European Commission, 2018[1]). Firms that produce higher volumes of hazardous waste materials are forced to pay higher fees for its disposal. Traditionally the fees collected by landfill operators help to fund the overall waste management system in a particular region. Because each member nation has a different waste management strategy, the landfill fees vary greatly across the EU. Reggiani and Silvestri (2017) have found a positive correlation between landfill prices and the amount of waste that is separated. The higher the gate fees are the more incentive there is to improve material separation. Differences in waste volumes and disposal methods across the EU is shown in Figure 3, which shows Denmark as one of the largest waste producers per capita; with a high level of incineration. Romania, on the other hand, produces a low amount of waste per capita, but sends most of it to landfill.

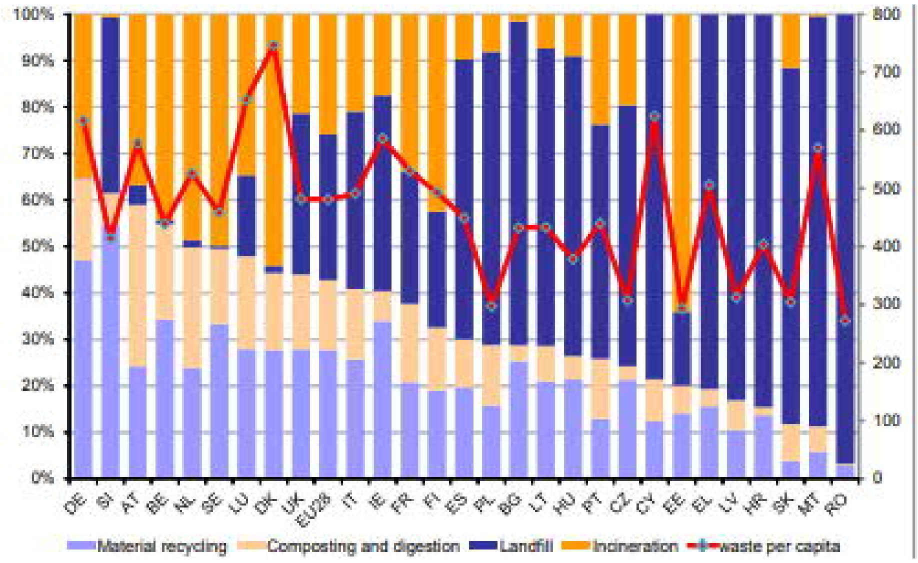

Figure 3: Waste generation by economic activity and household (Bourguignon, 2015)

One possible reason for regional disparities in waste management strategies between EU member states could be the different national approaches to infrastructure investment. Higher investment in waste treatment infrastructure and recycling programs in some nations resulted in more efficient waste separation and more developed waste management programs. However, even though disparities between EU member states exist, it is too simplistic to view the industry as being comprised of isolated regional actors. In addition to the local waste streams, there are also inter-regional flows. As a result, transboundary movement of waste in the EU has grown more complex in recent years, establishing shipping patterns across the continent. As some nations search for outlets for their growing waste volumes, others seek to import waste and utilize free capacity in local waste treatment infrastructure. Legislation has also expanded to account for the rising complexity of trans-border waste supply chains. It includes legal requirements to be followed when waste is transported across national borders to be treated (European Commission, 2018[2]).

2.1.2 EU Waste Management and Circular Economy Initiatives

For the past several decades, EU environmental legislation has been steadily expanding to encompass a wide range of waste related activities. Evolving since the 1970s EU environmental legislation has grown to include about 500 directives, regulation and decisions (EEA, 2016). The collection of EU environmental law forms the most comprehensive set of standards on the globe. While a full review of governmental legislation instruments is beyond the scope of this research, a summary of the basic principles is provided. In the following section, key ideas and legislation are covered.

In the EU various policy instruments are used to encourage economic actors to become more environmentally friendly and achieve long-term sustainability goals. Table 1 provides an overview of some of the policy instruments used in the EU concerning waste. The policy type can range from rewards for desired behaviour to non-compliance penalties. Alongside direct policy measures, such as legislation, there are several indirect instruments such as economic incentives, market-based instruments and information sharing.

Table 1: EU waste management policy instrument examples (EPRS, 2017, pp.22)

Policy Instrument	Examples used for waste management
Legislation	Directives and regulations used to: • Set targets for and reporting requirement for individual waste streams (e.g. recycling targets and landfill reduction targets) • Establish extended producer's responsibility schemes • Establish economic instruments • Encourage improved eco-design
Economic incentives	Investments in waste collection infrastructure supported through the Cohesion Fund, funding for R&D and innovation (e.g. Horizon 2020)
Market based instruments	Landfill tax and gate fees, incineration tax and fees, plastic bag taxed; Pay As You Throw schemes
Information requirements	Consumer recycling information on packaging, voluntary reporting of waste product and target setting by companies
Voluntary tools	Awareness raising campaigns for the public, voluntary industry commitments, product design and labelling (e.g. through the EU Ecolabel) provision of good practice information, business led initiatives.

Waste related legislation in the EU is a constantly evolving and growing in scope. As the economy grew more complex and environmental issues came to the forefront of public opinion the legislation was expanded. *"The Waste Framework Directive 2008/98/EC is the key legislative document on waste at the EU level"* (European Commission, 2018[1]). The directive applies a priority for waste management in the form of a waste hierarchy framework: (1) Prevention, (2) Preparing for Re-Use, (3) Recycling, (4) Recovery (including energy recovery), and (5) Disposal (EUR-Lex, 2008) shown in Figure 4. The waste hierarchy establishes ordinal categories from most preferred to least for dealing with waste. (EPRS 2017, pp. 63-77). Some authors have disagreed with the strict preference of recycling over recovery however (Pongrácz, 2002; Cucchiella et al., 2014).

Figure 4: EU Waste Hierarchy (European Commission, 2016[4])

The 2008 Waste Frame Directive is complimented by the Hazardous Waste Directive, and together they establish the structure of waste management and encompass two key groups of directives. First, is related to activities of waste disposal facilitates and the second is connected to specific waste types. Furthermore, the Shipment of Waste Regulation (259/93/EEC) regulates import, export and transit shipment of waste movement in Europe (European Commission, 2015).

The year 2015 was pivotal for transformation of EU legislation, when the Circular Economy Package was presented. Prior to that, several attempts were made to introduce key element of a circular waste model but were not as far-reaching or impactful. By coupling economic growth and environmental targets, the issue of sustainability developed more organically. The key points introduced in the 2015 Circular Economy Package include the following (European Commission, 2018[3]; EUR-Lex, 2015):

- *A common EU target for recycling 65% of municipal waste by 2030;*
- *A common EU target for recycling 75% of packaging waste by 2030;*
- *A binding landfill target to reduce landfill to maximum of 10% of municipal waste by 2030;*
- *A ban on landfilling of separately collected waste;*
- *Promotion of economic instruments to discourage landfilling;*
- *Simplified and improved definitions and harmonised calculation methods for recycling rates throughout the EU;*

- *Concrete measures to promote re-use and stimulate industrial symbiosis – turning one industry's by-product into another industry's raw material;*
- *Economic incentives for producers to put greener products on the market and support recovery and recycling schemes (e.g. for packaging, batteries, electric and electronic equipment, vehicles).*

Today the transition towards CE remains a strong focus of EU decision makers. In 2018, the European Commission signed into acts four legislative proposals related to CE. They introduced *"...new waste-management targets regarding reuse, recycling and landfilling, strengthening provisions on waste prevention and extended producer responsibility, and streamlining definitions, reporting obligations and calculation methods for targets."* (Bourguignon, 2018). The strategic focus is complimented by far-reaching bans on certain products seen as problematic for the broader CE agenda. In May 2018, the EU proposed new legislation to ban single-use plastic and replace them with more environmentally sustainable materials (EUR-Lex, 2018). While the correct pace of transition is still up for debate, it seems likely that, the EU will continue to move towards stricter regulation in the future. Currently in the EU, there are differences in how waste is managed in each nation, but decision makers see CE as a unifying objective for members.

2.1.3 Benefits of Circular Economies to the EU

The achieving of CE could create significant gains measured in sustainability and economic development. It could decouple economic growth from resource consumption and environmental degradation, whilst providing employment opportunities and economic development in the EU.

Decreased use of materials at the cost of the environment

According to the Ellen MacArthur Foundation (2015[2]) the consumption of material resources through car and construction materials, synthetic fertiliser, pesticides, agricultural water and land use, fuels and non-renewable electricity, and land for real estate could be reduced by up to 32% by 2030 and 53% by 2050 through CE adoption. Additionally, CE opportunities have been estimated to be able to provide 6-11% in saving in energy use for economic activity in the EU, as well as globally (Cooper et al., 2017).

CE adoption could therefore see a significant reduction of greenhouse gas emissions caused by current waste disposal and reduced use of resources in manufacturing. The reduction of waste in the oceans in particular could decrease the current loss of biodiversity. This would also have economic benefits, as it would decrease the risk caused by raw material supply volatility. As the EU currently imports about half the resources it consumes, in terms of raw materials needed to produce goods (Bourguignon, 2016), the underutilization of waste represents an unnecessary economic and environmental cost.

Economic benefits through job creation and economic savings

The European Commission has estimated that if the legislative proposals of the EU Circular Economy Package were adopted, in the EU 180 000 jobs could be directly created by 2030, and that an increase of 30% in resource productivity could bring an additional over 2 million jobs by 2030 (Bourguignon, 2016). Furthermore, the transition to CE by 2030 has been estimated to reduce spending on resources by 600 billion euros annually in the EU (Ellen MacArthur Foundation, 2015[2]).

2.2 Circular Economy Theory

The CE concept is still contested in literature, despite having received growing attention in recent years. The core concept relates to the improving of utilizing raw materials and waste to reduce negative environmental impacts. The section illustrates that waste management is a significant part of transitioning towards a CE.

2.2.1 The State of Circular Economy Research

Concepts akin to or related to CE have been around since the 1970s, though being of less prominence until the 1990s (Ellen Macarthur Foundation, 2015[1]). The Concept of CE emerged in Europe in the 1980s and 1990s, driven by seeking the prevention of waste being put to landfills (Mcdowall et al., 2017). The development of CE theory has been particularly focused in China and Europe (Winans et al., 2017; McDowall et al., 2017). CE policies are most present in Asia, with Japan and China introducing national CE policies, and in Europe where multiple countries have implemented CE policies, initiatives, and pilot programs (Reike et al., 2018).

The concept of CE is receiving increased interest amongst policy makers, advocacies, consultancies, academia and industry in the past decade (Kirchherr et al., 2017; Geissdoerfer et al., 2017; Murray et al., 2015). Though CE has received significant and increasing attention in research, there remains confusion over CE semantics and debate over its viability (Prieto-Sandoval et al., 2018; Korhonen et al., 2018[1]; Skene, 2017). Furthermore, there is a lack of common ground on how industries should implement CE (Bocken et al., 2014;

Kalmykova et al., 2018), with business models and consumers being infrequent as mentioned enablers in CE literature (Kirchherr et al., 2017).

The contested definitions of CE may be explained by its somewhat unique emergence compared to other sustainability concepts however. As Murray et al. (2015) note, CE as a school of thought has arisen mainly due to legislation (though they caveat that this may only be the case in China), rather than through the development of a new academic field. Potentially this may be the cause of there not being journals or departments of circular economy to be act as an academic authority on the concept. Korhonen et al. (2018[2]), meanwhile argue that CE development and implementation has been practitioner rather than academia led; with policy-makers, businesses, business consultants, associations and foundations setting the terms of CE.

2.2.2 The Circular Economy Concept

"A [Circular Economy] describes an economic system that is based on business models which replace the 'end-of-life' concept with reducing, alternatively reusing… with the aim to accomplish sustainable development, which implies creating environmental quality, economic prosperity and social equity, to the benefit of current and future generations" (Kirchherr et al., 2017).

Based on the analysis of 114 definitions of CE, Kirchherr et al., (2017) found the concept to most frequently refer to a combination of reduce, reuse and recycle activities. They found definitions to have few explicit linkages to sustainable development, with the primary aim of CE's presented in connection economic prosperity, before environmental quality. CE systems increase sustainability by reducing waste generation and creating value from waste fed back as a material or product to decrease resource depletion (Lieder & Rashid, 2016). Unlike a linear economy, CE does not assume that natural resources are infinite and recognise that the capacity for the environment to absorb waste and pollution is limited (Cooper, 1999). The concept seeks a restorative and regenerative economy through increasing the utilisation of products, components and materials. Thus, it seeks to make global economic development consume less finite natural resources (Ellen MacArthur Foundation, 2015[1]).

The comparison of CE with natural ecosystems has been criticised as inaccurate, with CE argued to be unable to create sustainability without significant reductions in consumption and production (Fellner et al., 2017; Korhonen et al., 2018[2]). In fact, researchers like Skene (2017), have gone as far as to suggest that the idea of a completely renewable supply chain is a “Garden of Eden Fantasy” (p. 482), akin to a perpetual motion machine. However even if CE is unlikely to be a panacea without other additional sustainability efforts, it presents an important tool for improving sustainability. Though CE may never be able to create supply chains that are renewable into eternity, they can nonetheless reduce the rate of environmental decay and allow humanity to survive longer than it would otherwise.

CE goes beyond the mere reduction of raw materials use and instead seeks to create relatively self-sustaining loops with repeatedly used materials. This requires the taking into account of direct, indirect and total lifecycle impacts of resource use and waste utilization (Genovese et al., 2017). CE provides a reduction of the harms caused by waste disposal in landfills, due to methane emissions into the air and leachate of contaminants into the ground, and avoiding the related economic costs (Pongrácz, 2002).

The Isle of Wight based NGO, the Ellen Macarthur Foundation separates CE into Technical and Biological cycles. These two cycles seek to optimize the use of resources by extracting or utilizing organic content in waste (Biological) and reusing, repairing, recycling or utilizing inorganic material (Technical), shown in Figure 5.

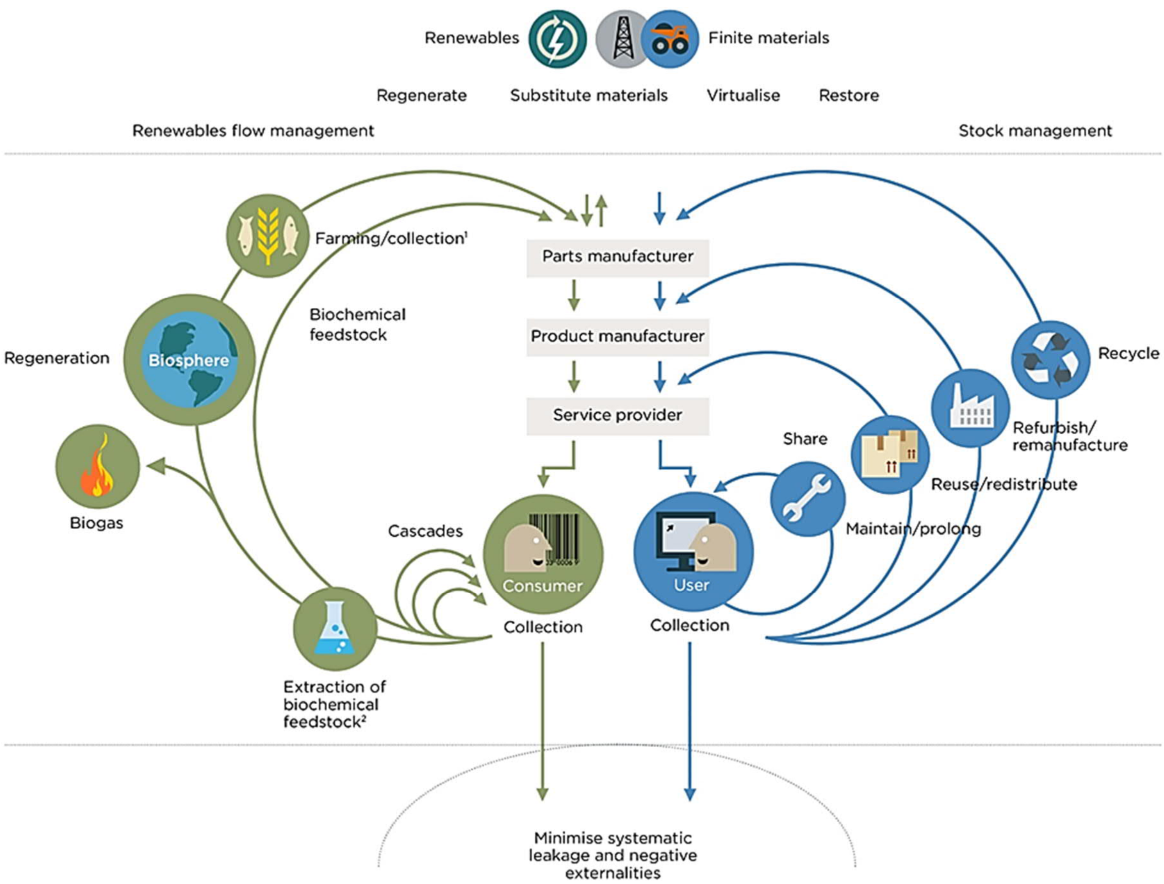

Figure 5: The circular economy diagram (Ellen Macarthur Foundation, 2014, p. 15)

CE requires the closing of product, material and waste loops, to transition from a traditional linear supply-chains (“cradle-to-grave”) to circular (“cradle-to-cradle”) loops where one systems waste is seen as a resource for another system. These waste loops, are split into biological and technical nutrients, based on whether they can be returned to the earth or utilized as materials in industrial cycles (Braungart & Mcdonough, 2009, pp. 105-115). Resource cycling, whereby traditionally linear systems for manufacturing or service creation are redesigned to feed back side streams can be done through different activities (Ellen Macarthur Foundation, 2012), often referred to as R-imperatives in literature.

2.2.3 The R-Imperatives of Circular Economies

CE seeks to reduce waste and the environmental impact of waste through many interrelated approaches that are often grouped into various R’s. The number and selected R’s can differ. For example 3R’s in the form of ‘Reduce, Reuse, Recycle’ sometimes including Recover to make 4R’s (Kirchherr et al., 2017) or ‘Reuse, Remanufacture, Recycle’ (Gaustad et al., 2018) or the 6R’s of ‘Reduce, Reuse, Recycle, Redesign, Remanufacture, Recover’ (Jawahir & Bradley, 2016). Reike et al., (2018) give an overview, outlining increments of CE R-imperatives and their ranking in academic literature. They classify these as totalling 10.

Table 2: 10 R-imperatives by Reike et al. (2018)

Short Loops (Client/user choices)	**Medium Loops (Product upgrade)**	**Long Loops (Downcycling)**
R0: Refuse	R4: Refurbish	R7: Recycle materials
R1: Reduce	R5: Remanufacture	R8: Recover energy
R2: Resell/Reuse	R6: Repurpose	R9: Re-mine
R3: Repair		

The various R’s of CE can be seen as an interrelated flow of loops returning materials into the supply chain, as seen in Figure 6. The delineation of CE R’s is not completely straightforward however. As Reike et al. (2018) note, many scholars use ‘Repair’ to refer to refurbishment or remanufacturing, or even as a part of re-use. ‘Repairing’ can also be a way to ‘Reduce’ the generation of waste. Furthermore ‘Refurbish’ and ‘Remanufacture’ are often used as synonyms by academics, and ‘Recover’ and ‘Recycling’ are often used as generic terms (see *Appendix A* for a summary of the R-imperatives*)*. This is not surprising as the extensions of a product or materials lifecycle often requires a combination of Rs. Whilst there can be thought to be something of a hierarchy of preference from R0 to R9 or at least between Short Loops (R0-R3) close to the consumer/customer requiring less resources, Middle Loops (R4-R6) with mainly businesses upgrading products and Long Loops (R7-

R9) requiring significant energy, labour and/or processing as well as deterioration with each lifecycle; their trade-offs can vary significantly based on circumstances.

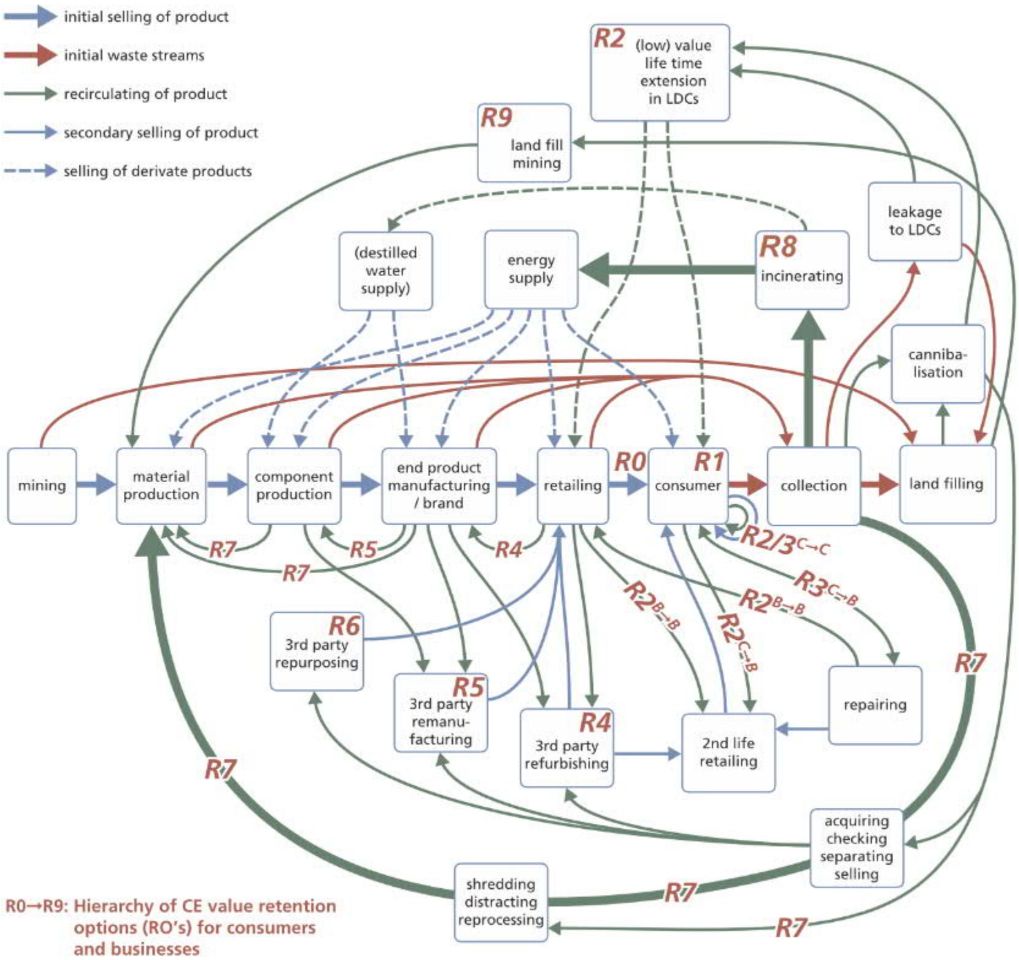

Figure 6: Circular economy R-imperatives mapped by Reike et al. (2018)

2.2.4 Types of Waste Loops

The utilizing of waste through imperatives R2-R8, shown in Figure 6, can take the form of closed or open loops as well as up- or downcycling. Categorization is based on the origin and destination of the waste stream and whether it increases or decreases in value. The flow of loops and the processing of waste materials is separated as the following:

Closed loop: is a re-use or recycling process whereby waste is used for the same purpose as originally or for another purpose with equally stringent requirements, leading to repeated use (Geyer et al., 2015). These closed-loops require in addition to forward supply chains to bring products or materials to their users, reverse flows for used products or residuals to return them to the manufacturer. (Souza, 2012).

Open loop: Is the re-use or recycling of waste in another process, that leads to the waste never returning into its original stream (Geyer et al., 2015).

Upcycling: Is the recovery of waste that converts part or all of a waste material or product into a material or product that has a higher value than it had. This avoids both the negative impacts of material being consigned to waste, and creates new value. Up-cycling requires significant creativity and innovation however, making it more challenging to achieve than down-cycling (Vats, 2016; Geyer et al., 2015).

Downcycling: Is the conversion of products or materials into lower value raw materials or products, avoiding waste, but at the cost of losing value. This can apply to any recovery operation, and is primarily caused by degradation as materials through their lifecycle. Though down-cycling is less desirable than up-cycling, it can nonetheless avoid losing all value and the negative impacts of material being consigned to waste. Additionally the resources consumed and energy used may in some cases make upcycling less sustainable than downcycling (Vats 2016).

Whilst the distinction of closed and open loop recycling, upcycling and downcycling are useful conceptually, they should not directly be used to assess the sustainability or recycling or recovery activities. Closed-loops should not automatically be favoured and the number of recycling cycles and the retention of a material's properties are not a clear proxy for environmental benefit (Geyer et al., 2015). They do however inform the processes and actors involved. On-site recycling and the re-use of a material for its original purpose in closed loops are considered forms of waste prevention. Off-site recycling and re-use of a material for a different purpose than it was produced for meanwhile is a waste management activity (Pongrácz 2002).

2.3 Waste Management Theory

The underpinnings of waste management theory (WMT) is the prevention of harm to persons and the environment otherwise caused by waste. (Pongrácz et al., 2004; Brunner & Rechberger, 2015). Understanding how waste management features into CE, requires understanding what it is waste management does, the nature of waste itself, how it is classified and can become non-waste. The expanded requirements of waste management means that it is important to see the industry as a system of interdependent actors.

2.3.1 The Role of Waste Management in Society

" 'waste management' means the collection, transport, recovery and disposal of waste, including the supervision of such operations and the after-care of disposal sites, and including actions taken as a dealer or broker" (EUR-Lex, 2008, Article 3)

Waste management is the handling of waste and waste-related activities to protect the environment and society, with the extended aim of avoiding the creation of waste and turning waste into non-wastes through utilisation (Pongrácz & Pohjola 2004). Waste management and resource efficiency have been around for centuries (Velis et al., 2009; Brunner & Rechberger 2015). Organized solid waste management systems have been driven by sanitation concerns, but also at times by the resource value of waste (Velis et al., 2009). Waste management priorities have developed from hygiene or public health concerns to protect persons and the environment, extended to the conservation of resources in the form of materials, energy and space. This has meant extending waste management from simply removing waste from the proximity of where people live and avoiding direct harms, to aftercare to avoid placing a burden on future generations through poor landfilling and unprocessed hazardous waste. It goes beyond avoiding the impact of waste itself, to avoiding the extraction of resources from the earth by replacing them with secondary materials from waste. Though it may seem costly, it should be recognized that the mining of resources requires significant amounts of energy, water, land and materials causing environmental pollution in addition to the depletion of finite resources. Therefore waste utilization can significantly avoid harm to persons and the environment beyond minimizing the harmful effects of waste itself (Brunner & Rechberger, 2015).

Waste management has traditionally been reactive, focused on the removal of waste after it has been generated and has to be dealt with whilst minimizing its negative impacts. Therefore, practice has often been focused on the relinquishing of responsibility, whether a consumer throwing away household waste into bins for pickup or companies having their waste collected on site, forgetting this waste afterwards. This view of ‘waste as a problem’ needs to transition towards seeing ‘waste as a resource’ in order to develop beyond the simple collection and disposal of waste (Aid et al, 2017). WMT extends the prevention of harm to human health and the environment to an explicit link between waste management and CE, in seeking the conservation of natural resources and the prevention of waste through producing useful products to transition ‘waste’ into ‘non-waste’ (Pongrácz 2002).

2.3.2 The Definition of Waste and Non-Waste

Waste is not a natural category for materials or objects, instead it is defined by the status of being unwanted or unusable. This can be seen by the examples of waste definitions by the EU, UN and OECD shown in the Table 3.

Table 3: Definitions of waste by international organisations

European Commission's *Waste Frame Directive* (EUR-Lex, 2018, Article 3)	'Waste' means any substance or object which the holder discards or intends or is required to discard
UN Environment Programme's *The Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal* (Basel Convention, 2014, Article 2)	"Wastes" are substances or objects which are disposed of or are intended to be disposed of or are required to be disposed of by the provisions of national law
OECD *Glossary of Statistical Terms* (OECD Statistics Directorate, 2001)	Waste refers to materials that are not prime products (that is, products produced for the market) for which the generator has no further use in terms of his/her own purposes of production, transformation or consumption, and of which he/she wants to dispose.
UN Statistics Division's *Glossary of Environment Statistics* (UN Statistics Division, 2001)	Materials that are not prime products (that is, products produced for the market) for which the generator has no further use in terms of his/her own purposes of production, transformation or consumption, and of which he/she wants to dispose. Wastes may be generated during the extraction of raw materials, the processing of raw materials into intermediate and final products, the consumption of final products, and other human activities. Residuals recycled or reused at the place of generation are excluded.

Pongrácz & Pohjola (2004, pp.146) suggest that the classification of something as waste, should necessarily be focused on how it becomes considered waste by its owner. They define waste (based on Pongrácz, 2002) as: "*a man-made thing, which in a given time and place, in its actual Structure and State, is not useful to its owner, or an output that does not have any owner.*" They further note that the concept of waste is dynamic, as waste belonging to one actor may be non-waste for another, and the status may change with time as new uses for a material are found or interest is created due to needs. The ability to use waste is relative to the technologies available to actors where it is generated, as well as their needs or the viability of transporting waste. Waste can therefore be seen as defined both by its properties and by its owners lack of desire for holding on to it.

If waste is defined by being unwanted, then non-waste is defined by finding a way to make waste wanted and useful. This is done through finding a new purpose, or a new owner who can use it for its original purpose, or through adjusting the state or structure to make the thing perform in respect to a new assigned purpose. When value is captured from waste it becomes a secondary raw material. In contrast to waste Pongrácz & Pohjola (2004, pp. 149) define non-waste as "*an object that has been assigned a Purpose by its (or a potential)* *owner, and this owner will either use it for that Purpose, or by adjustment of State or Structure ensures that the object will be able to perform in respect to the assigned Purpose.*"

The concept of waste and how it is distinguished from non-waste, guides how waste can be avoided or then repurposed to have utility again. Conceivably any waste could be transformed into non-waste through finding a new owner or purpose for it. Waste is after-all created when an owner decides to relinquish ownership or when they are required to dispose of materials, as waste stored prior to recovery longer than three years or prior to disposal longer than one year becomes subject to the EU's Landfill directive (EUR-Lex, 2008). In practice however, this is limited by the usability of waste, the costs of collecting and processing it to change its structure or state, as well as legislation defining waste.

The definition of waste can also be a source of barriers. The utilization of non-waste may be restricted by legislation, such as the Bazel Convention (2014) which restricts the movement of waste between EU and non-OECD states, due to the focus on waste as a potential pollutant first, and raw material second. Though this is in line with CEs seeking reuse of waste where it is produced, rather than shipping it long distances and avoiding countries transferring their waste burdens onto others it can lead to waste going unutilized (Pheifer, 2017). Additionally hazardous waste has additional restrictions on its transportation or use, compared to equally hazardous raw materials or chemicals.

The definition of waste can furthermore be an obstacle for recycling companies, as environmental protection obligations can place significant burdens or restrictions on transportation and processing. These increased costs exacerbate difficulties in competing with virgin materials. This can stand in the way of waste shifting from a problematic residual to a resource that can be efficiently used (de Jesus & Mendonça 2018; Pongrácz, 2006).

2.3.3 The Expanding Role of Waste Management in Circular Economies

Waste management is often seen as the last step of the material chain in linear economic models. Waste consigned to landfill or disposal translates to significant losses of resources in the form of materials and energy. Waste management should therefore be concerned with the improved utilisation of waste. In order for that to be achieved waste needs to be better classified and understood. Based on four classifications of waste from their past research, Pongrácz & Pohjola, (2004) suggest roles for waste management to turn wastes into non-wastes. These four classifications can be compared to the 10R imperatives previously mentioned (Section 2.2.3) to understand the role of waste management companies in extracting value from waste (see Table 4).

Table 4: Classes of Waste compared with 10R Imperatives

Pongrácz & Pohjola's (2004) Classes of Waste	10R Imperatives by Reike et al. (2018)
Class 1 Non-wanted things, created not intended, or not avoided, with no purpose.	R2: Resell/Reuse R5: Remanufacture R6: Re-purpose R7: Recycle materials R8: Recover energy
Class 2 Things that were given a finite purpose, thus destined to become useless after fulfilling it.	R6: Repurpose R7: Recycle materials R8: Recover energy
Class 3 Things with well-defined purpose, but their performance ceased being acceptable due to a flaw in their Structure or State.	R3: Repair R4: Refurbish R5: Remanufacture
Class 4 Things with well-defined purpose, and acceptable performance, but their users failed to use them for their intended purpose	R0: Refuse R1: Reduce

Waste management companies' ability to impact waste reduction is clearest in Class 1 and Class 2. As in the case of owners failing to use products for their intended use (Class 4), reduction is a question of placing legislative constraints, as well as educating consumers and companies to understand the impact of waste. Whilst for products no longer performing to their required standard (Class 3), impact is mainly in the hand of producers through the extension of product lifetimes in the design stage. (Pongrácz & Pohjola, 2004). Though waste management companies can provide information on how to ensure the sustainable end of life to product and process designers, they are not designing and manufacturing products.

Waste management companies need to evolve into stewards of waste, managing waste as a resource (Aid et al, 2017). This means considering more than final disposal; the entire waste creation cycle, transport, storage, treatment and recovery to prevent pollution and associated harm from occuring. In the case of industrial side streams (Class 1), the resulting by-products or residual materials of production, waste management should be focused on design, remanufacturing to use those residuals and the improving of process efficiencies. These can be used internally as a raw material that can be fed back into production, either internally or externally, or sold on a market. (Pongrácz & Pohjola, 2004) For Class 2 waste with single or limited use products that have fulfilled their purpose, waste management should seek repurposing, recycling or recovery (Reike et al. 2018).

2.3.4 The Waste Management Industry as a System

Viewing of production and waste management as separate systems can be problematic for achieving CE. The ability to process material sustainably is often dependent upon the manufacturing and design of products as well as the collection of waste on site. An example would be toxic or fossil-based materials used in packaging. These are costly to recycle or if used in energy recovery, cause emissions for which waste disposers or other energy users are held responsible (Ilic et al., 2018). A zero-burden assumption on actors consigning waste, whereby the total environmental burden is transferred to the waste management, leads to prices not taking into account the full environmental costs (Bourguignon, 2016; Pheifer, 2017, p.16). Rather than assuming waste can be avoided purely through waste management operations, CE requires product designs and manufacturing operations to consider the end-use of products or materials to enable ‘waste’ to be replaced with side streams that can be fed back into their products lifecycle or another process (Ilic et al., 2018). Waste management is therefore a multi-actor activity involving industry collaboration.

The coordination of waste material utilisation between supply chains demands a degree of cooperation as industry participants seek out the right partners and collaborate vertically. In a sense, firms must adopt a holistic perspective of how their current operations relate to others and impact the environment. Firms interacting with the objectives of achieving interrelated waste goals operating with a predetermined boundary can be defined as an industrial ecosystem (Korhonen, 2001). It refers to a group of companies that function as interdependent actors within a related industry or business area. Inside an ecosystem the actions of individual actors are linked and can be analysed as a collection of interactions that comprise the entire system. Ashton (2009) challenges the idea that industrial ecosystems can be used to analyse firms separately from their environment and maintains that an economic geography lens is necessary. The concept that a group of firms form an ecosystem that can function as a result of internal and external forces, has long been discussed in economics. For instance, evolutionary economics describes the complexity of the economy as an ecological system with actors operating in a fluctuating environment (Krugman, 1996).

When the ideas behind CE are combined with the characteristics of an ecosystem, the outcome is an interdisciplinary field of study known as industrial ecology (IE). The origins of IE can be traced back to the late 1960s, when it was proposed that ‘nature’ could serve as a model for *“...analysing existing industrial systems and for guiding new, more efficient and resilient forms.”* (Newell & Cousins, 2014). IE offers a systems-oriented perspective, and looks holistically at the impact of industrial design and manufacturing from finished material, components, and products, all the way to their disposal and return to material streams, something waste management should strive for (Lowe & Evans, 1995). IE established the idea that, waste producers do not operate in a vacuum and the actions of one actor is interlinked with others. Many of the ideas found in modern WMT, such as the goal of not leaving products without an owner or purpose come from IE (Pongrácz et al., 2004). Some authors view the ideas of IE connected to the concepts of industrial symbiosis (IS), which goes further and describes the interdependent relationship of firms operating in the same industry (Leigh & Li, 2015).

IS establishes the importance of *"...cooperation among industrial firms in managing resources, particularly by - products, such that the waste of one firm becomes the input of another"* (Mulrow et al., 2017). However, the concept of IS goes beyond creating the logic for reusing industrial waste materials. It also provides the means of collective transformation to a sustainable industrial system in which material and energy flows are viewed holistically and are redesigned to be more efficient. Chertow (2000) maintains, there are two key aspects of IS are a sense of collaboration and the synergistic possibilities enabled by geographic proximity. As a result, coordination effort seems to be localized involving regional partners. One reason could be that by doing so, the carbon footprint of transferring waste material is reduced. However, Leigh & Li, (2015) propose a conceptual framework for IE and IS implementation into a sustainable supply chain network (Figure 7). The framework present relationships between customer, end users, retailers or distributors, material processors or manufacturers and material extractors or growers. The benefits of applying IE & IS principles are presented in bold and are: reduced need for raw material, improved product design and more eco-friendly products. The link between product design and the transfer of waste information will be discussed again in the next sections. In the model, the role of retailers/distributors as central in the forward supply chain is critical, as is the importance of waste collectors/processors in the reverse supply chain.

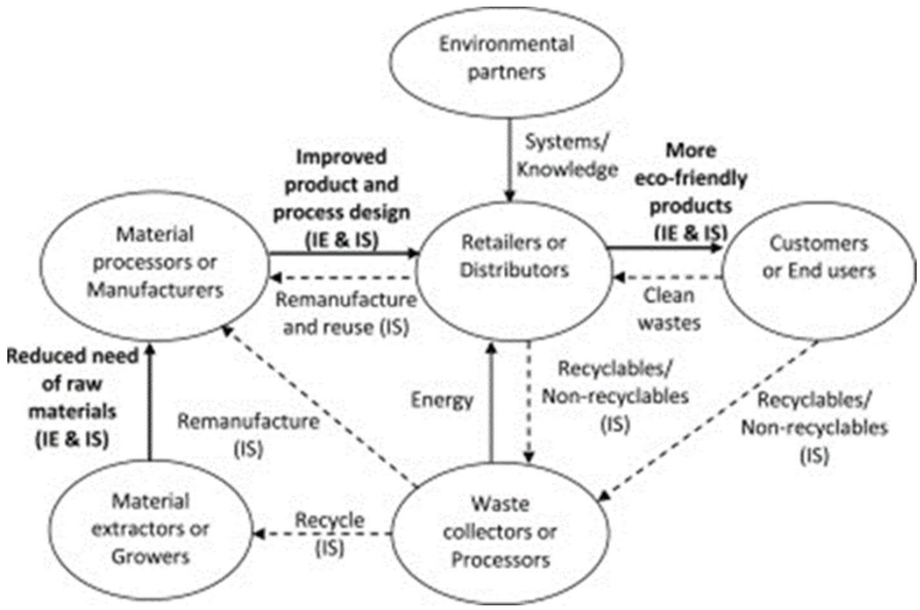

Figure 7: Industrial ecology and symbiosis in the supply chain (Leigh & Li, 2015)

The concepts related to IE offer a holistic perspective of the economy with interdependent actors who cooperate to achieve a more efficient flow of materials and energy. Closer linkages are especially important for the waste management sector since it is seen as a key challenge for a transition towards CE (EPRS, 2017). In order to establish closer industry cooperation in regards to waste management it could help to have a theoretical basis for discussion. IE fills that gap and provides the tools to guide the movement towards CE (Saavedra et al., 2018). Moreover, the versatility of IE related ideas is evident from their rise in popularity in recent years as an approach to analyse different types of industries. From manufacturing (Despeisse et al., 2012) and mining (Clifford & Matsubae, 2018) to construction industries (Freitas & Magrini, 2017). Furthermore, it is also successful applied across several regions of Europe to analyse production (Vukovic et al., 2017).

2.4 The Role of Innovation in the Waste Industry

Continuing with the analysis of the waste industry as a system, in the following section the interaction between technology and the waste industry will be analysed. While the impact of technological change seems evident on the forward supply-chain, its mark on the reverse supply-chain was less noticeable when the R&D intensity is taken into account (OECD, 2011). The pace of innovation is analysed within the context of CE.

2.4.1 Innovation Adoption in the Waste Sector

In the past several decades the term "innovation" has evolved to include a variety of meanings, ranging from a marketing buzzword to a defined industry term. In academia however, the word has a well-established meaning which varies slightly depending on the context or domain. Rogers (2003, p.11) defined an innovation as *"an idea, practice, or object that is perceived as new by an individual or other unit of adoption"*. Dicken (pp.77, 2011) proposes a more robust definition by offering four categories that describe the characteristics and impact of the innovation: incremental innovations, radical innovations, changes of technology system, and changes in the techno-economic paradigm. A different view of innovation is provided by the economist Schumpeter, who considers it as the initial market introduction of a new product, process, service or organizational structure (Kemp & Pearson, 2008; Horbach, et al., 2012). The Schumpeterian definition is better suited for the research since it connects the novelty of the innovation to the market and adoption.

A linear view of adoption would mean that as new machines emerge on the market, business owners decide whether to alter work processes to utilize potential benefits. One key criticism of this approach is that it applies an overly simplified and deterministic lens when analysing how individual actors view innovations (De Uriarte, 1990; Sica, 2016). It naively assumes, that the information related to new technologies, tools or processes flows equally to all agents of the economy. Moreover, it proposes that, individual adopters should have the sufficient capacity to analyse and understand the characteristics of the innovation. However, for operators in a low-tech industry with lower investment in R&D operations keeping up with emerging innovation may be a challenge. In practice, innovations can involve different levels of technological complexity that can be difficult to evaluate and can hinder adoption. The difficulty of individual agents operating with significant level of uncertainty and being faced with making a choice was labelled as 'bounded rationality' (Simon, 1999). Research on bounded rationality in relation to technology adoption showed it is possible for decision makers to make imperfect decisions about the suitability of technological solutions due to the scarcity of time and quality of information available (Gounaris, 2012; Cristofaro, 2017).

From the perspective of the organisation as the adopting unit, embracing new technologies can be seen from two opposing dimensions. First, by analysing adoption as a result of the characteristics of the firm (organisational structure, collective intelligence, etc.) and second, as a response to the stimuli of the external environment, such as competition and legislation (Tornatzky & Fleischer, 1990). When the effects of individual adoption are aggregated they form the picture of how innovations or technologies enter the industry ecosystem. One famous attempt to analyse the system effects of adoption was made popular by Rogers (2003, p.5) in his diffusion of innovation (DOI) theory, it as a communication process occurring through channels over a period among a social system's members. The transformative effect technology can have on the industrial system is at least in part related to the rate of adoption. Technological change can manifest itself in different forms and can also be the result of forces outside of the organisation or industry control. When studying the sources and direction of technical change in industry Pavitt (1984) found that relationship and market structure of the industry can have an impact and proposed a taxonomy of three types of firms: (1) supplier dominated; (2) production intensive and (3) science based. By examining the relationship between the various groups of firms, certain innovation linkages emerged that can describe the influence of technology adoption.

For firms operating in the waste industry the pace of innovation seems low and predictable, however, understanding the drivers and barriers of technological change could reveal more insight. In his analysis of drivers of waste treatment technologies in Sweden, Zaman (2013) identified three key drivers: economic, social and environmental (see Figure

8). Economic drivers refer to the shift from the perception that waste has little or no value to the notion that a profit can be made by processing or treatment. Environmental drivers include global phenomena related to the degradation of the biosphere such as global warming. Social drivers are related to the 'human aspect' of waste management, these include population growth, urbanization and attitudes affecting local waste management. The technology drivers proposed by Zaman (2013) resemble the concepts found in the Triple Bottom Line framework, used since the 1990s to *"...measure the financial, social and environmental performance of the corporation over a period of time"* (Elkington, 2018).

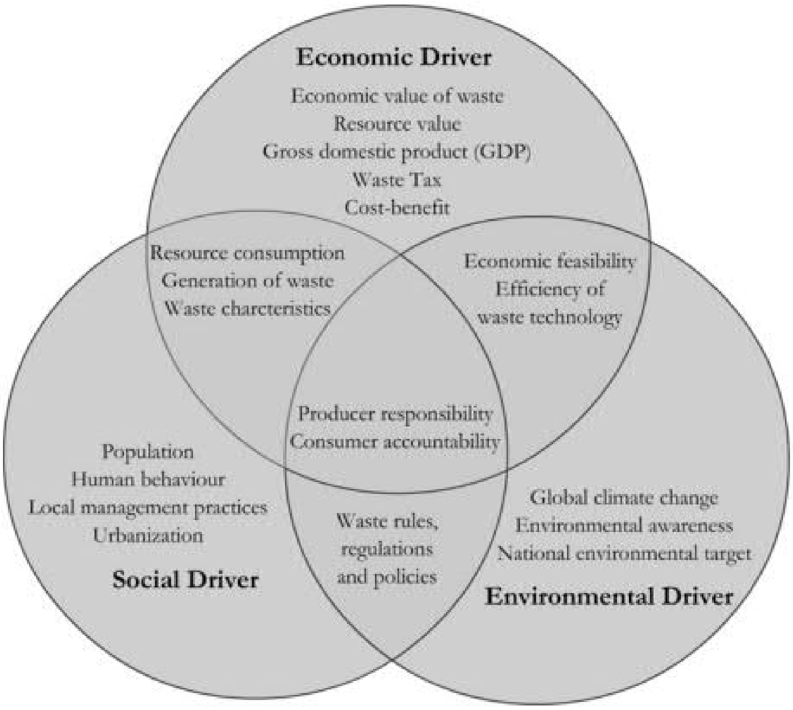

Figure 8: Drivers of sustainable waste treatment technology (Zaman, 2013)

In contrast to the drivers of technology in the waste sector there are also inhibitors that are outside the control of the companies. In their analysis of barriers to effective MSW management, Yukalang et al. (2017) found six factors as important: social-cultural, technical, financial, organizational, and legal-political barriers and population growth. Interestingly, the social-cultural aspect (human factor) arose once again, but this time as a barrier. It appears that, while the effects of economic and environmental drivers have unidirectional impact on adoption, social drivers can be both a driver and a barrier. The importance of technical, socio-political and cultural factors also emerged when national adoption of Waste-to-energy (WTE) solutions was analysed (Vujic, et al., 2017). However, Wilts et al. (2013) discovered that availability of information could also act as a barrier to adoption, in their research related to innovations in the field of waste prevention.

2.4.2 Overview of Waste Processing and Treatment Technologies

Dicken (2011, pp.455) views technology product or a process that can serve as an input in the overall system of material flows. Although the categorization is simplified, it offers a starting point for understanding how innovation shapes the waste management industry. As a technological process, waste solutions can be used to gather, process waste materials.

When productivity of the waste sector is examined, differences emerge when upstream and downstream operators are compared. Figure 9 shows apparent productivity levels in the industry, depicted as euros per person. It seems that, at the present the highest productivity occurs in the recovery and treatment activities of waste. One possible reason has to do with the role of technology and automation in those areas compared to upstream activities. Rogoff, & Ross, (2017) cite several emerging technologies for waste collection including: route planning software, RFID tracking and the use of hybrid fuel vehicles. However, these are recent innovations and seem to offer lower potential for efficiency gains than dedicated facilities for sorting materials such a materials recovery facility (MRF). The dedicated system of waste processing solutions *"…where recyclable materials that are collected from households are sorted into different types (e.g. plastics, cardboard, paper, metal) using a mixture of manual and automated methods."* (Veolia, 2018). Although there are different types of MRFs that depending on the waste types they handle (e.g. sorted vs unsorted) most can use various combinations of material processing solutions such as: conveyor systems, metal separation, screens and other separating technologies. Dubanowitz, (2000) agrees and states that the role of a MRF is to aggregate materials, process them and store them for later as: as raw materials for remanufacturing, reprocessing or as a fuel for energy.

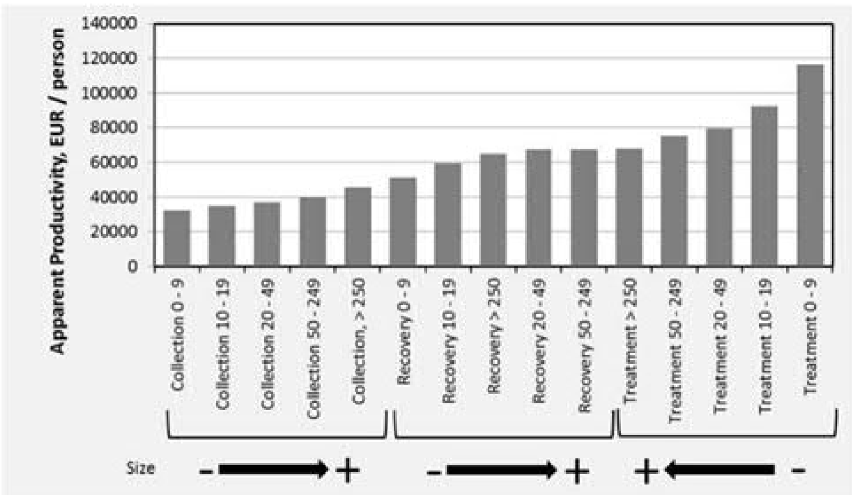

Figure 9: Apparent waste sector productivity in Europe (European Commission, 2016[2])

The largest segment of the literature evaluates material treatment technologies in the context of energy conversion (Zaman, 2013; Stehlík, 2009; Vujic et al., 2017). Figure 10 outlines the three most widely used groups of technologies involved in the process of converting MSW to energy. Thermal conversion solutions involve treatment using high temperatures with objectives of: destruction of the organic components of wastes, reducing waste volumes, obtaining a solid and/or gaseous inert product and achieving significant energetic valorisation (Puna & Santos, 2010). Biological conversion refers to solutions based on microbial decomposition of MSW waste with higher organic content. Landfilling is the most common treatment type in developing countries, when performed correctly it can lead to a controlled disposal of wastes and *"...reduce the negative impact on the environment through biogas recovery and leachate management."* (Kumar & Samadder, 2017).

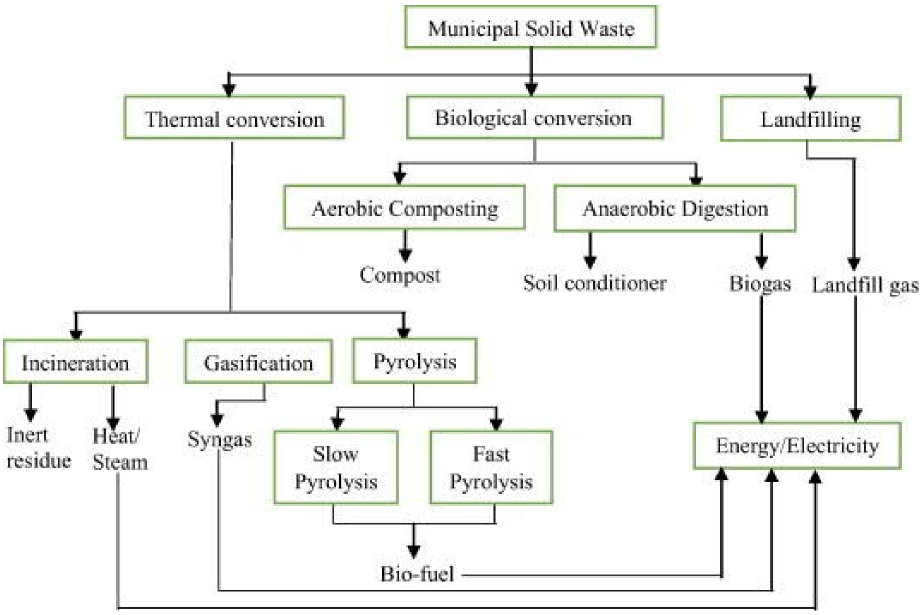

Figure 10: Solutions for waste to energy conversion (Kumar & Samadder, 2017)

2.4.3 The Concept of Eco-Innovation

Rather than being viewed as innovative processes technologies in the waste sector could also take form of products. Often when waste innovation is viewed as a product, it is mentioned in connection with eco-innovation (EI) in literature (Sica, 2016; Wilts, 2013; Horbach et al., 2012). According to Pansera (2011, pp.135), there is some disagreement on the exact definition of EI in the literature. Therefore, it is necessary to establish a starting point and expand the definition accordingly. As additional perspectives are presented, it will be shown that EI is a broad concept encompassing different parts of society, economy and technology. One rudimentary explanation of EI is as an approach to business that promotes sustainability throughout the entire life cycle of a product (Bisgaard, & Tuck, 2014). While the definition introduces the notion of the product life cycle it does not paint a clear enough picture. European Commission provides another view, by in recent years establishing a more practical definition of EI and enshrining it in its Entrepreneurship and Innovation Programme (European Commission, 2016[5]). From the EU definition EI is the development of products, techniques, services and processes that reduce CO2 emissions and are comprised of five strands:

- Materials recycling and recycling processes
- Sustainable building products
- Food and drink sector
- Water efficiency, treatment and distribution
- Greening business

EI is directly linked to product design and firm competitiveness and seen as a way to stimulate small and medium-sized enterprise business activity. The scope goes beyond simply designing the product to be more eco-friendly. It involves the transformation of the business model to ensure positives externalities that radiate to the rest of the society. Pansera (2011, pp.138), provides a description of a key feature of EI, and states that they *"generate a win-win effect"*, capable of preserving the environment while at the same time improving the competitiveness of firms. To ensure the link between sustainability and profits is strengthened the EU provides significant support to firms to embrace EI. Although it is unclear of the total amount invested in EI related initiatives, between 2008 and 2011 the funded projects generated €1.2 billion increasing to €227 billion in 2017 (European Commission, 2017[2]). It appears that EI is a long-term strategic plan to boost the economy and increase sustainability for the EU. The Eco-Innovation Scoreboard (Eco-IS) and the Eco-Innovation Index are examples of EU level initiatives established to track the EI performance across the bloc using 16 indicators (European Commission, 2018[4]). EI encompass more than product design, they could to a systematic transformation of business model and the re-shaping of economy.

2.4.4 Platform as Secondary Raw Material Marketplaces

The analysis of the waste industry thus far has focused on the exchange of materials and the redesign of products and processes to improve sustainability. Utilizing the capabilities of digital technologies, it will be shown that it is possible to increase the rate of information exchange and make an impact on the industry. The following section will establish a theoretical foundation for digital platforms and reveal how they can be leveraged to increase business value. Next, the features of a type of marketplace platform called a digital waste exchange (DWE), are presented in the context of the waste industry. Lastly, a summary of some existing waste marketplaces in the EU are evaluated.

According to Choudary, (2016), a platform is a business model connecting people, organisations and resources in technological ecosystems to exchange, goods, services and ideas. Although the definition establishes a conceptual link between the platform as a technology and a company's business model, it is too idealistic in its assumption that firm will automatically be able to use the platform to obtain new value. The successful adoption of a platform to engage with partners may require re-thinking old ways of doing business. Parmentier, & Gandia (2017) agree and mention that, in order of firm to capture new value it must redesign its previous one-sided business strategy into a multi-sided model. Traditional business models generate revenue linearly by sourcing materials or goods from the upstream supply chain and delivering it to downstream customers. Platforms on the other hand leverage groups of users (e.g. buyers and sellers) and act as an intermediary for interaction. Smorodinskaya et al. (2017), maintain that, that some platforms generate value *"…by coordinating transactions between two or more groups of consumers who would not have been able to connect without the platform"*. However, the idea that the platform only serves as a mechanism for connecting consumers is too limiting. Zhang, & He (2017) explain that the value users get from using a platform is not only connecting with others but also the ability to lower the transactions costs. Although digital platforms come in all shapes and sizes there are some universal aspects that are present in all. According to Smedlund and Faghankhani (2015) all functional platforms share: 1) co-creation of value, 2) interdependency and complementarity of components, 3) surplus value for the whole system (i.e. synergy) and 4) evolutionary growth.

Numerous topographies of platforms exist and full analysis of all platform types and characteristics is beyond the scope of the research. However, a platform classification approach will be selected that takes into the account the exchange of materials and information between parties. In recent years, much of the literature seem to focus on multi-sided platforms (MSP) which evaluate the role of the platform owner in managing groups of users (e.g. buyers and sellers) in order to generate business value (Haigu & Wright, 2014; Choudary, 2016; Parmentier & Gandia, 2017). In literature, value for participants is often discussed in relation to "network effects" or the overall change in value by the arrival of additional users to one side of the platform (Gawer & Cusumano, 2014). Network effects can be both positive and negative, and occur on either sides of the platform (Haigu, 2014).

Evaluating platforms through the MSP lens is not suitable for purpose of this research since the focus tends to be on information exchange by companies that rely on internet-based technologies to attract users (e.g. Airbnb, Uber, Facebook. etc.). When it comes to investigating the role of the platform to fulfil the needs of the waste industry in particular other characteristics should also be taken into account. When analysing the role of IS in connection with setting up or improving material exchanges Prosman et al. (2017) propose that, the role of internal coordination was important. Furthermore, the authors found that the absence of external coordinators and geographical proximity had negative effects on the assessment of waste quality and adherence to legal regulations. When selecting a suitable categorisation for platforms, the needs of the industrial ecosystem should be taken into account. One such approach, initial created by Gawer (2009) and cited by Angeren (2013), proposes the existence of four types of platforms:

1. *Internal platforms*
2. *Supply chain platforms*
3. *Industry platforms*
4. *Two-sided markets.*

Internal platform serves one firm and function within an organisation. Supply-chain platforms bind together firms operating with the same supply chain. Industry platforms can be internal or company-specific or external to include several firms that either buy or sell from each other or have products that depend on each other. *"External (industry) platforms … act as a foundation upon which external innovators, organized as an innovative business ecosystem, can develop their own complementary products, technologies, or services."* (Gawer & Cusumano, 2014). Lastly, two-sided markets serve several firms who interact with the purpose of making transactions that are served by a platform intermediary. The four mentioned platforms cover the platform mediated exchange of physical material in an industry, but they do not include sharing of information or knowledge. For a platform to serve the ambitions of the CE it must include components of collaboration that take into account trust between users (Rajala et al., 2018). Therefore, information and knowledge sharing should be considered. One example of a knowledge platform without a material exchange component is the European Circular Economy Stakeholder Platform. There participants can interact and exchange knowledge and best practices about sustainability (European Union, 2018).

Perhaps the most logical type of platform type to emerge in connection with the waste industry is a material exchange platform. Material exchanges are external industry platforms that facilitate the buying and selling of waste materials. Started in England in 1940s to conserve natural resources during World War II, they evolved from being physical spaces to become a catalogue for waste materials (Sapyta et al., 2017). With the arrival of the internet waste exchanges became digitized and accessible to more people. With the emerging digital platform technology, material exchanges evolved to digital waste marketplaces. They allowed companies to *"… both sell and purchase reusable waste, this will enable users to maximise the value of their waste."* (European Commission, 2011). Today waste platforms vary across regions and configuration types. Table 5 provides some examples of online platform for exchanging waste material in the EU. They range from simple information portals to online marketplaces for buying and selling waste. The material being traded or sold also differs and can include specific waste commodities (e.g. steel) or mixed waste material of same waste category (e.g. biowaste). Even though waste exchange platforms are ubiquitous in the EU, it appears most platforms have a regional focus. To the best knowledge of the researchers there is no functioning EU wide platform specifically for waste material exchange. The conclusion is supported by the 2017 study which found that there was no functioning internal market for waste collection and treatment in the EU (European Commission, 2017[3]). When it comes to information and data exchanges there have been several EU funded projects attempting to create knowledge sharing networks. One example is the Profile.Net Tool, created to serve the needs of two communities (Innovation Seeds and Inno4sd.net) and promote collaboration in the areas of EI and sustainable development. (Innovation Seeds, 2018).

Table 5: Examples of digital waste material exchange platforms in the EU

Platform	Country	Sector	Type	URL
Organix	France	Bio Waste	Marketplace	https://www.organix.suez.fr/
Smart Ground	EU	Secondary Raw Materials	Information Exchange	http://www.smart-ground.eu/
Bio Trading	UK	Bio Waste	Marketplace	https://www.biotrading.co.uk/
Essex Material Exchange	UK	Secondary Raw Materials	Material Exchange	http://www.databases.org.uk/eastex/portal.asp
RecyleBlu	Scotland	Secondary Raw Materials	Marketplace	https://www.recycleblu.com/
Recycling Europe	France	Secondary Raw Materials	Marketplace	https://www.recycling-europe.com/
RacyTraded	Hungary	Secondary Raw Materials	Marketplace	https://recytrader.com/
Restado	Germany	Construction	Marketplace	https://restado.de/
Profile.Net Tool	EU	Multi-actor network	Information Exchange	https://profilenet.innovationseeds.eu/
Urban Mine Platform	EU	Electronic & auto waste	Information Exchange	http://www.urbanmineplatform.eu/homepage

2.5 Barriers to Closing Waste Loops

As noted before CE research is a diverse and increasing area of research, spread out over multiple fields with a focus on waste generation, resource use and environmental impact, but lacking in business and economic perspectives to drive industry adoption, suggesting there are barriers to CE (Lieder & Rashid, 2016). The implementation of CE globally is still in the early stages, with a focus on recycling, though important results have been achieved in some sectors like waste management in developed countries (Ghisellini et al., 2016; Domenech & Bahn-Walkowiak, 2017). Often recycling rates for many materials are negligible however, which further suggests the existence of barriers to CE (Gaustad et al., 2018). To seek to understand barriers identified in research on companies, multiple articles dealing with barriers to CE and related activities were reviewed. As a result, two sets of barriers (CE implementation and platform related) have been identified that will be used for the analysis phase of the research.

2.5.1 Barriers to Developing Circular Economies

Though there are multiple types of barriers for CE initiatives, in this case researchers chose to distinguish between a relatively small group of six. As noted by Kirchherr et al. (2018), the number of barrier categories or subcategories is somewhat arbitrary and are complicated by the cross interactions of categories whereby for instance culture may affect what regulations are passed or regulation may create financial incentives. However, as this study sought to be exploratory, to understand the specific perspective of waste management and side streams, open to new insights provided by interviewees, broader categories were focused on.

Table 6 provides a summary of barriers that were identified in relation to the CE, as well as associated concepts (see *Appendix B* for a summary of barriers identified in literature on CE implementation). It can be seen that, ‘Technological’, ‘Financial’ and ‘Cultural’ aspects were mentioned the most, followed by ‘Regulatory’ and ‘Structural’. The category of Operational was also chosen, despite it only being used in one study, as it can include more detailed categories like Informational and Performance indicators, and how current ways of operating with companies and with their partners affect closing waste loops. The category of Contextual from Liu & Bai 2014 was seen as likely to be covered by Structural, Regulatory and Financial barriers, and so was left out. These categories could be split up in different ways, with for instance technical being included in Operational or Structural in

Cultural barriers but are distinct enough to provide. The six categories were used to code the interview transcripts for analysis of barriers to CE in relation to the research questions.

Table 6: Summary of barriers to circular economies

Category	Related Concepts	Sources
Technological	Technical	Pan et al. (2015), Shahbazi et al. (2016), Ritzén & Sandström, (2017), Galvão et al. (2018), Kirchherr, et al. (2018) **Technical** (de Jesus & Mendonça 2018)
Financial	Economical Market Customers	Pan et al. (2015), Ritzén & Sandström (2017) **Economic:** Shahbazi et al. (2016) **Economic/Financial/Market :** de Jesus & Mendonça (2018) **Financial/economic:** Galvão et al. (2018) **Customers:** Galvão et al. (2018) **Market:** Kirchherr, et al. (2018)
Cultural	Social Attitudinal	Liu & Bai (2014) **Social :** Shahbazi et al. (2016) Galvão et al. (2018) **Attitudinal :** Ritzén & Sandström (2017), Kirchherr et al. (2018) **Social/Cultural** de Jesus & Mendonça (2018)
Regulatory	Policy Institutional	Pan et al. (2015), Kirchherr, et al. (2018) **Institutional:** Pan et al. (2015) **Legal :** Shahbazi et al. (2016) **Institutional/Regulatory:** de Jesus & Mendonça (2018) **Policy and regulatory:** Galvão et al. (2018)
Structural	Organizational Managerial	Liu & Bai (2014), Ritzén & Sandström (2017) **Organizational:** Shahbazi et al. (2016) **Managerial:** Galvão et al. (2018)
Operational	Informational Performance indicators	**Operational:** Ritzén & Sandström (2017) **Informational:** Shahbazi et al. (2016) **Performance indicators :** Galvão et al. (2018)

2.5.2 Barriers to Platform Facilitated Circular Business Models

The reconfiguration of waste streams required to meet the demands of a CE requires the efficient coordination of waste material in the economy. In addition, technological infrastructure is necessary to facilitate the flow of information and knowledge in society to stimulate innovation. Digital platforms offer one possibility to fill the gap required to transition towards the CE because they help buyers and sellers of waste find each other, they lower transaction cost and enable information sharing. However, owing to the novelty of the research field, the amount of literature related to implementing digital platforms in connection with CE is limited. As a result, relying on prior research to establish possible barriers to platform adoption is not possible. One possibility to fill the gap is to construct categories using key concepts from the previously reviewed literature and unify them using a key idea that has been researched in connection with transitioning towards CE. One concept that connects provides the theoretical bridge between platform and CE is theory related to business models.

Evaluating business models could reveal insight into how firms could transition towards CE. Mouazan (2016) maintains that, due to their complex and systemic nature business models can a relevant unit of analysis when describing the changes resulting from the shift towards CE. According to Magretta (2002), business models require being able to answer important questions such as: *who the customer?* and *what do they value?* In addition, establishing how the company makes money through its offering and how they can deliver value to the customer at a cost that allows them to be profitable. As firms reconfigure their operations to adapt to the transition toward the CE, similar questions are being asked. According to researchers, the key challenge identified has been the difficulty of capturing value through CE and the complexity of related revenue models, cost structures and risks (Linder & Williander, 2017; Oghazi & Mostaghel, 2018). A similar approach is followed by Poutiainen (2015), who used Osterwalder's Business Model Canvas (Osterwalder et al. 2005) to research the use of business models by companies to design out waste and function in a circular economic system.

Providing a summary of all available business models that would be suitable for the CE is beyond the scope of this research. However, it is possible to establish the core elements of a CBM that will allow the investigation to be more fruitful. Cara & Magdani (2016, p.19) maintain that in connection with principals of CE, new business models would allow:

1. *Greater control of resource streams through the value chain so the added value can be identified and captured.*
2. *Innovation through the supply chain so new entities can be generated such as business in waste handling, refurbishment and reverse logistics.*
3. *Enhanced collaboration within the supply chain amongst all actors. Creation of services that capture valuable products / resources*

After considering the theory in the literature review the researchers conclude that adopting a CBM is vital to transitioning to CE. According to Oghazi & Mostaghel (2018), CBMs represent solutions that allow shift towards zero waste in the economy while at the same time, improving environmental impacts and increasing economic profit. The connection between sustainability and profit is essential for the shift toward CE, as it establishes the business logic for future investment, innovation through industry cooperation. Adopting a CBM allows firms to rationalize how they create, deliver and capture value functioning within closed material loops (Mentink, 2014). Establishing core components of CBMs that are suitable for this research will to take into account the social, financial and technical dimensions of proposed by Carra & Magdani (2016) during their analysis of CE related business models. Furthermore, key elements outlined in the literature review will be included such as: technology impact on business and characteristics of the EU waste industry. As a result, three components emerge as vital for transitioning to CE: Eco-Innovation, Industrial Symbiosis and the Digital Waste Exchange. Table 7 outlines the reasoning for selecting each barrier category and summarizes its popularity in literature.

Table 7: Summary of barriers to digital exchange platforms

Category	Reasoning	Literature
Eco-Innovation	Promotes industry innovation by coupling sustainable ideas and the market demand.	Pansera (2011), Sica (2016), Wilts (2013), Horbach et al. (2012)
Industrial Symbiosis	Establishes need for a mechanism that promotes industry cooperation.	Mulrow et al. (2017), Chertow (2000), Lowe & Evans (1995), Saavedra et al. (2018)
Digital Waste Exchange	Creates a platform for efficient coordination of waste material in the economy	Carra & Magdani (2016), Smorodinskaya et al. (2017), Rajala et al. (2018), Sapyta et al. (2017)

3 Methodology & Data

The section outlines the methodology used during investigation of research phenomena. Qualitative data was used, with research being informed by grounded theory and the systems approach. Data collection methods and the interview guide are presented that were used to gather evidence from respondents in relation to the research questions. The research participants are summarized to provide an overview of the scope of the investigation that occurred. Lastly, the methods used for analysing the data are outlined and explained.

3.1 Qualitative Research

The research objectives can be described as exploratory, since study goal was to understand the waste industry in the context of the research questions. The study utilized a qualitative data collections approach to obtain data from interview respondents. The approach was suitable because it explores social phenomena systematically in their natural settings (Teherani et al., 2015). In order to achieve the research aims, researchers had to ask preliminary questions such as: *what are the characteristics of the EU waste industry?*

The evidence used to make conclusions regarding the research phenomena was collected from interviewees directly connected with the industry and was supplemented by other respondents who had sufficient knowledge of relevant industry phenomena. Jupp (2006) maintains that qualitative research can be utilized to analyse events and phenomena that can be understood from the perspective of the actors involved in the system.

Since the research involved establishing truth by speaking with respondents and interpreting their opinions, the interpretivist research paradigm was well suited. *"This paradigm assumes a subjectivist epistemology, a relativist ontology, a naturalist methodology, and a balanced axiology"* (Kivunja & Kuyini, 2017, pp.33). Because the responses are based on the experiences of individuals, they are subjective in nature and must be taken as such. Applying a relativist ontology acknowledges that the phenomena being studied can exist in multiple realities. In other words, it is possible to have varying interpretations of the waste industry itself with different boundaries and constructs. Following a naturalist methodology allows the utilizing of data obtained from interactions such as interviews, whilst acting as a participant observer. Lastly, adhering to a balanced axiology acknowledges that research outcomes would be influenced by the values of the researchers. Effort was be made to present a balanced perspective.

3.2 Grounded Theory

Due to its robust nature, the analysis of gathered qualitative data gathered can be understood using several different methods. Denscombe maintains that there is no single correct approach to the analysis of qualitative data, which covers all situations (2010. pp. 272-306). The researchers enhanced the approach by relying on principles related to grounded theory to guide research focus. Applying the grounded theory involves collection and analysis of data in order to create and refine a theory (Jupp, 2006). The theory emerges from patterns found in the data that is collected during the research process. According to Engward, (2013), there are two main schools of grounded theory. The first was initially proposed in 1967 by Glaser and Strauss (1967/1999) that emphasizes neutrality in inquiry and a latter version introduced by Strauss and Corbin (1990), that allows for more intervention during the interview process. For the purposes of the research, the latter version was better suited because it allowed the research to proceed without constructing an outline of the relevant basic social process beforehand. Because the researchers had limited prior knowledge of the waste industry, it was seen as imperative to approach the research with an unbiased view. Furthermore, the approach proposed by Strauss and Corbin (1990) allowed the theory to be interpreted by the observer who fills in the gaps in the data (Engward, 2013).

In practice the application of the principles of grounded theory during the research process involved interviewing respondents to reveal a theory that was modified as new data became available. First, a general categorisation of the industry was constructed by utilising theoretical sampling and interviewing respondents directly involved in the waste supply chain. These were categorised (Group 1) and included: *Waste Sources, Waste Management Operators, End Users of Waste*. These respondent categories provided the theoretical representation of the waste industry and were seen as sufficient for answering the first research question. To answer the second research question other actors in the industry were also interviewed (Group 2) and the categories were expanded to include: *Waste Industry Experts* and *Industry Platforms*. After saturation was reached and no other categories emerged, they were used as groupings that were analysed using the theoretical frameworks obtained from the literature review. To answer the third question, data was gathered from respondents that were industry participants are (Group 1) was triangulated with responses from the other two categories (Group 2).

3.3 The Systems Approach

In order to achieve the research objectives, it was necessary to incorporate the subjective experiences of the respondents and construct a mental model of the waste industry. Applying such an approach would mean that the researchers were responsible to fill-in any gaps in knowledge that arose during the analysis. While that would be acceptable under the chosen research paradigm, there was a need to select an appropriate analysis method that would ensure that investigation was methodical. As a result, elements of systems theory were applied to evaluate how the main industry actors interacted with each other and how those interactions fit within the context of the research questions. The waste sector was viewed as a social system comprised of actors connected to each other to form patterns that could be understood as the characteristics of the industry itself.

Mulej et al. (2003) maintain that, systems thinking is the practice of holistic thinking, either informal or based on methods used in general systems theory. Since the research objectives were exploratory a more informal approach was more suitable, which did not rely on mathematical models. Starik and Rands (1995) successfully applied a similar approach when analysing ecological sustainability within organisations. They were able to gain a multilevel understanding of the phenomena by to applying a systems framework. Poutiainen (2015) also cited the value of systems thinking to reveal interconnectedness between industry actors, when researching business models with circular design. Williams, et al. (2017) performed a review of literature using systems thinking within the context of sustainability management research and found several core concepts including: interconnections, feedbacks, adaptive capacity, emergence and self-organization.

By applying elements of systems theory, it was possible to evaluate how the main industry actors interacted with each other and how those interactions fit within the context of the research questions. Sushil, (1990) successfully used a comparable approach when analysing the waste management industry and was able to gain a deeper industry understanding that went beyond analysing the basic industry operations (generation, reduction, collection, recycling, disposal). According to Rolando (2015), systems analysis involves, establishing a framework of understanding, identifying recurrences and seeking circular causalities. The results of the systems analysis of the industry was done in parallel with the research objectives and helped to guide the investigation. The mapping of the system for analysis is illustrated in *Appendix D2* (Figure 12).

3.4 Data Collection

Because of the exploratory nature of the research, semi-structured interviews were used to allow for discussion and the discovery of new insights. Theoretical sampling was based on a general categorisation of the waste supply chain. Researchers sought to be unbiased, but also to prompt conversation by increasing question specificity, giving examples and asking interviewee thoughts on findings from other interviews and research.

3.4.1 Sampling

The development of CE and the closing of waste loops requires multidimensional and multi-actor involvement (de Jesus & Mendonça, 2018). Interviews therefore sought to investigate the closing of waste loops from the perspective of different actors. Bicket et al. (2014), identified waste from agricultural products, wood and paper, plastics, metals and phosphorus as priority materials for the EU, and the sectors of packaging, food, electronic and electrical equipment, transport, furniture, buildings and construction as priorities. This was considered when contacting interviewees, with waste sources like forest, packaging, food (phosphorus plays a key role in fertilizers and feed), retail and construction companies contacted. Additionally waste management as well as recycling operators dealing with plastics and metals; and a recycling platform for electronic waste were approached.

Waste Management Operators involved with various transport activities related to waste materials in the EU were also contacted. Focus was kept on transporters of waste, with questions asked about the transportation of waste materials, rather than the transportation sector as a whole. Furniture manufacturers were not included in the research because it was seen that the bulk of the waste generated in that industry would already be represented by other categories (e.g. forest, plastic, metal). The decision to depart from the list proposed by Bicket et al. (2014), was made with the aim to keep the focus of the research broader.

3.4.2 Data Sources

After preliminary discussions with three managers from Tana Oy, with experience in the waste management industry, a total of 31 semi-structured interviews were conducted from April 4th to June 13th, 2018. 18 were made in person and 13 via Skype or phone. 26 of the interviews were in English and five in Finnish. Interview recordings had an average length of 65 minutes. Length was affected by the available time of interviewees, talking speed, and answer length; that depended on detail, digressions or eagerness for additional discussion.

These 31 interviews were the result of 114 interview requests through email or phone presenting the topic of the research. To increase likelihood of participation, researchers assured the interviewees that their responses would be anonymized and agreed to share the research results with respondents. As the aim of the study was to be a system analysis of different actors in the waste value chain, researchers sought to contact respondents from industry (Waste Sources), waste management or recycling providers (Waste Management Operators), end users of waste (End Users), technology providers (Platforms) and experts on waste management or CE (Experts). These five groups are presented on the next page. A full list of preliminary discussions and chronological list of interviews can be found in *Appendix C*.

Though the schedule of interviews depended significantly on the availability of interviewees, researchers sought to identify potential interviewees and leverage contacts found through interviews to increase successful interview requests. Primarily industrial companies, as well as experts were contacted first, followed by waste management operators, end users of waste, and those related to platforms.

List of interviews by category

A total of 10 industrial companies were contacted, of which seven agreed to participate in the research. One of these companies was also willing to allow a visit to one of their mill sites and interview two managers on site (Waste Sources 2, 8 and 9).

Table 8: Industrial waste sources

Interview	Company/Organization	Interviewee(s)
Waste Source 1 (Interview 1)	Finnish vegetable food company specializing in frozen vegetables and foods, ready-to-use vegetables, vegetable oils and animal feedstuffs Operations in the Northern Baltic region	2 Interviewees President & CEO Director, Communications and Investor Relations
Waste Source 2 (Interview 4)	Nordic pulp and paper manufacturer Global operations	Head of Operational and Environmental Affairs, Group Sustainability
Waste Source 3 (Interview 7)	French food services and facilities management company Global operations	Director QHSE (Quality, Health, Safety & Environment) Nordics
Waste Source 4 (Interview 8)	Finnish retailing conglomerate operating in the grocery trade, the building and technical trade and the car trade Operations in the Nordics, Central and Eastern Europe	2 interviewees Environmental Specialist Maintenance Manager
Waste Source 5 (Interview 10)	Finnish food company producing meat foods, ready meals and other products Operations in the Nordic and Baltic region	Energy and Environment Engineer
Waste Source 6 (Interview 14)	Finnish Construction Company Operations in Finland, Russia and Estonia	Environmental Specialist
Waste Source 7 (Interview 17)	Finnish Newspaper Printing House Operations in Southern Finland	Operational Manager
Waste Source 8 (Interview 27)	Nordic pulp and paper manufacturer Mill located in eastern Finland	Mill Environmental Manager
Waste Source 9 (Interview 28)	Nordic pulp and paper manufacturer Mill located in eastern Finland	Mill Senior Manager, Sustainability, Consumer Board

A total of 16 waste management or recycling companies were contacted, of which four agreed to be interviewed.

Table 9: Waste management and recycling operators

Interview	Company/Organization	Interviewee(s)
Waste Management Operator 1 (Interview 3)	Finnish waste management company Operations in Finland, Sweden & Russia	Process and Technology Manager
Waste Management Operator 2 (Interview 13)	Swedish waste management company Operations in Nordics and Poland	Market Area Manager
Waste Management Operator 3 (Interview 19)	Finnish recycling company specializing in metals Operations in Asia, Europe & North America	Former CEO (November 2013-January 2018)
Waste Management Operator 4 (Interview 20)	Finnish waste management company specializing in sensors and the tracking of waste generation Operations in Europe and North America	CTO and CO-Founder

A total of 15 end users of waste were identified and contacted, of which five agreed to be interviewed.

Table 10: End users of waste

Interview	Company/Organization	Interviewee(s)
End User 1 (Interview 2)	Finnish cement manufacturer Operations in Finland	Quality and Process Development Manager
End User 2 (Interview 21)	Finnish energy company and Waste-to-energy/Waste management services provider Operations in Nordics, Baltics, United Kingdom and Russia	Vice President, Strategy, City Solutions
End User 3 Interview 26)	A non-profit company managing the end-of-life for tires in Italy	Innovation Manager
End User 4 (Interview 29)	Danish End-Of-Life tires recycler Global operations	Director of Business Development
End User 5 (Interview 31)	Waste treatment solution provider, subsidiary of a Swiss multinational building materials company Global operations	Head of Function

A total of 30 experts on waste management and CE were contacted, of which eight agreed to be interviewed.

Table 11: Waste management industry and circular economy experts

Interview	Company/Organization	Interviewee(s)
Expert 1 (Interview 5)	Austrian consulting firm for sustainable resource management Based in Europe, projects around the world	CEO
Expert 2 (Interview 6)	Finnish municipal waste management company Operations in Southern Finland	Freelance Environment Manager Managing Director of Municipal Waste Management company (April 1994 – March 2014)
Expert 3 (Interview 9)	Finnish innovation fund, an independent public foundation	Director, Carbon Neutral Economy
Expert 4 (Interview 15)	A UK chartered body for Waste & Resource professionals	Deputy Chief Executive Officer
Expert 5 (Interview 22)	International non-profit association registered in Brussels Lobbying and Consulting Network for Circular Economy	Managing Director
Expert 6 (Interview 24)	UK trade association for Resource & Waste Management industry	Recycling Policy Adviser
Expert 7 (Interview 25)	Management consultant providing acquisition process, company turnaround, management for hire and boardroom work services. Projects in Asia, Europe, the Middle East, North America & South America	CEO
Expert 8 (Interview 30)	Belgian based federation for the European Waste and Resource Management industry	2 interviewees Policy Coordinator Legal and Communications Officer

A total of 13 Platforms relating to waste management and industrial collaboration were identified and contacted, of which five agreed to be interviewed.

Table 12: Platforms relating to waste management operations

Interview	Company/Organization	Interviewee(s)
Platform 1 (Interview 11)	Independent Innovation Community for the UK infrastructure industry	Knowledge Transfer Manager
Platform 2 (Interview 12)	Finnish bio economy, circular economy and energy systems open innovation cluster	Portfolio Manager
Platform 3 (Interview 16)	German reverse online auction platform for waste and secondary materials (Operational 2000-2005)	Former CEO
Platform 4 (Interview 18)	Finnish industrial service company specialising in maintenance and engineering services Part of a waste materials market platform accelerator	CEO
Platform 5 (Interview 23)	European Producer Responsibility organisation for electronic waste	Managing Director - Finland

Additionally, 30 non-platform technology providers were contacted, at the beginning of the study, of which only one agreed to be interviewed. This company was also a waste management company (Waste Management Operator 4). This company was therefore moved into the Waste Management and Recycling Operators category, and the technology providers category removed. At this point in the research the question of technology had become focused on platforms, making the dropping of the preliminary technology category sensible for maintaining the scope of the study.

3.4.3 Research Boundaries and Limitations

The study was delineated to focus on companies operating in the EU, a consequence of the regional access of the researchers, but also appropriate as the European Commission has long been involved with sustainability in waste management. The choice of semi-structured interviews as a research method and the sampling used present certain boundaries and limitations which require consideration. Interviews are less generalizable than randomly selected sampling that can be analysed quantitatively (Denscombe, 2010, pp. 175-176, 237-239). The interviews relied on the subjective perspectives and bounded knowledge of individual interviewees within an organization or company.

To increase reliability of responses, multiple interviewees from different companies were interviewed, with interviews being coded and compared to each other so that identified themes would correspond with reality as much as possible (Patton, 2015, p. 311). Interviewees and their companies were provided anonymization in the study, both to limit response bias as well as to increase the likelihood of interview requests being accepted. All the interviewees were subject matter experts, involved in either environmental /sustainability work or the company's strategy related to CE. Additionally, interviewees were provided with the topic of the interview, as well as a thematic guide or summary of the themes for discussion in advance so that they would be prepared for the interview.

3.4.4 Semi-structured interviews and analysis

Interviews were semi-structured. In order to have consistency and to ensure that relevant themes were covered, adapted interview guides were used based on identified areas to be investigated, as seen in the interview guide in *Appendix D*. The discussion time spent on themes and the questions was variable. The depth of discussion on questions was modified, and the order of questions varied depending on information coming up in discussion. Researchers ticked off questions that were covered through answers to other questions, or sometimes changed the order as topics were brought up in discussion earlier than in the interview guide. Additionally, new or more detailed questions were asked based on observations of interviewee responses.

Notes were taken during interviews, and all interviews were recorded and transcribed to allow for analysis afterwards by coding them in ATLAST.ti 8. After the coding of interviews, findings were grouped according to literature reviewed in section 2.5 to synthesize insights provided by individual interviews. The barriers to closing waste loops and adopting a CBM enabling platform were collected separately to understand both the barriers to closing waste loops themselves and to platforms being adopted in the waste management industry.

4 Findings and Analysis

The findings of the interviews were grouped into barriers to closing waste loops and utilizing a waste exchange platform to enable CBMs. This allowed for the underlying barriers to developing circular loops in the EU, to inform the analysis of interviewee insights on platforms.

4.1 Identified Barriers to the Closing of Waste Loops

Financial barriers appeared to be the most prominent. Waste management is focused on low costs and efficiency due to buyers of waste management services seeing waste management as a cost to be minimized that does not contribute to revenues. The lack of investment in waste management leads to decreased technological investment, affecting quality management, which makes the sourcing of waste more difficult for users of waste materials.

Limited financial incentives combined with high transaction costs for utilizing waste are challenging for waste management operators because regulations on landfilling have created a captive market for waste-based materials. Waste management operators are not able to control the input of waste materials. In their role as suppliers, waste management companies are not able to exit the market for waste materials when demand is low. Such a constraint limits the development of the industry to treat waste as a resource. Without increased demand for waste materials, investments into improved collection, separation and processing are difficult to justify. This appears to be the reason for a lack of developing solutions to operational and structural barriers in the way of closing waste loops. On the following page is a summary of identified barriers (Table 13) to the closing of waste loops, followed by insights from interviews related to these findings (Sections 4.1.1-4.1.6).

Table 13: Summary of barriers to closing waste loops identified in interviews

	Cultural	Regulatory	Financial	Operational	Structural	Technological
Waste Sources	Reliance on consumers for returns Lack of customer demand for CE Procurement of waste management services focused on cost efficiency	Permits required to utilize waste Restrictions on collaboration Varying regional legislation	Lack of investment in waste management Lack of marketplace for waste-based products High transaction costs to find partners or buyers Lack of business case Logistics and handling costs	Lack of waste management expertise Limited space for storage and processing Insufficient volumes	Decentralised waste management Dependence on external outlets	Lack of digitalisation in waste management
Waste Management Operators	Waste management is cost efficiency focused Resistance to sharing information	Restrictions on reuse or innovation of waste Municipal monopolies Varying regional legislation	Low value of secondary raw materials Logistics costs Captive market	Lack of control over waste input	Ownership of waste passes liability to Waste Management Operators Dependence on external outlets	Lack of technological development and adoption Lack of separation and identification technology
End Users of Waste	Waste management's focus on cost efficiency over quality Perception of Waste materials	Lack of incentives for utilizing waste Varying regional legislation	Uncertainty of investments being paid back Need for a business case High sourcing transaction costs Cost of extraction and logistics	Lack of reliable quality	Constant need to find new outlets and applications	Lack of digitalisation in waste management Lack of processing technology Lack of sorting technology

4.1.1 Cultural Barriers

All the persons interviewed recognized the term “circular economy” and mentioned it as being on the agenda of their company or organisation, though differing in the degrees of priority. For Waste Sources, customer awareness, company brand and potential of increased value from current products were seen as drivers for CE adoption (Expert 5, 6; Waste Source 1-9). Most of the waste sources considered CE a part of their strategy and themselves to be actively seeking CE solutions (Waste Source 1-6, 8, 9). However, CE was secondary to overall competitiveness or profitability (Waste Source 3-5, 7). Waste Management and End Users meanwhile saw CE as a business opportunity, with waste as a potential raw material and recycling as a growing business, whilst noting it placed increasing demands upon waste management (Waste Management Operator 1-4; End User 1-5). This suggests general awareness and interest in CE and the utilization of waste as something, which already exists.

Waste Sources:

Reliance on consumers for returns

Waste sources producing or providing goods were dependent upon consumer actions for the return of waste materials like packaging or plastics (Waste Source 4, 5) and could not directly affect waste due to excess consumption (Waste Source 3-5). Municipal waste can be particularly challenging to source separate, as private people may be resistant to the effort required (Expert 5). However free of charge containers for separation and education has allowed for successful separation of waste in many areas (Expert 2). The need for consumers to increase efforts in waste separation and regular returning of waste to producers’ places more of a burden on customer efforts, than more seldom returns like electronic waste. However, noted that it had the ability to inform customers through customer magazines and social media about the importance of sustainability, which could help increase customer efforts (Waste Source 4).

Lack of customer demand for CE

Though branding of operations as sustainable were considered driven by consumer awareness and company values, this did not necessarily extend to sales for CE solutions or products (Waste Source 4, 6-8). In the construction industry, those purchasing the construction of a building, were making a big investment with little interest in taking risks through the use of recycled materials (Waste Source 6). Likewise, in the forest industry, the reuse of biomaterials to improve agriculture was limited by customer perceptions of these waste which was inferior to virgin materials (Waste Source 8). Even in cases of accepted recycled materials, in the case of printing house customers (Waste Source 7) saw demand for sustainable printing and paper drop when publishers came under economic pressure. Customers of companies prioritized cost and service before environmental sustainability, lowering demand for CE solutions that were not at least cost neutral (Waste Source 3).

Procurement of waste management services focused on cost efficiency

Waste management requirements have traditionally been focused on cost efficiency through logistics and disposal. Cost efficiency and regular pickup tend to be what customers value most. In the past requirements have been low, with customers not demanding much beyond the safe and cost-efficient disposal of waste in the correct geographical region (Waste Source 4, 7, 8; Waste Management Operator 1, 4; End User 2; Expert 6,). At the same time waste management is often an afterthought, where owners of waste do not focus the same efforts as in production. Waste operators are often paid per collection, and so are incentivized to collect as many containers as possible in as short an amount of time as possible, Waste Operators are focused on logistics efficiencies rather than optimizing waste flows. This has led to a lack of interest in developing new technological solutions, sensors or reporting tools (Waste Management Operator 4). Waste Sources seem dependent on waste management companies for innovations to waste management (Waste Source 6, 7).

Waste Management Operators:

Waste management is currently cost focused

The waste management industry is characterized by cost optimization (Waste Management Operator 1; End User 2; Expert 7). Therefore, cost has been the most important consideration in investment decisions. As a result, technological adoption has mainly focused on optimizing collection and routes and decreasing immediate pollution (Waste Management Operator 4). Competitiveness is then seen coming from creating operational efficiency, rather than providing new solutions.

Resistance to sharing information

Waste Management Operators are resistant to sharing information about their outlets or technologies (Waste Management Operator 1, 2; Expert 2). As noted by (End User 2) which also operated waste management services, *"Knowledge of the waste and the flows* *that is what is valuable to us and to our competitors so typically companies are not so willing to share that so openly."* This makes competitive sense for waste operators, particularly those with secured outlets for their waste, but reduces the transparency of the market for waste materials, both for users looking to source waste and waste operators.

End Users of Waste:

Waste management focus on cost efficiency at the cost of quality

The sourcing of waste to be utilized was hampered by waste management companies not being used to needing to provide materials for users concerned with quality and standardization. This has led to significant learning curves, from three to six years for waste management operators to provide high-grade materials for Solid Recovered Fuel (SRF) for instance (End User 1). Often companies would need to spend significant resources training or monitoring their waste material providers, in order to ensure consistent quality (End User 2), increasing transaction costs involved in end users sourcing waste materials.

Perception of waste materials

For end users producing waste-based goods for markets, the perception of waste as something negative was a barrier. The utilization of materials or products made from waste is hampered by customer perception of waste. These can be health concerns, doubts about their durability, and resistance from producers of materials to be substituted by secondary raw materials. As stated by End User 3: *"So new virgin raw materials are still considered better than the recycled ones, so there's also a need for a change in mentality"*. Perceptions of waste materials is a barrier to waste sources participating in secondary raw material markets. Buyers not understanding the limitations of second-hand goods, like machines or spare parts, could result in potential complaints (Platform 4).

4.1.2 Regulatory Barriers

Regulations are a key driver, if regulators do not force companies to dispose of waste responsibly, then the cheapest choice would almost always be to simply dump waste, though some easily extractable valuable materials may still be taken care of (Waste Source 1; End User 1, 2; Expert 7). Waste sources identified regulation as a primary driver of developing and procuring sustainable waste management (Waste Source 1-5, 7-9). Regulations help create a level playing field, and make CE business models viable (End User 5), as legislation creates more demand for waste management and CE services. Increased CE legislation also requires more investment in technology and the sorting of material before it can be disposed however, disrupting the waste management industry (Waste Management Operator 1-4).

All actors in the supply chain:

Varying regional legislation

Waste regulations vary across the EU-28 and can be extremely complicated with in extreme cases products various components having to follow 90 different regulations (Platform 5). Waste regulations do not just vary from nation to nation however but can also vary within countries. These local regulations hinder efficient solutions on a large scale and can also be a barrier to companies centralizing their waste management to optimize it (Waste Source 3; End User 2, 4; Expert 2, 4, 7, 8). Even in cases where regulations were similar in regions, officials may interpret legislation to different degrees, creating uncertainty in being able to roll out similar solutions across the company (Waste Source 3, 8; Platform 2). The effect of regulation related uncertainty can also affect the production of goods.

Waste Sources:

Permits required to utilize waste

Waste sources cannot sell their waste materials to simply anyone. As they are liable for their waste, they have to confirm that the user of waste is authorized to handle and utilize waste materials (Waste Source 1, 8). Sites of waste creation often cannot be freely visited by outsiders, but permits are required for partners to come onsite. This limitation impacts the ability to sell waste materials directly. As safety training, permits to be on a construction or factory site, and to handle waste are necessary to be able to collect waste or even to consign waste to a partner (Waste Source 5, 6; End User 3; Expert 4; Platform 4). Though such legislation is important for proper waste disposal, it increases the transaction costs involved in seeking outlets and increases preferences for long-term partners.

Restrictions on reuse or innovation of waste

Regulations on pollution and hazardous materials often also restrict the reuse of waste. Though companies recognize the importance of waste utilisation, very strict limits on heavy metals or pH-values for instance, means that the reuse of ash or sludge in the forest industry is limited (Waste Source 2). In fact, every new application required new approval, with reporting on its contents (Waste Source 8). This limits experimentation with new materials that could reduce waste, as they are not expected to have enough value to justify costs incurred to receive government approval. Likewise, in the construction industry, legislation was considered a hindrance to building with recycled materials, as they would not be categorized as virgin materials and so have less demand. In the food industry, certain animal parts had to be burned or heat treated, rather than being able to seek reuse (Waste Source 5). Producers therefore saw regulation simultaneously making disposal more expensive, whilst not providing incentives to bring recycled products onto the market (Waste Source 6).

Restrictions on collaboration

Collaboration with direct competitors is often controversial, as waste markets or platforms need to be neutral arenas, without harming the competitiveness of the market. EU competition laws limit the ability for companies to be able to collaborate, even when it comes to combining waste streams. This requires a third party, a separate company or organization, if waste processes combining waste different company waste streams is to be developed (Waste Source 2; Expert 6, 7). The third party would facilitate needed collaboration whilst avoiding compromising the competitiveness of the market.

Waste Management Operators:

Municipal monopolies

Local regulations may give monopolies to municipal waste management companies for certain waste or operations (Waste Source 2, 3). Municipal monopolies were seen as limiting the opportunities for private waste management companies (Waste Management Operator 2). This could be particularly problematic with municipal company resistance to innovation (Waste Management Operator 1-4). Though municipal waste management companies may utilize private companies for services, as outlets for waste in the form of incineration or landfills is guaranteed, these lack an incentive to develop new solutions or technology (Expert 3). At the same time, monopolies were seen as helpful in enforcing a market by requiring companies buy services to cover the external costs of their waste, which is particularly important for negatively priced goods (Waste Management Operator 3).

End Users of Waste:

Lack of incentives for utilizing waste

Despite seeing value derived from waste as part of their key offering, many waste end users saw incentives for reusing waste materials as lacking. In the use of energy recovery for instance, companies did not receive compensation for avoiding fossil fuels (End User 1).

Recycled materials meanwhile often must compete with lower cost incineration for energy, and with virgin materials in the market, with a lack of EU subsidies to compensate the cost of recycling (End User 4).

4.1.3 Financial Barriers

Financial barriers can be seen as stemming from: Cultural, Regulatory and Operational barriers. For example, waste sources identified waste management as primarily being an expense to be minimized, even if some identified waste as a potential value provider in the future (Waste Source 1, Waste Source 7, 8). However, the value of waste was currently seen being plus or minus zero (at best) in compensating for waste management costs. This is partly due to the nature of waste itself, with large amounts of waste being negatively priced.

Waste Sources:

Lack of investment in waste management

Waste management is not a part of the core business for companies producing waste. Because waste management activities and equipment do not directly contribute to the bottom line of companies, there is often a lack of investment in such activities compared to production and distribution (Waste Source 7, 9; Platform 5). Old equipment and systems are often not renewed, and there is a lack of investment in digitalisation from waste sources (Waste Source 8, 9). Unless significant cost savings can be seen, it is difficult to motivate investment beyond regulatory requirements (Platform 2). It also hampers technological development, by a lack of investment until benefits are proven. When it came to new ways of handling waste, testing of a smaller site up to a year was required, before implementing it across a company (Waste Source 5). Unsurprisingly, companies are unwilling to invest in new technologies, if related services or products do not have buyers (Waste Source 6).

Lack of a marketplace for waste-based products

Waste sources generally did not see there currently existing a marketplace for their waste streams (Waste Source 6, 8, 9). They saw a lack of buyers for recycled materials and products made from recycled materials (Waste Source 1, 2, 6). In the case of construction, there was little public procurement of roads or other infrastructure projects utilizing recycled materials (Waste Source 6). The creation meanwhile of a real demand side for waste side streams and recycled materials is a challenge, making market creation by companies themselves seen as a risk (Waste Source 9).

High transaction costs in finding partners or buyers

The lack of ready marketplaces for waste-based products leads to high transaction costs to find partners or buyers for waste (Waste Source 2, 4). New applications for waste require significant testing, with laboratory tests and practical pilots that if successful may require the company to sort through complicated and demanding legislation such as the EU Reach legislation for chemicals. New products developed based on waste streams may also have to enter a completely new market, as the products may not fit their current sector of operations (Waste Source 2). Companies do not see themselves as having the resources to explore new markets with uncertain financial gains (Waste Source 8).

Lack of a business case for CE initiatives

Without a business case for CE initiatives they are unlikely to be undertaken by companies (Waste Source 2, 4, 6). Though compensation drives the adoption of CE, it is often not possible without monitoring and sorting, which alone does not create value for companies, making such investments difficult to justify (Waste Source 4). Comparatively sustainable solutions need to be at least equal in cost with other solutions in order for them to be chosen (Waste Source 5).

Logistics and handling costs

Logistics and handling costs are a significant barrier to utilizing low value waste. Often a concept to utilize waste falls apart if the solution is too far away, and transportation costs destroy any economic gains (Waste Source 8). Excessive transportation is not just a cost issue, but also an environmental one, as significant distances cause higher emissions (Waste Source 9). This has led to companies requiring local solutions, with end users near where waste is generated, (Waste Source 1, 2, 9) limiting the number of solutions they can consider.

Waste Management Operators:

Low value of secondary raw materials

Waste is defined by its unwantedness often due to it having low value or value that cannot be easily extracted. Waste with easily extractable or sufficient value is recovered first (Expert 7). Since seeking to utilize waste usually means substituting a virgin material, waste-based materials have to compete with virgin materials (End User 2). In the case of materials with sufficient value like metals, this sees companies seek to buy waste containing metal, in order to mine and sell it at extraction costs that are less than the value of metal (Waste

Management Operator 3, End User 1, 2). However, many waste materials are not cost competitive with virgin materials, due to the additional costs of collecting, transporting and processing, leading them to be negatively priced when they cannot simply be disposed. Often once valuable materials like metals are collected, little other use remains but incineration (Waste Management Operator 3). The low value limits the utilization of waste, as sufficient technologies and processes are not developed without a sufficient price (Expert 4, 7).

Captive market

" It's also true that waste company have the difficulty that they have to deal with the waste that they receive, it's not like any producer who can decide whatever they want to buy or not, waste producers they make products like new materials out of what they receive, and this is already difficult enough…" (Expert 8)

Compared to manufacturing industries, waste management cannot control its input, but has to find a use for waste (Expert 2, 7). Volumes are not produced based on demand, but based on the inflow of waste, creating a captive market, where sellers are not able to exit the market when prices decrease or even if negatively priced (Waste Management Operator 3). Due to bans or high gate fees on landfilling, companies can no longer landfill. At the same time regional shortages of incineration capacity, means that other outlets are necessary (Waste Management Operator 3; Expert 6). An artificial need arises to invent new uses for waste. This has forced innovation but also increased the burden on waste management operators (End User 3, 4). This phenomena has been exacerbated by the Chinese waste ban (End User 2). Raw material users meanwhile have not invested significantly in research to replace raw materials, whilst the waste management companies cannot pressure them to do so (End User 3), creating dependency on a relatively small number waste end users. Waste management companies are aware of this and price services according to their disposal costs (Waste Management Operator 1, 3). Competition significantly limits the potential for profits.

End Users of Waste:

Uncertainty over investments being paid back

"I'm not aiming to be the first to have a new waste idea I need to be the second player, to know that I'm investing into good things that are working, because the sorting facilities and stuff is really expensive…" (Waste Management Operator 2).

Facilities to process or utilize waste are significant investments. The building of a new WTE plant or processing plant requires contracts for decades to be in place to secure supply, tying companies or municipalities to a specific solution (End User 2, Expert 2, Platform 5). Unsurprisingly this makes waste management companies and end users resistant to investing in unproven solutions. Another respondent said that no one in the industry would invest before seeing a proven opportunity, creating a waiting game (Waste Source 6). Whilst these are understandable positions, it creates difficulties in finding first movers to create new waste solutions. For cement kilns utilizing alternative fuels, the investment was first motivated by sustainability, as in the beginning they could not know what the prices in the market of alternative fuels would be (End User 1).

Need for a business case

"So, we need to repeat that, in order for circular economy to happen it also has to make sense from an economic point of view for the industries… but everything that is recycled needs to find a market." (Expert 8)

For waste to be utilized there has to be a business case. Often this requires regulation restricting operators, so that sustainable operators can have compete with their solutions. This is important as companies are required to invest in re-processing facilities, logistics and technology to be able to utilize waste (End User 5). These technical constraints are manageable, but only so long as there is a business case. CE Business models are therefore dependent on regulation. The value can be cost savings, but is challenging if virgin prices are so low and restrictions on disposal are not in place (Waste Source 2; End User 5).

High transaction costs in sourcing

Waste material users have to invest significant resources in sourcing. The quality and capabilities of waste material providers lead to the need for partnerships (End User 4). Sourcing SRF for example requires site visits, test loads for samples and data collection, then trial loads and additional testing before agreements can be made. Furthermore, sourcing from abroad can be more complicated, when a company may have to rely on middlemen, since the company lacks the language, network and knowledge of the foreign market (End User 1). Additionally, with quality being vital, they often see long learning curves for suppliers (up to 10 years), and so have a preference for long term contracts (End User 1, 4).

Cost of extraction and logistics

The cost of extraction and the transportation of waste materials is a barrier for low value materials. Due to waste having low value or even negative value, companies cannot spend significant amounts on its extraction, logistics and storage (End User 2; Waste Management Operator 3). As recycling and waste management companies cannot change the chemical composition of waste or the designs of products, but only mechanically process them, extraction is limited (End User 3). Recycling often furthermore loses material in the process, as in the case of plastics for instance, multilayer plastics and black plastics are not recyclable at the moment and so must be discarded, increasing costs further (End User 2). This has led to sourcing preferably being within a couple hundred kilometres of waste end users (End User 4), which means that an oversupply of waste in regions leads to lower prices and often worse handling (End User 1).

4.1.4 Operational Barriers

Operational barriers were found mainly for waste sources, related to their capabilities and capacity for waste management. End users meanwhile did not present significant operational barriers, whilst the operational challenges for waste management operators whilst significant could be argued to be partly structural due to the role of the waste management industry, though barriers showed operational improvements that would be possible.

Waste sources:

Lack of waste management expertise

Waste management is not a core competency of most companies. Which means that their personnel's waste handling is dependent on the instructions, training and equipment provided by waste management companies (Waste Source 6). The attitude of onsite personnel and how important waste management is considered affects handling. Companies have limited resources to search for their own solutions, making them dependent on waste management company solutions (Waste Source 2, 4).

Limited space for storage and processing

Storage space for waste is limited at manufacturing and service locations (Waste Source 4, 6; End User 2) and companies may also be limited in being able to store waste due to if they exceed temporary storage times, having to pay fees on it (Waste Source 8). This makes timely and regular pickup vital, whilst the ability to separate on site may be limited. Therefore, the separation and collection of waste can often not be optimized, which affects the downstream process of waste utilization.

Insufficient volumes

"…the thing is you need tremendous volumes to do anything with the waste, and the thing is that it's not called waste without a reason, its unfortunately the material values are so low." (Waste Management Operator 3)

The viable utilization of waste streams requires sufficient volumes (Waste Source 1, 2; Waste Management Operator 3; Platform 2). Even when companies would be able to reuse some fraction of waste, that fraction may be too small or irregular to generate sufficient economies of scale for the company or interest from end users of waste (Waste Source 5). The lack of sufficient volumes also reduces investment in technologies to process waste for recycling or reuse. (Expert 2).

Waste Management Operators:

Lack of control over waste input

The qualities of waste-based products are largely defined by the composition of waste streams they are derived from. Though some end users of waste are strict in their sourcing, this is a general problem for recycling industries, as inputs are often variable and outside of their control (End User 4). This makes the separation and identification of waste critical.

Waste is produced from products and processes, designed by waste sources to meet their or their customer's needs, which then is consigned to waste management companies to handle. (End User 3). Waste management companies avoid refusing customers, as they are competing for valuable waste streams which may mean accepting non-valuable ones as well (End User 2, 5). However if waste is not separated and identified before the waste management company receives it, it is difficult to do anything with it (Expert 2). Waste increases in complication the further downstream it moves, as early waste streams are more uniform than later ones, where additional components or materials have been added to the product (Waste Source 5, 6, 8, 9).

End Users of Waste:

End users of waste did not present significant operational barriers to utilizing waste related to their own operations, instead being challenged by the difficulty in sourcing waste materials. This is perhaps not surprising as end users have outlets for waste in place, otherwise they would not be sourcing waste for their production. Instead, barriers that could be considered operational could better be considered as related to the operations of waste management companies, financial considerations and structural barriers to sourcing and utilization. One end user did mention however, that waste management operators and end users of waste lack efforts to sell products produced from waste (End User 3).

Lack of reliable quality

"*Well in some sense, for the waste trader, because the best price they can get that's their business, so they have an incentive to try to sneak in just a bit too much [contaminated material], or just enough so that it doesn't hurt the business relationship at least in the short term, but then that they get rid of the waste cheapest way possible.*" (End User 2)

The supply of sufficient quality is a limiting factor for companies seeking to increase the use of alternative fuels, as markets are not developing fast enough (End User 2, 5). Waste is variable, and the outcome of something else, making quality control difficult. Even industrial waste, more homogenous than municipal waste, can be complicated. There is often a lack of specifications and standardization for waste materials compared to virgin material (End User 2, Expert 8).

Despite attempts to standardize waste materials, such as SRF, there are still large variations in the quality produced by waste management firms (End User 1). Contamination such as chlorine from PVC pipes, are not just environmentally hazardous but can create hazardous gas, dioxins if burning temperatures are not high enough. It makes it difficult to source from long distances and may see companies exceed their environmental permits if they are not careful (End User 1, 2; Expert 1). Furthermore, there is often an incentive for waste operators to unload undesirable materials if possible. It is unviable to sample the entirety of waste that end users receive (End User 1, 2). Even if materials are sent back and substituted, this sees resources wasted and harms sustainability. End users therefore are often taking a risk when sourcing their waste from new providers (End User 4).

4.1.5 Structural Barriers

Structural barriers appeared to be the most present in the external context that interviewee companies/organizations were operating. These structural barriers are particularly challenging as they are difficult or costly for companies to change and may not be possible for a single company to change unilaterally.

Waste Sources:

Dependence on external outlets for utilizing waste

Closed loops were often difficult to achieve internally as fractions of residual materials or products might produce insufficient volumes for efficient utilization, and companies' core competencies and value offering do not necessarily match up with utilizing waste (Waste Source 1, 2, 4, 7). It means that using their waste would in many cases require a company to enter a new market, which is risky and not necessarily aligning with their strategy.

Decentralized waste management

The fragmented ownership of waste or responsibility for procuring waste management services, was mentioned by companies as a hinderance to improving waste utilization (Waste Source 2, 6). Owners of waste may also be decentralized in the case of cooperatives (Waste Source 4) or office buildings being served by a catering firm (Waste Source 3), meaning the contracting of waste management and data collection may not be in the control of the company itself. Likewise, there are many owners of materials on construction sites, such as subcontractors, owners of the building, and the construction company. This can lead to disagreements over who gets to financially benefit from the selling of waste, even if before a waste's liabilities have been carried by one actor, such as the construction company (Waste Source 6). For service companies, equipment or machines may be owned by their customers, meaning they do not have the ability to collect statistics on these (Platform 4). This leads to increased difficulties in gathering information on waste generation and reuse, as that information may belong to different actors (Waste Source 3, 4, 6).

Waste Management Operators:

Ownership of waste passes liabilities to waste management companies

The liabilities for waste are in large parts passed to waste management companies from waste producers. Companies are paid in-order to dispose of the waste, which with legislation limiting landfilling, means finding users for the materials at a lower cost than they were paid to take the waste (Waste Management Operator 1). The transfer of ownership is important in-order for waste management companies to utilize those materials (Waste Management Operator 2). However, it can be a challenge as Waste Companies are not in control of the composition of waste that they receive, and these companies are dependent on external outlets for the waste. If there is a big gap between the estimation and the actual quality of the waste, waste management companies bear the risk and pay the difference. This can be particularly challenging when contracts are based on expected waste amounts and types, but customers do not always know what waste they have (Waste Management Operator 1).

Dependence on external outlets

Waste Management companies are traditionally dependent on external outlets for waste (Waste Management Operator 1, 2, 4). There is limited time to find outlets, as they cannot store waste beyond permitted limits (Waste Management Operator 1). After all, one can ask what the difference would be between landfilling and merely maintaining large warehouses full of waste waiting for a user. These outlets for waste meanwhile are not a transparent market, but one in which there are thousands of agents collecting waste in exchange for a fee, utilizing their networks to be able to unload waste (Platform 3).

End Users of Waste:

Constant need to find new outlets and applications

Successful end users of waste were in some cases face with the need to repeatedly find new ways of using waste materials, as markets for waste materials become saturated, but the supply of waste continues to grow. For example, End User 4 noted that it had a successful application in utilizing rubber granules in artificial turf pitches, but that this was not going to be a viable outlet forever, whilst the supply of tires continued growing. Meanwhile, Waste Source 8 noted that the use of ash and sludge to stabilize landfills, whilst currently utilizing large amounts, would stop being a viable use once landfills in the area are stabilized.

4.1.6 Technological Barriers

Technological barriers related to a lack of adaption or investment, rather than a lack of technology existing. Technological solutions for separating or processing waste were thought as exciting for being able to utilize waste, however interviewees did not consider the invention of a new technology as a panacea for closing waste loops.

Waste Sources:

Lack of digitalisation in waste management

Internally waste management within companies is not prioritized compared to operations related to sourcing, production and sales in the linear chain. Furthermore, the waste management industry was not seen as a particularly developed or advanced sector by companies generating waste (Waste Source 2-7). This has meant a lack of reporting tools to track the amount and types of waste generated by different business areas (Waste Source 3). Though some companies had significant digital monitoring and reporting of their waste (Waste Source 4, 8) these were internally developed tools. Companies saw a need for active feedback on the quality of their waste and sorting from different business areas, as well as its impact on a weekly basis rather than together with invoices (Waste Source 3, 5, 7). These information and communication technologies appear to be lacking in waste management.

Waste Management Operators:

Lack of separation and identification technology

"In the past technologies to separate waste has not been motivated due to there not being money available through increasing waste separation." (Waste Management Operator 3)

Waste management operators generally do not use tools and technologies to identify waste. Instead, they rely on information provided by the waste producer, labels, markings and experience to judge waste quality (Waste Management Operator 1). It is particularly a challenge with plastics, which are difficult to distinguish from one another. In the case of municipal waste tend to be collected in one bin, and are often dirty, leading to material recycling not being viable and instead seeing them used for energy production. Industrial waste streams tend to be more likely to be knowable beforehand, so long as they are source separated (Waste Management Operator 1). The lack of technologies for separating waste was considered to have been due to there not being financial gain in improved separation technology (Waste Management Operator 3; Expert 4, 8).

Lack of technological development and adoption

The waste management industry has in the past not invested significantly in new technology, particularly Information and Communication Technology (Waste Management Operator 1-4; Platform 3). This has been due to the simplicity of the industry, as low-cost landfilling and the extraction of valuable materials like metals, made significant investment not considered necessary or producing a competitive advantage. Furthermore, new technology development lacks interest because of a lack of clear profits in developing monitoring, or new uncertain processing (Waste Management Operator 3). The industry has focused on logistics efficiency rather than productisation of waste materials (Waste Management Operator 2). Companies have begun to see the need to increase the control of waste material flows and quality throughout the supply chain, from collection to sale (Waste Management Operator 1, 2). Likewise, recent innovations in sensor solutions and software providing information on waste collected are emerging (Waste Management Operator 4).

End Users of Waste:

Lack of processing technology

In addition to improved handling of waste, End User 3 and End User 4, who were manufacturing products out of waste materials, saw improved processing of waste materials, with the possibility for varying particle sizes and shapes, for waste materials. End User 4 noted that their products needed particle sizes between 0.2 and 0.8mm, no longer granulate, but rubber powder produced through cryogenic freeing and crushing. There are also needs for rubber granules or powders in spherical or irregular shapes, to be able to use them in new applications (End User 3). This means that waste operators need to be able to customize the physical features of waste to better serve end users if they wish to find outlets for waste.

Lack of digitalization in waste management

End users did not consider waste management particularly technologically sophisticated, particularly in terms of information and communications technology (End User 2-4). The waste management industry as a whole was only now seen as industrializing, having in the past been characterized mainly by small local operators and outlets, with landfilling having been the primary form of disposal. This development to increase sophistication was seen as driven by regulation (End User 2).

Lack in sorting technology

Though sorting was recognized as an emerging technology, it is currently lacking for plastics (Waste Management Operator 1; End User 2). Meanwhile viable recycling requires the disassembly of products into their original components, for them to be comparable to raw materials like virgin rubber. Identifying the components and brands of tiers for instance was considered important, as tire manufacturers will often only accept reclaimed or devulcanized rubber from their own tires, due to the chemical composition (End User 3).

4.2 Identified Barriers to using a Digital Waste Exchange Platform

The most significant barriers related to using a waste exchange platform were related to the lack of accurate information regarding waste related materials. While EU level waste material categorizations exist, they focus on separating materials by chemical composition in order to determine the appropriate treatment type. Currently there is a lack of categorization and standardization for waste materials that would allow buyers to adequately understand available materials. As a result, there are concerns regarding the waste quality and composition that was shown to have an impact the respondents' view of the platform.

Furthermore, the current market imbalance in favour of downstream partners was found to impact the feasibility of a platform to be used as a material exchange mechanism. In the current market, organisations that have the infrastructure to adequately treat waste materials enjoy increased market power. One reason is that other alternatives, such as waste productisation processes are still underdeveloped. As a result, companies tend to favour already established methods like incineration rather than seeking other options for disposal. Below is a summary of identified barriers to using a waste exchange platform (Table 14), followed by insights from interviews related to these findings (Sections 4.2.1-4.2.3).

Table 14: Summary of barriers to digital platforms enabling circular business models

	Eco-Innovation	Industrial Symbiosis	Secondary Raw Material Market
Waste Sources	Uncertain market demand for recycled products	Sharing waste information is sensitive	Business requires long-term relationships
Waste Management Operators	R&D mostly focused on internal operations	Industry know-how is not currently shared	Existing market imbalance
End Users of Waste	Pace of innovation not sufficient enough	Business requires long-term relationships	Waste material is not suitable for spot market
Waste Industry Experts	Innovation is limited mostly to waste reduction	Competition & market power structure	Categorization & standardization need
Industry Platforms	Innovation hindered by insufficient information transfer	Logistics complexity a challenge	Quality & composition need to be known

4.2.1 Eco-Innovation

Waste Sources

Uncertain market demand for recycled products

Some respondents, who were users of waste management services, saw market demand as barrier for EI. For one operator in the construction industry the biggest obstacle to upcycling in their industry was customer demand. They stated that they attempted to innovate by reusing waste materials as building materials but saw that *"…there is no demand for recycled products"* (Waste Source 6). One possible reason mentioned for the demand was the fear that recycled building products would not be guaranteed to last as long as new products. Therefore, they did not see a platform as being able to remedy the situation. However, for a respondent from the retail sector the sustainability was seen as a part of their competitive advantage (Waste Source 4). As a result, offering new products made with innovative sustainable methods was essential to their business strategy. One example that mentioned was working with capable subcontractors to produce a line of food products made by utilizing biogas as an energy source. The intent was to use the sustainable production methods as a branding mechanism for their line of food products. It is important to note that, product based sustainable innovations were seen as part of the wider sustainability strategy and not a direct result of consumer demand.

Waste Management Operators

R&D mostly focused on internal operations

For some waste management operators, the issue of EI tended to be a reaction to the demand of customers. One firm explained that although they did not themselves focus on producing sustainable products, they did offer services that worked with customers seeking to close their own waste loops (Waste Management Operator 1). In one case, the firm altered their waste management services to help a customer to re-use plastic material in their production. Another respondent stated that their firm went even further, and mentioned that in addition to working with other they also have R&D operations that focused on better utilizing waste materials to create new value (Waste Management Operator 2, 3). In such cases innovations did not seem customer driven, rather they were aimed at taking a proactive approach to utilize industry knowledge and seize a market opportunity.

End Users of Waste

Pace of innovation not sufficient enough

End Users of waste and Experts both saw challenges with the ability of waste to be productized. End Users saw the current pace of innovation in the industry as slow (End User 3, 4). Interestingly, that view was especially true for firms that were directly involved in processing waste into products. They felt confident that currently innovation was not a strong enough driver for allowing firms to re-sell waste materials on the market (End User 4, 5). For some the lack of innovation stemmed from the lack customer awareness regarding existing waste derived raw material (End User 3). Others acknowledged the slow pace of innovation and stated that having the capability to turn waste into sellable products granted a significant competitive advantage to firms in the current market (End User 4).

Waste Industry Experts

Innovation focus relates to waste reduction

For Waste Industry Experts, the connection between innovation and the productizing of waste seems to be done mostly with waste reduction in mind. The redesign of packaging materials was often cited by respondents as having the most focus (Expert 4, 5, 6).

Respondents stressed the importance of products being designed with the capacity to be properly treated so that they could be upcycled and converted into other materials (Expert 3). However, it was also acknowledged that converting waste into products requires recycling infrastructure to be built to separate the materials into individual streams, however this is slowed by the proliferation of incineration plants that convert waste to energy (Expert 5, 8). From the view of respondents, the productisation of waste seems to be hindered by the immediate need for disposal.

Industry Platforms

Innovation hindered by insufficient information

"...to plan you have to have the status, and in order to have the status you need to have the statistics. If you don't measure it then you can't plan for it, so it's kind of if you don't have that kind of statistics or status of material you cannot start..." (Waste Source 3)

Most respondents in the platform category maintained that digital waste materials exchanges had the capacity to achieve the aims of the CE (Platform 1, 3, 5). However, there were concerns expressed in the ability of the relevant parties adequately communicate with each other. One respondent explained that parties often had to interact multiple times in order to complete the transition (Platform 3). While the potential of exchanging material using the platform was clearly demonstrated, significant transaction costs remained that could affect the pace of innovation. For the buyer looking to find waste materials, determining the characteristics of the waste material accurately is essential to creating a product. One respondent also mentioned that it was difficult for sellers to classify or catalogue the materials they wished to sell (Platform 4).

4.2.2 Industrial Symbiosis

Waste Sources

Sharing waste information is sensitive

"I think that companies are not willing to share their waste streams because if they share those, they also share their inefficiency" (Waste Source 3).

Several respondents expressed concern about their competitors joining the platform. They saw the sharing of waste related information, seeing it as a possible threat to business (Waste Source 5, 8). While for most share waste data was an important issue the level of willingness to disclose waste, information varied somewhat. For some food producers it was important to safeguard information from competitors (Waste Source 5). By analysing the waste streams of a company, it would be possible to obtain a picture of the internal operations.

Waste Management Operators

Industry know-how is not currently shared

The reluctance for sharing of information was echoed by the respondents in the Waste Management Operator Category. Some viewed as information sharing running against current industry practices. One respondents described the company's attitude to sharing information as closed in certain cases and stated *"if it's the know-how of the company then we don't share anything, if it's known everywhere then we can share"* (Waste Management Operator 2). This is supported by a respondent from a different category (Expert 2), who explains that companies operating in the industry are reluctant to share information as they are in direct competition with each other.

End Users of Waste

Business requires long-term relationships

The platform was not seen as suitable for fulfilling the needs of the industry (Expert 8) since business was usually done face-to-face (Expert 1). Several respondents agreed that long-term relationships are preferred when seeking partners to buy waste from (End User 1, 2, 3). The same was also seen for other respondents who preferred trusted partners when selling waste material. (Waste Sources 5,6). Respondents saw waste exchange as an activity that demanded a level of tacit knowledge exchange that needed time to develop. One respondent cited several times when waste materials arrived in unexpected condition and could not be utilized as intended and had to be sent back (Waste Source 1). Quality control seemed a key reason for preference of long-term partners. Other issues were also seen as important, such as establishing trust that the partner has proper certification to handle waste materials and that they will operate ethically.

Waste Industry Experts

Competition & market power structure

"*I think it's very difficult to combine these small guys with the big players because they're all direct [competing]..."* (Waste Expert 1)

Industry imbalances in favour of downstream operators was mentioned as a barrier to platforms (Waste Experts 4). The finding echoed some of the operational and structural barriers already discovered in section 4.1. Some saw the platform as a possible threat to dominant firms in the industry who were more resistant to change. Others agreed, regarding the market imbalances in the industry and were sceptical that a platform would be able to change the power structure. The imbalance create a captive market, which a secondary raw material market alone is inadequate to fix.

Industry Platforms

Logistics complexity a possible challenge

The operational details related to physical pick up or delivery of waste material was cited as a barrier to platform-based waste exchange interaction (Industry Platform 4). A similar view was expressed by another respondent in a different category (Waste Source 6). The issue was related scheduling difficulties and communication. For an example, for a company operating in the construction industry site access was restricted to authorized personnel due to government safety regulation. The communication structure present on the construction site made it difficult to schedule delivery or pick up for small individual waste materials. In most cases the standard practice was that a dedicated waste management partner would be permitted to enter the premise through scheduled pick-ups (Waste Source 3, 5, 6).

4.2.3 Secondary Raw Materials Market

Waste Sources

Business requires long-term relationships that are near

The importance of long-term relationships was once again mentioned. Several respondents mentioned they preferred to do business with long-term partners and therefore would find interaction on the platform difficult (Waste Source 1, 6). Further scepticism about the use of a platform was cited in relation to material transport and logistics, which were seen as negatively affecting the feasibility of a regional secondary raw material market (Waste Sources 1, 4). The relatively low value of waste made it economically unfeasible to transport over longer distances, limiting the area the platform could serve. That in turn limited the availability of buyers and sellers that would be visiting a platform. Once again, the concern regarding information quality was mentioned. Several respondents were sceptical that accurate information related to waste materials could be obtained on the platform (Waste Source 1, 6, 8).

Waste Management Operators & End Users of Waste

Existing market imbalance / Waste material is not suitable for spot market

"The downstream is dictating basically more than the upstream, and in that kind of situation there's no place for open market" (Waste Management Operator 3)

The issue of market structure was brought up once again by Waste Management Operators and End Users of waste in relation to the secondary raw materials market Platform. It seems that the firms were operating in an industry that has an over-supply of waste material. As a result, firms that could adequately dispose of material were enjoying strong market positioning power. If the pace of innovation is also taken into account (see 4.2.1) it means that new alternative outlets for waste may not be created fast enough in relation to the total waste generated (End User 3, 4). The result is that the market imbalance may continue for some time.

Waste Industry Experts & Industry Platforms

Categorization & standardization need / Quality & composition need to be known

Respondents from the Waste Industry Experts and Industry Platform Categories both saw the lack of certainty regarding the exact waste materials composition and characteristics. The issue related to the lack of quality information regarding materials appeared again as a barrier to exchanging waste materials on a platform (Expert 7). This was also supported by respondents in other categories, who said quality information was an impediment to exchanging waste materials with others (Waste Management Operator 4; End User 1,2,3). The issue relating to the need of reliable quality and composition information was once again brought up (Platform 2) as well as waste stream traceability (Platform 4). One respondents saw the need for the government to become a platform facilitator (Platform 2). Another valuable point was made about feasibility of a secondary raw material market being threatened by the constantly fluctuating global prices of virgin materials (Waste Expert 6).

5 Results and Discussion

To understand how platforms can be applied to closing waste loops, a cross analysis of the barriers to closing waste loops and for platforms was made. Based on this analysis, a framework for waste exchanges utilizing digital platforms was created to provide recommendations for the requirements of a successful DWE platform.

5.1 Closing Waste Loops using a Digital Waste Exchange Platform

Table 15: Cross-analysis of two types of barriers in relation to closing waste loops

	Eco-Innovation	Industrial Symbiosis	Marketplace
Cultural	Need for waste management operators to become solution providers	Increased involvement of waste sources in waste management	Need for increased appreciation of waste value
Regulatory	Regulation increasing levels of producer responsibility	Need for waste management companies to provide regulatory expertise	Decreasing regulatory burdens for waste utilisation and increasing demand
Financial	Linking innovation pace to market performance	Waste information sharing de-coupled from market competition	Protection from global markets for virgin materials
Operational	Better understanding of regional waste stream materials	Increased onsite waste management and source separation	Increased commoditisation of waste stream types
Structural	Need for increased productisation in waste management	Aggregation of waste streams with different volumes	Reducing the captive market structure
Technological	Development of processing and sorting technologies	Need for improved monitoring and tracking systems for waste	Investment into new infrastructure enabling waste utilization

Table 15 outlines the barriers to closing waste loops considered and compares them to the CBM elements that were selected. The result is a cross impact analysis of the parameters associated with closing waste loops and the core elements related to utilizing platforms in the waste industry. The method can be used to understand the future state of an industry or sector (European Commission, 2006). The objective is to gain a new vantage point on how the industry barriers relate to individual components of CBMs. In the case of a DWE platform, seven of the challenges can be tackled, whilst other needed changes are outside the impact of a platform. The analysis is summarized in the section below.

5.1.1 Industry challenges within the scope of a waste exchange platform

Better understanding of regional waste stream materials

Accurate information of the quantities and qualities of waste material allows for the finding of users for by-products, to turn them into non-waste (Waste Source 2; Expert 2, 4, 7). Knowing what the composition waste streams, is what allows companies to utilize them (Expert 4). The monitoring of waste streams can provide support for investment. As new plants will not be invested in until supply can be confirmed, meaning that knowing where for example waste paper, waste plastic or other streams are located, and their volumes is vital for investors selecting locations (Expert 7). Furthermore, monthly statistics on the different fractions of waste can allow waste sources to better understand their waste production and opportunities (Waste Source 3, 7, 8). Source separation and the identification of waste should ideally be done even in cases when there is not yet a use for the waste, since new uses could be potentially discovered in the future (Waste Source 8).

Need for increased productisation in waste management

The lack of reliable and consistent quality in waste is a significant challenge for its utilization. Waste materials are tough to standardize however, as buyers often have different requirements (Expert 2). Waste materials therefore require some degree of customization and processing based on their end users' needs (End User 3, 4). Furthermore, waste needs to find new outlets and applications if it is to be recovered, meaning that new uses for waste need to repeatedly be developed (Platform 2). Investment in disassembly of products, can allow for finding components that can have value, even if lower value or zero value components cannot immediately be reused. This can take a long time though, as companies may initially be losing money and not invest in such processes on their own. Improving the process over time however, creates possible value and innovation in the future (Platform 5). This requires joint ownership or a coordinating company organization to develop processes.

Waste information sharing de-coupled from market competition

The limitations placed upon utilizing waste due to logistics costs both in terms of environmental sustainability and harming profitability, means that waste utilization should ideally be close to the location of waste production. Knowledge over regional waste streams, and the sharing of successful waste utilization resources would be important to allow for waste sources to find outlets for their waste. This could additionally help support end users in being to ascertain waste supply, decreasing risk in investing in new waste facilities.

This is challenging however due to the resistance, noted under Cultural barriers, for waste management operators sharing information about their waste streams with competitors. Though waste sources could have been expected to be resistant to publishing detailed information about their waste streams, for fear of revealing information about their production, this was not found through interviews. This suggests that waste sources may be more open to aggregating information on waste streams.

Aggregation of waste streams with different volumes

The collection of small waste streams is required in order to create interest in them, as well as creating a steadier flow overall. Small waste streams may otherwise have insufficient volumes to find buyers or economies of scale (Waste Management Operator 3; Platform 2). Waste management companies are a key partner in aggregation, as they are in the position to connect end users and waste producers (Platform 2, 3). By aggregating waste streams waste management companies can also help mask the source of waste, which may be important for waste sources concerned that their competitors could find out about their operations through their waste contents.

Need for improved monitoring and tracking systems for waste

The tracking of waste and its transformation, knowing the quantities of waste, where it is being sent and segregating waste types is important for waste to find users and for end users to be able to source waste (Waste Source 3, 8; End User 3). Traceability and reporting were seen as the main requirement for ICT, (Expert 3, 8) as accurate information about the quantity and quality of waste available in a region would allow for end users to source waste more easily and potentially attract new end users of waste otherwise uncertain of being able to get sufficient materials (Expert 4).

Need for increased appreciation of waste value

Waste sources and waste operators need to approach waste as a source of potential value, rather than as something to be disposed of as cheaply as possible. Waste Sources should be regularly investigating the value of materials and components in residuals that are currently waste streams (Waste Source 2; Expert 3). Changing the perception of waste into a raw material is both a value question, but also something, waste operators can advance by working with experts in recycling and their customers (Waste Management Operator 1, 4). Increasing the separation of waste streams allows for differentiation of the value of those streams. This is ultimately dependant on the financial value of waste however.

Increased commoditisation of waste stream types

In order to establish a functioning waste exchange platform, it is necessary to attach a value (positive or negative) on all waste streams generated within the economy. Only by knowing the true cost material streams can producers have the required information to seek out substitutes or find mean of closing waste streams. Although in the EU waste information related to chemical composition is monitored uniformly, other characteristics (e.g. particle size, shape and quality), are not standardized. Obtaining more information could help drive EI and increase the market demand for a wider variety of waste material.

5.1.2 Industry challenges outside the scope of a waste exchange platform

Need for waste management operators to become solution providers

Waste Management is seeing increased demands for servitisation, and the increasing of recycling and reducing environmental impact (Waste Management Operator 1, 2, 4). Customer sophistication for waste management services appears to be increasing, as more customers are increasing demands on waste management (Waste Source 2, 3, 7, 8; Waste Management Operator 4; End User 2). Waste operators need to therefore evolve into finding operational models for how to create CE solutions for their customers (Expert 3).

Waste Management Operator 4 noted that part of its competitive offering was to increase the “management” of waste, providing data on the different waste streams and seeking actions to improve recycling. Offering solutions for waste sources, to optimize their waste management overall, beyond simple collection. This has meant an increased demand for total partnerships, where a waste management handles the process of finding solutions for waste (Waste Source 7, 8; Waste Management Operator 1, 4; End User 2). Waste Management needs to provide expertise, as well as expertise on legislation and what can be done with materials, in addition to waste collection and processing resources (Waste Source 8; Waste Management Operator 1, 4; End User 2). Waste Management companies have therefore a key role to play in CE development, acting as collectors and stewards of waste and creating awareness over the importance of waste management processes (Expert 3, 6).

Regulation increasing levels of producer responsibility

Regulation can target the sources of waste, by increasing producer responsibility for the external waste related costs of their production activities and sales. Producers through design and manufacturing ultimately define the quality of future waste, meaning that the taxation of non-renewable or unrecyclable products, can be a way to push improvements into the waste supply chain (Expert 4). This furthermore avoids municipalities and taxpayers funding the waste management costs of companies making unsustainable production and design choices (Expert 5, 7). Regulation has an important role in levelling the playing field, so that free riders cannot take advantage of a lack of regulation or enforcement to avoid sustainable waste management practices (Waste Management Operator 3, 4; Expert 5).

Extended producer responsibility, so that a company continues to carry the responsibility for the disposal/processing of a product once it is on the market, can make producers more aware of the impact of their products (End User 2, 3; Expert 6, 7). By linking the design phase with the end of life, increasing collaboration with waste management companies to ensure packaging and products are recyclable, and making waste producers invest in developing waste management, can help the closing of waste loops. Furthermore, it is worth considering that EU regulation has impact beyond the EU. Companies wanting to operate in Europe, are required to develop their product designs, manufacturing and waste management, leading to global improvement in many cases (Expert 5).

Linking innovation pace to market performance

It could be argued that a lack of financial value for many waste types and a lack of sufficient financial incentives or regulation compelling waste diversion is the fundamental barrier to increased reuse, recycling, recovery and other forms of waste utilization (Bourguignon, 2016). If currently undesirable waste types are found to be valuable, having demand and prices that both cover their processing costs and provide profit to waste owners, then investment would naturally follow with increased efforts to separate and sort waste streams (Waste Management Operator 3; Expert 2,7). One goal of EI is to increase the value of waste materials by turning into a product. It helps close waste loops by tying the pace of innovation in the waste industry to profit. As the amount of new processes increases, they allow for larger volumes of waste material to be converted into products.

Development of processing and sorting technologies

The interviews conducted found Technological barriers to be a question of a lack of adaption due to Cultural or Financial barriers, rather than a lack of available technology. One reason for low adoption often cited by respondents was the industry structure and the power configuration of firms operating downstream. The resistance of industry interest groups was also mentioned as relevant for technology adoption of tracking technology (Waste Management Operator 4). Respondents seemed more knowledgeable regarding the available solutions for processing materials than solutions for productizing waste.

For mixed municipal waste there needs to be increased sorting of materials, to extract value and to remove organics from the waste stream. The increased mining of waste, through optical sorting for instance, could allow for decreased damage due to failures of sorting (Expert 5). Waiting on technology can be problematic however, as it may mean actors deciding to not develop their waste management practices. For example, expectations of chemical recycling to break down polymer plastics back into monomers can mean companies choosing not to develop products that are mechanically recyclable (Expert 6).

Increased involvement of waste sources in waste management

Waste management needs to be considered before the generation of "waste", with producers being aware of the waste supply chain and treatment limitations. The design of products and packaging can reduce the amount of waste generated, as well as its ability to have value extracted when it is consigned to waste. Standardising components and the materials used, can make products more recyclable (Waste Source 1, 4, 5, 9; Expert 4). Additionally, producers can reuse materials, by returning packaging or containers to the manufacturer after delivery, such as wooden crates carrying auto parts or plastic boxes delivering goods to supermarkets (Waste Source 4; Expert 2).

Furthermore, increasing waste utilization is most challenging in the middle of the supply chain, by improving sorting and identification of materials and ascertaining usability. This is because the ability to affect the quality of waste is limited in the middle without cooperation. Increased vertical supply chain collaboration, can allow for improved development of new applications (End User 4). Two of the end users were also providing waste management services, coordinating collection and managing pre-processing plants to their WTE installations, giving them increased flexibility as they had their own outlets for a significant portion of waste (End User 2, 5). By moving up the value chain, data on materials and input control is improved. (Expert 2)

Need for waste management companies to provide regulatory expertise

Waste management operators have a role to play in providing expertise on legislation related to waste utilization (Waste Source 2, 8, 9). Regulatory uncertainty or complicated laws are difficult for waste sources, as they are not experts in the field (Waste Source 7; Platform 2, 4). The involvement of waste management operators would bring industry knowledge related to processing and handling of different waste streams and harmonize it with regulation. Understanding the pace of legislation could be beneficial for companies that are considering investing resources for R&D, considering partnerships or purchasing new equipment. Closer cooperation could result in companies that currently operate only as waste management operators to expand their business to become upstream partners offering stable volumes for companies seeking to use waste materials in their operations.

Increased onsite waste management and source separation

Waste management companies recognize the need to improve quality control in order to be successful in their sector (Waste Management Operator 1, 2, 4). Securing the quality and supply of waste materials is vital to make waste utilization viable (Platform 2). The output of waste-based commodities is largely dependent upon the input of waste. End users of waste are able to produce consistent quality by having strict input controls, in only taking certain types of waste or even brands of material. This needs to be supplemented by investments into quality testing to account for variability (End User 2-5).

Source separation of waste at the location of its creation, allows waste streams to be uncontaminated and more uniform. Waste management operator's involvement at the site of waste generation is important to improve standardisation of waste downstream. This allows for waste material and component streams to avoid being mixed (Waste Source 1, 2; End User 2; Platform 2). Providing regular feedback to waste sources, could motivate staff to handle waste properly, as they understand their impact on sustainability (Waste Source 6-8). This can be facilitated through the involvement of waste management companies onsite at customers, and providing training, education and devices to measure waste (Waste Management Operator 1). This also requires waste management to provide equipment, such as bins for waste to be sorted into (Waste Source 2-4, 6). This is easiest with industrial waste streams, where there is a clear partner with processes in place to avoid the contamination of materials through plastics being mixed with biowaste or other materials like in unsorted municipal waste (Waste Management Operator 1; End User 2).

Decreasing regulatory burdens for waste utilisation and increasing demand

Regulation has been key in driving CE adoption, and it cannot exist in significant form without it (Expert 1-5, 7, 8). Regulatory burdens are also a barrier to the utilization of waste however. Secondary raw materials need to have a level playing field against primary ones, rated according to their composition rather than origin (End User 4; Expert 3, 5). Reductions on waste shipment administrative burdens, could allow for non-hazardous waste to be transferred more easily across the EU for recycling or recovery. There also need to be considerations for legacy substances, materials previously legally allowed for manufacturing that later became waste. It needs to be considered whether they can be reused or incinerated (Expert 8). The unsustainability of waste is an EU wide issue, and requires harmonization across the EU, to reduce administrative burdens and uncertainty (Expert 5, 8). Increased standardisation of legislation would allow companies to more easily replicate successful waste loop closing solutions from one region to another (Waste Source 2).

Furthermore, as waste management operators, as suppliers of waste, can be considered a captive market, regulation can be used to influence the demand for recycled and waste-based materials. If producers of goods are mandated to use recycled content in their manufacturing, it can help balance a market where supply is independent of demand (Waste Management Operator 3; End User 3; Expert 5, 6). Other methods could include tax exemptions or lower VAT for recycled materials, or taxing virgin polymers (Expert 5, 6, 8).

Protection from global markets for virgin materials

The current lack of a marketplace for waste materials, has meant high transaction costs for waste sources to find partners to utilize their waste, as well as for end users in sourcing waste. However, the nature of waste, and the difficulty of standardizing waste streams compared to virgin raw materials, means that waste is not as easily traded even without regulatory restrictions. There is furthermore the question of whether creating a marketplace can give value to commodities. Valuable and more easily utilized waste like metals, after all have found a marketplace, and are able to compete with virgin materials. Therefore, the viability of a waste marketplace is likely to be dependent upon the demand and prices of waste materials, which if in place would see a marketplace be created. This is difficult when waste materials compete with virgin materials, particularly when prices for these fluctuate.

Reducing the captive market structure

For a platform to function as a marketplace the industry power dynamic must be more balanced. The exchange of waste materials in a captive market creates conditions where the dominant actors can act as inhibitors to change. Altering the structure cannot be done overnight due to the importance of downstream operators for the disposal of current waste streams. The industry seems to be in a transition period where the degree of EI is not sufficient to deal with large volumes of waste produced. The result is a reliance on asset heavy investment of waste treatment facilities. Acknowledging the hindering effect, the current market imbalance has on the pace of CE would be the first step require to a gradual transition toward closing of waste loops.

Investment into new infrastructure enabling waste utilization

Technological infrastructure investment represents increased waste treatment capability and the capacity for sharing waste related information. Investment in both types of infrastructure send a signal to the industry that new business approaches are possible. Government investment in infrastructure enabling utilization is important, particularly for low value waste materials that struggle to compete with virgin materials. Recycling plants for instance, often require subsidises or state ownership, as often incineration is more cost effective or even profitable than recycling (Expert 8). Although the role of government as a facilitator of change is undeniable, there is less agreement on its role as an owner. Some respondents believe that the government should not be the long-term owner of future waste platforms (Waste Source 4, 5). Others, agree but acknowledge the ability of the government to bring together the right ecosystem participants to facilitate large-scale transitions through focused investments in infrastructure (Waste Source 1).

5.2 Framework for Waste Exchange using Digital Platforms

Based on the capabilities and limitations of a DWE platform, a framework is created to understand the information required to exchange waste materials. After reviewing relevant literature and analyzing the insight provided by the respondents, an important gap emerges. At the present, there is a mismatch between CE ambitions to reuse waste, and the capabilities of digital platforms to facilitate the exchange of materials.

As noted in Section 5.1.1 platforms have the capacity to improve the flow of information between buyer and seller, however it does not automatically improve the physical exchange of materials between parties. One main reason is that, the proper "terminology" for sourcing and the negotiation of exchange is currently lacking. While initiatives like the European List of Waste, offers a foundation for classifying waste streams, they lack the scope needed to describe waste material with enough detail to remove uncertainty for buyers. It is clear that for a DWE platform to serve its intendent purpose, a new approach to waste material classification is required. Such a system would need to go beyond classification by chemical composition and take into account the needs of downstream users. It also needs to be reliable, consistent and harmonised to allow for data collection and monitoring to help make the transition toward the CE (EPRS, 2017).

To help fill the existing gap in waste data exchange, the researchers propose a set of seven dimensions that help define the waste material being traded. The framework in Figure

11, introduces the dimensions and provides a brief summary of the logic behind including each concept. Considering the dimension when attempting to exchange waste on a digital platform could help reduce uncertainty in the transaction. Some concepts are commonly found in platforms where goods are traded (e.g. Amazon), such as price, volume, time and transport. However, the proposed dimensions of “geography”, “property” and “purity” are specific to the nature of waste as commodity.

In addition, our investigation reveals that the dimensions need to be trusted, known in advance, and standardised. The seven proposed dimensions are categorised according to their connection to three requirements. The researchers maintain that the aforementioned three requirements relate to all dimensions. In the first category are dimensions related to trading and interaction between users and include both price and transport. Price, refers to the established market value of waste materials listed on the platform, which must be competitively priced compared to virgin materials. Transport, includes the agreement on the obligation related to the physical delivery of the materials and the mode of transportation.

The second category are related to sourcing related dimensions, and include: time, volume and geography. Time, appertains both to delivery details such as schedule and frequency of material availability. Volume includes details regarding material quantity and the rate of flow. Geography refers to the origin and location of waste materials, which is essential for both the sustainability and cost calculation of utilizing waste.

In the third category are dimensions related to the usability of waste material and include: property and purity. The material’s property are the characteristics of waste that affect how it can be utilized by others (mechanical, physical, chemical, etc.). Lastly, the purity of the material includes the acceptable contamination level of large volumes of waste.

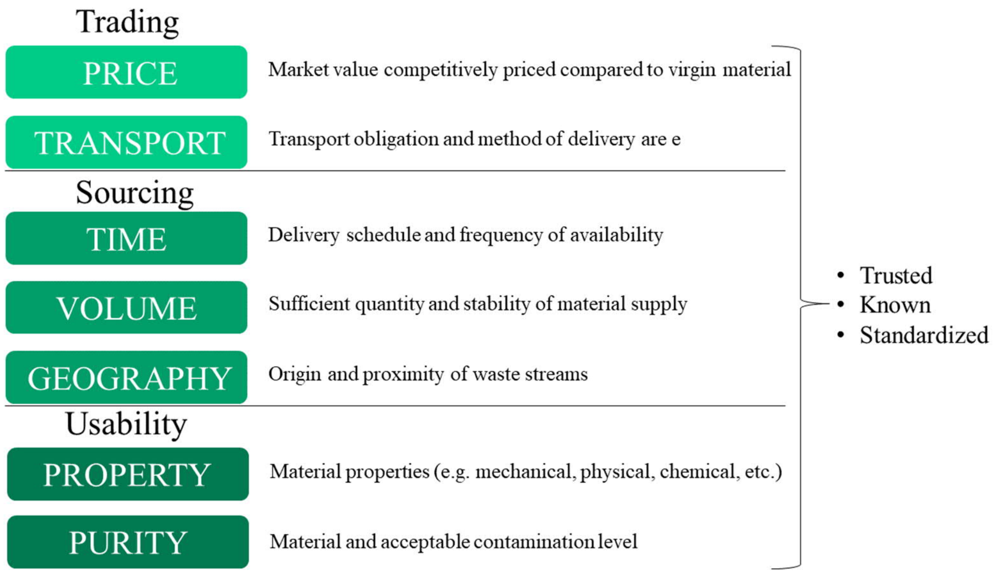

Figure 11: Framework of necessary material features for digital waste exchange

6 Conclusions and Recommendations

The increasing of waste utilization in the EU, requires an expanded role for waste management, with companies being involved further upstream to enable a CE. Waste management experts need to contribute to the discussion on circular product designs, in order for end-of-life of the product to be sufficiently taken into account. In fact, several upstream respondents appear to be looking more holistically at the waste operations, as more customers of waste management services are seeking to enact central steering (Waste Source 3, 7, 8; Waste Management Operator 4; End User 2). While there are early signs that there is an industry transition towards the CE, there are significant barriers ahead.

This research explored the waste industry from two perspectives. First, obstacles to closing waste loops from the industry perspective were evaluated to understand the current limitations. Second, obstacles related to the barriers to using a DWE platform were explored. Third, an attempt was made to solve some of the identified challenges related to closing waste loops and utilizing DWE platforms. Below is a summary of how the study addressed the research questions.

What are the barriers to closing waste loops and to waste utilization in the EU waste management supply chain?

In connection with the first question, it was found that financial barriers were the most significant for closing waste loops due to the current market configuration, which puts pressure on waste management companies to run operations focused on efficiency and cost savings, rather than innovation. Combined with the fact that waste management companies operate in a captive market, the technological evolution of the industry is affected, leading to decreased investment into new waste processing technologies. Similarly, to the study by Kirchherr et al (2018), our investigation did not find technology to be a key barrier to CE and the closing of waste loops. Rather, the lack of adoption of existing technologies was more meaningful. Unlike in the research by Kirchherr et al. however, which found culture to be the main barrier, our study did not reveal culture as significant. Cultural impacts and awareness were not seen as impactful as the potential of regulation to enable and encourage the closing of waste loops (End User 2; Expert 3, 4, 6, 8).

What are the barriers for utilizing a digital waste exchange platform to enable circular business models?

For the second question, it was found that the lack of sufficient standards in waste materials categorisation generated concerns about material quality. In order for waste materials to be exchanged on a digital waste platform on a wider scale, certain materials attributes need to be known and standardized. Respondents did not see the full potential of a digital waste material marketplace and preferred to deal with partners face-to-face in order to solve the tacit issues related to material control. There was also an attempt made to solve some of the identified challenges related to closing waste loops and utilizing waste exchange platforms.

How can the challenges to closing waste loops and utilizing digital waste exchange platforms be overcome?

In relation to the third research question, it was found that the platform as an interaction mechanism could not solve all the issues identified in the investigation. However there were seven industry challenges where a platform could make an impact. These were taken into account when creating the theoretical framework, which provides attributes of waste materials that need to be known in advance to reduce uncertainty when buying or selling waste materials on a platform. Our framework establishes seven features: price, transport, time, volume, geography, property and purity.

However, there may be significant effort in resources related to gathering all the material related information and uploading it to the platform. In other words, documenting the attributes of waste materials and inputting them onto the platform. Increased documentation of waste could then contribute to higher transactional costs involved in the exchanging of material. Therefore, the researchers found that while the platform has the ability to facilitate some aspects of a waste exchange, operational barriers continue to exist. Overcoming such barriers would be key towards making the transition to CE.

7 Limitations of Research

Due to the exploratory nature of the research a qualitative and broad scope of investigation was chosen. There was a therefore a trade-off between the depth of the study and the coverage of the subject. Furthermore, the use of interviews meant that the impact of culture and social desirability bias had to be considered.

Research Approach

The research was constructed using a qualitative approach involving the subjective responses of interviewees to construct an understanding of the waste industry structure and to reveal insight related to the research questions. Due to time constraints the research had to rely on respondents that were relevant and available during the time of investigation. The result was that the respondents formed a set of subjective experiences that were unique to the study. As a result, the replication of the exact results would be difficult since the collective opinions constituted a unique body of knowledge. However, to address this concern researchers attempted to extract insight that could be seen as universality true for future studies of a similar design. Furthermore, because the data collected in the interviews were based on subjective experiences, the researchers were responsible to extract meaning and determine relevance. However, the approach could be problematic since the researchers themselves make decisions that are also based on a subjective understanding of the world. A similar limitation is present in the analysis phase of research, especially when systems theory was used to form a holistic picture of the waste industry. Researchers attempted to simplify the complexities of the reality within the waste industry in order to make assumptions.

Breadth of the Study

The study sought to cover as many different parts of the waste supply chain as possible by interviewing different types of actors. It meant looking at companies with different maturity and scales of operation, which limited comparability and generalizability. However, there were limitations to the completeness of studying the waste management supply chain. The companies studied were not all part of the same supply chain necessarily. The geographic span of the study and the companies' operations meant that often companies had multiple different waste management companies in different regions, additionally there were differing levels of confidentiality in revealing the partners or suppliers/buyers of interviewees. Though some could be identified as partners or customers/suppliers, the complete chain of waste to end use or landfill could not necessarily be mapped. Furthermore, end users of waste products, including those selling processed waste-based materials/products onwards were treated the same as end users utilizing waste material in regular products or operations. Due to time and data collection constraints, these end users were treated as the end point of the waste value chain.

Additionally, landfill operators were not interviewed, though one of the interviewee experts had long experience in working for a municipal waste management company operating landfill (Expert 2). Though landfilling is certainly a part of waste disposal landfilling is primarily sought to be avoided by regulation banning it or imposing fines, and often at the point that waste has been landfilled, it is extremely difficult to recover.

The number of interviews was limited by the amount of time and resources available for the project however. Empirical data was collected through interviews from April 2018 to June 2018. Though researchers sought a diverse sample of respondents, sampling was not randomized. As 114 interview requests were made, leading to 31 interviews (about a quarter of requested participants); the interview sample was partly based on availability and access to respondents. This meant respondents being divided somewhat unevenly with 9 Industrial Waste Sources, 4 Waste Management Operators, 5 End Users of Waste, 8 Waste Management Industry Experts, and 5 Platforms relating to Waste Management Operations.

Furthermore, the exploratory nature of researching the role of waste management in the CE meant that these interviews were spread out over five categories. Because there are multiple different types of actors involved in whether waste is successfully reused, recycled or recovered, the focus of the research had to be relatively wide. This meant that with the constraints for the number of interviews, depth in fully understanding a category had to be sacrificed for coverage of the value chain. Though interviews began presenting saturation in many cases, it is difficult to say if significant barriers could have still been found through additional interviews. Moreover, due to the time constraints, it was not viable to return to previous interviewees to test findings from later interviews.

Cultural Differences

Respondents came from different countries across Europe. There were five Finnish industrial companies, one Nordic and one French company, with six of these companies having international operations. There were three Finnish waste operators and one Swedish one, with all of them having international operations and one of the Finnish companies operating mostly outside of Finland in Europe and North America. Amongst waste end users there were two Finnish companies, one Danish, one Italian and one Swiss; with one Finnish company operating in Europe, and both the Danish and Swiss companies operating globally. Experts were three Finnish based, two Belgian based, two UK based and one Austrian based organizations or companies, though all of these had EU wide or global perspectives. Platform respondents had two from Finland, one from Germany, one from the UK a Finnish subsidiary of a European organization. Having respondents from across the EU was important, as the literature review had shown waste management to operate across borders in Europe. However, since the waste industries differ across the EU, there could be diverse industry cultures. The perspectives of respondents may have different contexts. Despite the international operations of the majority of interviewees, there may therefore nonetheless be cultural differences between the individual respondents. Due to the sampling of the study, it was not possible to control for cultural differences.

Social Desirability Bias Towards Supporting Circular Economies

Though respondents in general viewed CE positively, there was a lack of this cultural driver leading to significant CE implementation to close waste loops. This could potentially be explained by social desirability bias by interviewees, which has been shown to in previous research to be present in surveys on sustainable development (Roxas & Lindsay, 2011). In profit driven organizations, it can be presumed that employees and management are aware that an indifference to CE could reflect poorly on the values of the company. Interviewees may therefore overstate the cultural inclination towards CE, even when supported by company values, strategies, executive positions or teams and sustainability reporting. To confirm whether this is the case it would be necessary to collect quantitative data on what proportion of a company’s net profit is invested in developing recycling or other sustainability initiatives.

8 Recommendations for Further Research

The aim of the study was to obtain holistic understanding of the EU waste industry and its ambition to make a transition towards CE using waste exchange platforms. In order to achieve the aims, researchers had to maintain a broad view of the phenomena. As a result, it was not feasible to deviate from the scope of the research and consider interesting and potentially important ideas that emerged along the way. Those themes are listed here to provide direction to future research.

The first recommendation for a direction of future research would be to examine the waste industry as a collection of distinct individual streams and focus on specific waste types (e.g. plastic) and gain deeper insight into how a specific waste streams could be exchanged on the platform. Waste materials possess different physical properties which could affect their ability to be recycled and processed into new states suitable for use as raw materials for production. The approach could reveal important differences between material types and establish why some products are suitable for trading on a platform while others are not.

The second recommendation for a possible direction of research is to focus on specific regions where waste platforms could be utilized. The research focus included analysing several EU countries and attempting to make general conclusion about the EU waste industry as a whole. However, it was found that significant differences exist between members states, which made it challenging to summarize. Waste value is linked to the geographical proximity since it may not be economically feasible to ship most materials across large distances to be utilized. Therefore, the functionality of a platform could be somewhat tied to a geographical area.

The third recommendation for a direction of future research is to further investigate the impact of the market structure on the evolution of the industry. In section 4.1 it was identified that the industry seemed to have a captive market structure that was having an impact on the actors involved. Similarly, in section 4.2 it was found that the downstream actors had more market power. Evaluating how the symmetry of the market structure impacts industry development could reveal important insight into the pace of innovation adoption. Furthermore, market imbalances could challenge the notion of a collaborative waste ecosystem.

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Appendix A: Summary of R-Imperatives outlined by Reike et al. (2018)

Refuse (R0) applies both to consumers buying or using less products/services, as well as avoiding packaging waste or shopping bags for instance, and to producers avoiding the use of certain hazardous materials or improving designs to avoid waste.

Reduce (R1) refers to the avoiding of the creation of waste in the first place, mainly focusing on production through material efficiency or servitisation, but also through consumers avoiding throwing away products by careful use and repair or avoiding purchasing of underutilized goods through sharing.

Resell/Reuse (R2) represents the direct second or further lifecycle for products or materials, through their repeat use for their original purpose, or at least without requiring adaptions such as 'refurbishment', 'rework', 'repair' or 'recycling' for instance, though it can include cleaning and minor repairs. This can be consumers buying/selling second hand goods, or producers selling returned items, finding uses for unsold goods, or reusing packaging for example.

Repair (R3) is the extension of a products lifetime, by restoring it to use or avoiding its downgrading through the fixing or replacing of parts/features. Though there is some conflation with 'refurbishment', they are distinct in that repairing can be done by different actors, without necessarily changing ownership. These repairs can be done by the user themselves, or by producers or third-party repairers, whether as a part of planned maintenance or repairs when needed.

Refurbish (R4) is a concept referring to a more significant overhaul of a product inorder to 'upgrade' or 'update' it and thereby extend its lifetime. This tends to refer to large multi-component products, where the overall structure can remain intact despite the replacement or repairing of multiple components. Examples include engines and machinery, as well as trains or aircraft.

Remanufacture (R5) is the industrial process of disassembling, checking, cleaning and replacing/repairing the entirety of a multi-component product. Unlike Refurbishment, remanufacturing is not necessarily an upgrade/update (although it can be) as the lifetime of the product is not extended beyond that of a comparable new product, and because recycled components should be used in remanufacturing. Reike et al. (2018) note that the synonyms Reconditioning, Reprocessing and Restoration are also used by scholars, increasing the variety of R imperatives.

Repurpose (R6) is the reuse of a product or component for another function than it was originally intended. Examples are focused on industrial design and art, such as jewellery made using microchips, glass bottles being used as mugs or textile waste repurposed to make quilts or plastic sheets used in handbags.

Recycle materials (R7) is a concept that is often used as a catchall term for the 'recovery' or waste materials. More specifically, it is the processing of consumer or producer waste streams through technologies such as shredding, melting and other processes to extract close to pure materials that can replace virgin materials or avoid landfilling. Compared to previous Rs, recycling breaks down original products/materials, and to create new 'secondary' materials from these with more flexible application. Recycling can be primary: between businesses, with side streams of materials or components being sent for recycling, or secondary recycling of waste collected by municipalities or waste management companies. Primary recycling allows for materials to not be mixed, saving efforts in separating materials or reduced quality of mixed materials.

The quality of recycled materials can vary significantly, and they are challenging as they must compete with the price for virgin materials with a more stable quality, whilst usually requiring significant use of energy and labour in collection and re-processing which incur costs. There are some recycled materials, like metals with their durability in being melted down and reused, and higher value relative to weight, that are able to compete with virgin materials.

Recover energy (R8) commonly refers to 'energy' contained in waste, through the production of energy or heat through the incineration of waste or production of biogas or other fuels. There are however examples of recover being used as a more generic term for the reutilization of waste or the extraction of value from waste.

Re-mine (R9) is the retrieving of value and materials from already landfilled waste. This is often driven by the value of materials found in landfills, as well as in cases of high urbanization making land prices high enough to justify expenditure on the dismantling of landfills. Due to indiscriminate landfilling practices in the past, and indeed currently in many countries in some cases, there is a higher concentration of valuable metals and minerals is landfills than in existing mines. Re-mining has received little attention from policymakers and businesses in the past, with often informal scavenging in developing countries putting persons at risk due to hazardous substances in landfills.

Appendix B: Circular Economy Barriers Identified in Literature

Table 16: Barriers identified in literature on circular economy implementation

Type	Barriers	Source
Structural	Employment term limits imposed on managers affect long-term circular economy strategies Staff must demonstrate to boss the ways in which new recommendations are consistent with past ways, thereby entrenching a particular path No incentives are built into the budgetary system that stimulates circular economy innovation Hierarchical system inhibits flexibility and innovation	Liu & Bai (2014) Survey and in-depth interviews with 157 firms from manufacturing clusters in China
Contextual	Competing priorities inhibit commitment to circular economy Uncertainty about the market place	
Cultural	Silos exist between planning and production Strong risk aversion of managers	
Technological	Lack of information on BAT (Best Available Technology) Technologies made locally available Difficulty choosing cost-effective technologies	Pan et al. (2015) Review of WTE technologies and barriers for a WTE supply chain, as well as an evaluation of successful WTE business models around the world
Financial	Inaccurate electricity pricing High capital costs Grid Interconnection and associated infrastructure	
Institutional	Coordination and cooperation of the policy enacting authority Competition with more established forms of energy supply Low social acceptance by local communities	
Regulatory	Unclear National Visions and Goals for energy technology development Not comprehensive and appropriate policies Lack of policy enforcement and compliance Challenge of government authority allocation	
Technological	Engineering Lack of sufficient volume of waste Contamination of waste Incorrect ordering system Lack of sufficient number of bins Engineering barriers, e.g. layout New material in low volume Design constraints, e.g. quality vs environment for packaging or function vs. environment for product Material substitution Technology, machine and equipment Old technology, machines and equipment Environmental tools Lack of relevant/suitable tools for environmental initiatives	Shahbazi et al. (2016) A case study of 6 Swedish Manufacturing Companies

Economic	<u>Budgetary</u> Economic limitations and incentives <u>Material and product cost</u>	
Organizational	<u>Management</u> Higher priority of other matters or requirements, e.g. production expansion/market share Low top management commitment and support for initiating sustainability efforts Limited environmental awareness of the directors Lack of support and guidance, limited in-plant expertise/capability <u>Supplier</u> Different plant involved in outsourcing Supplier quality Packaging standardization Overseas supply chain constraints Uncooperative suppliers <u>Vision and culture</u> Unclear/weak business model Lack of vision, lack of environmental goals and corporate values Lack of sources (time and human) <u>Employee</u> White-collar oversight Oversight and reluctance of employees due to indolence, weariness, exhaustion Lack of life cycle thinking Lack of LCC thinking (especially when buying new equipment) Insufficient technical and environmental training and education	
Legal	<u>Legislation and regulation</u> Lack of means of pressure/ lack of or low environmental enforcement No assistance from government agencies Lack of ambition, sufficiency of just following the regulations and legislations <u>Methodology and measurement</u>	
Informational	<u>Communication</u> Visualization of (lack or inaccurate) Lack of communication Lack of eco-design and communication with product development <u>Uncertainty and risk</u> Uncertainty of potential results, market benefits and performance impact, environmental benefits <u>Information</u> Lack of information and knowledge sharing	

Social	Preference and demand Lack of market preference and customer demands Low public pressure, lack of demand from shareholders, investors and community Understanding and perception Lack of awareness, understanding, knowledge and experience with environmental issues Lack of environmental education in general	
Financial	Theoretical: Measuring financial benefits of circular economy Financial profitability Empirical – Values and Finance Uncertainty over revenue generation by switching to product-service systems or increased sustainability of deliverables. (Lack of business case) Required time and investment for long-term system changes compete with rapid returns on investments and costsaving.	Ritzén & Sandström (2017) Case study of two mature large industrial companies (7 interviews at managerial positions and 11 interviews including 7 at managerial positions)
Structural	Theoretical: Missing exchange of information Unclear responsibility distribution Empirical – Integration between functions Sustainability issues are a matter for one specific department Low integration between company functions both in sustainability across functions and between hierarchical levels, with a lack of support functions for CE. Management and operational levels each expect the other to take responsibility for CE transition.	
Operational	Theoretical: Infrastructure/Supply chain management Empirical - Value chain structure: Loss of control of products at the point of sale Partnerships with suppliers limiting company control (Uncertainty over responsibilities and dependencies)	
Attitudinal	Theoretical: Perception of sustainability Risk aversion Empirical – Attitude and knowledge: Shallow understanding, insight and knowledge of CE Risk aversion and business logic of taking small safe steps in development Inertia in considering new business models or sustainability as a strategic issue	
Technological	Theoretical: Product design Integration into production processes Empirical – Technology Hesitance over major changes to production/take-back systems and uncertainty over functionality and cost. Quality concerns over product redesigns for improved circularity and for products manufactured from recycled or reused materials	

Technical **("Harder" factor)**	Driver: Availability of technologies that facilitate resource optimisation, remanufacturing and re-generation of by-products as input to other processes, development of sharing solutions with superior consumer experience and convenience Barriers: Inappropriate technology, lag between design and diffusion, lack of technical support and training	de Jesus & Mendonça (2018) A review cross-leveraging 141 papers (academic) and over 40 reports (grey) by various institutions and enterprises
Economic/Financial/Market **("Harder" factor)**	Driver: Related to demand-side trends (rising resource demand and consequent pressures resource depletion) and supply-side trends (resource cost increases and volatility, leading to incentives towards solutions for cost reduction and stability) Barriers: Large capital requirements, significant transaction costs, high initial costs, asymmetric information, uncertain return and profit	
Institutional/Regulatory **("Softer" factor)**	Driver: Associated with increasing environmental legislation, environmental standards and waste management directives Barriers: Misaligned incentives, lacking a conducive legal system, deficient institutional framework	
Social/Cultural **("Softer" factor)**	Driver: Connected to social awareness, environmental literacy and shifting consumer preferences (e.g. from ownership of assets to services models) Barriers: Rigidity of consumer behaviour and businesses routines	
Technological	Lack of technology to refill solid waste Poor pollution control Lack of technical know-how Lack of information	Galvão et al. (2018) Bibliometric study of 195 articles extracted from the Web of Science Core Collection and Scopus database
Policy and regulatory	Insufficient environmental taxes on for instance pollutant emissions Lack of government support	
Financial/ economic	Lack of capital Administrative burden	
Managerial	Lack of clear management structure and procedure Lack of 'Eco Champion' Lack of defined role for environmental teams Environmental culture of the company Lack of post-decommissioning management	
Performance indicators	The absence of adequate metrics and standards for material efficiency requirements Lack of effective performance evaluation	
Customers	Lack of viable strategies and initiatives capable of decouple economic growth from environmental pressure, within limited available resources Lack of supply and demand network	
Social	Lack of information, cooperation, community and commitment to sustainable development	

	The lack of societal pressure and knowledge of benefits of sustainable products or CE	
Cultural	Hesitant company culture Limited willingness to collaborate in the value chain Lacking consumer awareness and interest Operating in a linear system	Kirchherr, et al. (2018) Survey of 208 survey respondents, 47 expert interviews in the EU
Regulatory	Limited circular procurement Obstructing laws and regulations Lacking global consensus	
Market	Low virgin material prices Limited or lacking standardization High upfront investment costs Limited funding for circular business models	
Technological	Lacking ability to deliver high quality remanufactured product Limited circular designs Too few large-scale demonstration projects Lack of data e.g. on impacts	

Appendix C: Complete List of Discussions and Conducted Interviews

Prior to the beginning of the Thesis research discussions were held with persons from Tana Oy to gain an understanding of the Waste Management industry from their perspective as the researchers planned the thesis project. Notes were taken from the discussions by both researchers.

Table 17: Appendix C1, List of preliminary discussions for thesis

Dicussion Number (Date)	Company/Organization	Expert participant(s)	Notes
Discussion 1 (7.3.2018)	Aalto University Department of Information and Service Economy Tana Oy, Finnish waste management machinery provider	Markku Kuula Professor, Logistics at Department of Information and Service Economy at Aalto University Kari Kangas, Chairman & CEO of Tana Oy	In person discussion, in English with Misa Bakajic and Alf Parvi
Discussion 2 (29.3.2018)	Tana Oy, Finnish waste management machinery provider	Mirja Yli-Erkkilä, Vice President - Customer Experience and Marketing	In person discussion, in English with Misa Bakajic and Alf Parvi
Discussion 3 (6.4.2018)	Tana Oy, Finnish waste management machinery provider	Josef Imp, Vice President - Sales	Skype discussion, in English with Misa Bakajic and Alf Parvi

Additionally, during the thesis project researchers made two site visits to familiarize themselves with waste management operations.

Table 18: Appendix C2, List of site visits

Site Visit (Date)	Site	Company	Notes
Site Visit 1 Interview 11 (29.5.2018)	Circular Economy Village in Southern Finland	Finnish Hazardous Waste, Recycling and Waste Management Company	Misa Bakajic and Alf Parvi
Site Visit 2 (8.6.2018)	Visit to paper and consumer board mills in Eastern Finland	Nordic pulp and paper manufacturer	Alf Parvi

All interviews for the thesis research were semi-structured interviews conducted either in person, via skype or on the phone. All interviews were recorded and transcribed for analysis with the consent of the interviewee(s).

Table 19: Appendix C3, List of complete interviews in chronological order

Interview (Date)	Company/Organization	Interviewee(s)	Notes
Interview 1 (24.4.2018)	Finnish vegetable food company specializing in frozen vegetables and foods, ready-to-use vegetables, vegetable oils and animal feedstuffs Operations in northern Baltic region	2 Interviewees President & CEO Director, Communications and Investor Relations	Interview conducted in person, in English by Misa Bakajic and Alf Parvi Recording length 74 min
Interview 2 (26.04.2018)	Finnish cement manufacturer Operations in Finland	Quality and Process Development Manager	Interview conducted in person, in English by Misa Bakajic and Alf Parvi Recording length 104 min
Interview 3 (27.4.2018)	Finnish waste management company Operations in Finland, Sweden & Russia	Process and Technology Manager	Interview conducted in person, in English by Misa Bakajic and Alf Parvi Recording length min
Interview 4 (27.4.2018)	Nordic pulp and paper manufacturer Global Operations	Head of Operational and Environmental Affairs, Group Sustainability	Interview conducted via Skype, in English by Misa Bakajic and Alf Parvi Recording length 60 min
Interview 5 (4.5.2018)	Austrian consulting firm for sustainable resource management Projects globally	CEO	Interview conducted by phone, in English by Misa Bakajic Recording length 35 min
Interview 6 (4.5.2018)	Finnish municipal waste management company Operations in southern Finland	Freelance Environment Manager Managing Director of Municipal Waste Management company (April 1994 – March 2014)	Interview conducted in person, in English by Misa Bakajic and Alf Parvi Recording length 111 min
Interview 7 (7.5.2018)	French food services and facilities management company Global operations	Director QHSE (Quality, Health, Safety & Environment) Nordics	Interview conducted via Skype, in English by Misa Bakajic and Alf Parvi Recording length 60 min
Interview 8 (8.5.2018)	Finnish retailing conglomerate operating in the grocery trade, the building and technical trade and the car trade Operations in the Nordics and Central and Eastern Europe	2 interviewees Environmental Specialist Maintenance Manager	Interview conducted in person, in English by Misa Bakajic and Alf Parvi Recording length 59 min
Interview 9 (8.5.2018)	Finnish innovation fund, an independent public foundation	Director, Carbon Neutral Economy	Interview conducted in person, in English by Misa Bakajic and Alf Parvi Recording length 40 min
Interview 10 (9.5.2018)	Finnish food company producing meat foods, ready meals and other products Operations in the Nordic and Baltic region	Energy and Environment Engineer	Interview conducted in person, in English by Misa Bakajic and Alf Parvi Recording length 59 min
Interview 11 (11.5.2018)	Independent innovation community for the UK infrastructure industry	Knowledge Transfer Manager	Interview conducted in person, in English by Misa Bakajic and Alf Parvi Recording length 58 min

Interview 12 (14.5.2018)	Finnish bio economy, circular economy and energy systems open innovation cluster	Portfolio Manager	Interview conducted in person, in Finnish by Alf Parvi Recording length 73 min
Interview 13 (14.5.2018)	Swedish waste management company Operations in Nordics and Poland	Market Area Manager	Interview conducted via Skype, in English by Misa Bakajic and Alf Parvi Recording length 31 min
Interview 14 (15.5.2018)	Finnish construction company Operations in Finland, Russia and Estonia	Environmental Specialist	Interview conducted in person, in English by Misa Bakajic and Alf Parvi Recording length 75 min
Interview 15 (18.5.2018)	A UK chartered body for Waste & Resource professionals	Deputy Chief Executive Officer	Interview conducted via Skype, in English by Misa Bakajic and Alf Parvi Recording length 73 min
Interview 16 (18.5.2018)	German reverse online auction platform for waste and secondary materials (Operational 2000-2005)	Former CEO	Interview conducted via Skype, in English by Misa Bakajic and Alf Parvi Recording length 68 min
Interview 17 (21.5.2018)	Finnish newspaper printing house Operations in Southern Finland	Operational Manager	Interview conducted in person, in Finnish by Alf Parvi Recording length 50 min
Interview 18 (22.5.2018)	Finnish industrial service company specialising in maintenance and engineering services Part of a waste materials market platform accelerator	CEO	Interview conducted in person, in English by Misa Bakajic and Alf Parvi Recording length 65 min
Interview 19 (23.5.2018)	Finnish recycling company specializing in metals Operations in Asia, Europe & North America	Former CEO (November 2013-January 2018)	Interview conducted in person, in English by Misa Bakajic and Alf Parvi Recording length 77 min
Interview 20 (24.5.2018)	Finnish waste management company specializing in sensors and the tracking of waste generation Operations in Europe and North America	CTO and CO-Founder	Interview conducted via Skype, in English by Misa Bakajic and Alf Parvi Recording length 65 min
Interview 21 (28.5.2018)	Finnish energy company and Waste-to-energy/Waste management services provider Operations in Nordics, Baltics, United Kingdom and Russia	Vice President, Strategy, City Solutions	Interview conducted in person, in English by Misa Bakajic and Alf Parvi Recording length 68 min
Interview 22 (28.5.2018)	International non-profit association registered in Brussels Lobbying and consulting network for circular economy	Managing Director	Interview conducted via Skype, in English by Misa Bakajic and Alf Parvi Recording length 76 min
Interview 23 (30.5.2018)	European Producer Responsibility organisation for electronic waste	Managing Director - Finland	Interview conducted in person, in English by Misa Bakajic and Alf Parvi Recording length 63 min

Interview 24 (30.5.2018)	UK trade association for Resource & Waste Management industry	Recycling Policy Adviser	Interview conducted via Skype, in English by Misa Bakajic and Alf Parvi Recording length 71 min
Interview 25 (1.6.2018)	Management consultant providing acquisition process, company turnaround, management for hire and boardroom work services. Projects in Asia, Europe, the Middle East, North America & South America	CEO	Interview conducted in person, in Finnish by Alf Parvi Recording length 113 min
Interview 26 (6.6.2018)	A non-profit company managing the end-of-life for tires in Italy	Innovation Manager	Interview conducted by phone, in English by Misa Bakajic Recording length 65 min
Interview 27 (8.6.2018)	Nordic pulp and paper manufacturer Mill located in Eastern Finland	Mill Environmental Manager	Interview conducted in person, in Finnish by Alf Parvi Recording length 89 min
Interview 28 (8.6.2018)	Nordic pulp and paper manufacturer Mill located in Eastern Finland	Mill Senior Manager, Sustainability, Consumer Board	Interview conducted in person, in Finnish by Alf Parvi Approximately 41 min
Interview 29 (12.6.2018)	Danish End-Of-Life tires recycler Global operations	Director of Business Development	Interview conducted via Skype, in English by Alf Parvi Recording length 53 min
Interview 30 (13.6.2018)	Belgian based federation for the European Waste and Resource Management industry	2 interviewees Policy Coordinator Legal and Communications Officer	Interview conducted via Skype, in English by Alf Parvi Recording length 54 min
Interview 31 (13.6.2018)	Waste treatment solution provider, subsidiary of Swiss multinational building materials company Global operations	Head of Function	Interview conducted via Skype, in English by Alf Parvi Recording length 37 min

Appendix D: Interview Guide

Through interviews, the researchers sought to understand what drives CE development in the management of waste in companies and by waste management companies. The researchers sought to identify key barriers in transitioning towards CE and the reuse, recycling and recovery of waste. Though reduction is also an important and often the purest way of avoiding unnecessary waste, this occurs before waste management is involved, though it can be debatable if the reuse of overflow production or side streams before they are classified as waste is a form of reuse/recovery or then reduction. The interviews sought to find internal and external barriers on the market, supply chain or company level to understand the developing role of waste management.

Interview questions were tailored to the interviewee's company/organization's operations, position in the waste management value chain and experiences with CE, based on publicly available information such as company sustainability reports, strategies or blog posts about CE initiatives. Questions were worded to refer to the company and known partners by name, in place of generic tiles like "your company". Additional questions were included relating to specifics of the company and their operations.

Appendix D1, List of generic interview questions used in individual interview guides

Interviewee and company/organisation background:

1. Can you tell us a bit about your background and role at your company?
2. Can you tell us briefly about your company?
    - How would you describe your business model? (*Waste Management & Recycling companies and End Users of Waste)*
    - What are your cost drivers and most important costs?

Circular Economy

3. How do you see the circular economy and your company's role?
4. What is the current state of circular economy practices in your industry/region?
5. What are the drivers/causes of circular economy creation?

Waste Management Operations

6. What processes are in place for waste management at your company?
    - Do you sort waste yourself in any way?
    - Extraction of valuable materials, and what do you consider valuable waste?
    - How do you store waste?
    - What is the transportation process like?
7. How do you measure sustainability?

  - Do you know how much of your waste is landfilled or processed for reuse?

8. Who are your partners, upstream and downstream for waste management?
   - How are logistics organized?
   - Is there a learning curve involved?
   - Is source separation in use?
9. What is the role of waste management and waste treatment operators in the Circular Economy?
   - What is the role of waste treatment operators from your perspective?
   - Are these partnerships or simply a pick-up service?
   - Is the relationship collaborative?
   - What type of equipment are you using?
10. Do you see waste management as a cost or value provider?
11. How is legislation driving waste management from your perspective?
    - Is it a threat or opportunity?
    - How does legal definitions or categories or waste affect reuse of waste?

<u>Recycling, Reuse and Recovery of waste</u>

12. Is your company able to use any waste material itself? What for?
    - What is the alternative material to waste-based material?
    - Is waste-based material a cost saving versus traditional/virgin material?
    - What equipment do you use?
    - Where do you source from and what are your typical customers?
13. What features are important in for the supply of waste-based materials?
    - Volume and steady flow
    - Purity (for instance grade accuracy, chemical composition)
    - Size of particles
14. Where do you source from and what are your typical customers?
15. What incentives and opportunities for reusing, recycling or recovering waste are there?
    - Does waste product received represent a cost or revenue for you?
    - Does waste product shipped to end users represent a cost or revenue for you?
16. How do you consider the sustainability of Solid Recovered Fuel (also known as Refuse Derived Fuel)?
    - How to divide what should be used for recycling and what should be burned?
17. What is the market for recyclables or waste materials like?
    - Participants, costs/value, distribution
    - What is the role of merchants or traders?
    - What are the current industry trends and inhibitors?

<u>Technology trends in waste management</u>

18. How would you describe the technology level of the industry? (low-tech vs hi-tech)
19. What is the role of technology in enabling circular economy business models?
20. What do you think is the next technological innovation for waste management?

21. How are new technologies (for instance Internet of Things, Digitalisation and Big Data) affecting your Business Model and business environment?

22. How would you describe the general waste management industry attitude regarding new technology?

Digital platforms

23. Can you tell us a little about the your platform? (or the platform they were involved with)?
    - Who are the platform members and/or sponsors? Is it a closed community?
    - How would you describe the type of information that is shared?
    - How does the on-boarding process work from the perspective of new member joining?
    - Are there any similar platforms or projects like yours that you are aware of?
24. How would you describe interest in industry towards being connected with others?

25. How does knowledge exchange occur in the industry (between supply chain partners)?

26. How could digital platforms help companies innovate or share best practices to improve their sustainability?

27. If a digital platform would exist to connect buyer and sellers of waste materials what would be benefits?

28. What are the obstacles or opportunities involved in the creation or use of such a platform?

Closing

29. Is there anything you would like to add or that you feel we have missed in the discussion?

30. What would you recommend that we look at or keep our eyes open for in continuing our investigation? (*Experts*)

Appendix D2: Diagram of the waste supply chain shared for discussion with interviewees

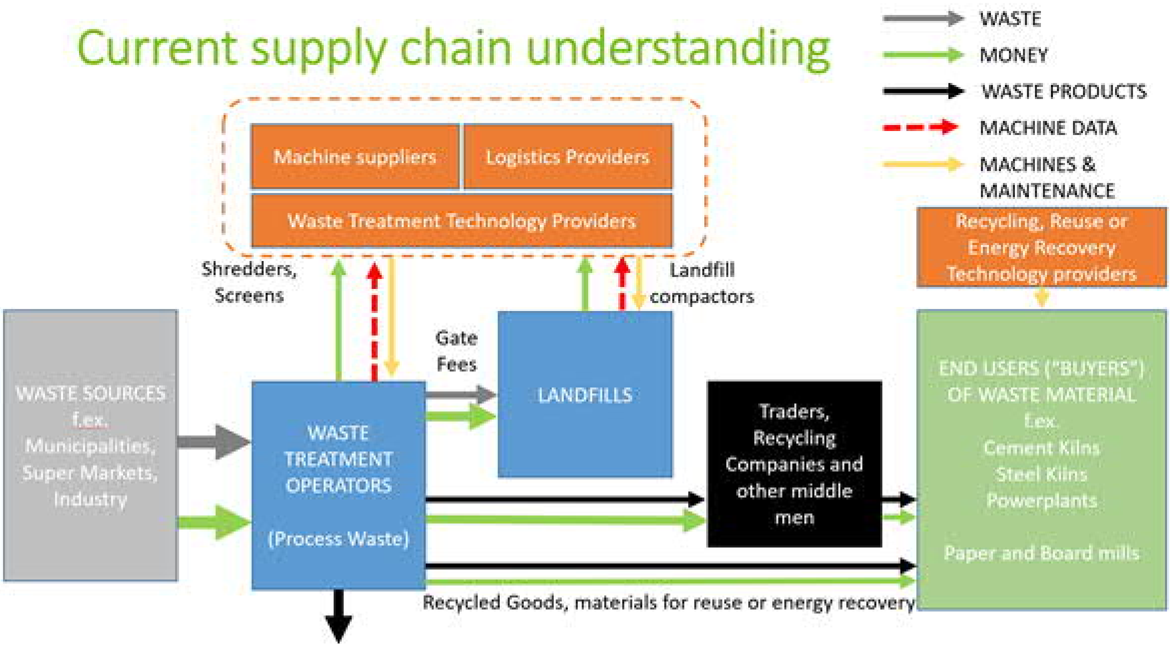

Figure 12: Researchers' interpretation of the waste supply chain