Master's thesis

NTNU
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Industry 4.0 in Waste Management

A case study of a Norwegian municipality

Master's thesis in Sustainable Manufacturing
Supervisor: Niels Peter Østbø
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Preface

This master thesis marks the end of the master programme Sustainable Manufacturing at Norwegian University of Science and Technology (NTNU). The process has been an incredible experience – educational, challenging, enjoyable and at times engrossing.

I want to thank everyone who made this thesis feasible. Thank you to the Agency for Waste Management and the Waste-to-Energy Agency and the people who were willing to be interviewed, without you it would never be possible to complete the thesis. Thank you so much for your time, friendliness and reflections.

I also want to pay tribute to my supervisor Niels Peter Østbø. Thank you so much for your motivating feedback and advice throughout this process.

Oslo, June 2019

Martine Sæther Fasting

Abstract

The aim of this research has been to understand what potential the technologies embodied in *Industry 4.0* hold for the management of municipal solid waste in Oslo.

Obtaining and exploiting the inherent resources of waste is becoming increasingly important. At the same time, the manufacturing industries are in what some call the fourth industrial revolution – new technologies such as IoT and artificial intelligence are disrupting the way products are made. Can the same technologies be used in the context of waste management?

Two research questions were formulated to address the problem statement:

1. What are the application areas of Industry 4.0 technologies for waste management?
2. How is the municipality of Oslo applying Industry 4.0 technologies for managing municipal waste?

To find answers, a literature review was conducted, as a well as a case study of the municipality of Oslo. Interviews and conversations were held with representatives of the Agency for Waste Management and the Waste-to-Energy Agency, and observations were made at the facility for waste treatment.

The literature review produced several findings relating to how Industry 4.0 technologies have been used within waste management. The areas identified are as follows:

- IoT solutions for real-time monitoring of waste generation
- The use of artificial intelligence for predicting waste generation
- The use of artificial intelligence and machine learning for waste classification
- Exploiting data stored in waste electronic and electric equipment (WEEE) for classification purposes

The case study found that the municipality of Oslo has implemented an IoT solution for monitoring waste, but that they have faced several obstacles that have made it hard for them to realize appreciable gains. The other application areas identified have not been put to use.

The municipality has started several digitalization initiatives, including a project on big data analytics. Furthermore, they are gradually improving their ICT infrastructure, which should enable them to proceed with even better solutions. Some identified challenges, e.g. poor data quality, should however be addressed when moving forward.

It is the author's opinion that the municipality should consider adjusting its goals and organizational structure to have a better alignment with the principles of a circular economy. The waste hierarchy dictates that most discarded products should be reused or recycled, not incinerated for energy recovery. The agency responsible for treating waste, the *Waste-to-Energy Agency*, does not seem to be incentivized towards this goal. Further application areas for industry 4.0 technologies within waste management are sure to be discovered, and the municipality seems eager to exploit new technology – it is crucial then that these technologies are put to good use.

CONTENTS

1 Introduction

How can wastes' inherent resources be obtained and exploited in the best way? This is a central issue today, which is becoming more and more relevant as more of the world's resources are depleted. In the present linear economy, innumerable resources go lost when their parent products are subject to inefficient waste treatment schemes. This problem is receiving a great deal of interest around the world for which various countries are implementing legislative measures to ensure a more efficient treatment of wastes; including source separation of wastes and stricter recycling targets.

One of the possible means at our disposal for reaching stricter recycling targets is utilizing new *technology*. This thesis will investigate whether the technologies that are currently transforming other industries, such as machine learning and internet-of-things, can have useful applications within the context of waste management.

The chapters to come will revolve around *Industry 4.0* technologies. A literature review was conducted to identify relevant application areas, and the results were then used in a case study of the municipality of Oslo. In the subchapters to follow, the background and structure of the thesis will be described in more detail.

1.1 Background

1.1.1 Circular economy and the current situation in Europe

Today's economic model can be characterized by the linear "take-make-dispose" path of production and consumption. Economic growth has led to increasing demand for goods and increasing amounts of wastes. To this end, circular economy (CE) is gaining more attention as a possible solution against the environmental degradation and over-exploitation of natural resources that is currently happening to feed the economy's insatiable need for new resources. With a circular economy, resources are thought to circulate in a restorative or regenerative economy by intention and design (Ellen McArthur Foundation, 2015).

In December 2015 the European Commission adopted an action plan for a circular economy, covering the whole cycle; from production to consumption to waste management; also including the market for secondary raw materials and revised legislative proposals on waste (European Commission, 2015). The action plan states that:

> *The transition to a more circular economy, where the value of products, materials and resources is maintained in the economy for as long as possible, and the generation of waste minimised, is an essential contribution to the EU's efforts to develop a sustainable, low carbon, resource efficient and competitive economy.*

Sound waste management plays a central role to circular economy and a prioritized list of measures are found in the EU waste hierarchy, which is also depicted in figure 1 below, in which the best option is to avoid the generation of waste at all (prevention) and the worst is disposal (e.g. landfill). Nonetheless, some materials and products are at the end of their lifecycle and should be recycled and introduced into the market again as secondary raw material, in the beginning of another product life cycle. Those end-of-life materials and products which cannot be re-entered into the market by reuse or recycling can undergo energy recovery. It is clarified in the action plan that energy recovery and disposal are inefficient options for recyclable waste (European Commission, 2015).

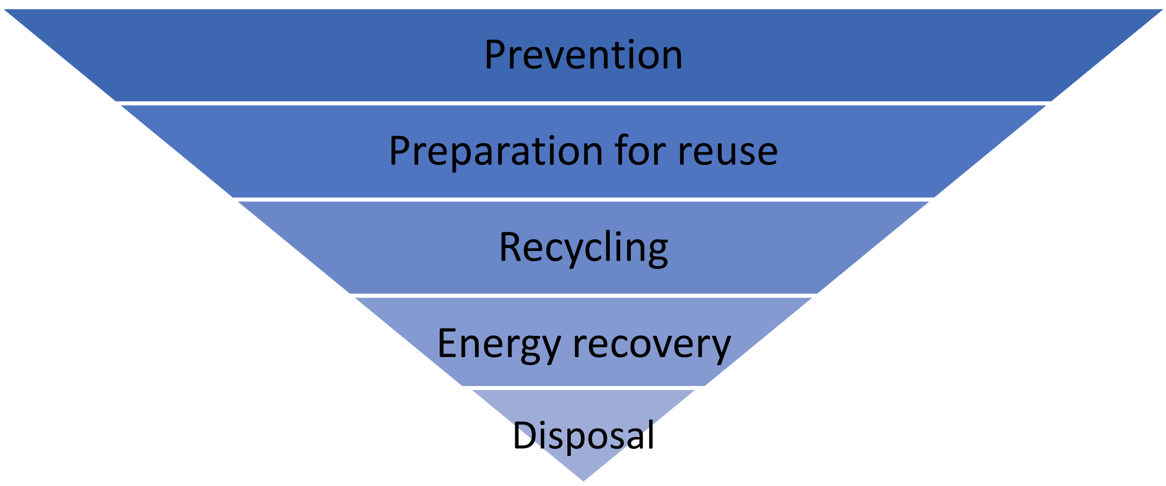

Figure 1 EU waste hierarchy (European Commission, 2015)

According to Statistics Norway there were produced a total of 11.7 million tonnes of wastes in 2017 (Statistics Norway, 2019a) in Norway, a 3 percent increase from 2016. A national goal states that "the growth in amounts of wastes shall be significantly lower than the economic growth …". Yet, the change in gross domestic product (GDP) from 2016 to 2017 was 2 percent. Furthermore, recovery of ordinary waste is decreasing in Norway, arriving at 70 % for 2017 (summing material recovery and incineration) while the amount to landfill is increasing. The development in waste treatment in Norway is depicted in figure 2.

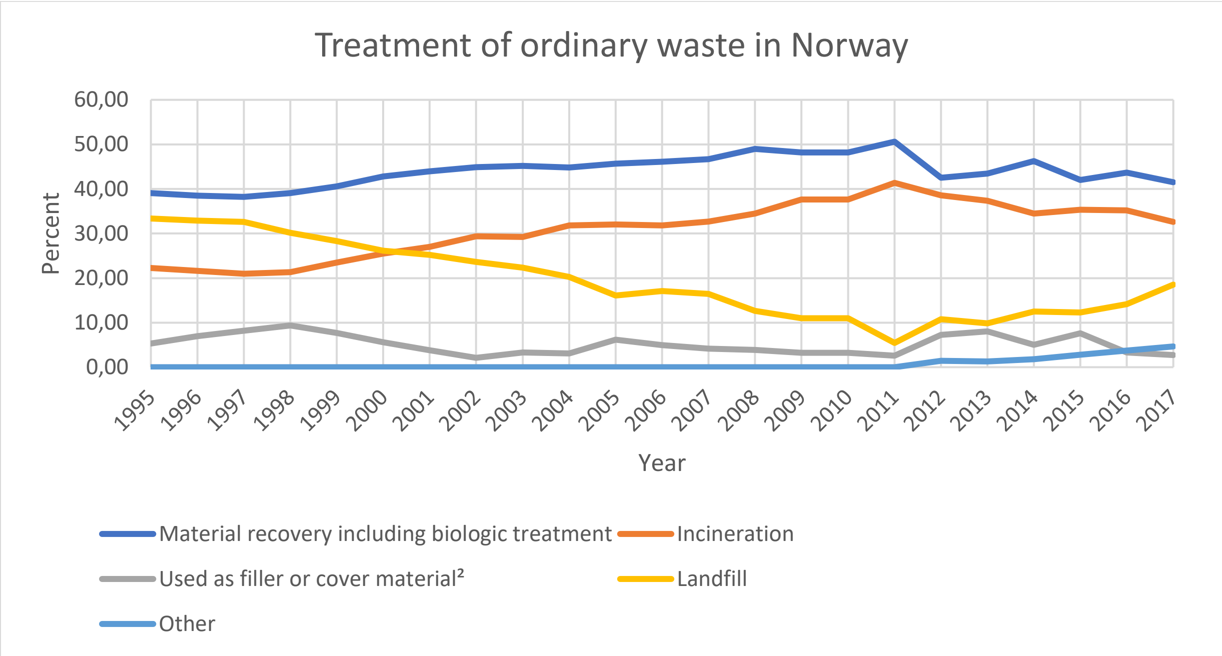

Figure 2 Treatment of ordinary waste. Source: Avfallsregnskapet.SSB

Due to the need for improved recycling in the context of circular economy the European Commission have updated the waste management rules which entered into force in May 2018 (European Commission, 2018). For municipal waste the recycling target is 55% by 2025, 60 % by 2030 and 65 % by 2035. For other waste streams there are also new rules, including:

- 65% of all packaging by 2025, and 70 % by 2030
- 50 % of plastic by 2025 and 55 % by 2030

In addition, bio-waste must be collected separately by 2023.

Norway is tightly connected to the EU through the EEA agreement and much of EU's environmental and climate policies are incorporated into Norwegian law. The significance of stricter waste regulations for Norway is currently under consideration by the EEA and EFTA, with potential changes to Directive 2008/98/EC on waste (Regjeringen, 2019). Norway is already obliged to 50 % re-use and recycling by weight of household waste and similar by 2020 (Directive 2008/98/EC, 2008). Otherwise waste management in Norway is regulated after the Pollution Control Act (Forurensningsloven - forurl, 1983) and the Waste Regulation (Avfallsforskriften, 1983), in which it is expressed that the municipalities are responsible for appropriate treatment of the waste generated by its inhabitant. So, what is the situation like for Oslo, the capital of Norway, and the focus of this thesis?

1.1.2 Current situation in Oslo

From table 1 in the appendix it is evident that the inhabitants in Oslo are generating less household waste per capita (324 kg) than the rest of the country (441 kg) in 2017, but the waste generation is decreasing in general in Norway. Considering the waste hierarchy in figure 1, Oslo is treating the generated waste a little bit worse than the national average, sending more waste to landfill and having a larger share of household waste sent to incineration. Considering material recovery (including biologic treatment) Oslo's share stays around 38 – 39 % while the national average (without Oslo) has increased steadily from 38 – 42 % from 2015. Thus, Oslo is not meeting the requirement of 50 % recycling within 2020 and it doesn't look like their waste treatment operations are changing the current trend. So how can they get there?

1.2 Problem statement and research questions

Succeeding with stricter regulations concerning waste management and recycling targets have shown to be challenging. It is of high interest to get closer to the target and a circular economy, where the waste management industry is moving closer to actors in the industry of raw material.

This master thesis is focused around a case study of the municipality of Oslo and their treatment of household waste, which will be evaluated based on interviews and documents concerning their operation, strategy and vision of future operation of waste management. The problem statement that I wish to answer in this thesis is what is the potential of Industry 4.0 technologies in waste management? Two research questions have been developed from this problem statement:

What potential does the technologies embodied in Industry 4.0 hold for the management of municipal solid waste in Oslo?

From this problem statement two research questions were constructed:

1. What are the application areas of Industry 4.0 technologies for waste management?
2. How is the municipality of Oslo applying Industry 4.0 technologies for managing municipal waste?

The first sub-question was answered through a systematic literature review and the second sub-question was answered through a qualitative case study with the municipality of Oslo as case unit. Interviews were conducted to establish current practice and how key people in the respective departments relate to waste management operations. The literature study in addition to government documents created the basis for a literature guide.

1.3 The structure of the thesis

This introductory chapter has revolved around circular economy for which sound waste management is an essential part. In addition, EU's initiatives and stricter waste regulations have been presented. Current status in Norway and Oslo have also been briefly mentioned, to which it was established that Oslo is not approaching 50 % material recovery. In chapter 2 the theoretical framework for the thesis is presented, including Industry 4.0, waste management, and strategy.

In chapter 3 the methodological choices for answering the thesis's research questions are provided. A detailed description of the research process is presented, including its limitations. At first the literature study is presented to find general application areas of Industry 4.0 technology in waste management. Then the accomplished case study is presented, in which waste management in Oslo is evaluated.

In chapter 4 the results from the literature study is presented. The literature resulted in an overview of general application areas of Industry 4.0 technology in waste management. These are grouped according to waste management stages and examined in light of the theoretical framework presented in chapter 2. Some overall considerations about the results relative to the available research on Industry 4.0 in waste management is also provided.

In chapter 5 the evaluation of waste management in Oslo is presented. The information that was provided from the interviews with the municipality's employees is presented together with explanations and discussion. Furthermore, an evaluation of this material is also provided in light of the results in chapter 4 and the theoretical foundation in chapter 2. In chapter 6 a summary of this evaluation is provided, and the important interpretations are discussed.

1.4 Abbreviations

Some abbreviations are used in various parts of the thesis. These are listed in the table below, with corresponding definitions.

Abbreviation	Definition
MSW	Municipal Solid Waste
MGP	Metal, Glass and Paper
ML	Machine Learning
AI	Artificial Intelligence
CNN	Convolutional Neural Networks
WEEE	Waste Electrical and Electronic Equipment
SPO	Smart Product Ontology
GRA	Grey-Relational-Analysis
CPS	Cyber-Physical System
CE	Circular Economy
EGE	Energigjenvinningsetaten (Waste-to-Energy Agency)
REN	Renovasjonsetaten (Agency for Waste Management)
IoT	Internet of Things
RFID	Radio Frequency Identification
LoRa LPWAN	Long Range (LoRa) Low-Power Wide-Area Network (LPWAN)
GPS	Global Positioning System
ANN	Artificial Neural Network
GBRT	Gradiant Boosting Regression Tree
ANFIS	Adaptive Neuro-Fuzzy Inference Systems
SVM	Support Vector Machines
GPRS	General Packet Radio Service

Table 1: Abbreviations

2 Theory

Chapter 1 introduced the concept of Industry 4.0 and the reasoning for studying waste management from an Industry 4.0 perspective. This chapter will give a more in-depth description of Industry 4.0 and some of the key technologies that are set to transform industries. Furthermore, an introduction to strategy and waste management will be given, thus setting the stage for further analysis and discussion.

Industry 4.0 interlinks and embodies both technology and strategy. This chapter will show that no unanimous definition exists for the name. The chapters to come will focus primarily on the technologies that are most commonly associated with Industry 4.0, and will draw on literature where these technologies have been utilized in a waste management scenario.

2.1 Industry 4.0 – background

Industry 4.0 has become a popular term, and numerous definitions exist. It was first launched in 2011 in Germany as Industrie 4.0 as part of the national High-tech Strategy 2020 to ensure their future leading position in the manufacturing industry (Kagermann, Wahlster and Helbig, 2013).

In the 'Final report of the Industrie 4.0 working group' Industry 4.0 represents a new type of industrialization in which fundamental improvements are made in processes for: manufacturing, engineering, material usage, supply chain and life cycle management (ibid.). These changes are made possible by the current integration of the virtual world of computers with the physical world of machines and other assets. These changes allow for a much higher degree of control, flexibility and adaptability than has previously been possible. Industry 4.0 entails significant technological changes and innumerable possibilities. For that reason, Industry 4.0 is often referred to as the fourth stage in industrialization or the fourth industrial revolution, elevating industrial processes to new heights (Kagermann, Wahlster and Helbig, 2013).

The (first) industrial revolution came about as mechanical manufacturing equipment started revolutionizing the production of goods in the end of the 18th century using steam power. The second came about in the late 20th century in which electricity ushered mass production. The third industrial revolution started by the 1970s in which information technology (IT) was introduced to the manufacturing environment to increase the level of automation. At this point machines could perform some computations and calculations (Kagermann, Wahlster and Helbig, 2013). The fourth industrial revolution continues to draw on the digitization of the third industrial revolution. Now industrialization is characterized by increasing integration of computation capabilities with physical assets, creating smart factories based on cyber-physical systems. This evolution is depicted in figure 3.

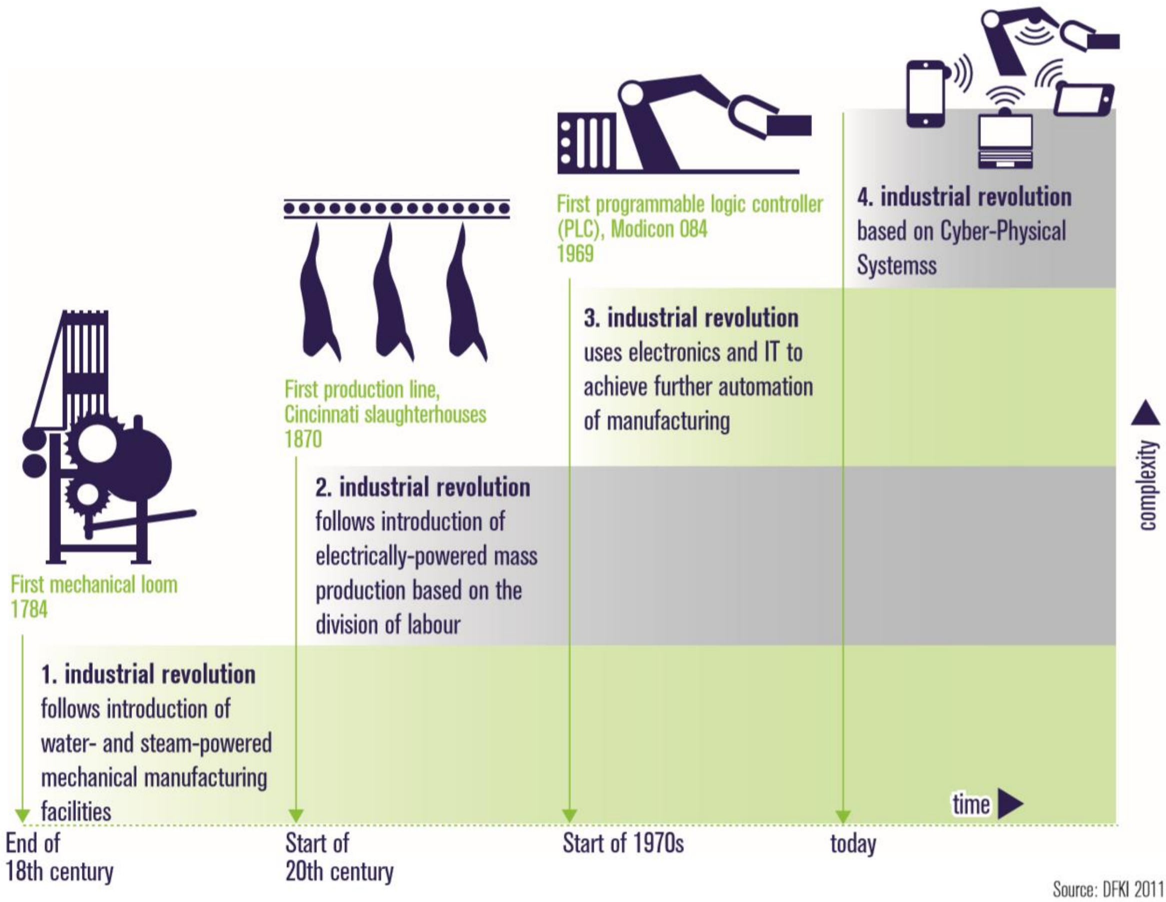

Figure 3 The four stages of the Industrial Revolution

Wang et al. (Wang *et al.*, 2016a) states that the core idea of industry 4.0 is to use emerging information technologies to implement Internet of Things and services so that business processes and engineering processes are deeply integrated making production operate in a flexible, efficient , and green way with constantly high quality and low cost. PwC (2016) regard Industry 4.0 as a shift towards digitalisation of industrial companies, in which all physical assets are integrated into digital ecosystems.

The heart of Industry 4.0 is the smart factory (Kagermann, Wahlster and Helbig, 2013, Gilchrist, 2016, Wang *et al.*, 2016b). In smart factories the products and machinery communicate and negotiate with each other to deliver the sought-after products and production methods, which translates into flexible production (Wang *et al.*, 2016b). Products and machines are integrated with manufacturing systems in horizontal integration, connecting all physical resources with information within the smart factory and other companies in the value chain. Furthermore these systems, resources and information are integrated vertically with different organizational levels, from the factory floor up to ERP systems (Kagermann, Wahlster and Helbig, 2013). Consequently, the smart factory is flexible and can adapt its processes and outcome to meet different requirements. Inherent in the smart factory and Industry 4.0 is the application of cyber-physical systems (CPS) (Drath and Horch, 2014).

According to the National Science Foundation (NSF, 2019) CPS are engineered systems that are built from, and depend upon, the seamless integration of computation and physical components. Lee (2008) state that Cyber-Physical Systems (CPS) are integrations of computation and physical processes. Embedded computers and networks monitor and control the physical processes, usually with feedback loops where physical processes affect computations and vice versa. Lee et al. (2015) explains that CPS consists of two main functional components: (1) the advanced connectivity that ensures real-time data acquisition from the physical world and information feedback from the cyber space; and (2) intelligent data management, analytics and computational capability. Cyber-physical systems record, collect, save and analyse data from sensors which ultimately causes a response in digital and physical processes (acatech - National Academy of Science and Engineering, 2011).

CPS is based on retrieving accurate and reliable data from machines, sensors, devices and monitoring systems so that information about current states and future states can be achieved (Fei *et al.*, 2019) (Lee, Bagheri and Kao, 2015). In this regard, tether-free communication between devices is essential, for which internet of things (IoT) has become essential (ibid.). Furthermore, the data to information conversion should happen rapidly because this data is ultimately what notifies the system about a change or state (anomaly or fault) which is supposed to cause an adjustment to the production system (Fei *et al.*, 2019). Information must also be visualized so that decision-makers receive the necessary support.

Regardless, the Industry 4.0 visions and proposed functionality of CPS depends on the clever connection and utilization of various technologies to exploit the generated data, which calls for strategic design. CPS architecture seek to facilitate the realization of CPS by establishing a structure for its implementation (Lee, Bagheri and Kao, 2015).

2.2 Industry 4.0 technologies

The technological advancements in Industry 4.0 have now been introduced, including key concepts like smart factory, cyber-physical system and internet of things. Now, a further presentation of Internet of Things and Artificial Intelligence/ Machine learning will be given. These two distinct technologies are relevant for Industry 4.0 but provide different application areas and need not be used together. In general, IoT generate data and provide monitoring capabilities. Machine Learning uses data and can give valuable insights into hidden meaning in the data, improve models or predict future events.

1.1.4 IoT

Internet of Things (IoT) refers to everyday devices and things such as RFID tags, sensors, actuators, etc. which are uniquely addressable in a network which can interact and reach common goals (Giusto *et al.*, 2010) (Atzori, Iera and Morabito, 2010). With IoT data and information about things which are connected to the internet can be retrieved. IoT are changing businesses by providing real-time visibility of resources and operations (Lee and Lee, 2015), which allows for large-scale remote monitoring and control.

In IoT architecture there are different layers, each of which corresponding to different functionality, technology and physical devices, but a three-layer architecture is common (Mahmoud *et al.*, 2015). Zheng et al. (2011) presented an IoT architecture model consisting of: 1) the sensing layer, 2) the network layer, and 3) the application layer. Together they represent comprehensive perception, reliable transmission, and intelligent processing. The sensing layer, also referred to as the perception layer (Mahmoud *et al.*, 2015), is the bottom level in the architecture and serves a twofold purpose of data management and coordination from and between sensing devices. Sensors perceive states and events in their physical environment that generates data, which is then acquired and processed in the sensing layer. Short-range and local networks are used in addition to middleware technology for coordinating the data acquisition (Zheng *et al.*, 2011).The network layer transfers the data from the sensing layer to the application layer and between heterogeneous networks by communication technology, e.g. 4G, Internet, GPS, etc. (Zheng *et al.*, 2011) (Mahmoud *et al.*, 2015). The application layer is the top layer and receives input from the network layer to perform the desired service, e.g. storage, analysis, etc. (Zheng *et al.*, 2011).

1.1.5 Machine learning / Artificial Intelligence

The devices in IoT can generate huge amounts of data difficult to store, process, and analyse through traditional database technologies. These Big Data can be heterogeneous resulting from various sources. Big data is often unstructured and pose a challenge to analyse (Gandomi and Haider, 2015). Big Data is worthless in a vacuum and its potential value is unlocked only when leveraged to drive decision making (Gandomi and Haider, 2015). Achieving insights from these data can be broken down in two main categories: data management and analytics. Inherent in data management are acquisition and recording; extraction, cleaning and annotation; and integration, aggregation and representation. Analytics can be further separated into modelling and analysis; and interpretation (ibid.). Artificial Intelligence and Machine learning are approaches emerging as suitable to facilitate drawing insights from data.

Artificial Intelligence (AI) is the science of training machines to perform human tasks (SAS). Machine learning is a sub-set of AI according to Shalev-Shwartz and Ben-David (2014) in that the goal is to learn from experience. ML draws on statistics, information theory, game theory and optimization. LeCun, Bengio and Hinton (2015) writes that machine learning systems can perform various tasks: e.g. identify objects on images, transcribe speech into text etc.

The experience part of machine learning is represented by various input data which are then used to create a model capable of predicting and draw conclusions. As the model get more data the model updates itself automatically, it learns, and the predictions and conclusions get better (SAS). Because the model is improved on its own from new data, machine learning is adaptive by nature. Based on examples the model is supposed to be able to generalize (Shalev-Shwartz and Ben-David, 2014).

In addition to being adaptable, machine learning can be used for performing tasks too complex to program (Shalev-Shwartz and Ben-David, 2014), for example fast and automatic image analysis (Mochida *et al.*, 2018) or learning to detect patterns and their value from large data sets (Shalev-Shwartz and Ben-David, 2014).

1.2 Waste management

Human activity has always led to the generation of wastes and as industrialization have led to wealth and better living standard for many, this development has also led to a massive increase in waste around the world. However, it became evident that waste pose a threat to human health and the environment if not dealt with. Water, soil and atmosphere could be seriously contaminated. To remedy the harmful effects of waste, governments issued various legislative measures to deal with the waste (Giusti, 2009). Today, there is a consensus that waste management should be performed according to the waste hierarchy presented in the introduction.

The waste hierarchy lists waste management activities in a prioritized list, according to their effect on the environment. Evidently, the reduction of waste altogether has the best impact on the environment, and hence, the prevention of waste is the number one priority. Succeeding prevention of waste, is the reuse of waste objects (including repair of objects for reuse) thus changing their status from waste to products. After that is recycling, which entail material recovery so that secondary materials can be included in the production of new products and thus replace virgin materials. Wastes that cannon be treated by any of the above-mentioned alternatives, should then be considered for energy recovery. At last, wastes that cannot undergo any of the previous activities must then be disposed of, e.g. at landfills.

The waste hierarchy explicitly lists the desired activities for managing waste, but waste management agents around the world have varying abilities to conform to the prioritized activities. Recycling and energy recovery entail technical aspects which calls for a certain degree of technological maturity and which put restraints on the waste intended for these activities. First of all, recirculating materials and waste to energy must receive waste, and secondly the waste stream must have a certain degree of homogeneity, so that foreign objects and other impurities don't cause too adverse effects on the waste treatment activities performed on the waste (Rousta *et al.*, 2017).

Treating waste through recycling or waste-to-energy is generally more environmentally friendly than not treating it, but all these activities require energy and produced an output in addition to the intended product (energy or recycled material). Recycling entail dust and residues. Incineration includes fly ash, release of certain gases to air including $S0_2$ and CO_2 and other pollutants. Landfilling entails leachate to water, soil contamination by heavy metals, emission of CO_2, CH_4, odours and is the worst option for wastes (Giusti, 2009).

Furthermore, the quality of the secondary material and the produced energy form municipal waste depend on the quality of the waste material entering the waste treatment activity (Rousta *et al.*, 2017). Therefore, waste segregation is crucial for the other chain of waste treatment activities constituted in waste management.

Waste segregation is crucial in the chain of activities leading up to recycling of materials (Gundupalli, Hait and Thakur, 2017). Waste segregation can be done at different locations in the waste management chain and by different techniques, including source separation carried out by the waste generators (people, businesses etc.) or by automated techniques at waste treatment facilities. Source separation of waste facilitates further sorting and is either mandatory or recommended in various countries. The possible source separation categories vary between countries. In direct sorting the waste components' physical properties such as mass, size, polarity, susceptibility to magnetism, density, hydrophobicity etc. are exploited by applying gravitational and electromagnetic forces in combination with movement (Gundupalli, Hait and Thakur, 2017). In indirect sorting sensors are utilized to detect the presence and location of different recyclables from which machines and robots are employed to remove the identified material or part (Gundupalli, Hait and Thakur, 2017).

2.3 Strategy and goals

The concept of Industry 4.0 was originally both a means and an end; an integral part of a national strategy to ensure Germany's leading position in the manufacturing industry (Kagermann, Wahlster and Helbig, 2013). A strategy must be comprised of more than technology utilization, it is a roadmap describing how *goals* will be reached.

The case study presented in this thesis revolves around how the municipality of Oslo has made use of the identified application areas for Industry 4.0 technology in waste management. In this context, goals are also important. The municipality's goals and future plans will have a profound effect on whether they will be successful in realizing results from the aforementioned technology utilization. A brief introduction to goals and strategy will here be presented, so as to give a theoretical backdrop for the later analysis.

Organizations are created to perform tasks and serve a purpose, to which they establish goals about what they want to accomplish in the future and a strategy which incorporates the means by which the goals can be reached (Jacobsen and Thorsvik, 2009, pp. 30-56).

Jacobsen and Thorsvik (2009) writes that a goal is a description of a desirable future state and that they can have aspects concerning time, differing degrees of realism and specificity.

Goals are often listed in a goal hierarchy in which the purpose of the organization, what makes it special from others, then form a vision of a desired future state, who they want to become. To transform a vision into reality its concretized into goals and sub-goals (Jacobsen and Thorsvik, 2009). Ideally, goal hierarchies should be shaped in a way that there is a clear and unambiguous relationship between the goals, sub-goals and means.

There are strong indications that goals with large time frames tend to be vague and unclear, and thus they are not suited for functioning as a management tool. However, large time frames also open up for freedom of action which opens up for new thinking and innovations.

Goals differ in terms of continuity, for which some are of a degree in which its impossible to determine its fulfilment, this is particularly the case for public organizations. Almost without exception, continuous goals are more complex than definitive goals. With ambiguous goals the means to reach the goal poorly understood, and many have stated that this is particularly a problem in public organizations, due to the fact that many of its responsibilities are providing complex services. Therefore, it becomes difficult to state the relationship between goals and the means to these goals. Symbolic goals are utilized for the most part to convey a message about what the organization wants the consumer to see. Real goals however are defined to change behaviour and serve as evaluation criteria, and give the public a realistic image of what they are actually trying to achieve.

An organization’s goals, strategy and structure set the boundaries for employees’ freedom in form of guidelines and limitations; it is expected that employees’ work toward the organization’s goals, prioritize tasks aligned with the strategy and act according to the job title (Jacobsen and Thorsvik, 2009, p. 17).

Public organizations are formally governed by politicians through state or communal authority and therefore they are (1) obliged to conform with democratically elected groups; (2) required to meet many and possibly opposing considerations; (3) they don’t sell their goods and services in a market, and therefore don't receive feedback that other privately organizations do (Jacobsen and Thorsvik, 2009, p. 23). It is however argued that public and private organizations are not that different, that it is a question of magnitude, as private organizations are also governed by different stakeholders which can have different goals (Jacobsen and Thorsvik, 2009, p. 23).

A strategy is a description of how one plans to realize a goal, in other words, a strategy is the road towards the goal. Generally speaking, there are two groups of strategies. The first one is “generic strategies” and is foremost connected to how an organization position itself in relation to its environment. The other group is the resource based, in which the focus is more towards internal relations, those characteristics giving them advantages in comparison with other organizations. Strategic choices should be based both on internal and external factors. The classical theories about strategy cannot be directly transferred to public organizations because they operate under different conditions. Public organizations often must include elements that private organizations would not find profitable. However, strategic thinking can and have been adapted to public organizations to a large degree,

The reason behind studying strategy is an assumption that it affects actions and behaviours on employees in an organization, and how the organizations adapts to external environment. Strategy can be motivating on the employees, they can have a management role by giving direction for line of work, grounds for taking decisions and boundaries on the employees. Goals can also work as evaluation criteria for the work that is done. Without goals it is difficult to talk about efficiency.

Organizations can have very different goals but common for them all is the wish to accomplish them the best possible way, which also means to utilize its resources in the best way.

3 Research method

In the previous chapter a presentation of Industry 4.0 and inherent technologies, waste management, and strategy was provided which creates the theoretical backdrop for this thesis. Before that, the thesis' problem statement given: What potential does the technologies embodied in Industry 4.0 hold for the management of municipal solid waste in Oslo?

In this chapter the methodological choices taken to enlighten the problem statement is provided. A detailed description of the research process, including its limitations.

The chapter has two major sub-sections because the thesis seeks to answer two different research questions which are sought answered by two different research methodologies. The chapter starts with the systematic literature which is performed to map applications of Industry 4.0 technologies in waste management. The case study will then be presented where the identified applications in addition to theory are basis for evaluating management of municipal solid waste in Oslo.

At the very beginning of this chapter a general description and model of the research will be presented.

3.1 General research model

The starting point for this thesis was a genuine curiosity about waste management practices and how to do it better - especially considering the new technologies in the Industry 4.0 paradigm currently revolutionizing the manufacturing industry. The overarching problem statement creating the foundation for this thesis was what potential does the technologies embodied in Industry 4.0 hold for the management of municipal solid waste in Oslo.

Two research questions were derived from this problem statement:

Research question 1: What are the application areas of Industry 4.0 technologies for waste management?
Research question 2: How is the municipality of Oslo applying Industry 4.0 technologies for managing municipal waste?

With the first research question it was desirable to identify the significance of Industry 4.0 technology in waste management. Central to this question was what objectives are tried for? With the second question it was desirable to unveil how Industry 4.0 technologies are being applied in the municipality of Oslo for managing municipal waste. Central to this question was the organization of the agencies responsible for waste management and the goals they are working towards. Studying a municipality, it is desirable to relate the theoretical basis of Industry 4.0 technologies to a real-world system of waste management.

To answer the first research question, a systematic literature review was conducted. This literature review resulted in a record of application areas of Industry 4.0 technologies in waste management. This record was then used as basis to study the current management of household waste in Oslo. A case study was then conducted of the departments responsible for municipal solid waste in Oslo, constituting the Agency for Waste Management and the Waste-to-Energy Agency. An interview guide was created based on the literature review and the theoretical basis presented in chapter 2.

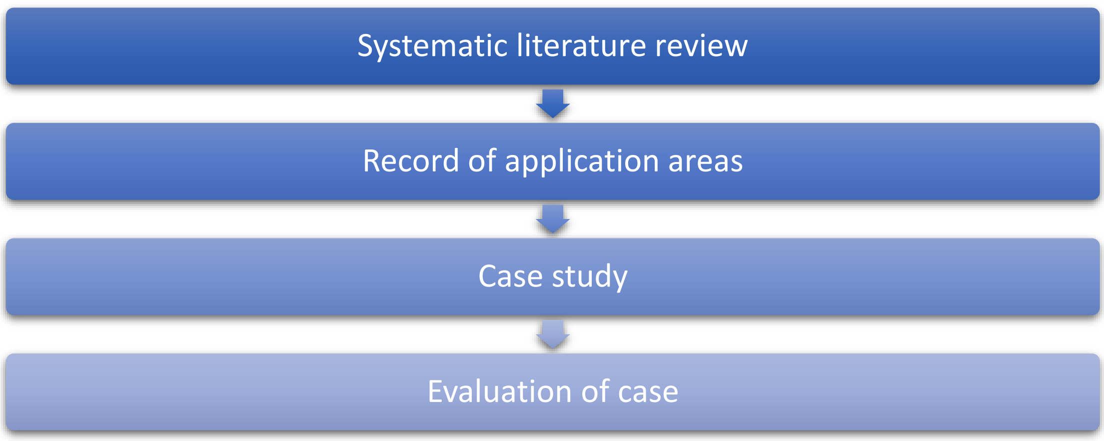

Figure 4 General research model

3.2 Literature study – application areas of Industry 4.0 technology in waste management

In an effort to find an answer to the thesis' first research question I carried out a systematic literature review. It was desirable to use the results from the literature review as basis to evaluate the application potential of Industry 4.0 technologies in management of municipal waste in Oslo. To this end a record of Industry 4.0 technology applications in waste management was created. The results of the literature review are presented in chapter 4.

1.2.1 Data collection method and analysis

Searches were done in Oria and Scopus to find relevant literature. To avoid missing out on relevant literature, and to get a good grasp on the literature on Industry 4.0 I started with general search strings like "Industry 4.0" and "Industry 4.0 and recycling". I discovered early on that the literature on Industry 4.0 is becoming rich, but that Industry 4.0 in context of waste management is mostly undiscovered terrain. Therefore, I focused on the technologies in Industry 4.0 and waste management. This search strategy will be described in the following. I tried to keep an open mind throughout the completion of the thesis, and I tried to follow up on clues and potential search strings as I went along.

The search strategy for this thesis consisted of combining technologies of Industry 4.0 (see chapter 2) with stages in waste management (collection and sorting) and associated terms. A list of used search strings and combinations is shown in table 2 below. The search criteria "Article title" was also used for searches in Scopus. In case of few results, the search criteria changed to "Article title, Abstract, Keywords" to cover a larger basis. To exemplify: one of the first search strings in Scopus with this strategy was: "waste management" and "IoT" or "Internet of things".

Table 2 Combinations of these search strings were used to find relevant literature

Search phrase in relation to waste management	Search phrase in relation to Industry 4.0 technology
"waste management" "waste" "recycl*" "waste identification" "segregat*" "sort*" "collect*"	"IoT" or "Internet of things" "CPS" or "CPPS" or "cyber-physical" or "cyber physical" or "cyberphysical" "Big Data" "Cloud" "machine learning" or "artificial intelligence" or "AI" or "ML" "sensor*" "RFID" "Industry 4.0" or "Industrie 4.0" "technolog*"

Titles of all the articles provided by Scopus with established search criteria were read, and if found relevant, the abstracts were read too. If the abstracts were found relevant to my problem statement, the whole article was read and downloaded to my personal One Drive account under a folder named after the search criteria that generated the result in Scopus. This way it would be easy to locate the article for later use and this was also a supportive activity to the coding procedure used to analyse the contents of the articles and their interrelationships.

Corbin and Strauss (2008) defines coding as a process consisting of three parts: breaking down, interpreting and compile data in new ways. These steps are referred to as open, axial and selective coding. However, the last step was not performed as I did not intend to establish new theory. Open and axial coding were however helpful in systemizing the articles and their contents, otherwise perceived as overwhelming. Due to the novelty of Industry 4.0 in context of waste management, and the variety of the search strings used, a coding procedure was regarded as particularly beneficial for this thesis to find links and relationships.

Open coding is the initial phase for the researcher, in which the data is split into different segments, studied for common features and then categorized according to the discovered features. In this thesis open coding was used to identify the combination of technologies used. The different articles which were read were continuously organized and labelled using Excel. Keywords, affiliation to waste management and purpose of study are all categories used in Excel to organize the contents of the articles. From the open coding some core categories emerged.

Corbin and Strauss (2008) describes axial coding as the next step to open coding, in which the connection between the categories resulting from the open coding emerges. In this thesis this step consisted of relating the application of Industry 4.0 technologies in waste management. From the emerging core categories, articles were re-read to establish their connection to the core categories.

The literature review was partially concluded when I had finished the list of search strings. I did however follow leads on these articles and used cited articles to find new search strings. For example, “identification” was added to the list.

1.2.2 Assessment of research method

The literature review presented in this thesis resulted in a record of applications of Industry 4.0 technologies in waste management. I want to elucidate that that the purpose was never to produce a record of *all possible existing* applications, as I don’t believe that all such applications may necessarily exist in literature or be reduced to “applications”. Rather, I have been interested in technologies which can facilitate waste management.

Jacobsen (2005) writes that reality is comprehensive and complex, and it is not possible to register everything about it. In this regard, research data is more or less successful representations of reality. He continues to write that it is impossible to achieve complete perception of a phenomenon and that already at the beginning of an observation the researcher will overlook significant actuality.

Before I started the formal work on this thesis, I had previous knowledge of Industry 4.0 from the study program at NTNU. It could be the case that conversations with fellow students and professors have shaped my view on Industry 4.0 and key technologies more than I realize, even though I have sought to “listen” to the evidence of the identified literature. I have however tried to remedy this possibility by using many different search strings and following up on leads provided in the literature. This way I hope that I have achieved to throw a wide web, and not be too led my own preconceptions.

3.3 Case study – Relevance of Industry 4.0 technology for management of municipal waste in Oslo

The literature review was carried out to find application areas of Industry 4.0 technology in waste management. Now a case study will be presented in which the municipality of Oslo was evaluated based on their application of Industry 4.0 technology to manage municipal waste and what their future plans are. The purpose of the case study was to answer the second research question - *How is the municipality of Oslo applying Industry 4.0 technologies for managing municipal waste?*

Based on the research question it was natural to choose a qualitative method. Jacobsen (2005) writes that qualitative method is appropriate when knowledge about how people understand and interprets a given situation is desired , and when its beneficial with nuanced descriptions. In this case it was desired to acquire knowledge about the interviewees' interpretations of complex concepts as data processing, waste management operations and strategy. Furthermore it was desirable to ask the interviewees to recollect events, which is not possible to do by quantitative methods (Johannessen, Christoffersen and Tufte, 2011).

A case study was the natural approach to answering my research question because I was interested in *how* technology is applied for the purpose of managing waste. A comprehensive understanding of the circumstances leading up to the municipality's decisions to implement new technology was necessary; including current practice, plans, and strategy. Thus, the nature of this research question also revolved around *why* and its context.

Yin (2018) states that case studies are especially advantageous when a *how* or *why* question is in focus for a contemporary set of events and for which the researcher has no or little control. In addition, the case is investigated in depth and in a real-world context (Yin, 2018). Johannessen, Christoffersen and Tufte (2011) writes that case design allows for a deep comprehension of a confined phenomenon. By studying management of municipal waste in Oslo, it was possible to achieve a more detailed and thorough description of the departments practice. By documenting how the municipality of Oslo deals with municipal waste, compared to what theory and literature study suggests, I hope to shed light on issues worthy of more attention. I also hope to advance the field of Industry 4.0 in context of waste management, by shedding light on organizational factors influencing practical applicability in a real system.

1.2.3 About the case

The case in this thesis is the administrative units in the municipality of Oslo concerned with managing municipal waste; the Agency for Waste Management (In Norwegian: Renovasjonsetaten, REN) and the Waste-to-Energy Agency (In Norwegian: Energigjenvinningsetaten, EGE). The Agency for Waste Management is responsible for collecting municipal waste generated by the inhabitants in Oslo and facilitate source separation of this waste at households by informing the inhabitants of their obligation to source separate and to encourage. The collected waste becomes the responsibility of the

Waste-to-Energy Agency once it has been delivered at their facilities. The Waste-to-Energy Agency is then responsible for treating the waste for energy and material recovery and performs the following waste treatment operations: incineration of residual waste, production of biofuel and bio fertilizer from food waste.

The case unit was chosen because the municipality of Oslo oversees the municipal waste generated in the most populous county in Norway. The municipality of Oslo is thus a significant actor of the total municipal waste that is generated in Norway.

It was my initial curiosity about waste management practices and Industry 4.0 that set the basis for this thesis. For that reason, it was also I who initiated contact with the municipality of Oslo and established a relationship. I first contacted technical director in the Waste-to-Energy Agency who became my informal contact person from the municipality regarding municipal waste and who introduced me to two other key persons who could be essential for my thesis - which they certainly were!

1.2.4 Data collection method

Interviews with employees at the Waste-to-Energy Agency and the Agency for Waste Management were conducted to gather necessary information. Interviews are one of the most important case study evidence (Yin, 2018) and people's experiences and perceptions are obtained the best way when the interviewees can participate in shaping the interview (Johannessen, Christoffersen and Tufte, 2011). Explanations were particularly important for this thesis, because I wanted to know about the driving forces behind implementing certain technologies; how and why are these decisions taken?

This also meant that I had to speak with experienced and knowledgeable people within planning, strategy, current operations and technology. Therefore, I contacted technical director at EGE and had preliminary conversations with this person and had the first interview with this person. This person became my informal contact person and established contact between me and two other people in the municipality of Oslo who he thought could be helpful for my thesis. All of the interviewees have more than 10 years of experience within waste management in the municipality of Oslo and thus they were deemed suitable as interviewees for my problem statement and thesis in general.

The interviews were conducted one on one for practical reasons and because some of the central issues in the interview could result in social conformity. One-on-one interviews were also more practical as there were questions specific for the Agency for Waste Management and the Waste-to-Energy Agency. All of the interviews were conducted in person at a location chosen by the interviewee, which was at their offices and at the city centre. In addition to interviews, reports and strategies for the two departments were used as a supplementary source of information.

Prior to the interviews I prepared an interview guide with both open and structured questions see attachment 2 in the appendix. The interview guide was written considering the literature review, public documents about REN and EGE in addition to questions that evoked from these documents. The literature review showed that the research is severely fragmented in terms of implementation of Industry 4.0 technology in waste management and their meaning in a larger system with recycling as overarching goal. In addition, the literature review showed how acquisition of data about the waste is a precondition for all of the technologies in Industry 4.0. Therefore, many questions revolved around the interviewees' perception of the value of data and how data is generated and treated today. Furthermore, the literature review revealed that there are various gaps in the research in waste management, but which are of principal interest when considering these technologies in an organization. I started with some open questions about data, before I asked more precise questions. I first wanted their spontaneous answer.

The interviewees were asked close to all the questions presented in the interview guide, and relevant follow-up questions. They were initially asked to describe their current positions and responsibilities, in addition to previous experience in the municipality. From there I asked about the central issues in the interview guide: data, strategy and previous projects. The interviews lasted from 60 minutes to 90 minutes. All of the interviews were recorded with a sound recording app on my cell phone, and later transcribed. I also wrote notes during the interviews. Relevant statements were then translated to English before presented in the thesis.

1.2.5 Data analysis

The data analysis was conducted under the influence of Creswell and Poth (2016), Yin (2018), and (Leedy and Ormrod, 2015b). As shown in figure 4, the data analysis was conducted of 5 major development steps. However, the three steps depicted in circles were carried out iteratively, especially the steps of read-through and coding. It is noted by Leedy and Ormrod (2015b) and Creswell and Poth (2016) that analysis and interpretation begins early in the research, usually occurring simultaneously. I recognized something analogous in my research. Even though the analysis of interview data was actively pursued at some point, reasoning from the interviews started from the first time I spoke with employees from REN and EGE in relation to my thesis. I had previously visited the waste facility for sorting household waste, and from the first conversation related to the master thesis I started comparing the impressions I was left with.

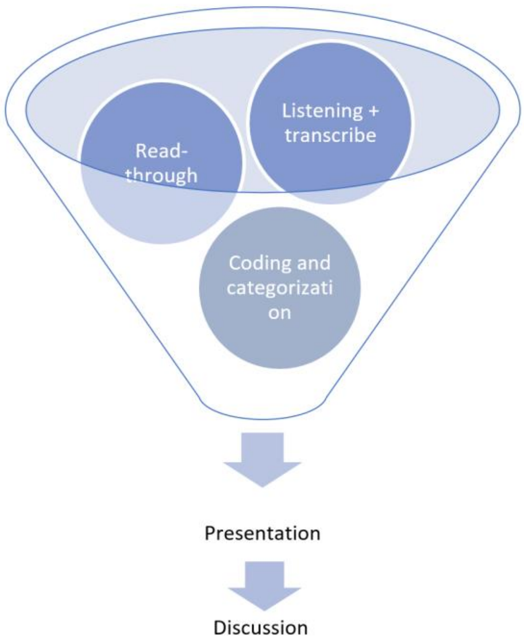

Figure 5 Model for data analysis

The first "formal" step of the analysis was to listen carefully to the recorded interviews and write close to exact transcriptions of what was said. Then, I read through the transcriptions a first time, quickly, to get an overview and check if some topics immediately stood out. This led to a short list of parent categories for further coding. By organizing the data in a preliminary way, I believe it was easier to recollect and use them as the analysis proceeded (Leedy and Ormrod, 2015b). I created a table with the main categories at this point.

I then read through the interviews again, thoroughly, one at a time, and started to fill in the preliminary table. The table expanded to cover categories and sub-categories (codes) on one axis, and the respective interviewee on the other, I also started memoing (Creswell and Poth, 2016), filling in statements and ideas from the interviews into the corresponding categories in the table, trying to achieve a higher level of information from the interview data. The interviews proceeded close to the structure of the interview guide, so main categories from the coding procedure coincided closely with the topics from the interview guide. There were however findings from the interviews which resulted in new categories.

I tried to have an objective mind while coding and interpreting the data, but I realize that objectivity in conveying meaning from words and utterings, is close to impossible. To remedy the lack of objectivity, I also asked myself continuously to find evidence in my data that could suggest something opposite of my conclusions or reasoning. I have strived to explain and clarify my reasoning and thinking in the analysis chapter (chapter 5).

1.2.6 Assessment of research method

Reliability and validity are central concepts in judging the quality of the conducted research (Yin, 2018). Reliability refers to the ability to reconstruct the same results from a study if it was to be repeated. A question to be asked is: Will another researcher obtain the same findings and conclusion? Because I conducted a case study it would be difficult for somebody else to get the exact same results as I. However, from the literature guide given in the appendix, it is shown that many of the questions asked refers to actions, what they do, and how they do it. Consequently, I believe that many of the answers would be given again as they represent common procedures in the departments. In an effort to improve reliability I have visualized somebody looking over my shoulder (Yin, 2018), trying to be as explicit as possible in presenting the research method, explaining what I have done and how the data has been collected.

Validity in qualitative studies is about the degree to which the researcher's methods and findings accurately reflect the purpose of the study and represent the reality (Jacobsen, 2005). Internal validity in research is the extent to which the methods and data permit that the right conclusions about cause-and-effect and other relationships can be drawn (Leedy and Ormrod, 2015a). In this study, cause-and-effect relationships was not a goal. In qualitative studies, the relationship between the conducted research and the purpose of the study – are they in line – is important (Jacobsen, 2005). Here, transparency is important, which I have strived to provide. I have also collected data from multiple sources, including public documents, visiting one sorting facility and interviews with key employees.

External validity refers to the extent that the research provided results which are valid for other situations than the specific study, hence, the generalizability of the study. Seeing that this was a case study conducted under relatively non-controllable conditions in comparison with lab experiments etc., the results are not generalizable, which was not the intention of the study either. The study was not performed to provide insights into all municipalities, or even the complete municipality of Oslo, but in the two departments managing waste. Nonetheless, the study do provide information about conditions that might be transferable to other municipalities dealing with MSW.

1.2.7 Ethical considerations

The topic under investigation in this thesis does not invite many ethical issues, as no personal or sensitive information was required. None of the respondents were in any danger physically or psychologically either, as I did not ask about personal information. In addition, I asked about the organization and how the departments conduct stuff, not the interviewees. The most important measure related to ethics was to anonymize the who said what during the interview. However, the interviewees accepted that their working title was given in the thesis, and I informed that their names would be omitted.

4 Industry 4.0 technology applications in waste management

What application areas exist for industry 4.0 technology in waste management? What gains have been realized using these technologies? What challenges remain? This chapter will present the findings from the literature review, which sought to answer these questions.

The method behind the systematic literature conducted was presented in the previous chapter, and resulted in the identification of various applications of Industry 4.0 technologies in waste management. These are here presented in the context of the value chain stage of which they are relevant. The focus is primarily on the application areas of industry 4.0 technologies that have been shown to improve upon the recycling process from a circular economy perspective – technology use that have more generic benefits is in this context are deemed non-relevant (e.g. maintenance of equipment).

Of technologies relevant to Industry 4.0, monitoring abilities by IoT systems, and predictions and classification facilitated by machine learning stand out as the most researched areas. However, overall the reviewed literature reflects research efforts that overall are fragmented. For the most part realized gains are yet to occur.

4.1 Overall remarks about the findings from the literature review

The literature review, the method of which is described in chapter 3, produced a survey of Industry 4.0 technology applications in waste management. Some general observations from the literature review will be presented first, followed by a complete record of identified applications of Industry 4.0 technology in waste management.

The research on Industry 4.0 technologies in waste management are in general in short supply, and most describe pressing issues due to urbanization as main concern for the research. Most attention revolves around the collection of waste and less is on treating the waste.

The main applications of Industry 4.0 technologies in waste management from the literature review are:

- IoT systems can be used to monitor the real-time generation of waste
- Machine learning techniques can be used to forecast the generation of waste
- Machine learning techniques can be used to classify waste objects into different categories

The application areas identified in the literature review will now be presented according to their applicability in various waste management activities, starting with waste collection and continuing with waste identification and then a unique situation for managing WEEE due to the information stored in EEE and smart objects.

4.2 Improving waste collection

Improving the collection of waste is a widespread priority in the reviewed articles and many authors concur that this is of principal concern for efficient waste management. There are primarily two reasons for this. The first one, and encountered the most times, is due to the pressing issue of increased urbanization in several developing countries (Anagnostopoulos *et al.*, 2018, Misra *et al.*, 2018, Wen *et al.*, 2018). It is feared that if the collection of waste is not improved, harmful consequences will affect the population in these areas. The second reason is to improve the waste-to-energy processes following collection.

To this end, research have been conducted to achieve information about the rate to which waste is generated over time, and to use this information for planning and controlling the collection of waste. Without rich data about the waste that is generated it becomes difficult to develop a waste management infrastructure capable of satisfying the requirements from government and other stakeholders. Therefore, monitoring and forecasting solutions exploiting Industry 4.0 technologies have been developed to improve the efficiency of waste collection.

1.2.8 IoT solutions for real-time monitoring of waste generation

To remedy the increase in waste generation, various monitoring systems have been developed to monitor the generation of waste (Misra *et al.*, 2018, Wen *et al.*, 2018). In general, these systems are able to sense changes in waste bin filling levels, transfer information concerning the change, and display this information for signaling a need for emptying of waste bins. The aim is that collection of waste can be carried out based on actual need instead of static route planning (Wen *et al.*, 2018).

In response to the increased interest for improving collection of waste, efforts have been made to apply Internet of Things (IoT) systems. As presented in chapter 2, IoT permits data to be collected from various objects and shared with other objects for storage, processing and actuation. IoT systems have been developed to monitor the status or filling levels of waste bins to facilitate the logistics concerning the collection of waste. Common for most of the reviewed IoT systems for monitoring bin status is that they all collect, share, process data and display information using various sensors, communication technology, data storage and processing software. Despite the common features of the IoT systems, the systems diverge in how the generated data is exploited and how the data is acted upon. The authors concur that the system facilitate collection of waste and waste management in general (Misra *et al.*, 2018) (Wen *et al.*, 2018, Cerchecci *et al.*, 2018).

Various sensors can be used to measure weight, occupied space, and/or production of gases resulting from waste being disposed of in waste bins, thus generating data concerning the status or filling level of the bin. Cerchecci *et al.* (2018) showed that ultrasound sensors can provide accuracy by 1 cm in measuring the height occupied in the waste bin when they are not full. The sensors are usually located inside the waste bins, but for measuring weight the sensor can also be attached to the collection car measuring the weight when the waste is being transferred from the waste bins over to the collection car. In addition to data concerning waste, GPS systems are used to gather data on the location of collection cars. Misra et al. (2018) states that precision of the ultrasound sensor is ~3.0 mm.

Transferring data can be accomplished by different communication and network technologies. Cerchecci (2018) utilized LoRa LPWAN technology to convey sensor data in real time from the waste bins and demonstrated that the transmission range for their prototype IoT node to gateway node was 1.1 km in the city center, while 2.7 km in clear sight between the nodes. Furthermore, 10 seconds was required for the transmission. Wen *et al.* (2018) uses a GPRS module to send data and information in real time from the collection car from on-board sensing devices (including weight data on waste and concerning the generator of the waste from the corresponding RFID tag) to a background server / control center. Misra *et al.* (2018) uses a Wi-Fi module to transfer sensor data from the waste bins to a remote server.

Wen *et al.* (2018) also developed a data management platform to which data from all on-board sensing devices are transferred and visualized to realize real-time management for decision makers. Misra *et al.* (2018) utilized an open-source application for data processing. Data is visualized in a mobile app and can be accessed to get a status update on the waste bins concerning gases and filling volume. Using a cloud server, applications for sensor logging, location tracking, and network of things can be created (Misra *et al.*, 2018).

4.2.1.1 Evaluation of the findings

In general, the articles show that IoT systems can be used to monitor the generation of waste, but their real effects on waste management and collection of waste are absent for the most part. All the IoT solutions permit collecting data concerning waste bin status with high degree of accuracy, but the outcome of the solutions varies from proof of concept to clear benefits for waste management from year-long operation. Clear benefits are demonstrated in the three year-long research of Wen *et al.* (2018) on current waste management practices and included better control of the sources to waste generation, better control of waste management regulations, and formalization of the complete waste management chain from waste generation to waste disposal at waste treatment facility. However, they also reported that the trustworthiness of the information was questioned by different government actors.

With the exception of the research conducted by Wen *et al.* (2018), none of the IoT monitoring solutions were utilized by waste collecting agents, and thus the solutions did not show to have any operational effect on waste management, other than presenting the possibilities for stakeholders. Nevertheless, the IoT solutions does permit data-driven proactive waste management (Wen *et al.*, 2018) based on the visualization and presentation of waste data, instead of the static collection of waste that is common in most cities and countries worldwide. For example, the solution by Misra *et al.* (2018) did provide information and visualization about the time of day when the waste bins are filled, so this information can be acted upon by waste management agencies to improve their logistics concerning collection of waste. Furthermore, the research of (Cerchecci *et al.*, 2018) gave valuable insights into range constraints of communication technology in IoT solutions in a city.

Both Wen *et al.* (2018) and Misra *et al.* (2018) states that their solutions can provide dynamic allocation of waste collection trucks, but this remains a task for future research and projects. Overall, it remains to be seen which measures can be put into effect automatically based on real-time monitoring, but the literature suggests that real-time monitoring with visualization can facilitate logistics and planning of waste collection and provide support to decision-makers. I postulate that the possibilities are much greater than what is presented in the current literature on Industry 4.0 technologies in waste management.

1.2.9 Artificial Intelligence for predicting generation of waste

To facilitate waste management services in urban areas according to continuously stricter regulations and strategies to improve waste treatment operations of MSW, data-driven projections of future waste streams are important (Abbasi and El Hanandeh, 2016, Kontokosta *et al.*, 2018). In Canada waste management operations varies between provinces and cities and there is a desire to replace some of the diesel used today for power generated with energy from waste (Kannangara *et al.*, 2018). To meet both these goals AI and ML have been used for predicting future waste generation.

Accurate predictions of upcoming waste streams can provide stakeholders with information to improve current waste management systems and to design new waste management systems according to future need (Abbasi and El Hanandeh, 2016). Indeed, data-driven approaches to forecast MSW have been published in more than 80 studies from 1970 (Abbasi and El Hanandeh, 2016). Development of existing and future waste management infrastructure relies on these estimations (ibid.). However, forecasting of MSW can be challenging due to the uncertainty of restrictions (Beigl, Lebersorger and Salhofer, 2008).

Forecasting of MSW can be characterized by how far into the future the forecasting is targeting and can in general be classified as short-term, mid-term and long-term. Artificial intelligence and machine learning are now being applied for improving predictions of waste, to tackle the problems at its roots (Abbasi and El Hanandeh, 2016). Kannangara *et al.* (2018) state that ML algorithms adjust model structure and parameters to fit data and hence are usually better at modelling complex non-linear behaviour than regression methods.

In chapter 2 artificial intelligence and machine learning were presented as data-driven modelling approaches. For predicting waste generation rich data about waste (type), the waste generators (socio-economic, population density, etc.), and about the conditions in which the waste is generated (weather, etc.) can be the basis of AI and ML modelling. Artificial intelligence models have shown to be applicable for forecasting with non-linear historical data (Abbasi and El Hanandeh, 2016). Artificial Neural Networks (ANN) have shown to be especially applicable in this regard capable of constructing predictions from non-linear input/output examples.

(Kontokosta *et al.*, 2018) integrated nearly 4 years' worth of data from five sources (daily waste collection tonnages, urban form, demographic and socioeconomic, weather and holiday) to estimate daily and weekly tonnages of three types of waste (refuse, paper and MGP). Training data from 2013 – 2015 were used to predict the waste generation in 2016 for 608 sub-sections in New York using machine learning. Specifically, gradient boosting regression tree (GBRT) was used due to their superior abilities compared to other ML methods well-suited for complex, non-linear relationships (Kontokosta *et al.*, 2018). Building level population was then estimated with small area population estimates.

(Abbasi and El Hanandeh, 2016) applied four different ML techniques, namely artificial neural networks (ANN), adaptive neuro-fuzzy inference systems (ANFIS), support vector machines (SVM), and k-nearest neighbours (kNN) to forecast monthly generation of MSW by using weight data on generated monthly MSW from 18 years.

Kannangara *et al.* (2018) used decision trees and artificial neural networks to build prediction models for predicting MSW generation and paper diversion of a given region in Canada. The data used in the prediction stemmed from cross-sectional residential waste data from 220 municipalities in Ontario in Canada for 9 years. The parameters used included the predictor variables socio-economic and demographic parameters.

Kontokosta *et al.* (2018) report that their machine learning predicting capabilities perform well for total waste generation, refuse, paper and metal, glass and plastic (MGP) for all 609 sub-sections of New York in 2016. For total generation of waste and refuse the model predicted accurate within 10 % of actual waste generation in 83 % of New York's 609 sub-sections. Important factors for the prediction model was weather variables (temperature, precipitation, etc.), population density, household characteristics and educational level. They validated their model by comparing their results with data from two individual routes for collection trucks and found that their predictions were accurate by 99.8 % and 93.9 % for predicting the total amount of waste collected (and thus generated) from buildings connected to the two routes.

Abbasi and El Hanandeh (2016) used monthly time series data of MSW generation (weight) from 18 years to predict the monthly waste generation in 2015 - 2020. 85 % of the data was used for training, 15 % for testing and 10% for validation. They found that ANFIS performed the best predictions (R^2 =0.98), followed by SVM (R^2 = 0.73), kNN, and ANN (R^2 = 0.46). Their prediction model suggests that the waste generation in Logan city in Australia will increase by 2020, adding 1,270 tonnes to the monthly value of average waste generation. With this information, it is inferred that the government should consider new ways of managing the increasing waste.

The results of (Kannangara *et al.*, 2018) showed that rich explanatory variables can build models that accurately predicts waste generation. They found that the prediction models using ANN were superior to the ones using decision trees, in which the former could predict generated MSW with 72 % accuracy from the sample data. For the paper however, the models predicted accurately at best 36 % from the sample data.

4.2.1.2 Evaluation of the findings

The ability to predict waste generation provides municipalities a unique opportunity to plan and optimize their waste management operations.

The high accuracy of the prediction models used by Kontokosta *et al.* (2018) can have significant positive impact on the waste management in New York, including reducing the cost of operation by reducing the number of collections and man-hours needed to fulfil the job. Furthermore, the model used by Kontokosta *et al.* (2018) can also predict which sub-sections of New York are inclined to classify waste into refuse, paper and MGP, and thus initialize targeted programs in boroughs suffering from poor waste handling. The research of

Abbasi and El Hanandeh (2016) did however demonstrate that different machine learning approaches have different success in forecasting MSW generation. The research conducted by Kannangara *et al.* (2018) demonstrated that poor data quality can have a strong negative impact on the predicting capabilities of ML and IA approaches.

Artificial intelligence and machine learning can likely be used for short-time predictions (one year ahead) when the data foundation is rich and consists of various predicting variables, as was seen in the research of Kontokosta *et al.* (2018). When predictions show to conform more than 90 % with reality concerning waste generation of a collection route, this information can potentially facilitate waste collection greatly in terms of logistics. As opposed to real-time monitoring presented and discussed in the previous sub-chapter, ML and AI approaches entail the advantage of less equipment exposed to wear and tear as large corporations offer ML and AI as services.

However, these approaches require large data sets for training with a high level of quality, so without these data the real application gains are less likely to appear. For urban areas, cities and regions where these data are lacking real-time monitoring can offer support to waste management stakeholders for planning and designing future waste management operations. In any case, ML and AI have huge potential in waste management and if adequate data about waste and waste predictors are present, these approaches can provide insightful information about future waste generation and subsequent measures to deal with it in an appropriate manner.

4.3 Improving waste classification using machine learning techniques

In the previous chapter it was communicated that collection of waste is of principal concern in many developing countries. Increasing waste streams, overflowing waste bins and littering pose immediate challenges in the form of pollution and harmful effects imposed on the public health. As a response, IoT solutions have been tested, some longer than others, with promising results to improve the logistics concerning collection of waste. Various machine learning algorithms have also been developed to accurately predict (although with varying success) the generation of waste in some developed countries with the aim to optimize collection and waste management services in general.

In most developed countries (and some developing countries), the focus is shifting from collection of waste to environmentally friendly treatment of waste according to the waste hierarchy presented earlier. Beigl, Lebersorger and Salhofer (2008) state that the amount and composition of waste generated comprise the basic information needed for the planning, operation and optimization of waste management systems. In this regard it is widely known that some form of waste separation is required for appropriate treatment, in which a high level of sorting is generally desired from an environmentally point of view. The literature review unveiled that research have been conducted to improve the separation of waste by different technologies, both at waste treatment facilities and in the setting in which the waste is generated.

In the theory chapter, an overview of current sorting techniques was presented. In developed countries, MSW recycling is facilitated by source separation at households for consecutive segregation at waste facilities using mechanical and optical sorting techniques. This way, the generated waste is sorted by collaborating efforts by inhabitants and waste treatment actors. Nevertheless, in many developed countries the recycling rates are still low and waste-to-energy operations are still the go-to waste treatment scheme.

The literature review showed that there is scarcity of publications on automatic waste segregation using Industry 4.0 technologies. However, there are a few articles on data-driven approaches for waste classification and characterization for which environmental concerns and cost reduction possibilities are reasons behind the research (Chu *et al.*, 2018).

1.2.10 AI and ML for waste classification

The literature review showed that there is a scarcity of publications on waste segregation using Industry 4.0 technologies. In general, the interest in waste sorting technologies (supported by Industry 4.0 technologies or not) is low and lower than for collection of waste. There are however a few articles on data-driven approaches and technology for automatic sorting of waste. Many countries are struggling with inefficient waste management schemes, in which wastes are being disposed of at landfills or incinerated without further considerations. If recycling is an option, then it is usually dependent on manual waste sorting beforehand or superficial sorting into major waste fractions like paper, metal, glass, and others (Gundupalli Paulraj, Hait and Thakur, 2016, Bonello, Saliba and Camilleri, 2017). People who perform manual sorting of waste are subject to unwelcome work environment and potentially various health effects from being in contact with waste on a daily basis (Sudha *et al.*, 2016). Consequently, countries are enforcing stricter regulations concerning waste treatment to remedy the serious consequences imposed on workers and the environment due to landfills.

The most recurring approach to facilitate waste separation was the use of automatic waste classification methods resulting from image processing. In this regard machine learning and artificial intelligence are proposed to improve the classification. Ruiz *et al.* (2019) state that current computer vision for waste separation are oriented towards object detection and classification using image analysis techniques, which consists of the three steps of segmentation, feature extraction and learning and classification. Classification of images are often based on convolutional neural network model or deep learning. Vrancken, Longhurst and Wagland (2019) state that CNN usually are trained with large dataset of labelled images, with many examples of each classification category. The trained CNN is then tested with new and separate images within the waste categories.

Ruiz *et al.* (2019) trained and tested different CNN models for classifying six different types of waste (plastic, metal, cardboard, paper, glass and general trash) and accomplished 88.6 % accuracy on average. Deep learning in combination with CNN were compared with SVM for classifying waste into three categories (plastic, paper, and metal) in the research of Sakr *et al.* (2016), who found that SVM could achieve classification rate of 95 % while CNN could achieve 83 %. Chu *et al.* (2018) used a multilayer hybrid deep learning technique, combining images in addition to sensorial data, for classifying waste into 6 categories (paper, plastic, metal, glass, biodegradable and others) and obtained accuracy rates above 90 %.

4.3.1.1 Evaluation of the findings

Overall, the accuracy rates for ML approaches for classifying waste obtain high degree of precision. However, the reviewed articles are mostly proof of concept papers with limited experiments, and none of the reviewed papers have results from operation in a waste treatment facility. With the exception of Sakr *et al.* (2016), time constraints are also missing from the evaluation, which would be an important factor for real-time classification with subsequent sorting of waste. In addition to accuracy in classification, the prediction models must analyse the data rapidly so that the physical motion of removing waste objects can keep up with the necessary speed for separating waste.

Most of the reviewed research is concerned with a few classification categories only, hence the classification is not necessarily matching the requirement for homogeneous waste streams intended for recycling. However, if waste is subject to a high degree of source separation previous of the automatic separation at waste facilities, the easier the classification and subsequent separation.

Automatic waste classification by ML and AI approaches have just started to emerge, but they are likely to facilitate waste management processes by a great deal. The reviewed literature failed to link the classification with consecutive separation and hence, no examples of automatic response to analysis by ML are provided. The link between classification and segregation will be an important research field in the future, especially how analysis, which happens in cyber-space, will lead to the physical action of waste separation, moving towards cyber-physical waste treatment systems.

4.4 Exploiting data stored in WEEE introduces new possibilities

The findings from the literature review have so far focused on common waste, and how some Industry 4.0 technologies can be used to gain more information about the generation of waste, collection of waste and classification of waste, which are crucial activities for proper waste treatment. In addition to these applications, the literature review provided some unique findings of Industry 4.0 technologies for managing waste electronic and electric equipment (WEEE), exploiting the data that is already stored in smart products and other electric waste in the form of RFID tags, and other identifiers. This research have also moved the ideas and possibilities of WEEE management from "means to an end" to new business opportunities, drawing on the ideas of smart factory and CPS in that the (waste) object can communicate with the waste treatment systems, and decide on the proper WEEE treatment in unison.

1.2.11 WEEE management is approaching cloud manufacturing

Waste Electrical and electronic equipment (WEEE) has experienced a massive increase in recent years due to a decrease in product lifecycle of many EEE products. Furthermore, when EEE products stop working it's most cost-effective for the consumer to dispose of them and buy a new products instead of repairing them. Despite the increasing rate of WEEE generation, the recycling rates are low which calls for strategies for improved management and control (Vincent Wang *et al.*, 2015). To succeed with WEEE management an intelligent recovery and recycling system must be developed, based on material and functionality levels (Vincent Wang *et al.*, 2015).

Treating waste from electronic and electric equipment (EEE) poses both some unique challenges and opportunities. The identified application area for industry 4.0 technology in this context rely on gathering data electronically stored in the waste itself, allowing for more accurate waste segregation. In a broader sense, the identified application area showcases and demonstrates how modern technologies can innovatively improve upon the waste management process.

Waste electronic and electric equipment (WEEE) pose a threat to the environment and public health if not treated appropriately at their end of life stage. Cloud solutions and cloud manufacturing are emerging as possible solutions to facilitate WEEE treatment by exploiting the information that is already stored in several electronic and smart products today. Disassembly of WEEE is a labour-intensive activity, so automation of this process is likely beneficial. The waste hierarchy is also valid for WEEE, for which especially re-use is emerging as a facilitated by the technologies embodied in Industry 4.0 In addition, WEEE that can be repaired and put back in the market are also more valuable than the stripped materials from disassembly and recycling operations. Thus, there are business opportunities present in addition to environmental gains.

Due to the increase in embedded sensors in EEE and tags containing information, e.g. RFID tags and QR codes, information relevant for assigning the appropriate waste treatment method, and ultimately its fate, can also be stored on the specific device. Sensors and microprocessors in smart products can measure, collect and process data about how it has been used and the overall state of the product once it has reached its end of life in the eyes of its current owner/ user. In RFID tags and QR codes, information about its production, material composition etc. can be stored. When this EEE becomes WEEE and enters the waste facility, the stored information can then be retrieved and communicated to the facility automatically. Are they fit for re-use, repair, material recovery or something else?

In the research of Jiang *et al.* (2019) a cloud-based recycling system is developed based on smart product ontology (SPO) in which data from beginning of life and middle of life are integrated to create a virtual representation of the physical object. This data is then analysed, and fuzzy rules (machine learning) are applied to decide if the object is intended for reuse, remanufacturing, material recovery, incineration, landfill and special handling (classification). To respond to this information in an appropriate way, waste treatment facilities' abilities are also virtualised. The proposed fate of the WEEE and available waste treatment services can then be accommodated by assigning recycling resources by grey-relational-analysis (GRA) (Jiang *et al.*, 2019). Different recycling resources have different characteristics which affect the outcome of the waste treatment, such as cost, the quality of the service and environmental effects which can also be taken into consideration by GRA (Jiang *et al.*, 2019).

For managing the end-of-life treatment of WEEE Vincent Wang *et al.* (2015) develops a waste data management system, called WEEE recovery/ recycling Cloud (WR2Cloud). As presented in chapter 2, cloud technology offers scalability, on-demand services and customization. The cloud concept has also traversed into manufacturing, for which the concept of cloud manufacturing has evolved. Cloud manufacturing in this context then offers scalable, on-demand access to digital and physical manufacturing services.

Using a virtual representation of a robot vacuum cleaner as test object, fuzzy logic and GRA, Jiang *et al.* (2019) showed that their system is able to decide upon WEEE treatment scheme and to assign recycling resources to the decided WEEE treatment. WEEE treatment was decided from fuzzy logic analysis from data about the condition and material composition of the robot vacuum cleaner, and recycling resource was assigned based on various criteria using GRA. Overall, it is demonstrated that disassembly is not necessary for taking a well-informed decision about waste treatment if information can be read and processes rapidly, also considering environmental and cost restraints.

Cloud solutions can provide support to management of waste flows, e.g. as virtual depository (Vincent Wang *et al.*, 2015). The cloud system developed by Vincent Wang *et al.* (2015) was able to distribute WEEE in the waste treatment chain according to the waste constituents. They showed that by using the cloud, customers, users and other stakeholders can gain information about the WEEE at waste treatment centres which means that the market for secondary raw material can become more predictable and trustworthy. An integrated and unified data sharing/ management mechanisms is an important prerequisite for recovery and recycling services. With cloud databases, information about the WEEE can be retrieved continuously. Vincent Wang *et al.* (2015) suggests that a cloud-based approach to support recycling activities can include evaluation of best treatment scheme based on information about the WEEE product's constituents. Identification of substances' material flow can be achieved and monitored using cloud.

4.4.1.1 Evaluation of the findings

The literature review disclosed that research on Industry 4.0 applications for separation of waste is especially advanced for waste electronic and electric equipment (WEEE) compared to MSW and other forms of waste. One of the reasons behind the research is new business opportunities. The research described here integrated various ideas relevant for Industry 4.0.

The most striking compared to management of common waste (or MSW) is the potential brought about by identifiers on smart object and EEE, which are bringing WEEE management towards smart factories and Cyber-Physical systems. In the research of Jiang *et al.* (2019) the communication and negotiation capabilities of CPS were proposed. Overall, this means that WEEE management have a potential advantage in the execution of waste management, as many EEE products are likely fitted with identifiers or embedded microcomputers in the future.

However, the research is still at proof-of-concept level, as is the case for most of the findings of this literature review. The applicability of the proposed solution presupposes certain conditions, e.g. standardization or cooperation between electronic product manufacturers. This need not hinder waste management actors wanting to explore the technology, but it will most likely take some years before the potential is fully realized.

4.5 Final thoughts on the findings from the literature review

From the superjacent text it can be inferred that Industry 4.0 technologies have been applied to waste management and that the potential gains are huge, especially in monitoring and predicting waste flows. In common for all the reviewed articles is the perception that data and information about the waste is necessary to make sound decisions and improve waste management in general, now and in the future. Thus, a data-driven mindset is important when utilizing these technologies.

Clear, operational gains are for the most part absent in the literature. The majority of the reviewed literature present proof-of-concept use-cases of technologies relevant for Industry 4.0, but most of them have only been tested in small-scale experiments or by prototypes. Hence, there might be serious challenges associated with the solutions, which will have major impact on the overall success of the solutions if they were to be implemented, e.g. the solutions robustness in their operation environment, and how the solutions affect the waste collectors and vice versa. The presented technologies and applications cannot operate separately from human interaction, thus the affect they will have on workers in waste management is also an aspect which deserves attention.

The findings presented in this chapter will now serve as basis to study waste management practices in Oslo, the capital in Norway. Special focus is on data, as the presented applications of Industry 4.0 technologies in waste management are all data-driven.

5 Waste management practices in the municipality of Oslo

To what extent is the municipality of Oslo taking advantage of the industry 4.0 technologies that have the potential for improving waste management? What potential is left untapped? This chapter seeks to answer these questions by presenting the findings from the conducted case study.

The previous chapter presented application areas of Industry 4.0 technology in waste management. Monitoring and predictions of waste generation and improved identification of waste constituents were identified as major application areas. In the subchapters that follow, the current practices of the municipality of Oslo is analysed and discussed in the context of these findings.

5.1 Collection of waste

In this part of the analysis I will evaluate the application potential of Industry 4.0 technology for collecting waste in Oslo. The case will be analysed considering theory (chapter 2) and the literature review (chapter 4). In chapter 4 application areas of Industry 4.0 technology in waste management was presented based on a systematic literature review. This review showed that the most researched step in the waste management is regarding waste collection. To this end, efforts are made in the area of monitoring the filling levels of waste bins using various technologies such as sensors, RFID tags, IoT and cloud solutions to facilitate collection based on current need. Another researched approach entail predicting or forecasting the waste generation based on weight data. Both approaches show promise, and the municipality of Oslo have in fact attempted to do something similar.

When asked about what data the agency for waste management are currently in possession of, and are acquiring, it became known that they have a system capable of monitoring the generation of household waste in Oslo at household level. This system was acquired in 2016 when a new fleet of collection cars were put into operation.

The system comprises RFID tags attached to the waste containers located outside people's homes, RFID readers attached to the collection cars, in addition to built-in scales in the lift mechanism on the collection cars. For each emptying which is performed by the collection car, the system registers the location (the household), point of time, and the weight of the waste container's contents. Furthermore, the agency knows the location of each of the collection cars and when they are filled up.

The generated data from this system was intended for further analysis to improve the waste collection in Oslo and to facilitate target measures for certain neighbourhoods where source separation of household waste is not satisfactory.

However, the interviewee could further inform that the system proved to be challenging in many ways. They experienced that waste bins could be misplaced during the collection, which means that future data about that waste bin would result from the wrong household, in which case the usefulness of the data would decrease. Other issues revolved around the weight scales which in the beginning required manual start-up. This issue was later fixed, but there was still a problem with periodical failures. In total, these issues resulted in useful data amounting to 30%.

Then there was a change in the organization of the waste collection, which have been subject to tendering for the last 20 years. When the system was first purchased in 2016 it was under organization of Veireno, a privately-run company. But after they went bankrupt after 6 months, the waste agency decided to assume responsibility. At this point waste collection in Oslo was dissatisfactory, and many households experienced overflowing waste bins. The system had not resulted in the expected gains, and collecting waste based on the monitoring system showed to be unsuccessful, to which the interviewee stated:

"We haven't really had the competency to operate a department like that, so we've been working on building it. In the meanwhile, it's been little focus on the system with automatic registration, so it has sort of been running on its own. In addition, we have had to purchase new collection cars, because we didn't have enough, and these are older cars without the monitoring system. The monitoring system haven't been prioritized on the new cars and so we haven't got good data."

This statement is very interesting in that it reveals several new and highly relevant factors to consider in realizing the desired benefits, and ultimately the success, by using such a monitoring system. The findings from the literature review showed that the technology and monitoring systems works well in the controlled environments in which they are operating in, and also for the three-year study by Wen *et al.* (2018), and concludes in general with adequate monitoring, and concludes with success.

However, the operation of the monitoring system in Oslo represent various challenging factors, e.g. that waste bins are put back incorrectly (e.g. to the neighbour's house) and occasionally non-functional weight scales. These factors amount to a certain degree of uncertainty in the collected data considering the *true* waste generation at household level, in that the data concerning weight can be missing, or that the waste being emptied is registered to the wrong household, or both.

Processing and mining of data can lose some of its potential value if they do not represent the actual conditions to which they are supposed to represent. However, uncertainty in the data doesn't automatically mean a deal-breaker, and the data can likely generate information about neighbourhoods or regions in Oslo, and thus still holds great potential for improving the collection route. Nonetheless, these aspects are not widely represented in literature concerning monitoring systems of waste generation.

During the interviews I also asked about the importance of better waste utilization, from which one of the interviewees could provide the following answer: "… we need much more control of our value chains… so one thing we're looking at is fastening cameras on the rear of the collection car which films continuously the waste and use machine learning to recognize foreign objects, see the amount of blue and green bags in each emptying. This way be gain better control of the value chain and we can inform the responsible household and inform them about their source separation and also compare with the neighbour." "There are many things that happen from the green bags are thrown into the waste bin until they arrive at the biogas facility in Nes, so to improve those processes we have to monitor the value chain continuously. I think that's very important."

Similar solutions as those described by the interviewee were not found in the literature review, which might suggest that the municipality of Oslo has come a far way in regard to technology utilization and innovation within waste management. The solution has not yet been implemented however, and relies on the usage of specially coloured bags, that might be replaced when the municipality later replaces its waste treatment facility.

5.2 Automatic waste identification and consecutive waste separation in Oslo

In this part of the analysis I will evaluate the application possibilities of Industry 4.0 technology for identification of waste in Oslo. From the literature review it was revealed that the first priority in waste management is to collect waste. From there on, landfill or incineration are common methods to “deal” with the waste. However, serious health risks imposed on those who work with waste and new business opportunities to sell materials inherent in the waste are motivating actors to improve the separation processes. In this regard, source sorting of waste is an essential activity for which research show that various machine learning techniques can be utilized for waste classification, with potentially very accurate classification algorithms. However, the reviewed research failed to show how these techniques can be utilized for tonnes of waste, which is what waste treatment facilities must deal with. Moreover, the reviewed research did not show how the automatic classification had and effect on the physical sorting of waste (direct or indirect). In comparison, the automatic separation currently in operation in Oslo is highly efficient.

After the waste has been collected by the Agency for Waste Management it is delivered at one of two sorting facilities in Oslo. The waste is tipped onto slowly moving bands which lead the waste further into the facility, through various mechanic sorting operations to remove foreign objects from the waste stream, including contents of bags that are ripped apart or which are otherwise loose on the conveyor belt. This mechanical sorting results in objects of a certain size and consistency is removed from the moving waste stream. The remaining bags are then subject to optical sorting. A camera reads the colour of all passing bags, and if “special green” or “special blue” bags are detected, a shovel moves across the conveyor belt. This movement leads to the creation of two separate waste streams in addition to the original waste stream consisting of only “special blue” bags in one and “special green” bags in the other. This knowledge was attained when I visited the sorting facility at Haraldrud in October of 2018. The removed blue bags then go through an additional separation step, in which an air jet ensures that bags heavier than 600 grams are removed from this waste flow. This piece of information was provided during the visit and confirmed again at the interviews.

Knowing the general procedure of the optical sorting, I was curious to know the features about the data they are currently collecting and how this is put into use. For that reason, I asked the interviewees from the Waste-to-Energy Agency about the data which they are collecting today about the waste and waste management process. It was revealed that most of the gathered data concerns operational aspects of the facilities (which, for the most part, were low-level noisy data and data that they are legally required to collect), and that little data is collected concerning the actual waste which is processed at their facilities and under their responsibility. To be specific, the current waste-related data which is collected is (1) the total weight of the waste that is delivered to the sorting facilities, and (2) the number of special green and blue bags in the waste flow on the conveyor belts. The former is performed by weighing, and the latter by automatic counting of shovel movements across the conveyor belt, in which one movement corresponds to one bag being removed.

A first step in improving the sorting of waste would be to introduce technology or other methods to detect more of the actual contents in the bags. Today, the current sorting procedure is relatively accurate relative to colour of the bags, although one interviewee could reveal that the contents of the bags affect the detected colour which is read by the sorting robot. Nonetheless, even with 100% accuracy in sorting of special blue and green bags the actual sorting of the wastes' constituents is at best as good as the source separation at households. In addition, there is wastage in special blue bags, in that bags of a certain weight are put back into the general waste stream, then treated as residual waste (which is processed by incineration for waste to energy). Overall, this means that the data characteristics today are likely of such an immature nature that machine learning and other measures such as data analytics are excessive at best.

Once a year, the actual contents of the waste is analysed manually by the Agency for Waste Management. These show that the waste streams generated after the sorting has taken place do not accurately reflect the actual waste fractions in the household waste generated in Oslo when compared to the yearly manual analysis. When asked about how the waste data is processed and used one of the interviewees from the Waste-to-Energy Agency stated that: "We know that our data is of lower detail than what is gained from the manual analysis, and that there is a discrepancy. Today these data cannot be used interchangeably. We've now learned that it is difficult to initiate the appropriate actions before we get better data."

When I then asked about what information and data which they seek to acquire in the future about the waste I got the following answer: "We have no future plans other than to continue with counting bags and manual waste analysis". This response leads me to believe that the Waste-to-Energy Agency are somewhat ineffectual based on their lack of action concerning current information, knowledge and experience that they hold about the waste and processes. They are aware that they have periodical issues with emissions due to foreign material in the waste stream, but they are still not planning on changing the way in which information about this waste can be collected.

Further into the interview it was revealed that both the sorting facilities and incineration facilities are reaching their final days. It was also explained to me that the Waste-to-Energy Agency are in the early stages of acquiring knowledge about how to replace the current facilities, and about more powerful technology. I then followed up with questions about desired capabilities and desired information about the processes and it was stated that: "Composition analysis to determine if its organic or inorganic would be beneficia for feed forward regulation, so instruments that analyse the waste when it is entering the facility... Today we measure the smoke gas and regulate after that".

Its thus evident that better control of the waste's composition is desired for managing the incineration process and remedy certain problems with emissions. Previously in this chapter, various other methods and technologies for identification and consecutive sorting of waste was discussed. Everything taken into consideration there are various mechanical and automatic methods to do just that, all of which have the potential to improve the current waste sorting procedures by a fair amount.

Industry 4.0 can potentially provide an add-on bonus and overall lead to more detailed information about the waste, but these technologies would then require massive amounts of data about the waste. To this, I did not get the impression that there is special interest in the waste's composition other than to improve the control of the incineration process. This impression was strengthened after the second interview with another interview from the Waste-to-Energy Agency who, upon asked about desired information about the waste, stated that: "It would be interesting to know what waste is being incinerated, because today we only know the incineration values." Upon question about desires to learn more about the actual waste flow in Oslo the interviewee stated that: "The Agancy for Waste Management are in charge of the waste collection. We deliver a service to them in which we accept the waste that is delivered. So, for us it's irrelevant for us what we get. We must deal with it anyway."

To this end, the Waste-to-Energy Agency have extensive potential to improve segregation of waste by using less data-dependent technologies and improve sorting of waste without going to the data acquiring lengths that Industry 4.0 technologies require.

The theory chapter and literature review have demonstrated that Industry 4.0 technology in general and data analytics for valuable information depends entirely on data from the processes which are of interest. However, if waste is being analysed thoroughly by different automatic data generating means, e.g. spectroscopic methods to determine chemical structure, or photo analysis for shape detection or surface detection, or weight measurements of batches, then data analytics such as machine learning can be utilized for improving identification algorithms. However, if these technologies are to yield fast identification in addition to accurate identification, the waste is likely subject to certain pre requirements concerning homogeneity. Machine learning for instance requires heavy training from data sets.

The waste sorting, which is carried out today are in real-time, but the sorting is limited to the colour of the waste bags, and not actually what the bags contain. The current sorting and ambition presented is thus nowhere near the possibilities which are depicted in literature. My impression is that the agency dealing with the waste are not particularly interested in the waste other than how the waste affects the incineration process. The level of ambition in waste management activities shown are low in comparison to the waste hierarchy presented in the introduction.

5.3 Digitalization initiatives

The municipality of Oslo has launched a large-scale digitalization strategy to improve their services towards Oslo's residents. To that end "Oslo Origo" was launched in 2017 to be the driving force behind this commitment. Their mission is to facilitate faster development of personalized services for Oslo's residents, with high degree of accuracy and proactivity. A stated goal of the digitalization strategy is that Oslo's residents shall meet with one unified municipality when they are in need for services, where all necessary information and proposals are collected in one place. One interviewee could inform that execution of this commitment depends on integration of data from the different departments, which will be accomplished by building a collective data platform. The data platform will contain all relevant data necessary to develop new digitalized services. From this data platform some information will be made accessible for external users too, so that the municipally will succeed in becoming more transparent.

Because of the municipal digitalization strategy, a subordinate project, the Big Data project, was initiated in the agency for waste management to make use of their digitalization ideas, specifically about exploiting their massive amount of data. One interviewee said that:

"I visualize the data laying nicely next to each other in the platform, and next to our data is data from EGE, Bymiljøetaten and so forth. It's still a while until we're there, but that's the vision. I think that the possibilities are unimaginable and that's sort of what the Big Data project is about."

The Big Data project is one example of projects that has resulted from the municipality's digital strategy, but there are other initiatives too which are directly linked with infrastructure. For fast, integrated and digital services the data must be collected fast too. The municipality realized this a few years ago, and in 2016 they started working on establishing highspeed internet between all their locations.

High-speed internet is one of the prerequisites of Industry 4.0 in general (see theory), but also a necessity for the technologies. Considering the massive improvement of digital infrastructure then, Industry 4.0 is technically a possible reality.

5.4 Structural challenges

EGE are responsible for treating the municipal waste, but they are not free to set their own operating frame – this is decided by The City Council. They set the economical frame of how they are supposed to reach decided recycling targets. In addition, EGE are bound by a cost recovery principle which means that they cannot operate in the traditional commercial market as other would do, and this put strains on how they can earn money. Furthermore, EGE's main task is to incinerate waste to energy, which is stated in their name, and this also what they make the most money from doing.

Technology implementation is to a large degree dependent on the overall business strategy to achieve its ambitions and goals. In this regard technology's role is to facilitate reaching these goals. The municipality of Oslo has many diverse goals and ambitions, becoming more sustainable being one. In the agency for waste management the parent strategy and ambitions transform into specific sub-goals and tasks, which currently is to deal with the municipal waste in a way that makes the best use of its resources.

It was previously shown that there are various applications of Industry 4.0 technology to improve waste management: more efficient collection, improved separation of waste constituents, and better control of specific recycling operations. However, the realisation of these applications in management of municipal waste in Oslo depends on the department's plans and strategy to reach their goals; The relationship between technology and strategy was presented in the theory. For this reason, the interviewees were asked about their department's current plans, goals and strategies.

Concerning current plans, it was revealed that the incineration facilities are to be exchanged in 2030 and changes are pending for the current sorting robot Bagsy, which is responsible for separating blue, green and regular waste bags from each other. One interviewee stated that: "We think that by 2030 the need and requirement to sort differently and more will be present, and also technology that is better and more impactful". When asked about specific plans to accommodate the pending requirements for improved waste segregation, one interviewee stated that:

"It's in the very early stages. First of all, instruction must be received from city hall."

When asked how far along their planning of new segregation solution was, one said that:

"I don't think that is started up yet. I know that the EU requirements are coming, so I expect it will be coming soon. A normal project in that dimension takes about 4- 5 years, so somebody should probably start thinking about it soon if it is to be ready by 2024."

When asked how they facilitate for circular economy and resource effective waste treatment one person said that: "We are building competency now about what we know is coming. We have some parent strategic people which are working with the city hall, but people who work in the technical department must have focus on what we are supposed to do, which, first and foremost, is the allocation letter. This is what we must do. We are supposed to operate this facility most efficiently. We operate on direct cost of the citizens of Oslo and we have as goal to reduce the contribution to the fee, because all the money that we earn goes straight back to the cash register and all the money we use goes straight out of the cash register.”

Another stated that “we’re steered mainly by two things: the law and permissions issued by the county governor which sets the conditions for the facilities: You must do this. And targets for recycling. We try to choose technology which facilitate these goals. There are things we can suggest out of scope of these things, but it is usually enough with staying afloat. CO2 is one thing, fly ash another, biogas, bio fertilizer is all new stuff. We learn as we go along.”

6 Discussion

What potential does the technologies embodied in Industry 4.0 hold for the management of municipal solid waste in Oslo? This problem statement has guided the research which has been presented in the previous chapters. It has been shown that there are in fact several application areas that hold relevance for waste management, and that these should be considered by the municipality of Oslo.

In this final chapter, the findings from both literature review and case study will be discussed and summarized.

6.1 Summary

In this thesis I have investigated the application potential of Industry 4.0 technologies in waste management. I did this by performing a literature review on Industry 4.0 technologies in waste management and using these as basis for evaluating the municipality of Oslo.

The literature review resulted in a record of Industry 4.0 applications in waste management, in which the most research have been conducted in relation to collection of waste. In this regard, there are promising monitoring solutions emerging from the use of IoT systems. In addition, machine learning techniques are being used to predict the generation of waste. These two applications are both intended for improving the logistics concerning collection of waste, the former to actual need and the latter to optimize the collection route.

For the later stages in waste management, the research is scattered. There is however some research on using machine learning for identification and classification of waste in an effort to improve waste segregation. However, the review failed to produce findings connecting the classification to physical separation, so this is still a step which calls for more research.

6.2 Roadblocks for the municipality of Oslo

During the duration of research, several observations were made concerning how the municipality of Oslo is working towards improving waste management, and what challenges lay ahead. The more prevalent observations will be presented here.

1. Poor data quality

Research shows that poor data quality can have a strong, negative impact on the predicting capabilities of machine learning, and curtails the overall value of the data gathered (Kannangara *et al.*, 2018). Several of the people interviewed stated that much of the data gathered today has poor quality, making them less likely to trust it. Improving the quality of gathered data should be highly prioritized going forward, if the municipality is to succeed in gaining positive results from technology utilization.

2. Limitations of current system

The current system for waste management in Oslo relies on using special blue and green bags for sorting plastic packaging waste and food waste, respectively. The waste management facilities sort these bags using cameras. Even with 100 % accuracy, the actual sorting of the wastes' constituents is at best as good as the source separation at households.

3. Misalignment of goals

Goals was presented in the theory as what an organization strives to accomplish. A strategy is usually derived to reach the established goals. During the interviews it became clear that the Waste to Energy Agency's primary goal is energy recovery from waste, which was brought up multiple times during the interviews with employees from the Waste-to-Energy Agency.

When asked about what knowledge or information they wanted about the waste in the future, composition analysis of the waste was mentioned. But it was clarified that this information would benefit the incineration process. The other waste-products (biofuel or biofertilizer) were not mentioned specifically. At last, the name of the department, the Waste-to-Energy Agency, underlines where the apparent ambition lies.

If the current strategy and goals for the waste-to-energy agency are disregarded, it is evident that Industry 4.0 technology can facilitate better control of the waste stream and better sorting of waste, which can lead to much more homogenous waste streams towards the intended waste treatment operations, which also means a cleaner incineration process. If the goals don't change to accommodate the waste hierarchy presented in the introduction and theory, then it is unlikely that the recycling rates will improve.

6.3 Conclusion

To address the thesis' problem statement, two research questions were formulated:

3. What are the application areas of Industry 4.0 technologies for waste management?
4. How is the municipality of Oslo applying Industry 4.0 technologies for managing municipal waste?

The literature review produced several findings relating to how Industry 4.0 technologies have been used within waste management. These application areas have been described in the previous chapters, alongside comments and reflections. The areas identified are as follows:

- IoT solutions for real-time monitoring of waste generation
- The use of artificial intelligence for predicting waste generation
- The use of artificial intelligence and machine learning for waste classification
- Exploiting data stored in waste electronic and electric equipment (WEEE) for classification purposes

The case study found that the municipality of Oslo has implemented an IoT solution for monitoring waste, but that they have faced several obstacles that have made it hard for them to realize appreciable gains. The other application areas identified have not been put to use.

The municipality has started several digitalization initiatives, including a project on big data analytics. Furthermore, they are gradually improving their ICT infrastructure, which should enable them to proceed with even better solutions. Some identified challenges, e.g. poor data quality, should however be addressed when moving forward.

It is the author's opinion that the municipality should consider adjusting its goals and organizational structure to have a better alignment with the principles of a circular economy. The waste hierarchy dictates that most discarded products should be reused or recycled, not incinerated for energy recovery. The agency responsible for treating waste, the *Waste-to-Energy Agency*, does not seem to be incentivized towards this goal. Further application areas for industry 4.0 technologies within waste management are sure to be discovered, and the municipality seems eager to exploit new technology – it is crucial then that these technologies are put to good use.

6.4 Suggestions for further research

From the findings in this thesis it would be beneficial to map the organization and execution of MSW management in other municipalities in Norway and relate this to the waste hierarchy. What are the goals and plans in other municipalities? What measures do they think are important to reach higher recycling rates and facilitate reuse and work towards prevention of waste? If these answers could be given, it would provide the public and authorities with 1) current practice in waste management in Norway and 2) what accomplishments they are associated with. Hopefully, these answers can illuminate the likelihood of Norway reaching the ever-stricter waste treatment targets set by the European commission. In addition, these findings could unveil a gap between the level of automation and technology implementation in Norway compared to other countries, for I suspect that waste treatment operations in Norway and other similar countries are much more advanced than what literature have revealed during this thesis.

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7 Appendix

Table 3 12241: Household waste. Key figures, by region, contents, and year. (Statistics Norway, 2019b)

	Household waste per capita (county and country) (kg)				Sent to material recovery incl. Biological treatment per capita (county and country) (kg)				Sent to recovery incl. Biological treatment and energy use (per cent)				Share of household waste sent to material recovery incl. biological treatment (per cent)				Share of household waste sent to incineration (per cent)				Share of household waste sent to landfill (per cent)			
Year	2015	2016	2017	2018	2015	2016	2017	2018	2015	2016	2017	2018	2015	2016	2017	2018	2015	2016	2017	2018	2015	2016	2017	2018
EAK Landet	439	433	426	…	166	165	166	…	82.4	82.8	82.8	85.4	37.9	38.1	39	41.5	57.8	58.1	56.9	56.4	3	2.8	3.2	1.6
EAK UO Landet uten Oslo	454	449	441	…	171	171	172	…	82.3	82.7	82.7	85.6	37.8	38	39	41.9	57.8	58.1	56.8	56	2.9	2.8	3.2	1.5
EKA 03 Oslo	336	327	324	…	130	127	128	…	83.4	83.7	83.8	84.4	38.8	39.0	39.4	38.2	57.9	58.0	57.6	59.2	3.3	3.0	3.0	2.5

7.1 Interview Guide

DATA

Hva har skjedd

Hvordan har datainnhenting om avfall og prosesser endret seg gjennom årene?

- Hvordan ble det gjort før og hva var det man ønsket å vite?

Var det på eget initiativ eller lovmessig bestemt?

Status

Hva slags data samler dere i dag om drift/maskiner/ avfall?

- Altså hva er det som måles og overvåkes angående det operasjonelle og om avfallet?

Hvordan samles dataen inn?

Hvor ofte måles det og hvor ofte samles dataen inn?

- Kan du «walk me through it»?

Hva brukes dataen til i dag?

- Hvis hjelp: overvåking av maskinhelse

Hva gjøres med dataen? (blir den lagret? Hvor)

Blir den behandlet på noe vis? Hvor?

Hvordan er denne dataen nyttig i dag?

Hvis hjelp:

Har denne dataen/ informasjonen påvirkningskraft på avgjørelser for fremtiden og planer generelt?

- Hvorfor/ hvorfor ikke?
- Hvordan?

Påvirker denne dataen/ informasjonen nåværende drift?

- Hvis ja, hvordan da?
- Hvis nei, hvorfor ikke?

Påvirker denne dataen/ informasjonen fremtidige planer om drift?

- Hvis ja, hvordan da? (For eksempel krav til fleksibilitet eller flere sorteringsmuligheter?)
- Hvis nei, hvorfor ikke?

Påvirker denne dataen/ informasjonen fremtidige planer om økt utsortering?

- Hvis ja, hvordan da?
- Hvis nei, hvorfor ikke?

Fremtiden

Hvordan ser du for deg at denne dataen kan være nyttig i fremtiden?

Er det en type data/ informasjon eller kunnskap dere gjerne skulle hatt om anleggene/ prosesser/ maskiner som dere ikke har i dag?

Har dere konkrete planer om å implementere teknologi for å få mere kunnskap om avfallsstrømmen i dag eller i fremtiden?

Har dere konkrete planer om å implementere teknologi for å få bedre oversikt over driften av anleggene?

Utvikling av anleggene

Hva har skjedd før

Hvilke kriterier skulle imøtekommes når ettersorteringsanleggene ble bygget?

Hvor lang tid tok det fra planlegging til åpning?

Har det skjedd forandringer på anleggene siden åpning og til i dag som har ført til forbedring av drift eller økt materialgjenvinning?

Status

Hvor lang levetid har ettersorteringsanleggene, og de forskjellige forbrenningsanleggene og biogassanleggene?

Kan de skaleres opp eller ned som følge av visse kriterier (f.eks. avfallsmengde osv.)? F.eks. hastighet? Eller tilpasse det på noe vis, f.eks. strømpris?

Hvordan utvikles anleggene i dag?

Hvordan jobbes det med å få optimalisert drift?

Har dere ellers noen utfordringer? (f.eks. flaskehalser, effektivitet, nedetid, vedlikehold, strømforbruk etc.)?

Hvordan jobber dere for å løse disse utfordringene?

Hvordan jobber dere med å utvikle og endre sorteringsanleggene for å sikre at avfallet får den mest ressurseffektive skjebnen?

Fremtiden

Helt konkret – hvordan skal dere nå målet om 50 % materialgjenvinning innen 2020?

Og hva med i fremtiden? Det ligger an til at krav om resirkulering blir høyere?

Hvilke andre kortsiktige og langsiktige planer/mål har dere for drift av anleggene?

Hvilke andre kortsiktige og langsiktige planer/mål har dere for EGE?

<u>Om avfallet</u>

Stutus

Hvordan måler dere avfallet som kommer inn til anleggene (masse eller volum)?

Hvordan måler dere avfallet som prosesseres i anleggene (altså masse eller volum)?

Hvordan måler dere andel avfallstyper?

Kontrollerer dere innholdet i posene/ avfallet generelt opp mot mengden som leveres til anleggene?

- Hvis ja, hvordan?
- Hvis nei, hvorfor ikke?

Hva gjøres med denne dataen? Blir den lagret eller bearbeidet på noe vis? Hvor skjer dette (f.eks. på anleggene eller, outsourcet eller i sky?)

Er datamengden uhåndterlig stor?

Har dere planer om å ta i bruk teknologi for å bearbeide dataen raskere eller for å hente ut informasjon mer effektivt?

Fremtiden

I forbindelse med avfallsfraksjoner – er det data eller informasjon som dere savner eller gjerne skulle ha hatt? Hva skal denne brukes til i så fall?

Har dere konkrete planer om å implementere teknologi for å hente ut denne dataen?

Samarbeid/ Integrasjon

Er deres systemer eller data integrert mot REN eller aktører senere i verdikjeden?

- Hvis nei, har dere planer om dette? Hvordan?
- Hvis nei, hvorfor ikke?

Eller med andre kommuner/ anlegg som har omtrent samme oppgave som dere?

- Hvis nei, har dere planer om dette?
-

Kan du si litt om prosjektet Big Data som dere har med REN?

- Hva slags produksjonsdata og logistikkdata er det dere prøver å sammenstille?
- Hvorfor det?
- Hva skal denne brukes til?

Kan du fortelle litt om gjenbruks-id?

- Hva gjør dere med dataen som genereres?
- Lagres den? Hvor da i så fall?

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