Preparing for the Use of Big Data in Denmark's Waste Management Sector

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Abstract

This project explored the challenges and opportunities associated with prospective implementations of big data analytics in Denmark's waste industry. We found that while some waste management companies collect detailed data, they do not use or share their data adequately. We identified that, to begin implementing big data into Denmark's waste industry, companies must: expand data collection on internal operations and waste per household; develop better data management systems; and review technical, ethical, and legal practices surrounding personal data on waste.

Executive Summary

This project is concerned with the waste management system in Denmark. Denmark has been the greatest producer of waste per capita in Europe for several years. Denmark's high waste production rate is a concern because the vast majority of non-recycled waste is either converted to energy or landfilled. Although Denmark's overall recycling rate is 68%, this statistic can be further improved. Denmark is aiming to move towards a circular economy, in which maximum value is extracted from waste through reuse and recirculation of materials.

An important player in improving Denmark's waste management is the Danish Waste Association (DWA), which is a political interest organization with 54 members throughout Denmark's 98 municipalities. These members include Danish municipalities, inter-municipal waste management companies, and facilities for hazardous waste. The DWA works to influence politicians, media, and other entities to improve waste management systems.

The responsibility for waste management is split among Denmark's municipalities, each with different waste management systems. Both public and private companies take part in these waste management systems. Responsibility over different processes of waste management, namely collection and treatment, is often handed off from one company to another. As a result, no single company or municipality has total control over a local waste management operation.

To help facilitate the improvement of Denmark's waste management, the Environmental Protection Agency (EPA) has developed several strategies to reduce waste and increase recycling. These strategies revolve around maximizing the extraction of value from resources and promoting better waste habits in citizens. The EPA has also set a specific goal of reaching a 50% household recycling rate for seven waste types by the year 2022. In order to reach this goal, the EPA seeks maximum participation from citizens and municipalities.

One tool that could help reach the EPA's recycling goal and improve Denmark's waste management is through the use of **big data analytics**. Big data analytics encompasses the process of analyzing complex data sets for the extraction of insights. Other industries have used big data analytics to produce significant benefits by optimizing operations and discovering new insights.

The waste industry has yet to implement adequate infrastructure or expertise to make use of big data. The DWA hopes to encourage the industry's efforts to implement big data analytics. Our sponsor expressed particular interest in investigating the prospective expansion of data collection, the uses of data to provide feedback to citizens, and the privacy issues that could be associated with big data in the waste industry.

This project explored the challenges and opportunities associated with prospective implementations of big data analytics into Denmark's waste sector. To do this, we identified the following objectives:

1. To assess how data on waste is currently collected, managed, and used in Denmark's municipalities
2. To synthesize practical uses of big data in Denmark's waste management operations
3. To identify potential social and legal issues accompanying big data in Denmark's waste industry
4. To develop guidelines on how the Danish Waste Association can aid municipalities in implementing big data

To complete these objectives, we made use of background research, interviews, and a survey. We visited and interviewed individuals from the four waste management companies Arwos, Nomi4s, Renosyd, Vestforbrænding, and from the waste management officials at the municipality of

Frederiksberg. We also conducted interviews with four field experts: Dr. Bjarne Ersbøll, a data science researcher at DTU; Dr. Christian Jensen, a data security expert at DTU; Mr. Jacob Nyborg, a data analyst and consultations expert from JHN processor; and Ms. Ane Sandager, a legal officer at DTU. *Figure* 1 shows the geographical locations of the waste management companies' head offices and experts that we interviewed. We administered a survey to 81 Danish citizens to gather information about their opinions on having their data on waste collected and shared. The survey also attempted to gather opinions that would help inform how to provide feedback to citizens.

Figure 1. Interview and field trip locations with Waste Management Companies

Through our interviews and observations of municipal waste management companies, we were able to gain various perspectives about data collection in Denmark's waste industry. Many companies already collect some data about the waste management process but fail to make full use of it. We also observed that many companies lacked strong data management schemes. Additionally, we recognized a lack of data sharing among waste management companies.

Through our interviews, survey, and research, we identified the following three uses of big data to be most impactful to Denmark's waste industry:

I. **Predictive Analytics**, to identify trends in and make predictions about waste production
II. **Performance Analysis**, to assess detailed performance metrics about various operations
III. **Feedback to Citizens**, to provide tailored feedback to citizens about their waste habits

These applications can be put into practice with small-scale data, but become much more powerful with the increased volume and variety entailed by big data.

To identify the social and legal issues accompanying data in the waste industry, we primarily made use of background research and our survey. We used our interviews with field experts to conduct further background research into legal issues. In particular, we were able to narrow down

our scope of research regarding the EU's General Data Protection Regulation (GDPR) and related personal data rights.

Our team found that waste management companies should look into three main sources of improvement to prepare for the prospective implementation of big data into the waste industry. The first source of improvement is **data collection**. The waste management companies we visited had room to expand their data collection. We recommend that companies expand the collection of data on internal operations, investigate the cost-benefit of using household sensors for route optimization and feedback programs, and further research the most effective ways to use feedback.

The second source of improvement is **data management**. Good data management schemes are paramount to storing and using large quantities of data. Additionally, developing a standardized data structure for waste management companies to use will enable better data sharing among both companies and municipalities. As waste management companies expand their capability to share data, they will also need to begin identifying clear incentives to encourage other companies to share data.

The third source of improvement is the **handling of personal data**. Through our project, we encountered various situations where data on waste per household could lead to privacy issues; to prevent such issues from occurring, waste management companies should begin treating the data on waste per household they collect as personal data. In order to properly handle data on waste as personal data, waste management companies also need to strengthen their cybersecurity practices. Our recommendations for handling personal data and improving cybersecurity are:

1. Properly document what data is collected and what happens to it
2. Only collect data for a specific use
3. Do not share personal data
4. Only store personal data for as long as necessary
5. Anonymize personal data when possible
6. Limit access and control over data systems based on job function
7. Improve cybersecurity practices
8. Consider having compliance with other aspects of the GDPR

In addition to our recommendations, we produced a set of guidelines outlining specific actions that the DWA can take to help municipalities make use of our recommendations. These guidelines for the DWA to:

1. Study the viability of collecting household data by region
2. Develop a standardized format to share data
3. Inform municipalities of the importance of strong data management platforms
4. Consult legal experts in preparation for the GDPR

Through this project we were able to explore the challenges and opportunities that we expect Denmark's waste industry will encounter as it begins implementing big data analytics. Waste management companies still have a great deal of room to improve their data collection and management schemes, but through our findings we believe that big data analytics has great potential to revolutionize the waste industry.

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Authorship Page

This report was written and revised collaboratively by Diana Celaj, Josh Desmond, Akshaye Shah, and Sola Shirai.

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1.0 Introduction

Globally, three and a half million tonnes of waste are produced every day, and this number is forecasted to increase to 6 million tonnes of waste per day by the year 2025 [Hoornweg, Bhada-Tata, & Kennedy, 2013]. As waste production increases, the amount of work needed to manage and dispose of the waste increases. The rising rate of waste production is a growing concern because a common waste disposal method, landfilling, pollutes the environment and fails to extract value from resources. To combat this issue, many international organizations have set goals to reduce waste production and increase waste reuse and recycling.

Danish authorities have been working to improve Denmark's waste management. While Denmark currently has one of the best overall recycling rates at 68% [Danish EPA, 2017], it produces the most municipal waste per capita in Europe ["Municipal waste by waste operations," 2017]. The vast majority of un-recycled waste is either converted to energy or landfilled [Danish EPA, 2016]. Moving towards a circular economy, where maximum value is extracted from waste through reuse and recirculation of materials, will help Denmark offset its high resource consumption and improve its waste management practices. To facilitate the movement towards a circular economy, the Danish government has set several goals to increase recycling rates and reduce waste production. A key player in achieving these goals is our sponsor, the Danish Waste Association (DWA). The DWA is a political interest organization consisting of municipalities, inter-municipal waste management companies, and facilities for hazardous waste. The DWA works towards influencing politicians, media, and others in the direction of their members' best interests.

Identifying areas for improvement in current operations will help optimize Denmark's waste management sector, but this can be difficult to do with conventional methods. One tool that can aid in identifying areas of potential improvement and making informed decisions is data analytics. Data analytics involves the collection and analysis of data to better identify inefficiencies and make decisions. Modern day data analytics is increasingly associated with the field of **big data** and **big data analytics**, which describes the use of large complex data sets.

The DWA recognizes the potential benefits and uses of big data, but it currently does not have a concrete strategy to implement its use in the waste management sector. Current data on waste in Denmark is not "big" data; the quality, quantity, and variety of data is insufficient, and the infrastructure for the management and sharing of data among municipalities is lacking. Before the DWA can encourage the collection of more data, it must first consider the social and legal issues surrounding the collection and management of data on waste. Additionally, a standardized process for data management is needed to facilitate better collaboration and data sharing among waste management agencies. The goal of our project is to explore the challenges and opportunities of implementing big data into Denmark's waste management sector. We completed our project through the following objectives.

1. To assess how data on waste is currently collected, managed, and used in Denmark's municipalities
2. To synthesize practical uses of big data in Denmark's waste management operations
3. To identify potential social and legal issues accompanying big data in Denmark's waste industry
4. To develop guidelines on how the Danish Waste Association can aid municipalities in implementing big data

Our project provides the Danish Waste Association with information about implementing and regulating the collection and analysis of big data into the Danish waste sector, which in turn will aid waste management companies and municipalities in improving their operations.

2.0 Background

In 2015, Danish households produced approximately 593 kg of waste per person [Danish EPA, 2017], which was the highest per capita amount of Europe ["Municipal waste by waste operations," 2017]. In 2015, Denmark produced 11.31 million tonnes of waste, of which over 3 million tonnes came from Danish household waste [Danish EPA, 2017]. In order to better manage this large quantity of waste, it is vital to explore methods to decrease waste production and improve waste resource reuse [Bhada-Tata & Hoornweg, 2012]. The Danish Waste Association (DWA) is a central figure in implementing positive changes to Denmark's waste management operations. A promising method to improve waste management in Denmark is to use big data analytics.

The DWA is a Danish political interest organization with 54 members throughout the 98 municipalities of Denmark. These members include Danish municipalities, inter-municipal waste management companies, and facilities for hazardous waste. The DWA aims to promote the interests of its members by influencing politicians, media, and other entities. The DWA's goal is to "create value for the members by working for an improved and transparent waste management that is paying respect to environment, climate, and resources" ["About the Danish Waste Association," 2016].

2.1 Waste Management in Denmark

Municipalities are all in charge of their own waste management process. While specific practices differ among municipalities, all household waste management operates according to Denmark's requirements and regulations. Both the European Union (EU) and Danish Parliament develop regulations on waste. The EU produces regulatory frameworks, and Parliament decides on legislation and organization in further detail [Ministry of Environment and Energy, 1999]. Denmark's Environmental Protection Agency (EPA), which is a branch of Denmark's Ministry of Environment and Food, is responsible for legislation and guidelines pertaining to waste handling.

2.1.1 The Waste Management Cycle

Although specific waste management practices differ among municipalities in Denmark, the life cycle of waste from production to treatment is generally the same. Waste producers, such as households, begin the cycle. Waste collectors then take the waste to transfer stations. Waste then goes on to treatment facilities. The most common treatment methods are recycling, converting to energy (waste-to-energy), and landfilling. The type of waste determines which treatment method is used; environmental and economic factors are also taken into consideration [Danish Government, 2013].

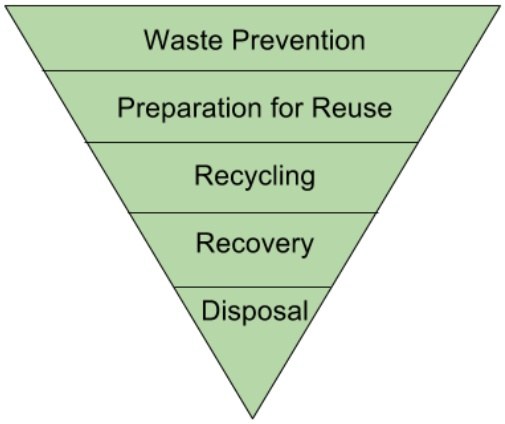

Figure 2. DWA Waste Treatment Priority Hierarchy'

Figure 2 illustrates the Danish EPA's hierarchy that guides waste policy and prioritizes treatments. The size and level of the tiers is representative of the priority given to each treatment method. The first tier is **waste prevention** because of its minimal impact on the environment and emphasis on saving resources. The second tier is **preparation for reuse** which examines and repairs products and resources in order for them to be placed back into the economy. This tier has a lower priority than waste prevention because of the use of extra energy as well as the possibility that materials may be deemed unfit for reuse. The third tier is **recycling**, where products that are unfit for reuse can re-enter the production chain. The third tier is **recovery**, which attempts to regain a portion of value using waste-to-energy. The last tier of the hierarchy is **disposal**, i.e. landfilling. Landfilling is the lowest tier because it wastes space, causes severe pollution, emits greenhouse and toxic gases, and fails to recapture value from resources [Danish Government, 2015]. This five-tier hierarchy allows for a process that more efficiently uses waste resources.

2.1.2 Municipal Waste Management

Denmark's waste management is split among the country's 98 municipalities, each with different waste management systems. A variety of public and private companies take part in these waste management systems, and such waste management companies can service multiple municipalities. Many waste management companies in Denmark are entirely owned by one or more municipalities. Some municipalities choose to carry out all waste management operations themselves, while others contract out specific operations (such as waste collection or treatment) to third party companies.

2.1.3 Denmark's Waste Reduction Goals

Producing large amounts of waste is particularly problematic if a significant portion of the waste is treated with methods that are harmful to the environment. It is best to treat waste through re-use or recycling, as these methods have greater environmental benefits than land filling or waste-to-energy [Perugini, Mastellone, & Arena, 2003, 2005]. *Figure 3* shows that although over 65% was recycled between 2013 and 2015, at least 30% of Denmark's waste was either converted to energy or landfilled [Danish EPA, 2017].

Figure 3. Methods of waste removal percentages in Denmark, 2013-2015 [Danish EPA, 2017]

The percentage of waste that is recycled has increased over the years as the Danish government has become more conscious of the need for better resource utilization, but Denmark's waste management still has room to improve. To further improve Denmark's waste management, the Danish EPA has taken the initiative to improve waste management by adopting two strategies, *Denmark Without Waste I, Recycle more - Incinerate Less* and *Denmark Without Waste II, A Waste Prevention Strategy*. These strategies provide initiatives and policies to improve waste management and prevention [Danish Government, 2013, 2015].

Denmark Without Waste I was developed by the EPA in 2013 and focuses on increasing recycling and reducing the use of waste-to-energy and landfilling. *Figure 4* illustrates the expected change in recycling rates under this plan. The red line represents the projected mass of recycling (in tonnes) that will occur under the plan, while the green line represents the expected mass of recycling if the plans were not implemented.

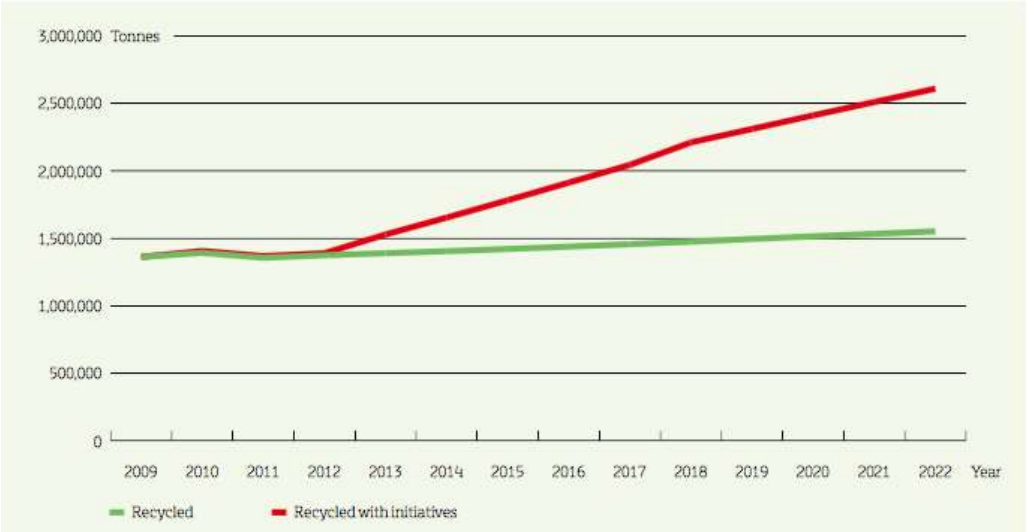

Figure 4. Expected changes in incineration, landfilling, and recycling with initiative strategies applied [Danish Government, 2013]

Denmark Without Waste II, adopted in 2015, takes the approach of reducing waste production to increase reuse rates. The plan focuses on resource efficiency within the following five focus areas: food waste, construction, clothing and textiles, electrical and electronic equipment, and packaging [Danish Government, 2015].

Both of these plans share common goals of using resources more efficiently and making strides towards achieving what is known as a circular economy. Within a circular economy, resources and products re-enter the production stream after being used rather than just being thrown out. This allows for resources and products to be reused and continuously cycled through the economy, taking full advantage of the materials. Denmark has also set a specific goal of reaching a 50% household recycling rate for seven waste types by the year 2022. In order to reach this goal, the EPA and Danish government seek maximum participation from citizens and municipalities [Danish Government, 2015; European Environment Agency, 2016].

2.2 Data Collection on Waste in Denmark

In order to reach the EPA's target recycling rate, waste management companies need to identify and make informed decisions about issues in their operations. To perform these tasks, it is critical to collect and analyze data on waste. All of Denmark's transportation companies and waste treatment plants are required to collect and report some basic data to the EPA, but the EPA's data is of limited scope and quality. There is also no uniform method of data collection amongst municipalities. However, as technology becomes more affordable and versatile, we can expect to see improvements in data collection and accuracy in Denmark's waste management industry.

2.2.1 National Requirements for Data on Waste in Denmark

While waste management companies and municipalities across Denmark do not operate in the same way, there are uniform data reporting rules specified by the EPA. Most notably, the Danish government's 2012 *Statutory Order on the Waste Database* [Ministry of the Environment and Food] requires waste importers, exporters, collectors, beneficiaries, and receivers to report:

1. Amount in tonnes and an indication of whether the weight is measured, calculated or estimated
2. EWC code; Level 1, 2 and 3
3. Waste fraction
4. Treatment

EWC codes are numeric codes defined in the European Waste Catalog to standardize categorization of the type and source of waste (e.g. metal scraps from households versus from construction companies). The term "waste fraction" refers to the grouping of waste according to its properties (e.g. paper, glass, and metal). Specific codes exist for the types of household and commercial waste fractions in Denmark as well. Treatment refers to which treatment method (e.g. recycling, waste-to-energy, landfilling) is prescribed to the waste.

The EPA collects and manages this data in their system known as *Affaldsdatasystemet* (ADS). The EPA makes use of this data to produce annual reports about the general state of waste production in Denmark. *Figure 5* shows the principle of reporting data to the ADS. The solid lines show the flow of waste from producers to collectors and reception facilities, and the dotted lines show the flow of data reporting to the ADS.

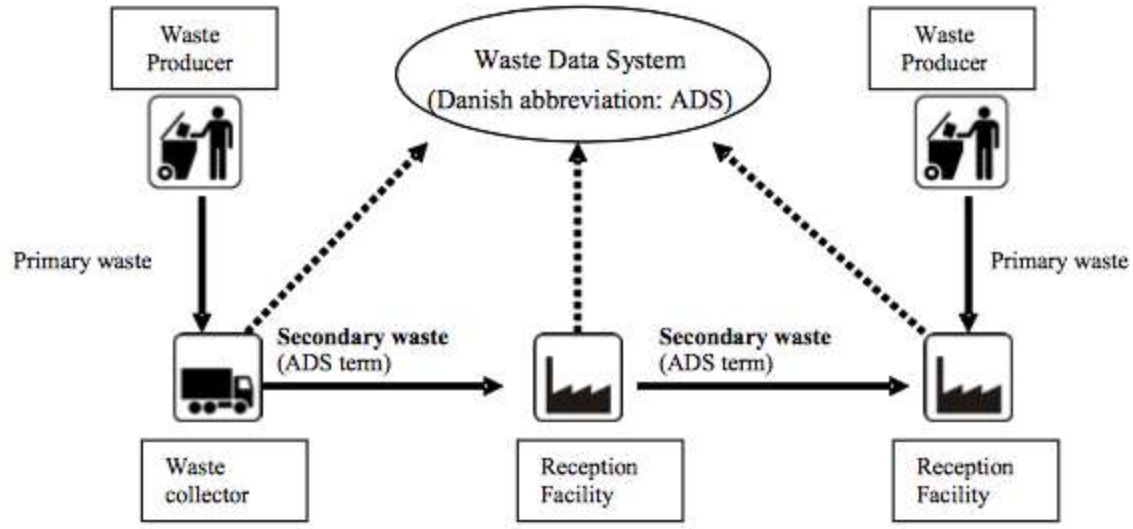

Figure 5. Data flow for reporting to the ADS [Danish EPA, 2017]

2.2.2 Limitations of Data Collection on Waste in Denmark

In general, data that is collected in the waste industry is limited and has poor accuracy [Bhada-Tata & Hoornweg, 2012; see also Hoornweg, 1999; Tsilemou & Panagiotakopoulos, 2006]. Bhada-Tata cites the following as reasons why data on waste is unreliable across the world:

- Undefined words or phrases
- Inconsistent or omitted units
- Dates, methodologies, or sources of data not indicated
- Estimates made without basis
- Incomplete or inconsistent data
- Information collected at non-representative moments

Adam Minter, an expert journalist on the global recycling industry and author of Junkyard Planet, argues that the "recycling and refurbishment industry is a notoriously difficult business to turn into clean data." He attributes this to the nature of data regarding waste [2015, p. xiii]. Furthermore, he notes that "numbers tabulated by environmental organizations, despite their widespread use and circulation in media" are rarely the best data. In his own research, Minter instead relies heavily on the information from organizations involved in the physical process of handling waste.

Data on waste in Denmark suffers from similar problems of accuracy and reliability. Our project mentor, Ms. Mette Godiksen, remarked that while Denmark has some of the best data about waste worldwide, discrepancies still exist between observed and reported recycling rates in many municipalities [M. Godiksen, personal communication, August 2017]. While the Danish EPA mandates the reporting basic data on the amount and type of waste collected, there is no requirement on how exactly this data must be collected; the reported weights can be "measured, calculated, or estimated." Furthermore, detailed information about the waste collection process and associated data are not collected by the EPA. As a result, data on waste that is aggregated by the EPA has a very low resolution and fails to provide any context for in-depth analysis.

2.2.3 Expanding the Collection Methods of Data on Waste

As technology has become more affordable and accessible, the possibilities of data collection on waste have expanded. One way that the collection of data is being expanded is through the use of sensors in waste bins. Using sonar or infrared technologies, advanced sensors can detect how full an associated waste bin is and upload the information in real-time. Notable examples of waste bins with such sensors include Bigbelly Smart Waste Stations ["Bigbelly – Waste & Recycling Stations," n.d.] and WECO wireless recycling sensors [Gomes, Brito, Mendes, Cabral, & Tavares, 2012]. Such containers that automatically collect data have been implemented in countries like Sweden, where 3300 recycling containers were monitored in a similar way [Johansson, 2006]. Further examples of data that can be collected in the waste industry include:

- The time of pick-up
- The weight of bins during pick-up.
- The GPS location of pickup trucks
- The license plates and times of entry of all visitors to transfer stations
- The weight, type, time, and cost of waste shipments from one facility to another
- The content of recycled materials (via automated sorting mechanisms)

2.3 Big Data Uses

Many definitions of the term **big data** exist; the expression can be used to describe a broad range of concepts surrounding the collection, management, and analysis of large quantities of data. **Volume**, however, is only one component of what constitutes big data; the **variety** and **velocity** of data are the other features that distinguish big data from traditional data sets [Gandomi & Haider, 2015]. Data with a high velocity indicates a near real-time collection and integration of information, and data with a high variety implies heterogeneity in the structure and type of data stored. This breakdown of big data into the three V's of volume, variety, and velocity is important because these traits render traditional data analysis techniques inadequate. Throughout this paper, the term big data analytics will refer to the qualitative and quantitative process of **analyzing complex data sets** for the extraction of insights used to enhance operational efficiency.

2.3.1 Uses of Big Data in the Waste Industry

While waste industry as a whole is lacking in reliable data, data on waste has been used for multiple experiments. The leading example is **route optimization**, which is the process of using per-bin data to optimize routes. Data about trends of household waste production can be analyzed to predict when waste bins will be full and create optimal routes of waste collection. Route optimization can also become even more impactful by incorporating real-time data. This can allow waste collection trucks to conduct live route optimization using information such as the current traffic or the current fullness of household waste bins [Beliën, De Boeck, & Van Ackere, 2012; Faccio, Persona, & Zanin, 2011]. A 2012 review on vehicle routing problems specific to waste management found 26 papers published on route optimization with associated case studies in Europe alone [Beliën, De Boeck, & Van Ackere, 2012]. The use of in-house waste bins that report how full they are has enabled real-time routing solutions [Ustundag & Cevikcan, 2008]. In Stockholm, Sweden, big data about waste collection was aggregated using geographical mapping, helping to identify major inefficiencies in waste collection routes [Shahrokni, 2014]. These projects are especially important to the waste industry, because the process of physically collecting waste is

estimated to account for up to **80%** of waste management costs [Beliën, De Boeck, & Van Ackere, 2012].

Other examples where data on waste is useful are in economic and environmental impact modeling. Life cycle assessment (LCA) is a standardized procedure for capturing and modeling the impact of waste on the environment involving the "compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle" ["Life Cycle Assessment," 2006]. In Denmark, LCA (along with cost-benefit analysis) has been used to direct the goals of the waste industry as a whole [Villanueva, Kristensen, & Hedal, 2006]. Economic models of waste management are also important in providing accurate estimates of costs in the waste industry. The scarcity of data available to researchers is, however, one of the biggest problems in studying the industry [Tsilemou & Panagiotakopoulos, 2006].

2.3.2 Providing Feedback to Citizens about Waste

An important use of data in the waste industry is to provide feedback to citizens to reduce waste production and encourage recycling. However, effective feedback programs that properly affect citizens are difficult to construct. A synthesis report funded by the Department for Environment, Food, and Rural Affairs (DEFRA) of the United Kingdom lays out key information about "what makes an effective model for reward and recognition schemes intended to encourage household waste-related behavior change" [Bell, S., McGeevor, K., Mocca, E. and Shaw, B., 2013]. Some notable findings from the DEFRA report include:

- Rewards for recycling should be given alongside publicity, information, and feedback so that citizens are fully aware of the purpose and impact of their actions.
- To facilitate public engagement, rewards and recognition must be tailored to local communities and interests.
- Feedback should emphasize positive publicity over sustained periods of time to maximize participation.
- High performing recyclers might reduce their efforts to recycle after receiving feedback that they are recycling better than average.
- Isolating the true impact of rewards or recognition is difficult, and few conclusive examples exist in the waste industry.
- Rewards tend to influence one-off actions rather than sustained changes in habits.
- Effective feedback should empower citizens to recycle more.
- Observed effects of rewards programs may be influenced more by the attention given to recycling issues than by the reward itself.

2.3.3 Uses of Big Data in Other Industries

The most valuable use of big data is to facilitate **decision-making** based on empirical evidence. While the idea of using data to make decisions in general is not a new concept, it becomes much more powerful with the quantity and complexity of information in big data. Using data to inform decision-making has proven benefits such as providing businesses with more accurate insights and quantification of risk [Russom, 2011], improving financial management and budgeting [LaValle et al., 2011], and generating greater revenue globally [Davies, 2016]. Notable examples of how other industries have been impacted by big data can be seen in the manufacturing, retail, and electric power industries.

In the manufacturing industry, General Electric (GE) has demonstrated the use of big data to create value through improving efficiency, productivity, and maintenance. GE developed a cloud-based software platform, Predix, to collect, manage, and analyze real-time data about various equipment. One of the many inefficiencies that Predix's data analytics has helped to address is jet engine productivity. Using massive amounts of data collected from their engines, GE was able to identify environmental factors that degraded engine efficiency as well as maintenance practices that would help mitigate those factors. This insight saves GE's customers an average of $7 million annually due to the increased productivity of the engines [Winig, 2016].

In the retail industry, Tesco PLC provides insight into the uses of big data to better understand customers as well as optimizing operations. For over 20 years, Tesco has made use of their membership card to gather insight into their customers. Such insights have been used to personalize coupons as well as predict how much certain products would sell in certain locations. Detailed data about how minor details like weather affect sales of certain products have been used to optimize depot stockholding [Hebbert, 2012]. Such analyses have resulted annual savings of $78 million by optimizing warehouse stocking.

In the electric power industry, various studies have been conducted in that indicate that using data to provide feedback to consumers can help to reduce household electricity consumption [Darby, 2010]. A 2012 study has shown that pattern recognition based on electricity usage can explain roughly 80% of household electricity use [Abreu, Câmara Pereira, & Ferrão]. A 2011 case study conducted in Denmark demonstrates the practical outcomes of performing such feedback programs. The case study found an average reduction in electricity consumption of 8.1% in participating Danish households [Grønhøj & Thøgersen, 2011].

While there are many other examples of concrete use cases of big data in other industries, it is also important to note a much less concrete benefit: Big data can be used to discover new insights. By studying large amounts of seemingly chaotic data, the latest data analysis technologies may be able to discover unforeseen trends and correlations. Additionally, big data analytics can use unstructured data (e.g. video, audio, and images), which constitutes the majority of all existing data [Gandomi & Haider, 2015]. This further expands the scope of what data is considered to be "useful."

2.4 Big Data Issues

While big data analytics has been enthusiastically received across many industries, it is far from without fault. The most significant challenges that accompany big data involve the management of data, protection of privacy, and legality of data collection and use.

2.4.1 Management Challenges of Big Data

The process of managing big data is difficult, time-consuming, and often overlooked. Well-designed organizational strategies must be implemented before complex data sets can be effectively used. It is ideal for data to be well-managed at the time of collection because once data is unorganized, it is difficult to reorganize and refactor into a usable form. Dr. Bjarne Ersbøll, an expert on data science at DTU, proposes that, "Just to get data organized, our experience shows, by interviewing different companies, is something like 2 years' worth of work" [Bjarne Ersbøll, 2016].

In addition to the challenge of managing data, the process of sharing data between organizations can be difficult. This issue was recognized in the metropolitan county of Greater Manchester, United Kingdom, waste management services have collaborated with the University of Manchester

in order to explore how to use data about waste in their decision-making processes. The researchers speculate that the **collaborative process** of **managing** and **sharing** data is the greatest challenge preventing widespread use of more big data analytics and advocate for more social discussions between organizations to facilitate better data sharing policies [Ruppert et al., 2015].

2.4.2 Privacy Issues Surrounding Big Data

Privacy is a major issue accompanying big data. A side effect of amassing large quantities of data is that **personally identifiable data**, or data that can be used to identify a unique individual, is often captured. When large data sets contain personally identifiable information, it is possible to make intersections among seemingly irrelevant data to draw unforeseen conclusions about an individual. Furthermore, as data collection increases, the extent of the possible malicious uses of the data also increases.

An example of potential data misuse can be seen in the insurance industry. Modern technology allows for simple DNA tests to reveal information about individuals' ancestry and possible ailments they may have in the future. If this kind of data were to be made public, insurance companies might be able to charge higher premiums based on an individual's genetic disposition towards certain ailments or diseases [Klitzman, Appelbaum, & Chung, 2014].

One example of data misuse for marketing purposes was publicized in 2012. Target, a major retail store in the United States, made headlines after correctly identifying that a teenager was pregnant before even her parents were aware. Target was able to identify the girl's pregnancy due to big data analysis conducted on shopping trends of pregnant women. According to Andrew Pole, a statistician who worked to create this pregnancy-detection system, Target's analytics is capable of estimating the date of delivery only based on the mother's purchase patterns [Duhigg, 2012].

In order to prevent such breaches of privacy, personally identifiable data must be sufficiently protected. One method of protecting data privacy is to anonymize the data to not be personally identifiable. However, conventional anonymization practices are inadequate as studies have repeatedly shown that anonymized data can be re-identified with a high probability of success [Tene & Polonetsky, 2012]. Additionally, security measures need to keep up with technological advances to keep data secure. The discussion of privacy is further complicated if we consider the viewpoint that all data is "personally identifiable."

To fully address concerns of personal information leaks, privacy measures must be integrated into the design process of big data systems [Cavoukian & Jonas, 2012]. This concept, commonly referred to as privacy by design, has gained widespread support in recent years as a tool to combat the growing concern of privacy in personal data. Despite the widespread support, many criticisms and challenges surround privacy by design. From the perspective of communicating the associated standards, privacy by design is typically cited as being too vague [Rest et al, 2014]. Additionally, privacy by design faces considerable challenges in both the creation and enforcement of policies that adequately address all of the design process [Klitou, 2014]. Despite such criticisms, the core idea of considering privacy throughout a system's design process is still supported by many critics.

2.4.3 Legal Issues Surrounding Big Data

With the rapid increase in personal data collection and accompanying threats, legal systems are evolving to better protect individuals from data misuse. Big data analytics involving personal data encounters substantial legal complications. This is especially true within the EU due to the *General Data Protection Regulation* (GDPR). This directive was passed in 2016 by the European Parliament, and will go into effect during the second quarter of 2018 ["Regulation (EU) 2016/679," 2016]. The

GPDR is expected to bring about substantial changes to Denmark's current privacy laws prescribed in the *Act of Processing Personal Data*; most notably, the GDPR expands what rights citizens have with regards to the collection, management, and use of their personal data. The GDPR also mandates that entities make use of privacy by design concepts.

The extent to which the GDPR will apply to Danish waste collection organizations is unclear; the law denotes that personal data collected in "the public interest" can be subject to different standards [DI Digital, 2016]. The Danish Parliament is still in the process of updating the national data privacy laws to comply with the GDPR. Companies, especially in the public utility industry, are not ready for GDPR compliance; as such it is crucial that the waste industry evaluate its current data flow and work to understand the upcoming regulations.

3.0 Methodology

This project explored the challenges and opportunities associated with prospective implementations of big data analytics into Denmark's waste sector. To do this, we identified the following objectives:

1. To assess how data on waste is currently collected, managed, and used in Denmark's municipalities
2. To synthesize practical uses of big data in Denmark's waste management operations
3. To identify potential social and legal issues accompanying big data in Denmark's waste industry
4. To develop guidelines on how the Danish Waste Association can aid municipalities in implementing big data

3.1 Assessing the Collection, Management, and Use of Data on Waste

The first step of this objective was to investigate the current state of the collection, management, and use of data on waste in Denmark at the national scale. We used background research and discussions with DWA employees to understand what data was required to be reported across the entire nation. Before moving forward with synthesizing practical uses of big data, it was important to assess and understand the various operational differences in current data collection and management among municipalities.

We conducted field trips to and interviewed workers of the waste management companies (Renosyd, Arwos, Nomi4s, and Vestforbrænding) and the Frederiksberg municipality. Each of these municipal companies service a different number of citizens in rural and urban areas and carry out unique operations: Renosyd, Arwos, and Nomi4s are leading innovators regarding technology; Vestforbrænding is Denmark's largest waste management company that serves 19 municipalities around Copenhagen; and Frederiksberg is a single municipality that manages its own waste. At the five locations, we interviewed employees at various levels of responsibility. The basic interview agendas and guiding questions can be seen in *Appendices A* through *E*. To gain as much information as possible about how data was involved in the waste management processes at each location, we consistently sought to obtain the following information from each waste management company:

- How data on waste is physically recorded
- What kind of data is measured and in what form
- How frequently data on waste is collected
- How accurate and reliable is the collected data
- Where the data is stored and how it can be accessed
- How data is currently used to influence waste management operations

After learning about how data is collected, managed, and used at each company, we compared and assessed the different waste management operations. The differences in operations among the five companies informed us on the benefits and drawbacks of different systems in place in Denmark. The varying locations of these companies allowed us to gain further insight on what types of systems work well for urban and rural areas. Assessing the different systems and operations provided us with unique perspectives about data on waste, which in turn informed us about what uses of big data might be practical in the future.

3.2 Synthesizing the Practical Uses of Big Data in Waste Management

The use of big data analytics has yet to be fully explored in the waste industry. We broke down the uses of big data into two categories requested by our sponsor:

1. The use of big data to optimize waste management operations
2. The use of big data to provide feedback to citizens

Our background research focused on identifying how big data had been used in other industries. Using this research, we extrapolated how the uses in other industries could be applied to the waste industry in Denmark.

To gain more insight about the use of big data to provide feedback, we conducted a survey to gather information about how Danish citizens might view feedback about their waste habits. The survey questions mostly looked into assessing the level of interest that citizens had in learning more about their waste habits and were created with approval and guidance from our sponsors. The survey also served to provide some information us about citizens' opinions on privacy and legal issues, to help us complete our third objective. A complete set of the survey questions can be seen in *Appendix J* Survey Questions*,* and the results can be seen in *Appendix K* Data Collection and Feedback Survey Results. The results from our survey helped to further inform us about the potential uses of big data with regards to feedback to citizens.

In order to brainstorm and discover new ideas, we conducted interviews with data science experts. The first expert we interviewed was Dr. Bjarne Ersbøll of the Technical University of Denmark (DTU). We wanted to learn the most important concepts required to facilitate data sharing and management among multiple groups. Our second interview was with Jacob Høg Nyborg from JHN processor. JHN processor is a consultation company that works closely with municipal waste companies and specializes in analysis, user surveys, and fee calculations. Mr. Nyborg was able to give us insight into a wide range of topics surrounding the data that municipalities collect and how they analyze it. A list of guiding questions for these interviews is in *Appendix F* JHN Processor Interviewand *Appendix H* Bjarne Ersbøll Interview.

Using background research about big data in other industries, our own survey, interviews at municipal waste management companies, and interviews with data science experts, we synthesized the practical uses that big data might have in the waste management industry. These practical uses were not made with the intent of being immediately implementable, but rather to serve as ideas of how big data could actually be used if adequately collected and managed. After we synthesized practical uses, we moved on to examining the potential issues that could arise from implementing big data.

3.3 Identifying Social and Legal Issues

As part of our background research, we investigated the social and legal issues that generally accompany the use of data in Denmark and the EU. Then, based on our background research, we conducted a survey and interviews on the most important social and legal issues that were identified.

3.3.1 Social Issues Surrounding Personal Data in Denmark

The primary social issue surrounding big data is the issue of privacy. This issue can be broken down into the personal component (what information people would not want to be shared publicly) and the technical component (how to protect private data that is collected). We made use of the survey from our previous objective to also gather information pertaining to individuals'

opinions of the collection and analysis of data on waste. Since the citizens themselves are a central component of the implementation of big data strategies, it is imperative to collect and use data only in ways the public would approve. We also made use of our interviews with municipal waste management companies to gain further insight into what privacy issues companies foresee with the use of big data. Additionally, we conducted an interview with Dr. Christian Jensen, a cybersecurity expert. We focused our interview with Dr. Jensen on the topics of protecting collected data and preventing personal data leaks. The guiding questions used in this interview can be found in *Appendix I* Christian Jensen Interview.

3.3.2 Legal Issues Surrounding Data in Denmark

The laws surrounding the collection, management, and use of personal data are significantly stricter in Denmark than in the United States. Furthermore, the strictness of these laws is expected to be strengthened further as the EU GDPR comes into effect next year. As data in the waste industry expands to big data, it is imperative that the industry be prepared to adhere to proper legal guidelines regarding personal data. To garner an understanding of the current laws regarding personal data in Denmark, we interviewed Ms. Ane Sandager, a legal officer at DTU. The guiding questions used in our interview with Ms. Sandager can be seen in *Appendix G* Ane Sandager Interview.

3.4 Developing Guidelines

After gathering adequate information from our previous three objectives, we developed clear guidelines about how the DWA can aid municipalities in moving forward with the process of implementing big data into the waste sector. These guidelines include recommendations on how to organize and manage data, what studies to conduct regarding data collection, how to properly share data between municipalities, and how to help minimize potential legal issues.

4.0 Results & Analysis

The following results and analysis informed us in creating a set of recommendations for our sponsor based on our interviews, field trips, and survey results. This chapter assesses the current state of data collection and management in Denmark's waste sector, synthesizes the projected uses of big data in the waste industry, and identifies social and legal concerns that accompany current waste management practices and the prospective implementation of big data in the waste industry.

4.1 The Current State of Data on Waste in Denmark

Through our interviews and field trips, we observed a variety of collection and management schemes of data on waste. Understanding the various data practices helped to further inform us about the potential that big data holds within the waste industry.

4.1.1 State of Data Collection on Waste

The Danish EPA has a national platform for the collection of data on waste that is the minimum standard for municipalities to follow. In our interviews with various experts and waste management companies, we were able to reinforce the idea that data uploaded to the EPA's ADS is unreliable. EPA data is especially unreliable because waste companies may use different methods to collect data or may have differing definitions for operations. Jacob Nyborg, CEO and founder of JHN Processor, noticed these inconsistencies in data and created an alternate database that seeks to simplify the process of sharing municipal data on a national level. He noted that waste management companies often had difficulty collecting and reporting consistent data to him due to differences in what municipalities defined certain operations. For example, "what is considered organic waste in one municipality might be different in another and that is where we lose [quality], and have less than 10% uncertainty with the data" [J. Nyborg, personal communication, Sept 2017].

We encountered a variety of data collection schemes at the five waste management companies we visited that build off of the EPA's minimum standard. The scope of data collection by companies can be limited because not all companies have the ability to carry out on-site recycling, waste-to-energy treatment, and waste collection.

Three waste management companies collect data on residual waste per household: Frederiksberg, Nomi4s, and Renosyd. The Frederiksberg municipality collected data on the frequency of collection. Waste collectors recorded data semi-automatically on whether a household's waste bin was emptied on a given week using a system built into waste trucks. Bin sizes for each household are registered at the municipality, and Frederiksberg uses this information in conjunction with collection frequency for billing purposes. Nomi4s only collects data on waste per household at one of their four municipalities. The weight of residual waste in bins, collection times, and the associated addresses are automatically collected and upload when emptying bins. The weight of residual waste is used to calculate payment for collection, where the cost increases with the weight. Renosyd is another company that collects data on the weight of waste bins. Renosyd's residual waste bins are equipped with sensors to automatically collect information about the time, location, and weight of waste during collection. However, unlike Nomi4s, Renosyd does not use this data for a specific purpose.

None of the waste management companies that we visited collect data per household on recycled waste, but Renosyd does collect some data about citizens' recycling practices. Renosyd automatically records the license plates of cars that enter their recycling station. They have the capability to then connect the recorded license plates of visitors to the citizens who own the

vehicles. This means that Renosyd effectively collects data on who comes into its recycling station and how long they stay. However, exact details about what the citizens recycle is not collected. Another company that collects large scale recycling data is Arwos. Arwos's employees use a mobile platform to report data about the weight, type, destination, and price of shipment when waste is transported to third party organizations. They use visual inspections to estimate how full recycling bins are and use this data to predict when the recycling containers need to be picked up.

Two companies that we visited collect detailed data on the waste via automated machines for the processing and handling of waste. Nomi4s collects data on the type of plastics that are collected and recycled. They accomplish this using an automated waste sorting facility that is able to differentiate between 30 different types of plastics and physically sort them. Vestforbrænding is a company that collects data from their waste-to-energy plant. The data that is collected includes the amount of CO_2 produced, weight of waste converted to energy, and amount of energy produced. Both of these data sets show how automation can be a major source of data in the future.

Waste collection trucks follow fixed collection routes for all waste management companies we visited. Although the municipal waste management companies have yet to make use of data per household to optimize routes, they have been looking into the possibilities of using data for dynamic route planning. The Frederiksberg municipality has been participating in an ongoing study with Aarhus University to determine whether fixed or dynamic waste collection routes are optimal for their municipality. Ms. Annemette Fuglsang, the CEO of Renosyd, mentioned how they are interested in using dynamic waste collection routes, but expect that fixed routes would be more practical for some areas. She stated that her company "would never use resources to go to a bin, see if it is full, and not collect the trash. We would work with collected data and create new routes for the truck" [A. Fuglsang, personal communication, Sept 2017].

4.1.2 State of Data Management on Waste

In order to understand the national state of data management in the waste industry, we need to understand the flow of data on waste within and among waste management organizations.

All waste management companies that we visited use third party software to store and manage their data. We observed notable examples of this at Renosyd and Arwos. Renosyd uses a system called Net Dialog to manage some of their data, but not all of Renosyd's data is integrated into that system. Arwos makes use of a system called Pick-up to manage their data about various operations, including data on the time, destination, weight, and type of waste transportation from their transfer station. Pick-up is also used by several other municipalities to manage data, but they do not utilize the potential of data sharing through a shared platform.

Data on waste in Denmark is also processed by external entities. Many waste management companies report their data to and receive consultation from JHN Processor. JHN Processor collects and compiles various types of data about waste management companies to produce key performance indicators and detect trends in waste operations. This data encompasses both the qualitative descriptions and performance metrics of waste management operations within municipalities. JHN Processor avoids sharing sensitive data about individual municipalities by only sharing key figures.

Currently, the level and method of organization varies among waste management companies. Both Arwos and Nomi4s have well organized and centralized systems created by third party companies. This centralized management makes the data easy to access and analyze. Frederiksberg's data is well organized, but it is also quite simple as they collect small amounts of data to bill customers. Renosyd's data management system is poorly organized. *Figure 6* shows a visualization of

Renosyd's data management system, which is composed of many smaller systems with poor connections and flow of data. This makes for analysis and sharing of data difficult.

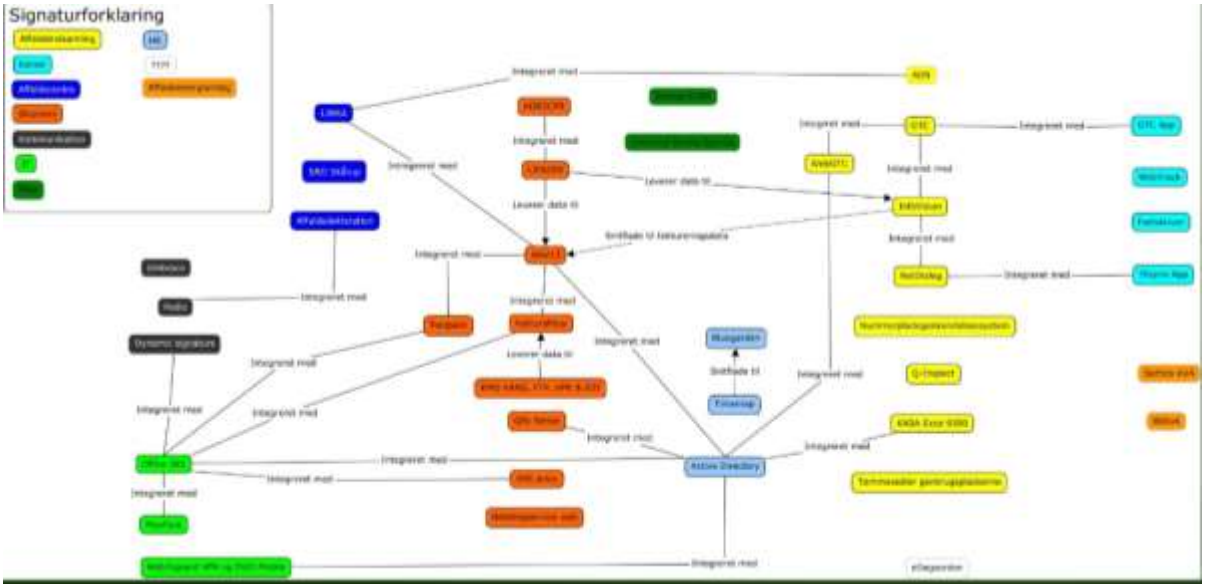

Figure 6. A diagram of Renosyd's data flow

None of the waste management companies that we visited shared data with each other. With the notable exception of one of Nomi4s's municipalities, data on waste was not shared with the public. Frederiksberg only communicated data necessary for the purposes of billing. Without making data shared with other municipalities or the public, innovation in the waste management sector may be hindered. While companies do not share data, they do still share information with each other. During our interview with Arwos, their recycling facility manager mentioned that many municipalities conduct events where waste management companies share information with each other about any recent developments or successful programs.

4.2 Projected Uses of Big Data in the Waste Industry

We compiled a set of uses for big data in the waste industry which we project will be the most impactful. The three categories of data-use we identified are:

- Predictive Analytics
- Performance Analysis
- Feedback to Citizens

Predictive analytics is the use of past and current data to make predictions about the future. Performance analysis is the process of assessing an organization's performance. Feedback to citizens is the use of data to inform and educate the public about various topics.

4.2.1 Predictive Analytics

Big data can be used to identify trends and make predictions by analyzing current and historical data through a variety of statistical and modeling techniques. Some examples of predictive analytics in the waste industry include:

- Identifying seasonal trends of waste generation.
- Optimizing collection routes (Route Optimization)
- Predicting costs and finances

Arwos is one company in the waste industry already making use of predictive analytics. Arwos manages seven waste facilities and regularly transfers large quantities of waste between their facilities. By recording and analyzing data on how full the waste containers are at the time of pick-up, Arwos is able to predict when they will need to collect and transfer waste between facilities. They accomplish this by analyzing how full waste bins were during the last six visits along with analyzing yearly trends in waste production rates. Arwos cited themselves as able to reduce the number of transportation trucks in use by 50% as a result of their data analysis.

Arwos's technique is a form of route optimization, which can be described as the use of data to analyze and compute optimal waste collection routes. While Arwos accomplishes this in the context of transferring waste between facilities, it can also be done with the collection of household waste. By recording how full waste bins are at the time of collection, it is possible to predict when bins will be full; this can be used to optimize routes by reducing the likelihood of collecting waste before it is necessary. Collecting the weight of household waste, as we saw at Renosyd, could also be used for route optimization. The cost effectiveness of route optimization is heavily dependent on population density and the ability to implement automated technology.

Financial data is another prime use-case of predictive analytics. Municipalities must predict their yearly costs in order to determine how much to charge citizens; having detailed historical data on finances can enable more accurate predictions. With enough detailed data, facilities can predict and handle anomalies like truck repairs or accidents in the cost of operations. Big data will allow municipalities to detect yearly trends in waste contents, run economic calculations on the supply and demand of waste products, and foresee exceptional cases of waste management.

4.2.2 Performance Analysis

Data on waste can be used to assess the performance of a company's operations. Performance can be measured through various metrics, such as return on investment, recycling rates, CO2 emissions, or customer satisfaction. Performance analysis is useful for either identifying specific areas for improvement, or for evaluating the success of changes an organization made to their waste handling process. Big data allows performance analysis to be conducted on more metrics with greater accuracy and better insight.

Performance measures are also useful in the context of inter-municipal comparisons. If municipalities share data on waste, they can gain insight on what type of operations work and can learn from each other. If municipalities collect a large variety of data, others will be able to narrow in on specific operations to analyze in detail. This type of data sharing can provide mutual benefit by teaching successful practices to poor performing companies and enabling novel analysis and insight into the operations of high performing companies.

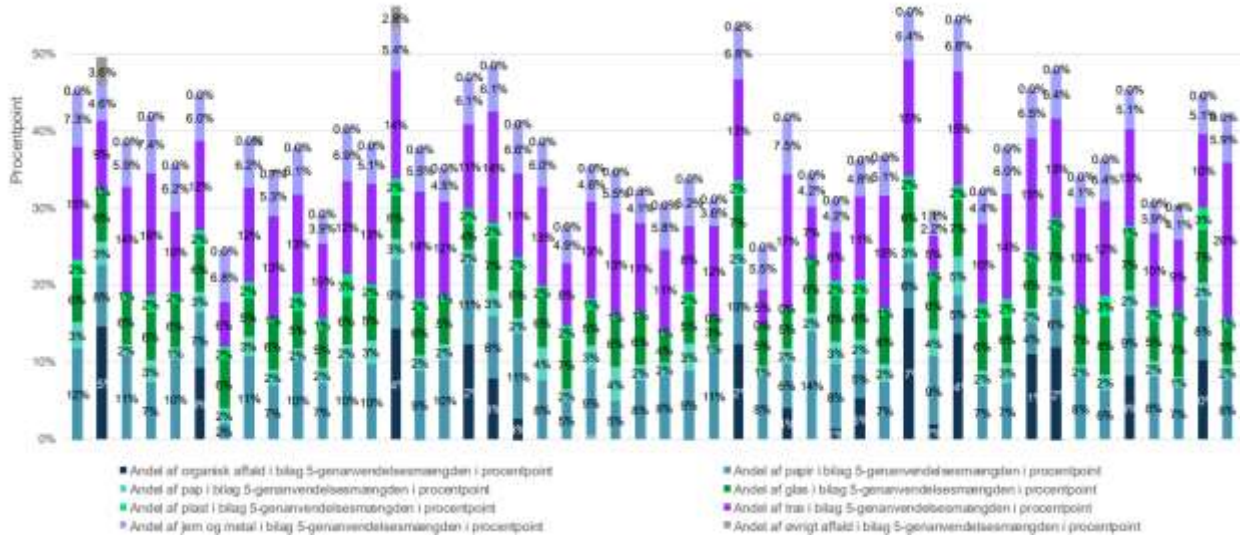

Figure 7. Total percent recycling rates broken down by waste type per municipality

Figure 7 was produced by the analytics company JHN Processor and is an example of inter-municipal performance comparisons. The graph displays the rate of recycling by percent of different municipalities broken down into specific fractions of waste. The graph shows that top performing municipalities are all distinguishable by having successful organic waste programs. Municipalities with access to this data would be able to see the importance of handling organic waste, which may inspire them to focus their efforts to develop composting programs. Detailed data about waste and more data sharing will allow for enhanced comparisons and evaluations of performance to be made.

4.2.3 Feedback to Citizens

Big data can be used to provide citizens detailed feedback about their waste production. Feedback could be provided in the form of rewards and recognition to reinforce good waste habits. A simple example of a feedback program is to charge citizens based on the weight of residual waste they produce (commonly known as a "pay-as-you-throw" program). This indirectly provides rewards for producing less waste. This type of feedback is already being conducted by Frederiksberg and one of Nomi4s's municipalities. Feedback programs can also provide recognition to citizens or neighborhoods with good recycling habits. Using big data could make feedback even better by identifying and tailoring feedback programs to different regions and demographics.

To better inform the potential uses of feedback to citizens, we distributed an online survey to Danish citizens. From this survey, we saw that a majority of citizens are interested in receiving feedback about how much waste they produced and how their waste production compares to their neighbors'. Most citizens also expressed that they would reduce waste production if they knew their neighbors produced less waste. Citizens also had interest in knowing what happened to their waste after it was recycled. These results further support the viability of using feedback to citizens to improve waste habits.

4.3 Social and Legal Concerns with Current Waste Management

Through our field trips to waste management companies and interviews with various experts we identified social and legal concerns that accompany the current management of data on waste and the potential uses of big data.

4.3.1 Social and Legal Issues Regarding Municipal Data on Waste

In identifying social issues related to data on waste, it is important to first identify whether or not Danish citizens consider their waste to be personal data. From our survey, we found that only about 17% of respondents considered their data on waste to be personal data. *Figure 8* shows that over 90% of respondents were open to having their data collected if it improved waste management within their community. Overall, there were positive responses to the idea of data collection on waste.

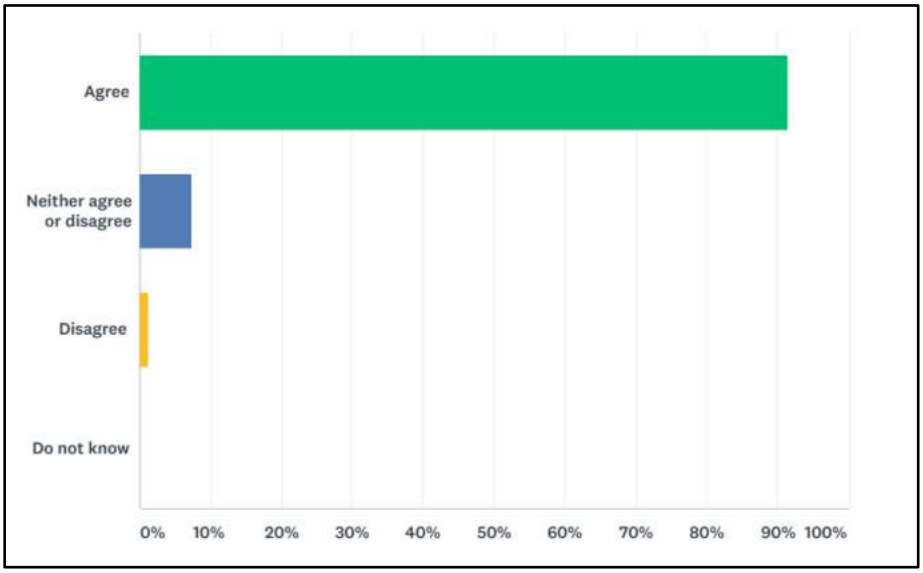

Figure 8. Results of survey question "I would be more inclined to having information about how much waste I produce collected if it helped to improve waste management in my community" [Appendix J Survey Questions]

While respondents to our survey were not concerned with the collection of data on waste, privacy issues still arise. We observed some companies with data management practices that present security and privacy risks. Nomi4s hosts a website that, in real time, displays information about waste collection at any address within one of their municipalities. This website is open for anyone to access and allows for users to the search a specific address' waste production. Renosyd is another company that stores data on waste per household. While Renosyd records the weight of waste collected at an address, they do not use the data for any specific purpose. The practices surrounding data on waste per household at these companies leads to privacy concerns due to the malicious acts that can be carried out with this data.

Data on household waste production can be used to identify whether or not homeowners are present, allowing criminals to break into a house at an opportune time. The availability of real-time data can increase this risk even more. Additionally, if enough data is available, yearly trends could reveal what times of the year a household tends to be unoccupied. Household waste habits can also be used to correlate waste habits with certain behaviors or demographics. For example, companies might market specific products to households that recycle a lot of glass by drawing statistical assumptions about the household's demographics. Yet another issue is that in the future, new datasets, technologies, and ideas may surface that cause previously harmless data to become dangerous. There must be efforts to protect data that can lead to negative uses.

Some municipalities that we visited use data management systems that protect the privacy of personal data. Frederiksberg collects data on waste per household, but only those who need it to perform their job functions actually have access to it. Limiting who has access to personal datasets lowers the risks of security breaches and data misuse. JHN Processor also makes an effort to preserve privacy as much as possible when using his model. JHN Processor's model only presents aggregate data in order to protect privacy of specific municipalities.

4.3.2 Potential Future Issues of Data on Waste

In the near future, waste management companies will have more issues to consider in order to adequately address privacy and legal issues surrounding data on waste. The most prominent challenges that we expect the waste industry to encounter are issues with cybersecurity practices and potential legal restrictions specified by the GDPR.

The need for proper cybersecurity measures becomes apparent when considering the implementation of big data. As the quantity and type of data collected increases, the risks associated with security breaches also increases. Our interview with Dr. Christian Jensen highlighted a few key vulnerabilities that waste management companies will need to consider as they expand data collection and implement new sensors. It is important to keep up with technological advances so that system security does not erode. Dr. Jensen illustrated how this is especially true with sensors in waste bins. Sensors in waste bins can pose cybersecurity threats, but most people do not consider security and software maintenance of sensors to be a high priority. Additionally, Dr. Jensen highlighted the security concerns that arise from sharing data. As more organizations gain access over datasets, points of vulnerability and risks of human error increase. Waste management companies will need to beware of the increased cybersecurity risks that can be caused by widespread data sharing.

The implementation of the GDPR presents additional changes that Denmark's waste management companies will need to consider. The GDPR will expand personal data rights, and data on waste per household would be considered "personal data" if the GDPR is applied directly to the waste industry. If the limitations of collection and use of personal data are applied to data on waste, it will severely limit the potential of big data. The GDPR mandates that data should only be collected that has a specific purpose in mind and that "secondary use is forbidden according to the GDPR… you would have to get new consent" [C. Jensen, personal communication, Sept 2017]. This could be problematic with sharing data between municipalities as well as trying to use big data to discover new insights. Furthermore, companies like Renosyd and Nomi4s would need to significantly scale back their data collection if the full extent of personal data limitations is imposed in the waste management industry.

In our interview with Ms. Ane Sandager, we learned that Denmark's implementation of the GDPR would probably impose fewer limitations on public companies. However, regardless of the actual implementation of the GDPR in Denmark, it would still be beneficial for waste management companies to consider many of the GDPR's initiatives when expanding data collection and use.

5.0 Conclusions & Recommendations

We have developed a set of recommendations that address suggested data collection methods, stronger data management schemes, and privacy and legal issues. These recommendations will help prepare for the advent of big data into the waste management industry and will allow waste management companies to increase their productivity. Additionally, based on our recommendations, we created a set of guidelines for the DWA to aid municipalities in implementing big data. When interpreting these recommendations, consider the following caveats:

- Not all recommendations will be applicable to all waste management organizations
- We are not authoritative experts on data management, cybersecurity, or the GDPR
- It is not compulsory that organizations follow these recommendations

5.1 Recommendations Regarding Data Collection

To expedite the implementation of big data into Denmark's waste sector, waste management companies should aim to collect more data. We especially encourage the collection of more data to track the internal processes of waste management. Investment in new technologies and data collection can likely benefit waste management companies through the various potential uses of big data.

5.1.1 Investigate the Viability of Collecting Data on Waste per Household

We recommend that companies conduct a thorough cost-benefit analysis on the viability of different per household data collection schemes before pushing for implementation of sensors. The primary uses of household data on waste are:

- Route optimization
- Pay-as-you-throw programs
- Citizen feedback
- General research

One of the more significant reasons to investigate the potential of collecting data on waste per household is **route optimization**, which is the use of data per household to analyze and compute optimal routes for collecting waste. This can also be done through live route optimization, which would require more sophisticated equipment such as sensors built into waste bins.

There are many things to consider when investigating the viability of collecting data on waste per household. Companies should only look into collecting data per household for a specific use. The collection of large amounts of data without an explicit use in mind is a waste of resources and could lead to privacy issues. The uses presented would also have to be beneficial within their specific municipality, as potential value of these initiatives depends on the level of urbanization and household demographics of specific municipalities. Also, when considering the potential for large scale data collection, the implementation of sensors or semi-automated technologies may be necessary. A waste management company must understand that buying and implementing such technology within waste bins or trucks, especially at a household level, can be costly.

5.1.2 Determine if Feedback to Citizens is Beneficial before Giving Feedback

We recommend that companies look into providing feedback to improve the waste habits of citizens. Before implementing feedback programs, companies should conduct studies and trial runs

to identify the most effective feedback programs for their municipality. Companies should especially be aware of causing negative side effects such as citizens increasing consumption plastics in order to recycle more. While providing any form of feedback it is important to ensure that the privacy of citizens is protected and that poor performers cannot be singled out.

Sustained positive feedback will most likely be able to help improve the waste habits of Danish citizens. We recommend that companies look into implementing feedback programs such as:

- Charging citizens by weight of waste produced (Pay-as-you-throw)
- Informing citizens on the life cycle of their waste
- Comparing waste and recycling habits of citizens with that of their neighbors
- Notifying citizens of the amount of waste they produced and recycled

From the survey we conducted, we saw that citizens want to receive information such as how much waste that they produce and recycle every week, where their waste and recycling goes, and if they are producing more waste than their neighbors. To conduct feedback programs, companies will need to collect data per household such as the weight of residual waste, the amount recycled, and how often waste is collected.

5.1.3 Collect More Data on Internal Operations

We recommend that companies collect more data on their internal operations in order to optimize their waste management practices. Internal data includes:

- Data on financial operations
- Data collected at transfer stations
- Data on the shipment of waste between facilities

Collecting more data on internal operations entails expanding the collection of data as well as expanding the integration of datasets within companies. Using detailed data about the inner workings of companies can lead to increased productivity by predicting waste trends at facilities and enabling companies to better measure their performance.

Collecting more data on internal operations can be done through automated or semi-automated collection methods. We advise that companies explore the use of available technologies to record data on internal processes because useful data can still be collected without investing in new technology.

5.2 Recommendations Regarding Data Management

As companies expand the scope and scale of data collection, they must also improve their data management practices. In making the move to big data, managing data is arguably more difficult and important than expanding data collection. Large quantities of data cannot associate with each other if data structures are poorly designed and managed.

5.2.1 Develop Strong Data Management Platforms before Collecting Large Amounts of Data

We recommend that companies invest time and resources into designing and developing strong data management platforms. This development ideally should occur before actually beginning to collect larger amounts of data. Furthermore, real value cannot be extracted from datasets without

the proper knowledge. To properly extract valuable information from big data, teams of computer scientists, domain experts, and data analysis experts are needed.

Data management platforms should be scalable to accommodate the increasing volume and variety of data on waste. We also recommend that companies work with data science experts to develop their platforms because handling large scale data requires a specific expertise.

5.2.2 Clearly Articulate Incentives to Encourage Data Sharing

In order to encourage municipalities and waste processing organizations to share their data, the proper incentives need to be found between organizations. All parties can benefit from data sharing, but the incentives need to be clearly identified and articulated before real efforts to share data will be made. Companies, regardless of their individual performance, can compare their performance with other municipalities to discover insights on how to improve. We think a particularly good area to look for data sharing is between waste collection and waste processing facilities.

5.2.3 Develop a Standardized Format to Share Data

We recommend that waste management companies build a standardized data structure or framework to expand the sharing of data across Denmark. Using a standard will enable easier and faster data sharing by ensuring semantics, format, and quality of data is uniform. The DWA can take the initiative to create this standard, but should meet and work with the waste management companies that already are leaders in data management to develop standard formats. Working with current leaders in data management is important to avoid the existence of multiple conflicting standards. We believe that the best place to start looking into data sharing is in tracking waste shipments among different organizations, waste collection, and waste processing facilities.

5.3 Recommendations Regarding Social and Legal Concerns

Data on waste per household should be treated as **personal data.** Municipalities choosing to collect data per household must take adequate steps to ensure that all personal data is properly managed and secured. To secure their data, an organization must limit access to personal data, limit how personal data is used, and develop clear cybersecurity practices. Privacy must be integrated into the process of designing and implementing data collection and management systems.

The establishment of strong cybersecurity standards might be important in a legal context due to the impending implementation of the EU's GDPR. The GDPR will restructure laws on personal data collection to better reflect the modern technological landscape of data processing. We advise companies to seek legal consultation in order to update their standards for data collection and processing once the specific legal implementations of the GDPR in Denmark are finalized. Even disregarding GDPR compliance, municipal waste organizations have an ethical obligation as a government organization to properly manage personal data.

Below are a set of guidelines that apply to waste management companies choosing to collect personal data. We compiled these guidelines based on both our experience with the topic and from existing standards produced for other industries. Further elaboration on these recommendations can be seen in *Appendix L* Elaborations on Recommendations for Social and Legal Concerns.

1. Properly document what data is collected and what happens to it
2. Only collect data for a specific use
3. Do not share personal data

4. Only store personal data for as long as necessary
5. Anonymize personal data when possible
6. Limit access and control over data systems based on job function
7. Improve cybersecurity practices
8. Consider having compliance with other aspects of the GDPR

5.4 Guidelines for the DWA

Using the above recommendations regarding data collection, data management, and social and legal concerns, we compiled a set of guidelines for the DWA. These guidelines inform the DWA on what actions they must take to aid municipalities and waste management companies in implementing big data. The guidelines, which can be seen in *Appendix M* Guidelines for DWA to Aid Municipalities, inform the DWA to:

1. Study the viability of collecting household data by region
2. Develop a standardized format to share data
3. Inform municipalities of the importance of strong data management platforms
4. Consult legal experts in preparation for the GDPR

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Appendices

Appendix A Frederiksberg Municipality Interviews (English and Danish)

Introduction: We are four students from Worcester Polytechnic Institute working on a project with the Danish Waste Association. Our project involves investigating the potential challenges that could arise in the process of implementing "big data" into Denmark's waste management sector. We are hoping that these questions can act as a guide for discussions that will allow us to better understand the waste operations of this municipality. We also want to ask for your permission to record this interview for our paper and research purposes.

Guiding Questions:

1. Can you provide us with a general overview of waste management in your municipality?
2. What companies or entities are there in the city? Transfer stations, landfills, recycling plants? Is there a system of extracting recyclables from waste stream? Are there plants outside the municipality that waste is sent to specifically?
3. With regards to all data you collect - How is it collected, what type is collected, how frequently is it collected, how accurate is it, where is it stored, who has access to it?
4. Is there data sharing between companies/municipality?
5. Do you currently provide any type of feedback to citizens?
6. What ideas do you have of how big data might help waste management in your municipality?
7. What do think of the quality of data that you have right now?
8. What do you think are challenges in collecting/managing/sharing data within your municipality/between municipalities?
9. What kinds of opinions do the companies within your municipality have about sharing their data?
10. How do you think you can use data to make waste management better?
11. Are you aware of the upcoming changes to data regulations (EU general data protection regulation), (if aware) does it apply to this kind of waste sector data?

Appendix B Renosyd Interview

Introduction: We are four students from Worcester Polytechnic Institute working on a project with the Danish Waste Association. Our project involves investigating the potential challenges that could arise in the process of implementing "big data" into Denmark's waste management sector. We are hoping that these questions can act as a guide for discussions that will allow us to better understand the waste operations of this municipality. We also want to ask for your permission to record this interview for our paper and research purposes.

Guiding Questions:

1. Can you provide us with a general overview of how your company works?
2. With regards to all data you collect - How is it collected, what type is collected, how frequently is it collected, how accurate is it, where is it stored, who has access to it?
3. Do you currently provide any feedback to citizens about their waste?
4. What kind of challenges have you encountered in providing feedback?
5. How do you think big data analytics can improve citizen feedback programs?
6. How is Renosyd's waste management structured?
7. What other private or public companies are involved in the processing or treatment of waste?
8. Is any aspect of the waste management process shared with other municipalities?
9. Do you share any data and information with other waste companies or municipalities? Have there been any efforts made to share data?
10. What effects has your app had on waste in your municipalities?
11. What kind of measures are in place to protect the privacy of citizens whose data you collect?

Appendix C Arwos Interview

Introduction: We are four students from Worcester Polytechnic Institute working on a project with the Danish Waste Association. Our project involves investigating the potential challenges that could arise in the process of implementing "big data" into Denmark's waste management sector. We are hoping that these questions can act as a guide for discussions that will allow us to better understand the waste operations of this municipality. We also want to ask for your permission to record this interview for our paper and research purposes.

Guiding Questions:

1. Can you provide us with a general overview of how your company works?
2. With regards to all data you collect - How is it collected, what type is collected, how frequently is it collected, how accurate is it, where is it stored, who has access to it?
3. The Pickup web app:
4. How is Pickup incorporated into waste management operations?
5. What challenges or limitations are encountered when using Pickup?
6. Do you think there is untapped potential in the data collected from Pickup that you haven't yet made use of?
7. We know you worked with Maack-IT for the development/implementation of Pickup. How has been the experience of interacting with a third-party company to handle waste data?
8. How is Arwos' waste management structured?
9. What other private or public companies are involved in the processing or treatment of waste?
10. Is any aspect of the waste management process shared with other municipalities?
11. Do you share any data and information with other waste companies or municipalities? Have there been any efforts made to share data?
12. What kind of measures are in place to protect the privacy of citizens whose data you collect (security & anonymity)?

Appendix D Nomi4s Interview

Introduction: We are four students from Worcester Polytechnic Institute working on a project with the Danish Waste Association. Our project involves investigating the potential challenges that could arise in the process of implementing "big data" into Denmark's waste management sector. We are hoping that these questions can act as a guide for discussions that will allow us to better understand the waste operations of this municipality. We also want to ask for your permission to record this interview for our paper and research purposes.

Guiding Questions:

1. Can you give us a general overview of how your company works?
2. With regards to all data you collect - How is it collected, what type is collected, how frequently is it collected, how accurate is it, where is it stored, who has access to it?
3. How do you think big data analytics can improve the waste industry?
4. In what ways do you think big data could help provide feedback to citizens about their waste habits?
5. Do you think your automatic sorting mechanism can provide useful data to provide feedback to citizens?
6. How might big data be able to further optimize your waste management operations?
7. How is Nomi4s' waste management structured?
8. What other private or public companies are involved in the processing or treatment of waste?
9. Is any aspect of the waste management process shared with other municipalities?
10. Do you share any data and information with other waste companies or municipalities? Have there been any efforts made to share data?
11. The robotic sorting mechanism:
12. How can the robotic sorting benefit from using big data?
13. How can the robotic sorting contribute to collecting big data?

Appendix E Vestforbrænding Interview

Introduction: We are four students from Worcester Polytechnic Institute working on a project with the Danish Waste Association. Our project involves investigating the potential challenges that could arise in the process of implementing "big data" into Denmark's waste management sector. We are hoping that these questions can act as a guide for discussions that will allow us to better understand the waste operations of this company and the municipalities under it. We also want to ask for your permission to record this interview for our paper and research purposes.

Guiding Questions:

1. Can you provide us with a general overview of waste management in your municipalities?
2. Other than the waste-to-energy plant on-site, what other waste treatments occur here, if any?
3. With regards to all data you collect - How is it collected, what type is collected, how frequently is it collected, how accurate is it, where is it stored, who has access to it?
4. Is there data sharing between companies/municipalities?
5. Do you currently provide any type of feedback to citizens?
6. What ideas do you have of how big data might help waste management in your municipalities?
7. What do think of the quality of data that you have right now?
8. What do you think are challenges in collecting/managing/sharing data within your municipalities/between municipalities?
9. What kinds of opinions do the companies within your municipalities have about sharing their data?
10. How do you think you can use data to make waste management better?
11. Are you aware of the upcoming changes to data regulations (EU general data protection regulation)? (if aware) does it apply to this kind of waste sector data?

Appendix F JHN Processor Interview

Introduction: We are four students from Worcester Polytechnic Institute working on a project with the Danish Waste Association. Our project involves investigating the potential challenges that could arise in the process of implementing "big data" into Denmark's waste management sector. We are hoping that these questions can act as a guide for discussions that will allow us to better understand your area of expertise. We also want to ask for your permission to record this interview for our paper and research purposes.

Guiding Questions:

1. Can you give us a general overview of how your company works?
2. Data Management Tool:
3. Can you explain the data management tool you created to us?
4. What impact has this tool had on municipal waste management operations?
5. What kinds of challenges exist with using this tool?
6. What privacy and security concerns have come up with the use of this tool?
7. What companies has JHN worked with, and what are some common consultation topics?
8. What role has data analysis played in improving waste management?
9. What kind of concerns have you encountered regarding privacy of waste management data?
10. How has your current guide to the Danish EPA helped municipalities in managing their cost for waste?
11. We've seen one past project of yours in which you helped to decrease the amount of cans that ended up in a combustion plant. What lessons were learned from that project that waste management companies could learn from?

Appendix G Ane Sandager Interview

Introduction: We are four students from Worcester Polytechnic Institute working on a project with the Danish Waste Association. Our project involves investigating the potential challenges that could arise in the process of implementing "big data" into Denmark's waste management sector. This includes the privacy and legal concerns that could arise, and believe your insight is very important to us for the fact. We are hoping that these questions can act as a guide for discussions that will allow us to better understand your area of expertise. We also want to ask for your permission to record this interview for our paper and research purposes.

Guiding Questions:

1. Is privacy a major issue in today's politics? With how politics currently are, do you expect laws to become stricter or less strict with regards to the collection and use of personal data?
2. We are aware of the Danish Data Protection Agency, which is a council put together for the enforcement of The Act on Processing of Personal Data (APPD). We are, however, having trouble completely understanding its place or role in the government. If so, do they receive funding from The Folketing?
3. Given the language of the APPD and how it creates the Danish Data Protection Agency, does this mean that the district, high, and supreme courts cannot rule on violations of the APPD?
4. Do you know of any other industry that might have similar legal challenges (regarding data collection) as the waste industry?
5. New question: do you have any recommendations for the DWA in terms of how they should handle the GDPR?
6. The GDPR expand personal data rights - does this affect the scope of what is considered "personal" data? Do you know whether the changes mandated by this regulation will greatly affect Denmark's data law, or will it not change very much?
7. What kind of legal limitations are typically encountered when it comes to collecting, managing, and using any kind of personally identifiable data?
8. Are legal restrictions on collecting, managing, and using data different for the public sector and private sector? How might these differences affect data collection in waste management?
9. What challenges might exist with regards to the public and private sector splitting responsibility of managing personal waste data?

Appendix H Bjarne Ersbøll Interview

Introduction: We are four students from Worcester Polytechnic Institute working on a project with the Danish Waste Association. Our project involves investigating the potential challenges that could arise in the process of implementing "big data" into Denmark's waste management sector. We are hoping that these questions can act as a guide for discussions that will allow us to better understand your area of expertise. We also want to ask for your permission to record this interview for our paper and research purposes.

Guiding Questions:

- What's a good way to communicate the idea of "big data" to people who aren't very familiar with the field? Are there any terms/phrases that should be avoided when discussing the topic with people who are unfamiliar with the field?
- What kinds of mistakes are often made when they're new to using big data?

  How to use Big Data:
- What kinds of experts would need to be employed in order to properly utilize big data at the level that waste companies operate at?
- How much expertise is generally required to properly make use of insights that can be gained through big data?
- How much infrastructure would need to be built up to properly collect/manage/use waste data?
- Management Vs. Analysis. What are your thoughts on the difficulty of? - getting a clean database that's accurate and usable, or the process of analyzing clean data?

  Other:
- Let's hypothetically assume you can collect whatever kind of data you want in the waste industry-- what comes to mind regarding the ways we could use data to improve the waste industry
- Do you know anything about public opinion regarding big data (would especially be great to find specific resources/studies we could look up)?
- Are current data collection technologies affordable enough to collect the kind of data that would be relevant to waste management operations? What kinds of breakthroughs may be on the horizon for cheap/reliable data collection?

Appendix I Christian Jensen Interview

Introduction: We are four students from Worcester Polytechnic Institute working on a project with the Danish Waste Association. Our project involves investigating the potential challenges that could arise in the process of implementing "big data" into Denmark's waste management sector. This includes the privacy and security concerns that could arise, and believe your insight is very important to us for the fact. We are hoping that these questions can act as a guide for discussions that will allow us to better understand your area of expertise. We also want to ask for your permission to record this interview for our paper and research purposes.

Guiding Questions:

1. Privacy is a major area of concern that's been raised with regards to big data in waste management.
    a. What kinds of privacy risks do you think accompany big data?
    b. What about in the waste industry?
2. Privacy by design
    a. What are your thoughts on the topic?
    b. Can privacy by design fail to adequately protect privacy? Are there any extra steps that can be taken to better protect privacy?
3. Do you think there is a point of having too much privacy to the point of hindering the effectiveness of data?
4. With the collection of data on waste will come the need for database managers. How does security work for a database that's shared between municipalities? What are the biggest concerns- hacking, negligence, unethical breaches or snooping?
5. Are there security concerns regarding devices used for recording data in the waste industry? Is there a threat that sensors and automated waste treatment facilities could be tampered with remotely?
6. How big of a threat is privacy and data re-identification? Could we run through a hypothetical you imagine, either in the context of personal waste data or from other similar fields?

Appendix J Survey Questions

The following survey is being administered to further understand the waste habits of citizens. The results of this survey will be used to inform what kind of feedback Danish citizens may want about their waste habits. Answer choices: [Agree, Neutral, Disagree]

1. I would be interested in knowing how much waste I produce every week.
2. I would be interested in knowing how much waste my neighbors produce every week.
3. I think I would change my waste habits if I knew that I was producing more waste than my neighbors.
4. If my neighbors shared information about how much waste they produced, I would be comfortable with sharing my information about how much waste I produce.
5. I think that I would recycle more if I knew how much waste I recycled.
6. I would recycle more if I knew what happened to my waste after I recycled it.
7. I consider the amount of waste that I produce to be "personal" information.
8. I would be more inclined to having information about how much waste I produce collected if the information isn't shared with the public.
9. I would be more inclined to having information about how much waste I produce collected if it helped to improve waste management in my community.
10. I would be more inclined to having information about how much waste I produce collected if it improved recycling and resource reuse throughout Denmark.

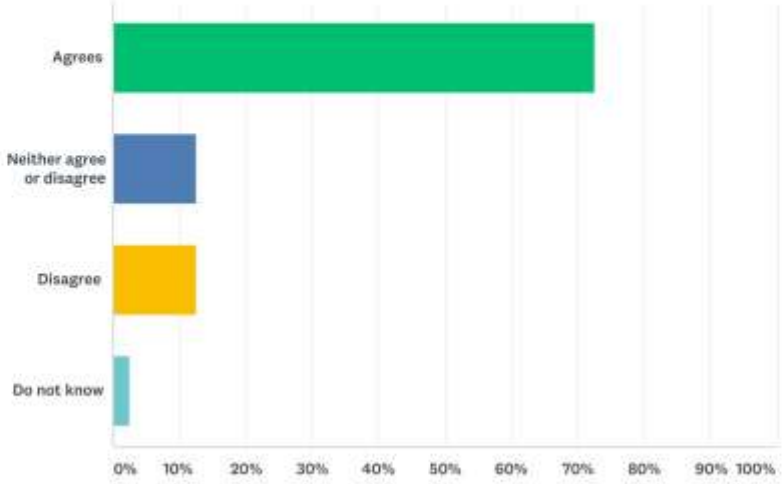
Følgende spørgeskemaundersøgelse skal bidrage til yderligere at forstå borgernes affaldsvaner. Resultaterne fra undersøgelsen vil blive brugt til at oplyse om, hvilken form for tilbagemelding danske borgere måtte ønske at få omkring deres affaldsvaner. Svarmuligheder: [Enig, Hverken enig eller uenig, Uenig, Ved ikke]

1. Jeg ville være interesseret i at vide, hvor meget affald jeg producerer hver uge.
2. Jeg ville være interesseret i at vide, hvor meget affald mine naboer producerer hver uge.
3. Jeg tror, at jeg ville ændre mine affaldsvaner, hvis jeg vidste, at jeg producerede mere affald end mine naboer.
4. Hvis mine naboer delte information om, hvor meget affald de producerer, ville jeg være mere komfortabel med at dele mine oplysninger om, hvor meget affald jeg selv producerer.
5. Jeg tror, at jeg ville genanvende mere, hvis jeg vidste, hvor meget affald jeg producerer.
6. Jeg ville genanvende mere, hvis jeg vidste, hvad der sker med mit affald efter, at jeg har genanvendt det.
7. Jeg anser den mængde affald, jeg producerer, for at være personlig information.
8. Jeg ville være mere tilbøjelig til at få indsamlet information om, hvor meget affald jeg producerer, hvis oplysningerne ikke deles med offentligheden.
9. Jeg ville være mere tilbøjelig til at få indsamlet information om, hvor meget affald jeg producerer, hvis det var med til at forbedre affaldshåndteringen i mit lokalsamfund.
10. Jeg ville være mere tilbøjelig til at få indsamlet information om, hvor meget affald jeg producerer, hvis det forbedrede genanvendelse og genbrug i hele Danmark.

Appendix K Data Collection and Feedback Survey Results

Q1 I would be interested in knowing how much waste I produce every week.

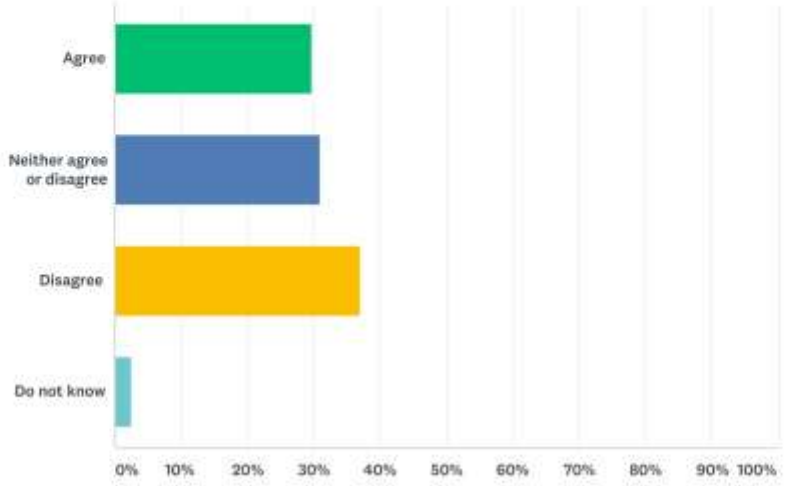
Answered: 80 Skipped: 1



ANSWER CHOICES	RESPONSES	
Agrees	72.50%	58
Neither agree or disagree	12.50%	10
Disagree	12.50%	10
Do not know	2.50%	2
TOTAL		80

Q2 I would be interested in knowing how much waste my neighbors produce every week.

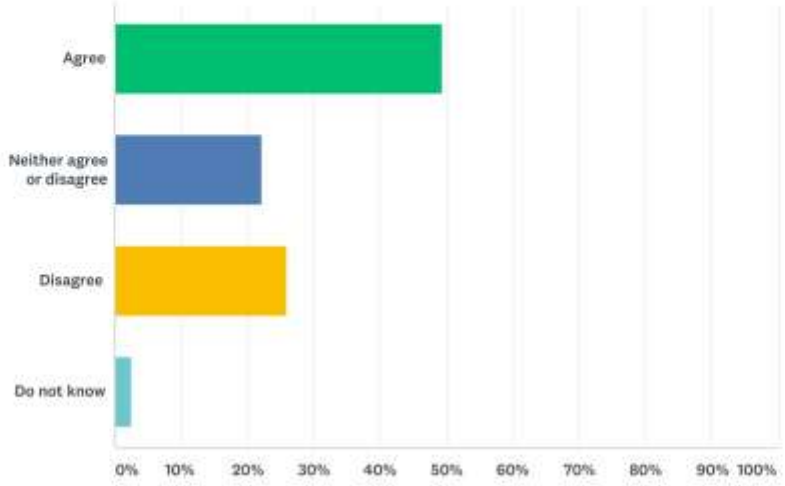
Answered: 81 Skipped: 0



ANSWER CHOICES	RESPONSES	
Agree	29.63%	24
Neither agree or disagree	30.86%	25
Disagree	37.04%	30
Do not know	2.47%	2
TOTAL		81

Q3 I think I would change my waste habits if I knew that I was producing more waste than my neighbors.

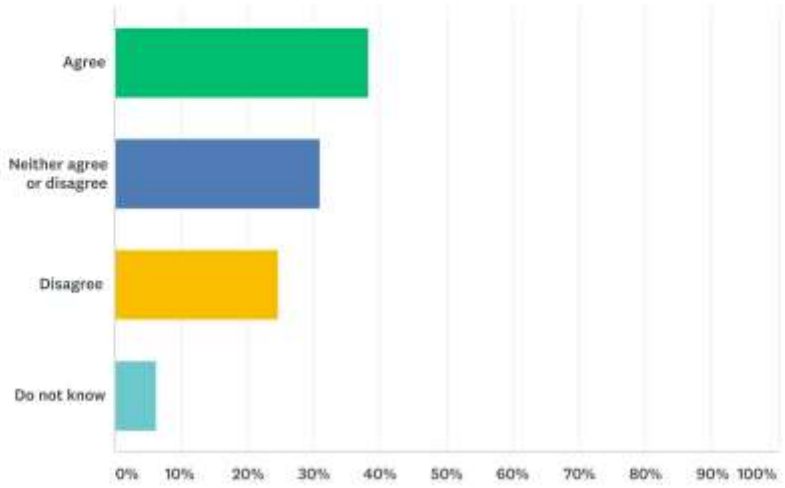
Answered: 81 Skipped: 0



ANSWER CHOICES	RESPONSES	
Agree	49.38%	40
Neither agree or disagree	22.22%	18
Disagree	25.93%	21
Do not know	2.47%	2
TOTAL		81

Q4 If my neighbors shared information about how much waste they produced, I would be comfortable with sharing my information about how much waste I produce.

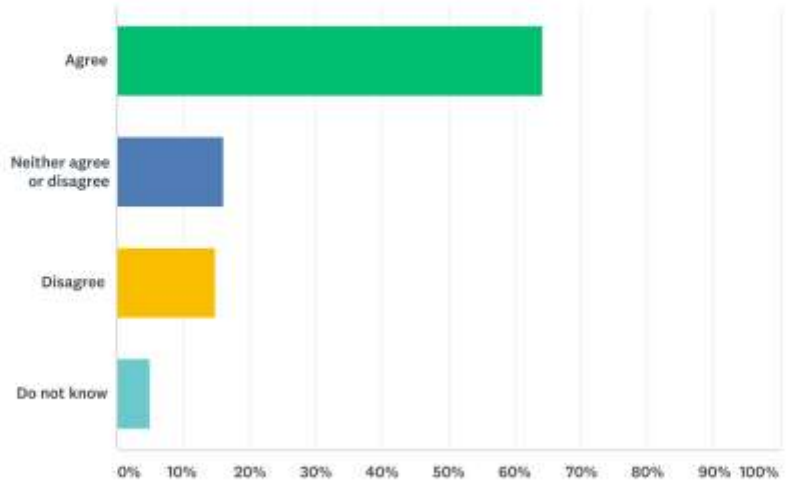
Answered: 81 Skipped: 0



ANSWER CHOICES	RESPONSES	
Agree	38.27%	31
Neither agree or disagree	30.86%	25
Disagree	24.69%	20
Do not know	6.17%	5
TOTAL		81

Q5 I think that I would recycle more if I knew how much waste I recycled.

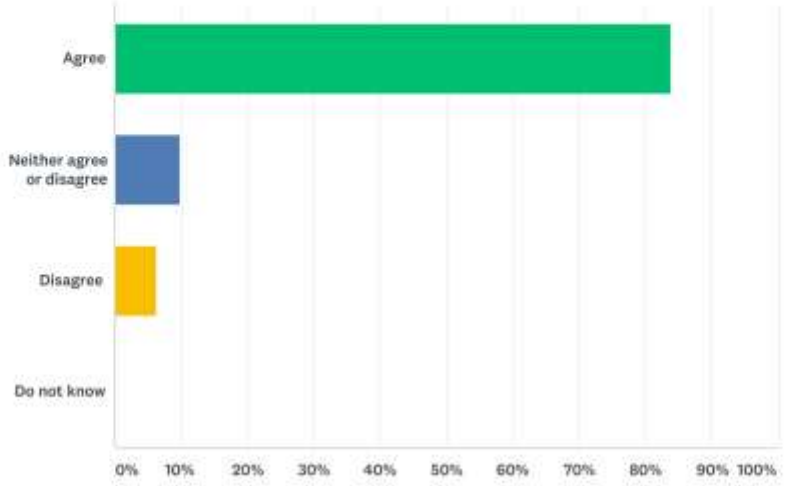
Answered: 81 Skipped: 0



ANSWER CHOICES	RESPONSES	
Agree	64.20%	52
Neither agree or disagree	16.05%	13
Disagree	14.81%	12
Do not know	4.94%	4
TOTAL		81

Q6 I would recycle more if I knew what happened to my waste after I recycled it.

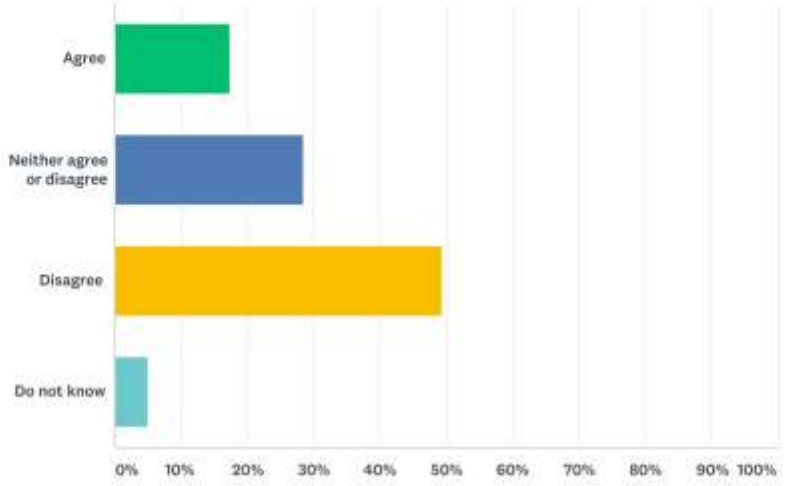
Answered: 81 Skipped: 0



ANSWER CHOICES	RESPONSES	
Agree	83.95%	68
Neither agree or disagree	9.88%	8
Disagree	6.17%	5
Do not know	0.00%	0
TOTAL		81

Q7 I consider the amount of waste that I produce to be "personal" information.

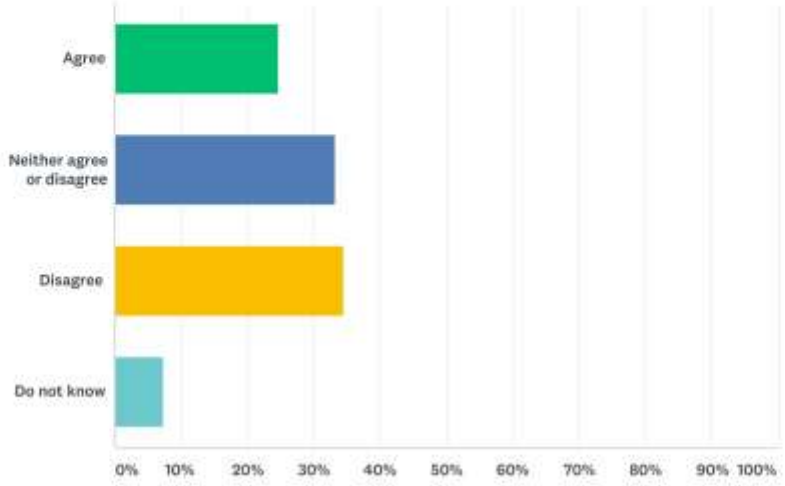
Answered: 81 Skipped: 0



ANSWER CHOICES	RESPONSES	
Agree	17.28%	14
Neither agree or disagree	28.40%	23
Disagree	49.38%	40
Do not know	4.94%	4
TOTAL		81

Q8 I would be more inclined to having information about how much waste I produce collected if the information isn't shared with the public.

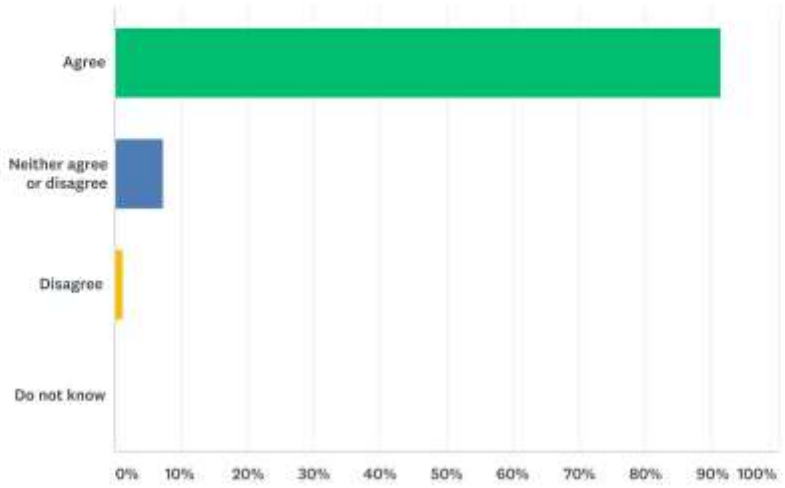
Answered: 81 Skipped: 0



ANSWER CHOICES	RESPONSES	
Agree	24.69%	20
Neither agree or disagree	33.33%	27
Disagree	34.57%	28
Do not know	7.41%	6
TOTAL		81

Q9 I would be more inclined to having information about how much waste I produce collected if it helped to improve waste management in my community.

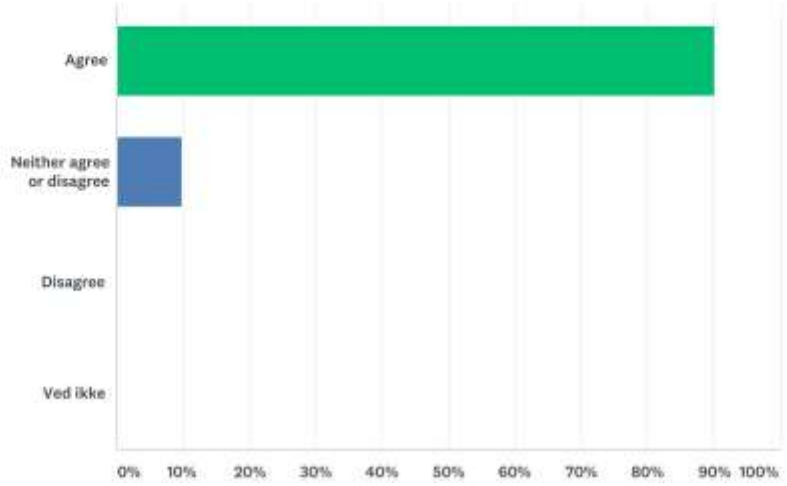
Answered: 81 Skipped: 0



ANSWER CHOICES	RESPONSES	
Agree	91.36%	74
Neither agree or disagree	7.41%	6
Disagree	1.23%	1
Do not know	0.00%	0
TOTAL		81

Q10 I would be more inclined to having information about how much waste I produce collected if it improved recycling and resource reuse throughout Denmark.

Answered: 81 Skipped: 0



ANSWER CHOICES	RESPONSES	
Agree	90.12%	73
Neither agree or disagree	9.88%	8
Disagree	0.00%	0
Ved ikke	0.00%	0
TOTAL		81

Appendix L Elaborations on Recommendations for Social and Legal Concerns

The following recommendations specify how to address privacy and legal concerns regarding personal data and are directed at waste management companies. Concepts in this appendix were heavily inspired by the following two reports:

- WaterISAC. (2015). *10 Basic Cybersecurity Measures- Best Practices to Reduce Exploitable Weaknesses and Attacks*.
- DI Digital. (2016). *General Data Protection Regulation - Implementation in Danish Companies*.

1. **Properly document what data is collected and what happens to it**

   Waste management organizations must have a precise understanding of what and how data is collected and used in order to properly protect data. Proper documentation should exist for all data collection and processing schemes, including the flow of data shared with other organizations. This recommendations also helps with prospective GDPR compliance, as "Accountability in the form of documentation is very central in the Regulation, and one may say that if something is not documented, it is not done" [*DI Digital, 2016*].
2. **Only collect data for a specific use**

   Waste management organizations should only collect data linked with an explicit purpose. Having explicit uses of data will help improve transparency of operations to the public and can reduce risks associated with personal data being exposed or leaked. Additionally, data should only be processed for the purpose with which it was collected; this will help ensure that personal data is never used in an inappropriate fashion, and will better align organizations data management practices with those prescribed in the GDPR.
3. **Do not share personal data**

   Data on waste per household can contain information about specific individuals or families; its association with a physical home address warrants classifying it as personal data. There are many risks when sharing personal data on waste, and as such organizations should withhold such information from the public. Simply not sharing data on waste is not enough, however; waste management organizations must actively prevent the disclosure of such information to the public from accidental negligence or hackers. Many of the subsequent objectives address specific ways in which organizations can avoid accidentally disclosing personal data.
4. **Only store personal data for as long as necessary**

   Personal data on waste that is collected should not remain in a database after its intended processing has been completed. This helps to further reduce the risk of personal data being leaked or misused and avoids the issues associated with unknown future technologies entirely.
5. **Anonymize personal data when possible**

   While anonymization is not a perfect solution for protecting privacy, it still can be useful. Unless data that is collected has a concrete need to identify individuals (such as for billing purposes) it should be anonymized. This could be done, for example, by permanently encrypting addresses. Pseudo-anonymization practices, such as encrypting addresses and retaining keys to access, can also help to reduce the risk of data subjects.

   An alternative anonymization method is to only present data at an aggregate level. By only exposing personal data as an aggregate, privacy risks such as re-identification of anonymized data can be avoided.
6. **Limit access and control over data systems based on job function**

   Access to databases that contain personal data should be limited to essential personnel only. Unrelated personnel within the organization should not be able to access this data. Limiting access to personal data will reduce risks of internal data misuse or leaks, both intentional and unintentional. In

addition to limiting access, it is also advisable to implement logging to track all access and processing of personal data.

7. **Improve cybersecurity practices**

   Waste management organizations should make use of general best practices of cybersecurity that are used across various industries. The following guidelines have been adopted from the 2015 ISAC document, *10 Basic Cybersecurity Measures*. These best practices include:

   - "Use Only Strong Passwords, Change Default Passwords, and Consider Other Access Controls." This would also entail implementing other password security features such as locking accounts if too many incorrect password inputs are detected. Organizations may also consider requiring multi-factor authentication, which entails users verifying their identities via codes sent to devices they previously registered whenever they attempt to sign-in.
   - "Maintain Awareness of Vulnerabilities and Implement Necessary Patches and Updates." This best practice will help keep data protection up to date as technologies evolve.
   - "Develop a Cybersecurity Incident Response Plan." Waste management organizations should have plans in place to respond to a breach of security. This will help to limit damage in the case that security measures fail.
   - "Use Secure Remote Access Methods." If remote access is available to an organization's database, it should make use of secure connection protocols and be heavily restricted.

8. **Consider having compliance with other aspects of the GDPR**

   Waste management organizations should consider reading through the GDPR to identify if it contains information that is applicable to their operations. Some of the components that we think are important to consider are the right to be forgotten, data portability, and acquiring consent for the collection of personal data.

Appendix M Guidelines for DWA to Aid Municipalities

1.) Study the viability of collecting household data by region

The use of sensors to assist in measuring data on waste per household is an exciting area for exploration in the waste industry. Sensors can enable the collection of per-bin or per household data on waste, which can be used for route optimization and feedback to citizens. Implementing sensors and an accompanying systems to manage the data requires an investment of resources that may not always be worth the results. The return on investment depends on the local effectiveness of routing solutions and feedback programs. We recommend that the Danish Waste Association assists with this issue in two ways:

1. **Measure** and **report** on the returns municipalities have achieved by investing in sensor based technologies
2. **Encourage** and **support** the development of research on route optimization and citizen feedback programs

The first action is limited by the number of municipalities using per-bin data collection schemes with reportable information. It is possible that very few, if any, municipalities will be able produce clear figures measuring the return on investment achieved via per-bin data collection. The effectiveness and exact method taken with this action will depend on what information can actually be reported by municipalities.

Action two will address the current lack of research on the cost-benefit analysis of per-bin sensor solutions. Below is an outline of how the Danish Waste Association could go about addressing this issue, broken down into the need for feedback and route optimization studies.

Studies on Feedback Programs

The Danish Waste Association should **identify** municipalities that are interested in implementing household feedback programs. The municipalities interested in feedback programs will most likely not be in urban environments, as cities hinder the ability to effectively measure an individual's waste habits.

Feedback programs themselves require some level of per household data collection, but it is not necessary to implement sensors before studying the effects of feedback. It is possible to **emulate** the effect of automatic household feedback programs by manually recording a household's waste production and providing feedback.

After interested municipalities have been identified, the Danish Waste Association should **encourage and support** scientific studies which will measure the effect that household feedback programs have on the waste habits. Studies should seek to measure the effect that *household feedback* programs, have on the *households' waste habits*. There is no specific experimental design which we propose, as there are many viable methods and an uncountable number of ways to measure waste habits. When approving experiments, the following points should be considered:

- Measure the effect on waste habits both before, while, and after feedback is being provided
- Use proper experimental design: Control for fake feedback or no feedback; use appropriate sampling techniques; and consider the presence of latent variables.
- Consider a variety of feedback programs

Studies on Route Optimization

In addition to feedback programs, the effectiveness of route optimization must be more accurately measured on a regional basis. The route optimization system needed and its cost effectiveness will depend on a variety of factors. Such factors may include the population density and layout of the region where route optimization will be applied; routing solutions built for cities differ from those built for rural regions.

Route optimization can be studied via **modeling** techniques, in which researchers simulate alternate routing systems to estimate the difference in the amount of distance traveled. We think studies like this will be beneficial to better understanding the potential returns of implementing sensors.

When studying routing solutions, the Danish Waste Association should try to compare different solutions. How effective are real-time routing solutions vs static ones? Is route optimization effective in the low population density areas? Are real-time routing solutions that account for traffic worth the cost? These are the questions necessary to answer before municipalities can conduct their own cost-benefit analyses of implementing routing solutions.

2.) Develop a standardized format to share data

We believe municipalities collecting big data will benefit from information sharing with other municipalities. Efforts to share data, however, are partially limited by the technical difficulty of facilitating the exchange of datasets that allow for meaningful comparisons. The practice of sharing data via excel sheets, email, and manual data entry will not be sufficient when working with big data.

The Danish Waste Association can kick start the development of such standards by hiring consultants and experts. Consultants with expertise in the data standards should work with the waste industry's leaders in data collection & management to develop a standardized format for the exchange of data on waste between waste organizations. Below is an outline of how the Danish Waste Association could accomplish this, along with our insight and commentary on potential pitfalls:

1. The first step is to **identify** municipalities that are leaders in data collection and management which are interested in the potential of data sharing. It is important to filter for and identify only companies that can demonstrate technically sound data management practices. During this process, determine specifically what data municipalities are interested in sharing.
2. Once potential candidates have been identified, the next step is to **facilitate discussions** on the feasibility of exchanging data. These discussions should involve both IT and business personnel to ensure that both the technical and financial challenges of sharing data are addressed. When discussing data sharing, organizations should clearly identify and articulate the **incentives** of data exchange in order to encourage interest among municipalities.
3. The next potential step is to **hire** data management consultants to work with industry leaders to develop an industry standard data model for sharing data. This step should be done only after verifying that municipalities have a desire for an industry standard data model. The experts hired should have expertise in database modeling and more specifically with the development of industry standard models. When developing a model, consider the following:
    a. Do not be overzealous when defining the scope of data sharing; only model information for which there is a demand.
    b. The data model does need not be universally prescribed to all of Denmark's municipalities; an industry standard data model should instead be a tool which municipali-

ties may use to more easily facilitate the exchange of data. This tool should not stifle the development of other data sharing platforms.

c. Ensure that personnel experienced in managing data on waste are involved in the process of modeling. This is to ensure the model does not deviate from the actual needs of those who will be working with it.

3.) Inform municipalities of the importance of strong data management platforms

Developing strong data management platforms will allow municipalities to fully utilize their current data and prepare for big data. Data management platforms should be scalable to accommodate the increasing volume and variety of data on waste. Below we provide a more specific breakdown of how the Danish Waste Association can take steps to ensure that municipalities are informed about the importance of strong data management platforms.

1. The Danish Waste Association should **inform** municipalities of the potential benefits associated with better data management platforms, such as:
    a. Easier sharing of data
    b. Better analysis of data
    c. Better organization of data
2. The Danish Waste Association should also **sustain awareness** in their members through various means of communication, including:
    a. E-mails
    b. Newsletters
    c. Conferences

4.) Consult legal experts in preparation for the GDPR

Waste management companies need to understand the legal issues that accompany the collection of data on waste, especially at the household level. With the General Data Protection Regulation (GDPR) coming into effect in May 2018, laws surrounding data collection, management, and use may change for the waste industry. The Danish Waste Association should consult with a legal expert with experience in laws surrounding personal data once Denmark's specific implementation of the GDPR is finalized. In order to ensure that waste management companies are prepared for potential changes in data law, the Danish Waste Association can compile and distribute key findings from their consultation. This will help reduce efforts by municipalities to collect redundant information. Legal consultation should, in effect, seek an answer to the question, *to what extent does the GDPR apply to waste companies*?