Potential and challenges of mixed municipal solid waste treatment from the perspective of circular economy: Case study for Vantaa City

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Abstract

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The objective of this study is to identify potential and challenges of mixed municipal solid waste (MMSW) treatment from the perspective of circular economy based on the analysis of Vantaa's MMSW treatment. This research paper also aims to understand how MMSW treatment in Vantaa City can be improved from the perspective of CO_2 emissions and its economic value.

This thesis is commissioned by Vantaa City as a research, results of which can contribute into "the six-city strategy" ("6Aika") project started in 2014 with a goal to strengthen cooperation of cities, businesses and research organisations in the field of circular economy, climate change mitigation and low-carbon footprint.

The thesis scope is limited by mixed municipal solid waste and ways of its treatment. Case study is narrowed to Vantaa City and characteristics of MMSW collected from Vantaa area. Delimitation of this thesis relates also to emissions produced within the Vantaa City and direct emissions from Vantaa Energy related to energy recovery from mixed municipal solid waste.

The theoretical framework of this thesis includes concepts of a circular economy and waste treatment, in particular mixed municipal solid waste.

The methodological approach of this study was descriptive, and a qualitative method was used by conducting semi-structured interviews with open-ended questions to gather data. In total, experts from four different organizations participated in interview representing Vantaa City, Helsinki Region Environmental Services (HSY), Vantaa Energy and private Waste Management company.

Results of this study showed that incineration of waste with energy recovery is applied as a main method for Vantaa's MMSW treatment. The main argument for this that it is economically efficient, can help to generate clean energy (heat and electricity), minimize landfilling of mixed municipal waste, and reduce GHG emissions. At the same time, it was highlighted that such waste treatment is out of the loop of circular economy and eliminates the possibility to inject the materials back into economy as secondary raw materials.

In conclusion, the findings showed that there are real opportunities regarding the possibilities for improvements in Vantaa's MMSW treatment. Further cooperation with all stakeholders involved in the process as well as improvements in technology will help to utilize maximum value from Vantaa's MMSW and speed up transition towards a circular economy.

Keywords
Circular economy, waste-to-energy, MMSW treatment, MMSW sorting, CO_2 emissions

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1 Introduction

Human beings have always produced waste wherever they went, however, according to Amasuomo & Baird (2016), the waste production became an issue at that moment, when humans began to live in communities. As the population of cities grew and demand for goods increased, the production of goods also grew which led to waste problems which we are facing today. The continues production of goods and consumerism have caused huge problems to the environment, hence, many corporations and countries started to manage the waste by working together and now the waste management have become a huge industry with a global market size of €1.73 trillion. (Tiseo 2020.)

Energy industry represents one of the global biggest industries by revenue, generating nearly 70% of the global GDP, €1,720,5B in 2021 (IBISWorld 2021). Overall demand for energy is constantly increasing due to a rapid growth of the population, which is predicted to reach 8.5 billion by 2030, 9.7 billion by 2050 and up to 11.2 billion by 2100 (United Nations 2021). Such fast growth of the population leads to environmental problems like high fossil fuels consumption, carbon dioxide emissions, massive pollution and negative climate change (OECD 2011).

Nowadays, more than 55 % of the current population lives in cities and according to further predictions this number will grow up to 68 %, which means that around 6 billion people will be in cities by 2050. So that to provide sufficient energy provision, sustainable growth and low carbon emission, cities should incorporate renewable sources of energy and transit towards a circular economy. All operations in cities should proceed to a new level, where products and materials are reused, recycled and repaired, materials are sourced locally, and cities are powered by renewable energy (Ellen MacArthur Foundation 2017a).

So that to minimize and slow down natural resources consumption, provide optimization of resources, mitigate issues connected with fast urbanization, waste management and energy supply, a concept of smart cities was developed (European Commission 2018). In a nutshell, a smart city is a city which utilizes technology to improve efficiency in transportation and mobility, energy and planning, reduce waste and increase social inclusions, develop social and economic quality through openness and a strong will to work together. Smart city solutions have been actively implemented in Finland starting from 2013, when a Smart City program was launched with a goal to strengthen a cooperation between cities and businesses via the projects. (Business Finland 2018.)

This thesis was commissioned by Vantaa City as a part of “Six cities strategy” project, which aims to create climate-positive smart cities and industrial areas with smart resource consumption, help companies to integrate low-carbon and low-emission solutions into their value chains, create efficient carbon roadmaps which can be incorporated as a model for development zero carbon cities (6 Aika 2015). The six cities strategy is an umbrella organization for the projects, which includes variety of them starting from smart mobility and well-being and ending with energy efficiency and circular economy implementation. Results of projects can be used not only by Vantaa City, but also by Helsinki, Espoo, Turku, Tampere and Oulu (6Aika 2014), as well as generate international interest for further research.

Due to complexity of the research topic, lack of coherent view, lots of debates and opinions, the current thesis intends to investigate potential and challenges of mixed municipal solid waste (MMSW) treatment from a perspective of circular economy for Vantaa City. Received results later can be integrated into research base of “6Aika” projects for further development by field experts. Current thesis covers mixed municipal solid waste and does not cover any hazardous waste, industrial and commercial waste or waste, which treatment comes under some special regulations.

The theoretical framework for this thesis includes academic articles, literature related to waste management and energy processes, materials from international webinars held by experts within a framework of “Waste-to-Energy and Circular Economy”, results from projects held in different countries as a part of “MMSW treatment”, materials provided by Vantaa City, Vantaa Energy, HSY and Waste Management Company X.

1.1 Objective and research questions

The objective of the following thesis is to investigate potential and challenges in MMSW treatment in Vantaa City from a perspective of circular economy. To reach this objective, the following questions should be answered:

- What are potential and challenges in Vantaa’s MMSW treatment from the perspective of circular economy?
- How MMSW treatment in Vantaa City can be improved from the perspective of CO_2 emissions and its economic value?

Results of the current project can be used not only by Vantaa city but also by other participants of “6Aika” project and by cities with similar prior metrics. Current research can contribute to European Union database in general, due to a fact that the project stimulates cities involvement in utilizing MMSW from the perspective of circular economy, it helps to map the potential of establishing ecosystem cooperation between municipalities, businesses and R&D&I actors in material flow operations related to energy needs and carbon neutrality goals.

The results of this research can be used by educational institutions in a framework of studies about circular economy and renewables, as well as for systematic evaluation of possible MMSW treatment and synergy with related systems. The outcome of this thesis can contribute to understanding of potential and challenges in MMSW treatment, its associations with CO_2 emissions and potential sources of revenue, as well as a path to a circular economy that is market-driven and sustainable.

Nowadays, businesses are looking for sustainability and one of the reasons for that is a scarcity of resources. The authors can benefit from the project in a form of learning about the concept of circular economy, its practical implementation and ways how to utilize maximum value from resources. The project also provides a possibility to network and acquire new business contacts with stakeholders involved in the project which will be useful for future work and career development.

1.2 Thesis scope and delimitations

The thesis scope is limited by mixed municipal solid waste and ways of its treatment. Case study is narrowed to Vantaa City and characteristics of MMSW collected from Vantaa area.

Delimitation of this thesis relates also to emissions produced within the Vantaa City from mixed municipal solid waste treatment. Indirect emissions of goods and services emitted outside Vantaa City in association with MMSW treatment will not be considered.

In the research part of the thesis, qualitative method is used by conducting semi-structured interviews to gather data. The structure of this thesis includes eight parts, where chapter 1 presents introduction, covers objective and research questions, as well as thesis scope and delimitations. Chapter 2 explains general information about commissioner of this thesis and projects interconnected with a current research. Chapters 3 and 4 cover main concepts and some previous findings related to the topic. Chapter 5 focuses on methods and tools for the current research. Chapter 6 explains results of the research and its reliability. Chapter 7 refers to development ideas for further research and reflection on own learning and finally, chapter 8 represents a conclusion.

2 Commissioner - Vantaa city

Commissioner of this thesis is Vantaa City - the fourth biggest city in Finland with a population of nearly 240 000 people. There are 7 main regions in Vantaa and more than eleven thousand different businesses operate in the city, giving a job to more than 100 000 people (Vantaa 2020). Thanks to developed infrastructure, public transportation system and central location, which is near the airport area close to Helsinki, Vantaa city considered to be a great place to live and work (EUROCITIES 2020). Moreover, Vantaa's residents are offered a variety of public services and activities, including a possibility to spend time outdoors in versatile natural parks for all residential areas.

2.1 Six-city strategy

Local food supply chain, construction sector, engineering and machine industries are important indicators of Vantaa forefront development. Vantaa City put lots of efforts to challenge rapid urbanization and climate change by developing efficient services and products which promotes innovativeness, digitalization, openness and low-carbon solutions (6Aika 2014). One of the result of such effort is Vantaa participation in a "6Aika" strategy, where six largest cities in Finland (Helsinki, Espoo, Vantaa, Tampere, Turku and Oulu) have joined together to solve urbanisation problems, improve overall services, meet environmental and economic goals (6Aika 2020).

The six-city strategy ("6Aika") started in 2014 and it is based on co-operation of cities, businesses and research organisations to contribute to climate change mitigation, circular economy and low-carbon footprint. Lots of projects are run in the framework of six-city strategy, covering variety of topics from health to environment. Open data and interfaces, open innovative networks and engagement, customer-centred co-creation and service growth in real urban environments are large-scale initiatives which are the foundation of the strategy. (6Aika 2020.)

The six-city strategy is a part of Finland's structural fund programme for sustainable growth, which is funded by European Regional Development Fund (ERDF), European Social Fund (ESF), the Finnish Government, the participating cities and project partners (6Aika 2020).

2.2 Climate Positive Business Areas and Value Chains project (CircHubs ILPO)

Within a framework of "6Aika", Vantaa city actively participates in a project called the "CircHubs ILPO" ("Climate-positive industrial areas and value chains"), which promotes cities to achieve far reaching goals with a focus on value chains from the perspective of energy, raw materials and material flows between multiple companies, innovative low-emission operating methods for businesses, create a practical model which everyone within the climate-positive industry could use as reference. The impact of the project on business economics will be measured, as well as the impact on climate. (6Aika 18 May 2020.)

"CircHubs ILPO" project includes multiple stakeholders and one of them is Vantaa Energy OY - the largest energy company in Finland with a hundred years of history. Vantaa Energy plays a big role in achieving Vantaa's aim to reduce CO_2 emissions and become carbon neutral by 2030. A big step towards that was made in 2014, when Vantaa Energy started its waste-to-energy plant which now burns 374 000 tonnes of unusable waste every year. The plant is responsible for 30% of the electricity of Vantaa and have reduced the carbon dioxide levels of Vantaa by 30%, lowered the use of fossil fuel by 40% and have minimized the size of landfills. (Vantaan Energia 2021a).

Currently, Vantaa is committed to reduce a greenhouse emission by at least 80% for its sustainable growth and development. To do that, in 2017 a focus was set to use materials wisely, integrate low-carbon solutions into a city structure and implement "Roadmaps to Resource Wisdom" in accordance with United Nations Sustainable Development Goals (UN SDGs). "Roadmaps to resource wisdom" have a focus on promoting sustainable use of natural resources, energy production and consumption, urban structure and transport, responsible citizens and move towards a circular economy. (City of Vantaa 2018.)

Vantaa's participation in "Circwaste", a 7-year project which supports and encourage recycling, waste reduction and efficient material flows, is an important step towards low-carbon emission, sustainability and transition towards a circular economy. Coordinated by Finnish environmental Institute, the "Circwaste" project includes more than 20 partners and receives large funding from the EU "Life program" (Circwaste 2020a). Additionally, within a framework of a national waste management plan, Vantaa cooperates with HSY to provide energy and material efficiency, reduce waste, and increase material recycling (HSY 2021).

2.3 Vantaa' s goals for CO_2 emissions and sustainable development

Vantaa city participates in multiple projects which contribute into transition towards a circular economy, positive climate change and low-carbon solutions for urban development. In 2016, Vantaa's emission level was 1078 ktCO_2 e, where nearly 36 % of it was caused by transport and 42% by heating (district, oil and electric heating) (figure 1).

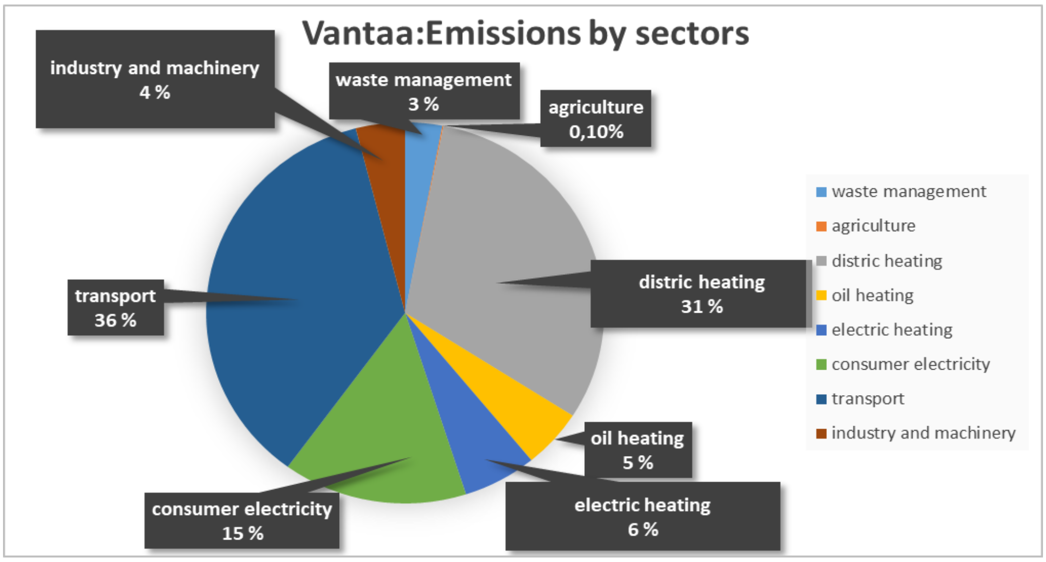

Figure 1. City of Vantaa: Emissions by sectors (adapted from City of Vantaa 2018)

By 2030, Vantaa's ambitious goal is to reduce emissions to 215 $ktCO_2$ e, which means gradual reduction of emission by nearly 7% per year (figure 2).

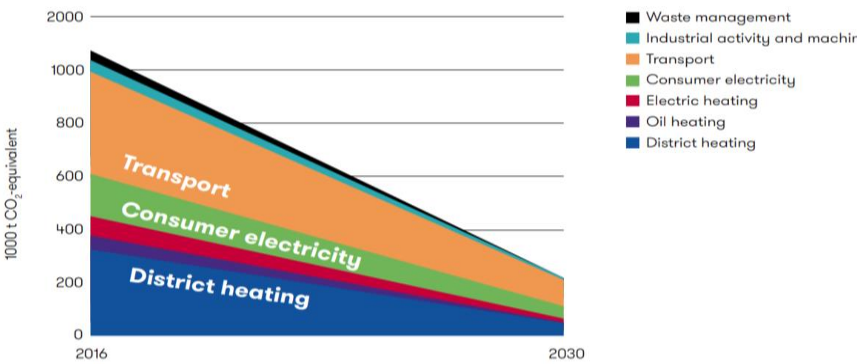

Figure 2. Vantaa's goal by 2030 (adapted from City of Vantaa 2018)

According to figures 1 and 2, energy production and consumption play a significant role in affecting climate change, that is why it is essential to invest and develop low-carbon energy solutions and climate positive model. To be at the forefront of sustainable development, City of Vantaa set a following timeline for energy production and consumption (City of Vantaa 2018):

- by 2021 end peat use in energy production
- by 2022 end coal use completely
- in 2024 waste processing services will expand to waste which cannot be processed normally
- by 2026 end fossil fuel use
- by 2026 a seasonal energy storage will be opened and instead of natural gas biogas will be used for the incineration plants
- by 2030 end the use of oil heating of buildings, which mostly relates to day-cares and schools owned by city, in total 37 buildings

2.4 PESTEL analysis of the commissioner

So that to understand major factors affecting on Vantaa City from outside and influencing on the way of MMSW treatment it is important to analyse six external factors such as political, economic, sociological, technological, environmental, and legal – PESTEL analysis (table 1).

Table 1. PESTEL analysis

	P E S T E L
P	**POLITICAL:** • MMSW treatment includes multiple stakeholders, for example, from public sector - Vantaa City, HSY, Vantaa Energy; from private sector- different sub-contractors which are responsible for parts of the treatment operations, for example, for transportation in the whole region (not only Vantaa), also including septic tank sludge • There is no set criteria for companies to use recycled materials • Tax laws do not motivate companies to become sustainable • Finland, EU, China and America are aiming towards a sustainable market • Clear regulations are essential to motivate companies to act more responsively, e.g. use recycled materials
E	**ECONOMIC:** • Sustainable market is growing, since EU, China and USA try to become carbon neutral • Recycling of MMSW is not cost-efficient yet and recycled materials quality is lower compared to cheaper virgin materials • Preferable way of MMSW treatment in Vantaa City is incineration since it is the most profitable way of treatment at the moment. • There is no relevant and updated research done on MMSW treatment, therefore, it is unknown what is the best way is of treating MMSW economically and environmentally
S	**SOCIOLOGICAL:** • Incineration might be profitable, but it produces massive amount of CO_2 and other hazardous substances which raises health concerns • One of the easiest and effective way of recycling is pre-sorting at a source, which depends on consumer's behavior. Changing people's attitude and mindset about consuming and sorting has been one of the biggest challenges for Vantaa. • Since Vantaa is a multicultural city, it is difficult to spread the message and promote presorting for everyone
T	**TECHNOLOGICAL:** • Vantaa city has possibilities to implement technologies into MMSW treatment, for example, sorting system for primer consumers and in the premises of Vantaa Energy; waste pre-heating system before incineration which will allow to emit less CO_2 and maximize amount of energy produced during the incineration process.

	• Vantaa City can utilize its social media channels to provide a persistent and precise message about necessity to sort-out waste. It is possible to network and cooperate closer with B2B sector, involve companies to work together in the field of recycling, CO_2 mitigation and innovations. • In Finland incineration rate is higher than recycling, which can be explained by cost efficiency of waste incineration rather than its recycling. Adopting best technologies and expertise from other European countries might help to collect required data which would initiate new pilot projects also in Vantaa City • Many existing technologies require innovations and financial justification of their implementation in the process of MMSW treatment • New technologies can positively influence of the process of MMSW treatment
E	**ENVIRONMENTAL:** • Along with other Finnish cities, Vantaa City actively participates in projects related to CO_2 mitigation and positive climate change, contributes with public procurement of recycled materials to reduce raw/virgin materials consumption • Waste Framework Directive (Directive 2008/98/EC on waste) determines right hierarchy/priority for MMSW treatment • By 2030, Vantaa's goal is to become a zero-carbon city which complies with EU goals and positively affects on environment and climate change • Together with other European countries Vantaa City is aiming to transit towards a circular economy model • Corporate social responsibility and sustainability are in priority for more and more companies in Vantaa City
L	**LEGAL:** • Currently there is no obligatory public procurement of recycled materials • There is no clear regulations and standards related to trades with recycled materials • There are no clear unified legal definitions for circular economy and renewables. Some existing criteria are unspecific and can cause issue of interpretation • There is no clear legal base for obligatory waste pre-sorting for primer consumers • Reporting about waste processing and treatment is vague and causes multiple interpretation • Existing regulations do not support recycled materials which have higher production price and lower quality compared to virgin materials.

3 Circular economy

Circular economy model implies production and consumption, which includes direct processing of materials and energy flows in closed loops, providing extension of products life and increase of their usage among others by means of sharing, repairing, recycling, reusing, renting and renovating (figure 3). Circular economy sets priorities for resources regeneration, including usage of waste as a secondary resource and its recovering for further reuse and recycling; extension of materials' lifetime via new business models based on interaction throughout the whole supply chain, design process and innovations which keeps materials to be used again and again, thus creating further value. (Circle economy 2021; European Parliament 2021.)

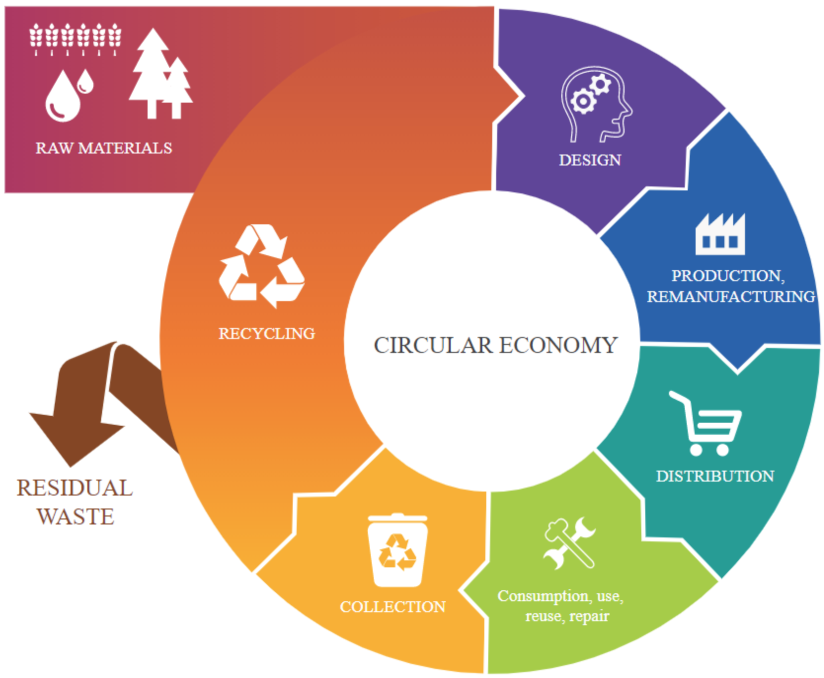

Figure 3. Circular economy (European Parliament 2021)

So far, an idea about circular economy: reuse, recycle and renew is considered to be the main one towards sustainable economic development, as well as to a positive climate change (World Economic Forum (WEF) 2021; European Commission 2021a). European Union also pays attention on interconnection between set objectives relating to energy and climate change, as well as to necessity move fast towards circular economy (European Commission 2021a; European Commission 2020).

Nowadays circular economy is a well-known concept which is gradually implemented by European Union within a framework of national economic development, for example, in

Sweden, Finland, France, The Netherlands. According to European parliamentary research service (EPRS 2018), circular economy has many social and economic benefits, for example:

- Circular economy could lower the material cost of EU companies by €250-€460 billion.
- Higher position jobs on waste hierarchy, which can affect economy positively.
- Reducing the size of landfills could lower the greenhouse emission by 30 million tonnes a year

According to European Commission estimation, changes towards circular economy can be beneficial for economic growth and increase economic profit up to €600 billion annually for the manufacturing sector in Europe (Ellen MacArthur Foundation 2013a; European Commission 2014; CIRAIG October 2015). By 2030, in Europe, through a circular economy it is possible to reach benefits up to €1.8 trillion, which means 11 % GDP which is nearly 3 times higher than via the current line of development (Ellen MacArthur Foundation 2015a; Ellen MacArthur Foundation 2013a).

Only in Finland, according to approximate calculations, incorporation of circular economy can provide economic increase up to €2.5 billion annually. To reach this goal it is necessary to strengthen three main driving forces (SITRA 2015; SITRA 2018):

- technology, which enables to bring new solutions
- customer centricity
- sustainability, which provides resource efficiency

Amid one of the goals set by Finnish government is to be the world's first fossil-free society by the end of 2030 and become carbon neutral by 2035, thus moving towards carbon-neutral circular economy (Finnish Government 2021).

Vantaa city amongst five other largest cities of Finland which have started working in six-city strategy to minimize fossil fuel consumption so that to be completely fossil fuel free by 2026 (Vantaan Energia 2021a). One of the ways to make this happen is to implement circular economy and turn waste into energy by using domestic and unusable waste rather than ordering fossil fuel from other countries. Waste-to-energy is a much cleaner, more sustainable and affordable alternative solution than traditional fossil fuel energy which is one of the biggest reasons of carbon dioxide emissions in the world.

However, despite variety of discussions around the topic about circular economy, there is still no unified term relating to definition of a circular economy. Most existing definitions present separate notions from different fields and seems to be superficial or incomplete.

This chapter presents main ideas relating to definition of a circular economy, principles and characteristics of a circular economy and understanding of major differences between a linear and circular economy.

3.1 Definitions of circular economy

Throughout the entire existence of mankind, humans always believed that we are living in an illimitable space, and whenever people faced scarcity of food or recourses in their habitant, they just simply moved to another location. According to Boulding (1966), this type of system is a “Cowboy economy’’ (linear economy) which is a flawed system and not sustainable in a long-term, since under that system people look at Earth like there is no limitations to our natural recourses which leads to pollution and exploitation.

However, now we know that the Earth is a closed sphere with limited reservoirs, like a “spaceship”, so we should understand that there are limits to how much we can consume, and to achieve sustainability, a circular economy system must take place where everything must be put into something else (Boulding 1966).

In western literature first mention about a term “circular economy” relates to 1980, where emphasis was on interactions in economy- environmental way. Later on, it was described as a “closed-loop system” with closed materials and resources cycle, enhanced durability and mutual interactions (Murray, Skene & Haynes 2017,10; Yang & Feng 2008, 814)

The term ‘circular economy’ is becoming increasingly popular even though there is no single understanding of it (Preston 2012; Cossu & Williams 2015; Zero Waste Scotland 2015). Kirchherr, Reike and Hekkert (2017) claim that lack of unified definition of “circular economy” might make the whole concept of circular economy obsolete. Some researchers admit that lack of common definition of “circular economy” might be a reason of its low approval and integration (Andrews 2015, 306-313; Rizos, Tuokko & Behrens 2017).

Some European countries are still far from passing the law about necessity to integrate a circular economy into a national legislation and one of the reasons for this - high concerns of “governmental interventions”, that may prioritize circular economy approach over other possible technologically innovative solutions incorporated along with recycling. Also, health impact and risks related with toxic emissions or substances which can be generated within a circular economy cycle should be closely investigated before setting a circular economy strategy as a national course (Cossu 2013, 497-498).

Such countries like China and Germany have a term “circular economy” within their legislation, although the emphasis can vary (Benton, Hazell & Hill 2015). Waste avoidance and closed-loop recycling are the key components within the German legislation (Bilitewski 2012), while in the Chinese policy, the definition is directed at eco-design, cleaner production, eco-industrial parks and networks to create a recycling-oriented society (Geng, Fu, Sarkis & Bing 2012). In most cases, the common components within a frame of a circular economy are waste elimination and increase of material value, avoiding the recycling stage at all costs, activating close-loop processes (European Commission 2015; Ellen MacArthur Foundation 2013a; Waste Resources Action Program 2021; Lemille 15 November 2019).

A popular definition of circular economy is described as regenerated system relying on renewable sources, minimizing use of chemicals and reduction of waste production (Ellen MacArthur Foundation 2013a, 22). Based on sustainability and reduced consumption of natural resources, the circular economy focuses on a closed loop of energy and material flow in a circular way (Ellen MacArthur Foundation 2013b; Liu 2012).

By summarizing aforementioned characteristics, circular economy can be defined as a concept aiming to preserve the environment and striving for zero waste production, minimal resource consumption, generating energy via reuse and recycling.

3.2 Principles of a circular economy

Better understanding of circular economy can be achieved via its principles. Ellen MacArthur Foundation (EMF 2015b, 5-7) highlights the following three principles of circular economy:

- Protect and intensify natural resources by controlling its consumption and supplementing it with renewables
- Optimize stock of natural resources by persistent circulation of components and materials in biological and technical cycles
- Intensify system efficiency via identifying negative external factors

Other schools rely on “three R’s” circular economy principles – recycle, reuse and reduce. (Preston 2012; Reh 2013, 119-132; Lett 2014). Further studies added two more principles

– reclamation and recovery (Pan, Du, Huang, Liu, Chang & Chiang 2015). Govindan & Hasanagic (2018, 279-310) complemented aforementioned principles with additional ones - remanufacture and redesign. In general, all circular principles are interconnected and complement each other, however, hierarchically, principle of reduction is on the top of the pyramid (figure 4).

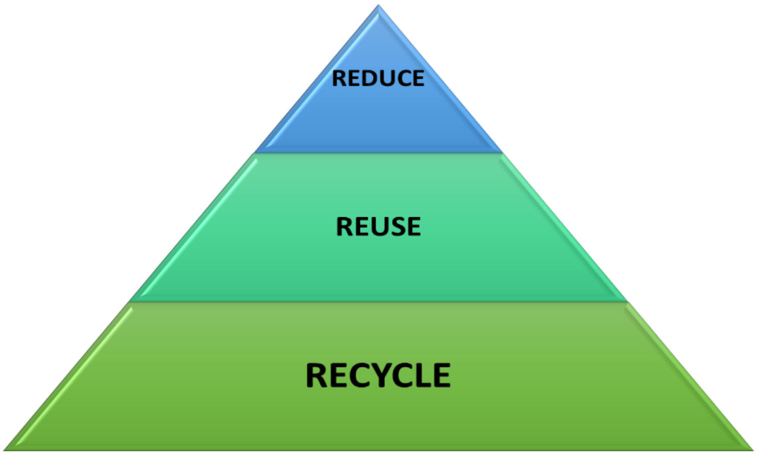

Figure 4. Hierarchy of circular economy principles (adapted from Ellen MacArthur Foundation 2015b, 5)

Reduction principal relates to energy and resource contribution in consumption and production processes with an aim to reduce waste, usage of energy as well as raw materials (Su, Heshmati, Geng, & Yu 2013; Ghisellini, Cialani, & Ulgiati 2016). Amid benefits of implementing reduction principle can be, for example, decrease of greenhouse emissions, less air pollution, preservation of raw materials, minimization of environmental impact.

Reuse principal can be explained as any processes by which materials or products are used repeatedly for similar purpose they were initially considered. Reuse may relate to re-sale of the product or parts of it with a purpose to reduce waste, minimize resource and energy consumption. Thus, some by-products or waste may be used as a resources or raw materials for new products. (Joint Research Center (JRC) 2008; Shi, Xing, Bi & Zhang 2006.)

Reuse can help local economy and have a positive environmental impact, for example, reduce emissions, cut energy and transportation costs. Stahel (2013,3) consider reuse principle as the most profitable and main principal of circular economy, which should be on the top of the hierarchical pyramid. However, effective implementation of reuse principal requires proper law regulations, education, marketing and willingness of final consumers to buy second-hand products (Lenzen, Murray, Sack & Wiedmann 2007, 27 - 42).

According to hierarchy of circular economy principles, recycling is on the bottom line, meaning reprocessing of products into new products, which can be used for their initial purpose or new purposes (Ellen MacArthur Foundation 2015b; Zeb & Kortelainen 2021).

Some research describe recycling as a process, associated with a last critical step, when a product cannot be recovered anymore but can be broken into pieces, which later can represent new value and functionality, minimize use of raw materials and reduce waste (Kane, Bakker & Balkenende 2018, 41; Shi & al. 2006; Su & al. 2013).

While some researchers point at benefits which recycle can bring, for example, energy use can be reduced by 52%, pollution and waste quantity can significantly decrease (Lazarevic, Buclet & Brandt 2012; Ellen MacArthur Foundation 2015b; Kane, Bakker & Balkenende 2018), others, criticize recycling because of its negative impact on the environment, reduction quality of the product, less efficiency and consumption of energy resources (Bartl 2015; Moreno, Braithwaite & Cooper 2015).

3.3 Main characteristics of a circular economy

Ellen MacArthur Foundation (2013a; 2015b) describes characteristics of circular economy via its main features, which are (figure 5):

- Designing out of waste, meaning that waste is a valuable resource and materials' cycle should be optimized for further reuse and separation; biological waste can be returned back to nature in a way of a compost; technical materials should be designed in a way that they can be reused or repaired
- Create viability via diversity, meaning that diversity is a main criteria for sustainability and versatility
- Make renewables as a source of energy, meaning that sustainable development of system should rely on renewables sources of energy
- Think in a framework of systems, meaning ability to comprehend how parts affect each other and function as a system
- Multilevel of thinking, meaning ability to understand the full extraction potential of materials till they are fully used

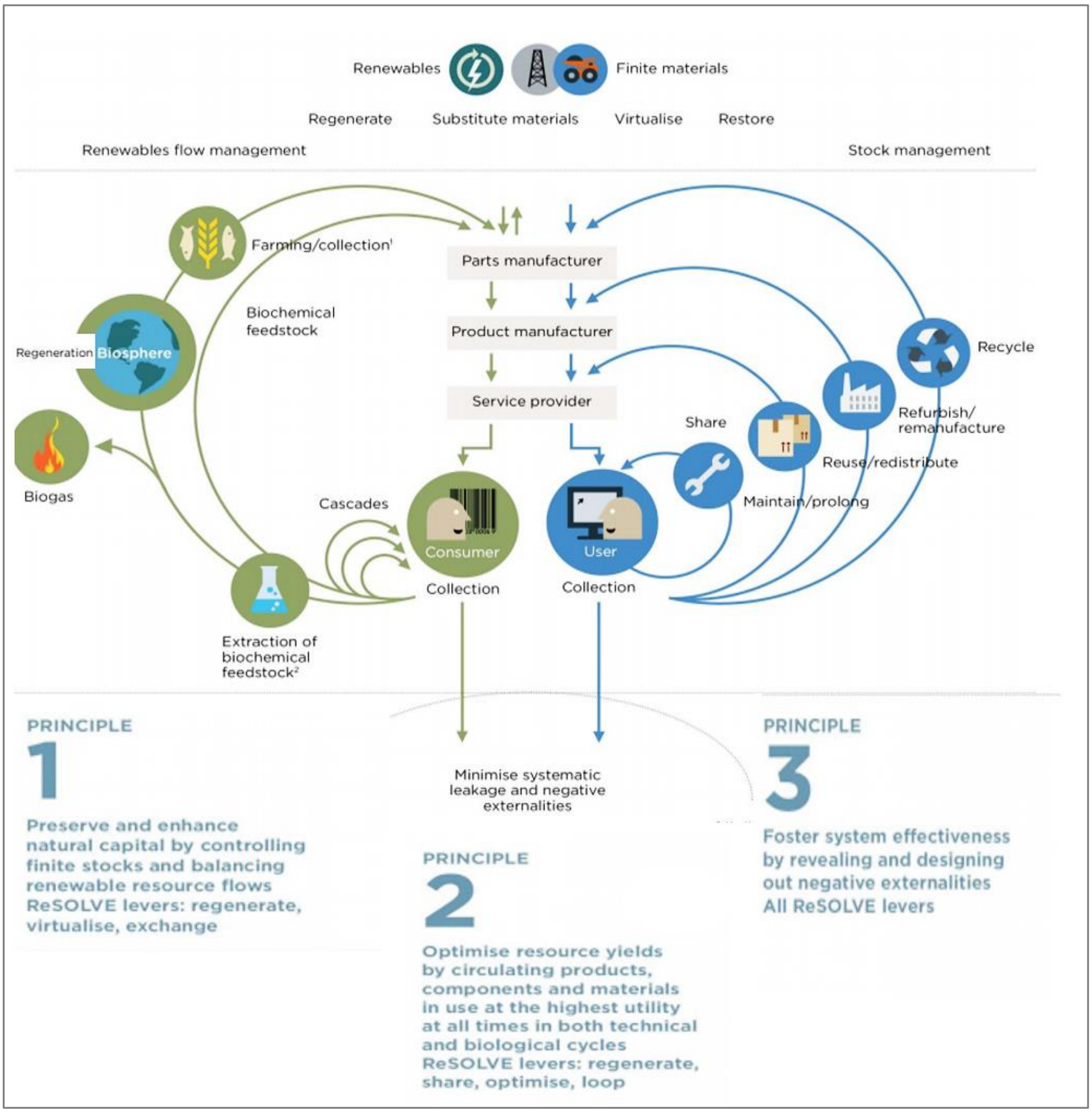

Figure 5. Circular economy characteristics (EMF 2015b, 6)

Amid other characteristics of circular economy can be low material consumption, reduced level of pollution along with a high efficiency, scrupulous use of resources (Murray & al. 2017).

3.4 Linear economy and circular economy, transition towards circular economy

So far, natural resources are used to make products which are later sold, used and disposed -linear economy. This model has been applied for more than 150 years and it has many flaws, for instance, there is a finite number of natural resources on earth, and this is not an efficient model in terms of sustainability. In linear economy the environment is treated as a waste pool, where sources are consumed but nothing is recycled, recovered or reused. (Pearce & Turner 1990.)

Historically, world wealth was distributed unevenly, where consumers mainly inhabited the most thriving regions, sourcing materials and energy from global resources. The price for resources was cheap compared to labour costs and the effective business model implied usage of extensive natural resources while minimizing human labour. As a result, competitive advantage was taken by those companies, which managed to consume most of energy and materials to maintain their business. Supported by existing regulations and fiscal rules, the natural outcome of such system was lots of waste and ignorance of recycling and reuse of materials (Sariatli 2017; Ellen MacArthur Foundation 2013a).

Based on data modelling, Sustainable Europe Research Institute estimates that nearly 21 billion tonnes of resources used for the purposes of production in linear economy are not implemented into the final product. Moreover, based on data of Eurostat, in 2010 out of 65 billion tonnes of resources nearly 2.8 billion tonnes were wasted on landfills. (Ellen MacArthur Foundation 2013a, 15.)

Linear economy approach with its waste generation and depleting of natural resources has been successfully implemented up to 20th century. Rapid demographic growth of population, global increase of consumption and scarcity of resources became the reason to challenge linear economy approach and propose a new sustainable model. This model is a circular economy concept (figure 6), which focuses on minimizing waste via recycling, reusing and renewing existing products instead of using raw materials and natural recourses, especially, considering that the amount of waste produced over the years is increasing which makes waste problem a global issue.

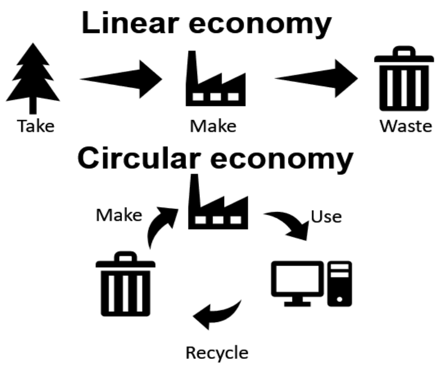

Figure 6. Linear economy vs circular economy (adapted from Stark 2019.)

A vision about circular economy as “Cradle-to-Cradle” by Braungart and McDonough, was represented as new industrial revolution, meaning that old approach to resources and consumption should be reconsidered towards shift to a more sustainable model- circular economy with alternative cyclical flows. In biological cycle, materials, for example food and wood, are supposed to go back to nature via anaerobic digestions and composting, thus recovering a system and generating renewables; while in technical cycle, products are supposed to be repaired, reused, restored or recycled. (Ellen MacArthur Foundation 2013a; Ellen MacArthur Foundation 2015a; Sariatli 2017.)

Developing a circular economy system enables the lifecycle of raw materials to be longer than usual and it is a viable option for society, economy and environment (Ghomi, Khosravi, Tahavori & Ramakrishna 2020; EPRS 2018). According to McKinsey & Company, integrating a circular economy business model can help to achieve a significant growth. Based on their studies, by 2030 circular economy approach can help to generate annual profit of more than €1,8 trillion, and by 2050 it is possible to reach savings in household costs by 60-80%, housing costs by 25-35 % and food costs by 25-40%. Circular economy approach will boost competitive advantage and durability of industries, will be beneficial for the environment, will help with climate change, for example, general CO_2 emissions will drop up to 48% by 2030 (versus 31% via the current path) and 83% by 2050 (versus 61% via the current path), see also figure 7. (McKinsey & Company 2016; Ellen MacArthur Foundation and the McKinsey Center for Business and Environment 2015, 33, 77.)

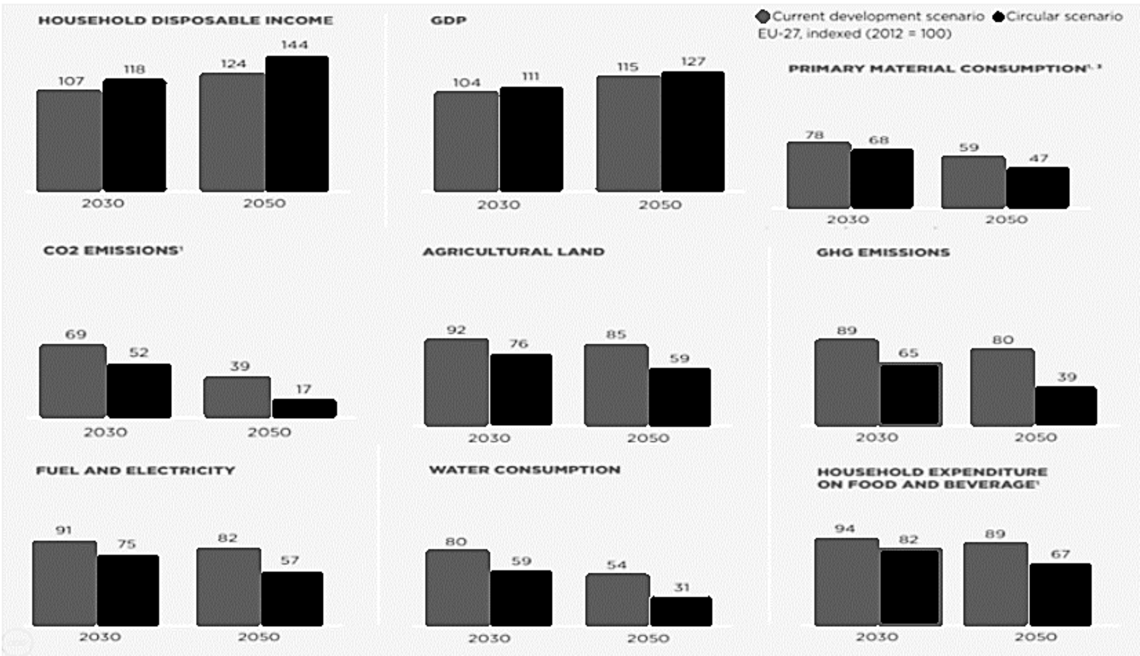

Figure 7. Circular versus linear economy approach (adapted from Ellen MacArthur Foundation and the McKinsey Center for Business and Environment 2015, 33,77)

Shifting from linear to circular economy requires actions one part of which is design of products with no waste. Ellen MacArthur Foundation in their model ReSOLVE (see also in figure 8) offers six main action areas which help transit towards circular economy (Ellen MacArthur Foundation 2013a; Ellen MacArthur Foundation 2015a):

- Shift towards renewables, regeneration of healthy ecosystems and resources recovery
- Increase usage of products via sharing; extension of life span via repairing and reuse
- Supply chain optimization and automation; improvement of products efficiency by removing waste from a product cycle
- Prioritize closed-loop systems, where finite materials are reused or recycled; renewable materials are going back to biological system
- Replace physical materials with a virtual one, for example, books, virtual offices, online shopping.
- Exchange old technology with new ones, which are more advanced and efficient

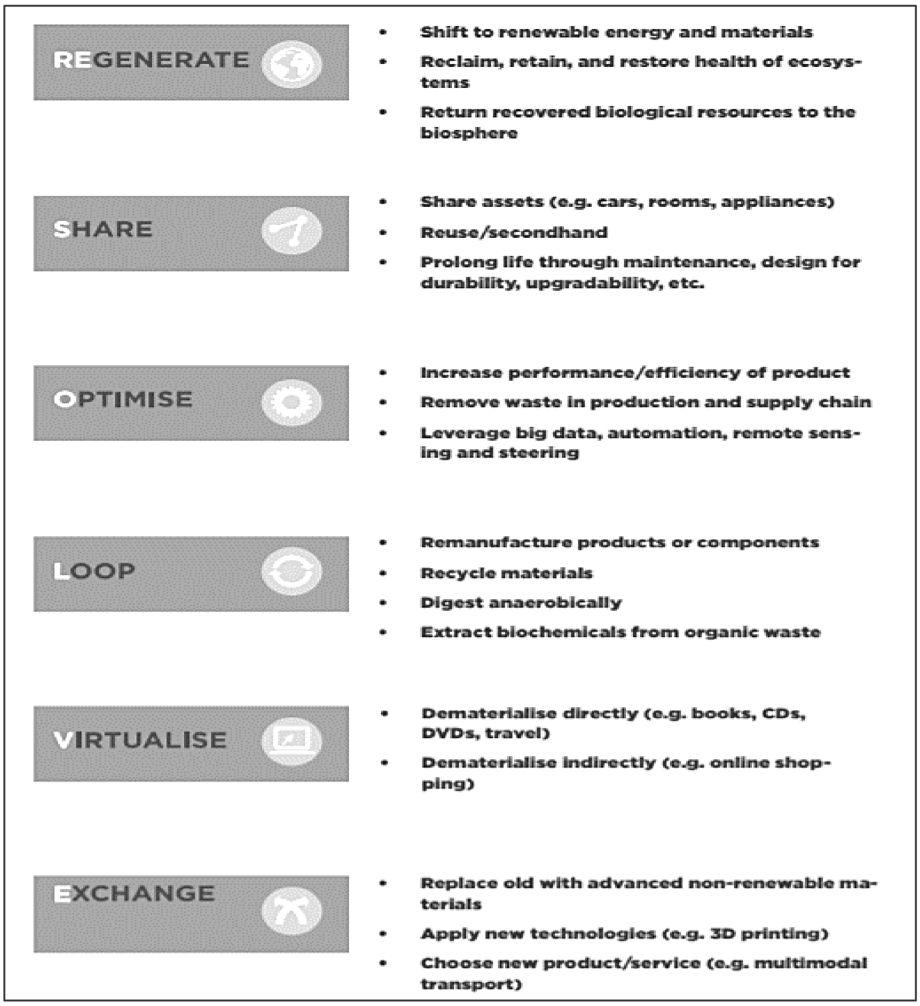

Figure 8. ReSOLVE framework for transition towards circular economy (adapted from Ellen MacArthur Foundation 2015c, 5)

Transition towards circular economy requires lots of changes, for example, in production it might be that producers shift to service providers, while in consumption it might be shift towards renting rather than owning (Mendoza, Sharmina, Gallego-Schmid, Heyes & Azapagic 2017, 530-533; Sitra 2018). Thus, business should function in a new way through implementing different business models, design of the products, tools and strategies.

Essential building blocks for transition towards circular economy can include product design, circular business models, favorable conditions and reverse communication (Sitra 2018; Bakker & Hollander 2013; European Commission 2012):

Product design helps to be cost effective and create durable products which are beneficial not only for the environment but also for consumers and producers. According to EC nearly 80% of impact on the environment depends on the proper design stage of the product (European Commission 2012).

Business models for circular economy are part of efficient circular value chain which can create value and reduce inefficiency. It is recommended main five circular business models: circular supply chain, recovery and recycling, sharing platform, product as a service and product life extension (figure 9).

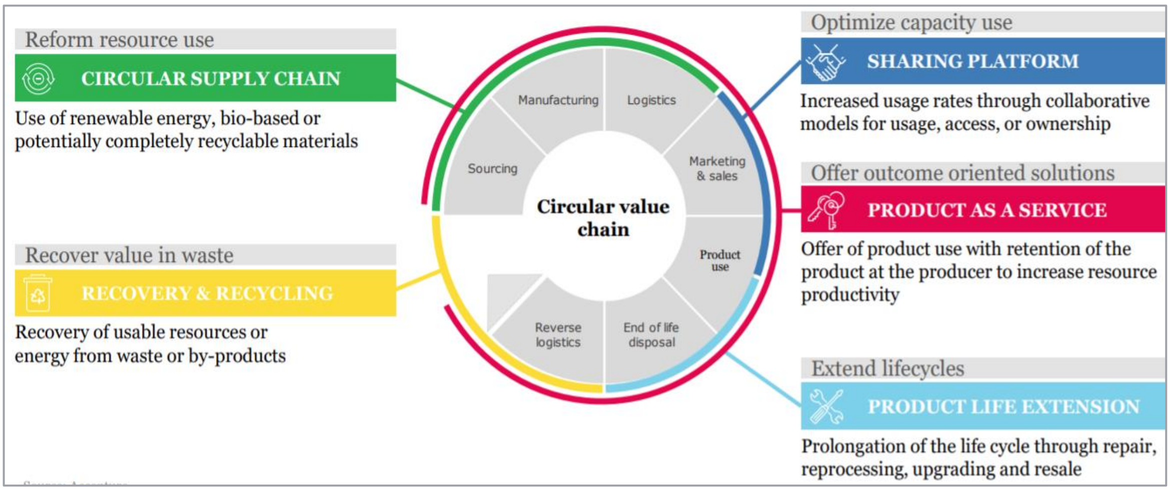

Figure 9. Circular business models (Sitra 2018, 12)

Favourable conditions, meaning consumer education, collaboration for minimizing impact on the environment, regulations and financial incentives.

Reverse communication and networks, meaning preparedness and readiness of manufactures to take products at the end of its life cycle.

Being part of European Union, Finland is one of the pioneers in carbon-neutral circular economy and first country which on a national level prepared road maps to a circular economy to ensure sustainability (SITRA 2021). In Finland, it was proposed that by 2035 the consumption of raw materials will be reduced to the level of 2015. Additionally, it was announced about necessity for close cooperation between state and municipalities towards circular economy and sustainability, necessity to reduce use of natural resources, increase the use of recycled materials and promotion of carbon neutral circular economy. Main steps in this direction are product design, innovations and cooperation between all actors, especially in energy and construction industries. (Työ- ja elinkeinoministeriö, Ympäristöministeriö 2021.)

4 Waste in a circular economy model

Rapid population growth and consumerism generated a huge amount of municipal waste (2.01 billion metric tonnes/year), and it is predicted that this amount will increase up to 70% (3.4 billion metric tonnes/year) by 2050 (Tiseo 2020). MSW is responsible for almost 3-4% of global GHG emissions and the total global waste causes 18 % of all methane emissions (within a 20-year span, methane is 84 times stronger as a GHG compared to CO_2) (Aleluia & Ferrão 2016; Singh, Kumar & Roy 2018; Intergovernmental panel on climate change (IPCC) 2006; Climate change connection 2021).

Modern cities are main consumers of energy, generators of waste and producers of more than 70% of CO_2 emissions. Waste and its utilization are associated with unreasonable resource consumption, depleting of natural resources and negative environmental impact. (Eurostat 2021.) In 2017 European countries generated more than 0.25 billion tonnes of municipal waste, which is nearly 486 kilos per capita (Eurostat 2019). In this perspective, estimated targets for waste generation per person and objective for “zero landfill” set in Waste Framework Directive (Directive 2008/98/EC on waste) can hardly be met (Ríos & Picazo-Tadeo 2021). Only in 2019 in the EU the amount of municipal waste generated per person increased up to 502 kg (Eurostat 2021).

Due to huge waste generation and massive energy demand, waste to energy incineration have gained popularity around the world and is becoming more reliable energy source than solar and wind. Waste to energy incineration plants are suitable for areas which are growing in population and have limited space for landfilling, cities which are seeking for profitable alternative to waste treatment and have a demand for renewable energy like heat and electricity. (Liu, Nishiyama, Kawamoto & Sasaki 2020.)

In Finland, reasons behind increase of waste to energy solutions and turning MMSW into energy are the following ones (Ministry of Economic Affairs and Employment 2020, 8):

- In 2019, in Finland the share of renewable energy was 43 %, which is the second highest in EU, and by 2030 a target to reach minimum 50% of renewable energy (Findicator 2020; Ministry of Economic Affairs and Employment 2020, 8)
- Finland wants to reach carbon neutrality by 2035 and reduce greenhouse emissions to 90 % by 2050 compared to 1990 (Gordon-Harper 2020)
- By 2029 Finland wants to quit use of coal and by 2030 reduce use of peat at least by half
- By 2030 increase the use of biofuel in transportation up to 30%
- By 2030 reach 55% self-sufficiency in energy supply

This chapter will review central aspects related to waste definition and waste hierarchy. Also, there will be explained ways of waste treatment according to Waste Framework Directive and principles of circular economy. Additionally, central waste to energy technologies and their synopsis will be covered, as well as feedstock required to start the process, products and by-products which might be received.

4.1 Historical glimpse on waste treatment

With fast industrialization and moving people close to cities, fast waste growth start to worry people due to deterioration of living environment and unsanitary. In the middle of 18th century English economist Morris, C. offered to clean London by removing all waste via Thames outside the city. At the end of 18th century, London and New York were amid first big cities which passed the law against waste dumping and where first incineration plants "destructors" were built. These actions were necessary to prevent spreading of diseases as well as making sure that people can live in cities without facing piles of waste and inhaling the stench. Waste collection apart from waste reduction also aimed to collect ash resulting from burning coal which had a further market value (soil fertilizer and bricks additive). (Herbert 2007.)

First destructors in Nottingham and New York were a very polluting idea because due to an open burning process ash clouds and flue gas were spreading all around neighbourhoods without any proper treatment. Nowadays, everything related to incineration comes under strict EU regulations and directives on emission limits, forcing industries to low down their emissions level and contribute to a further environment treatment (Directive (EU) 2015/2193). However, despite strict EU regulations on emission limits and treatment of residual waste, there has always been a strong neighboring resistance to incineration plants due to a negative health impact they might provide including associations with benign or malignant neoplasia, congenital anomalies, increase fatality rate and miscarriage (Tait, Brew, Che, Costanzo, Danyluk, Davis, Khalaf, McMahon, Watson, Rowcliff & Bowles 18 September 2019).

4.2 Definition of municipal waste

Rapid urbanization and fast growth of population led to increase of waste amount in cities worldwide, causing negative environmental impact and greenhouse emissions. However, definition of municipal waste and approaches to it are still challenging due to new technological processes which were introduced for waste pre-treatment and sorting last decade, as well as legal requirements for increase of waste recovery. What have been considered as a waste before now can be redefined as useful material through legislative measures.

Definition of municipal waste can significantly vary depending on the country, for example, in Europe, municipal waste generally includes household waste, including waste similar by composition and nature, regardless that it was generated by other sources than households, for example, waste from office buildings, schools, small businesses, government buildings, hospitals, street waste and waste from parks etc. However, sewage waste, construction and demolition waste are not included in municipal waste (European Comission 2017; European Commission 2003).

On the contrary, in some Asian regions, municipal waste has a broader definition which also includes waste from human settlements, like faeces and sewage sludge, animal excrements, wastewater, demolition debris, waste from agricultural and industrial sectors, thus representing hazardous risks compare to European municipal waste (Singh, Tyagi, Allen, Ibrahim & Kothari 2011; Song, Yang, Li, Higano & Wang 2016).

Directive (2018/851) on waste, defines municipal waste as mixed and collected separately household waste like paper, glass, plastics, metal, wood, electronics, furniture, etc. and waste from such sources like food services, administration and health services, retail and accommodation, activities similar by nature and composition to household waste. Street waste and waste from garden maintains are also included in municipal waste with the exception of sand, mud, rocks and dust. Large commercial and industrial waste, which is not similar to household waste, as well as demolition, construction, production, end of life vehicles waste, forestry and fishing waste, sewage and septic tanks waste cannot be included and treated as municipal waste. (Official Journal of the European Union 14 June 2018; European Commission 2017.)

Municipal solid waste (MSW) can be defined as a non-liquid waste produced by households, people, small businesses, which consists of everyday things which are broken, spoiled or not needed anymore. Mostly it includes food, plastics, paper, rubber, textiles which is collected by local waste management system and treated in a way of landfilling, incineration (with or without recovery of energy), recycling, digestions and composting. (European Commission 2017.)

Mixed municipal solid waste (MMSW) is a mixed residual waste collected from households or similar places except of separately collected waste. Mixed municipal waste is not accepted for composting and digestion. Biological treatment of MMSW should not be included in composting but should be distributed to incineration or landfilling. (European Commission 2017.)

4.3 Waste hierarchy

The Waste Framework Directive formulates basic principles of waste management, amid of which non harming the environment, human health, water, air, plants, soil and animals; non causing noises, odours; non influencing countryside. It also clarifies when waste stops to be a waste but turns into a secondary raw material and how to differentiate waste from by-products. According to Directive, waste stops being a waste after recovery operation (not excluding recycling), when received substance/material does not harm human health or environment but can be legally utilized for particular purposes and there is a demand/market for it. On the other hand, by-products can be defined as substances, production of which was not a primary aim of a process and which can have a different impact on the environment, thus requiring proper classification. (Directive 2008/98/EC; European Commission 2021b.)

Old Waste Directive (Directive 2006/12/EC) included 3 steps in a waste hierarchy: prevention, recovery and disposal), implying that waste preparation for re-use, recycling and other recovery where all on the same hierarchical level. To comply with EU approach to waste management and resource efficiency, a new Framework Directive (Directive 2008/98/EC) was developed with a hierarchy including the following 5 steps: prevention, reuse, recycling, recovery and disposal (see figure 10). Thus, compare to old waste hierarchy a new one highlight that “preparing for re-use” of waste has a higher level than recycling and recycling dominates above other types of recovery.

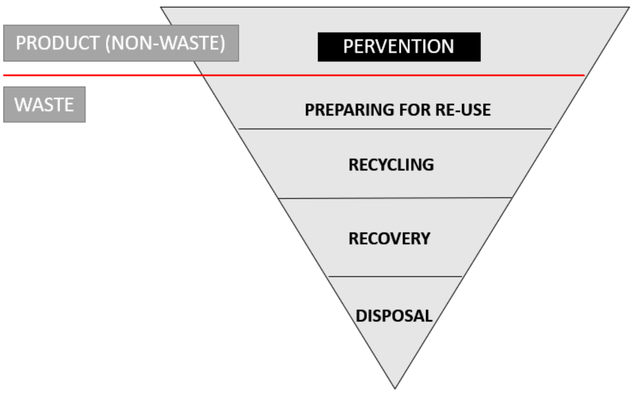

Figure 10. Waste hierarchy (adapted from Directive 2008/98/EC)

Current waste hierarchy framework comply with a concept of circular economy, as figure 11 shows, where recovery and disposal are on the bottom of the pyramid, thus representing final stages of cycle. At the same time, existing waste hierarchy order is not legally binding and for specific waste streams it is possible to deviate from it for environmental protection and economic efficiency (Directive 2008/98/EC Article 4(2)).

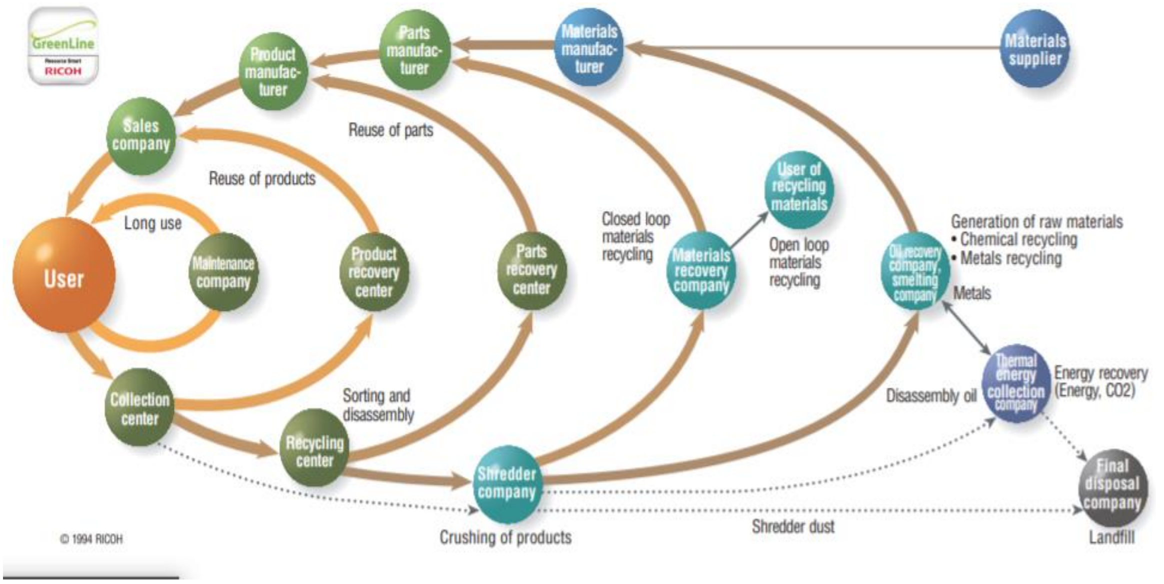

Figure 11. Circular economy cycle (Ellen MacArthur Foundation 2013, 29)

New Waste Framework Directive additionally highlights that waste should be treated in a way which does not harm nature and humans, does not produce unpleasant odour or loud noise, does not causing harm for places and inconvenience for people. The Waste Framework Directive also sets recycling rate for EU countries, which should be 50% by 2020, 55 % by 2025 and 65 % by 2035, meaning that landfilling of waste has to be replaced by recycling. (Directive 2008/98/EC.)

Aforementioned goal about replacing landfilling with recycling is good but challenging to perform due to a new Directive, which set EU goal to reduce the amount of municipal waste to be landfilled to 10% or less out of the total generated municipal waste by 2035 (Directive (EU) 2018/850). This target has two main aspects to discuss (Vähk 27 January 2021):

- Directive does not emphasize necessity to reduce produced waste, but rather focus on the percentage of waste which can be landfilled, which is calculated on a yearly basic on the remaining municipal waste, which practically means it is not important how much waste you do produce, but it is important that no more than 10 percent of it can be landfilled

- Directive focuses mainly on the waste incineration as a solution to reduce landfilling, it does not focus on recycling and reuse thus, contradicting circular economy principles of maximum material recovery

Meanwhile, efficient recycling can help to reduce costs of waste disposal and will be favourable for the environment. Products and material which cannot be recycled or reused should be recovered (with energy) (Directive 2008/98/EC).

4.4 Municipal waste treatment

Waste Framework Directive (Directive 2008/98/EC on waste) defines a hierarchy of waste treatment in the following way of priority:

- prevention
- preparation for re-use (for example, cleaning and repairing operations without other processing, after which product instead of becoming waste might be re-used)
- recycling
- recovery (implies any operations were waste can perform a useful function by substituting materials which would in other case be used, for example, energy recovery)
- disposal

According to Eurostat (European Commission 2017), municipal waste treatment includes:

- incineration (with or without energy),
- landfilling,
- recycling,
- composting and digestion

Recovery with energy and recycling, which also covers composting and digestion as recommended by EC (2017), are preferable methods of municipal solid waste treatment due to their less impact on the environment. However, incineration without energy recovery and landfilling are less preferable due to their greater effect on the environment. (European Commission 2017.) Last decade In Europe, there is an obvious tendency in shifting from landfilling towards material recovery and incineration (with energy recovery) (figure 12).

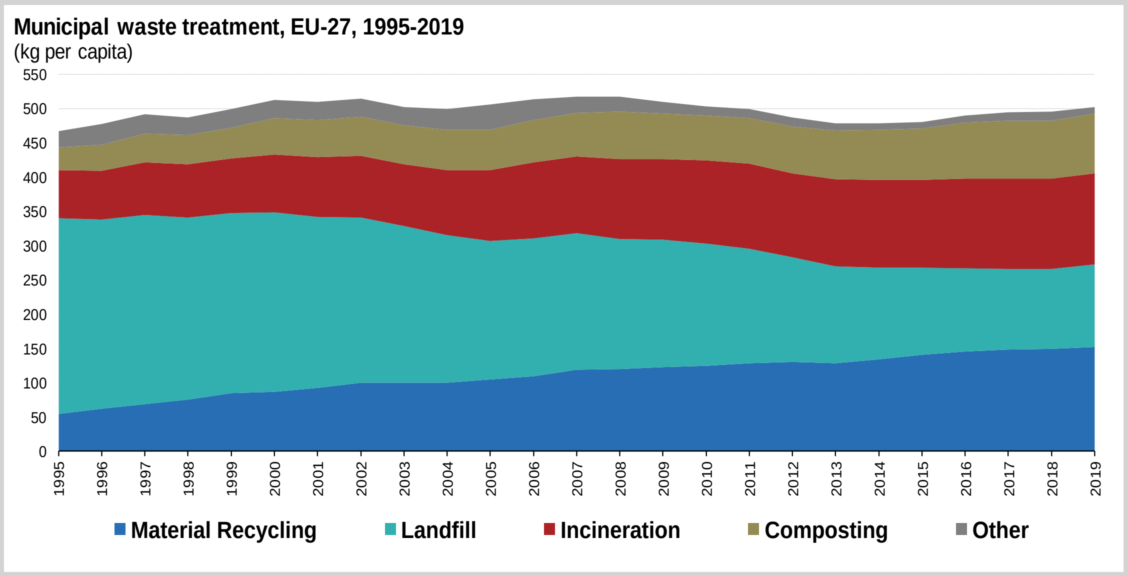

Figure 12. Municipal waste treatment in EU 1995-2019 (adapted from Eurostat 2021)

Incineration implies thermal waste treatment inside of incineration plant (it can be with energy recovery). Municipal waste can be sent to incineration plant directly or after treatment. Energy efficiency indicator helps to differentiate incineration with energy recovery and without. Incineration with energy recovery can produce electricity and heat, thus has a priority over incineration without energy recovery. (European Commission 2017; European Commission 2020.) Waste- to- energy model comply with principles of circular economy and provide the following advantages (European Economic and Social Committee 2021):

- Alternative energy source to fossil fuel, which can reduce the CO_2 emissions.
- Reduces the size of landfills, which will also reduce the methane gas emissions.
- Generates energy and heat, which can be used or sold
- Bottom ash can contain valuable materials.

At the same time, there are some drawbacks relating to waste-to- energy model, for example, it is very expensive to construct and operate, it does not generate enough income to cover the expenses and requires certain amount of waste for stable operation (Waste 2020).

Landfilling means waste dumping in or on the land, including specially build storages. Municipal waste can be directed to landfills directly or after treatment (European Commission 2017; European Commission 2020). Sanitary landfilling means waste disposal on land so that to minimize its negative environmental impact via biogas recovery and leachate treatment (figure 13). Landfilling is the least preferable option for waste treatment due to the highest level of environmental impact leading to land degradation, contamination of underground waters and leachate leak. (Kumar & Samadder 2017.)

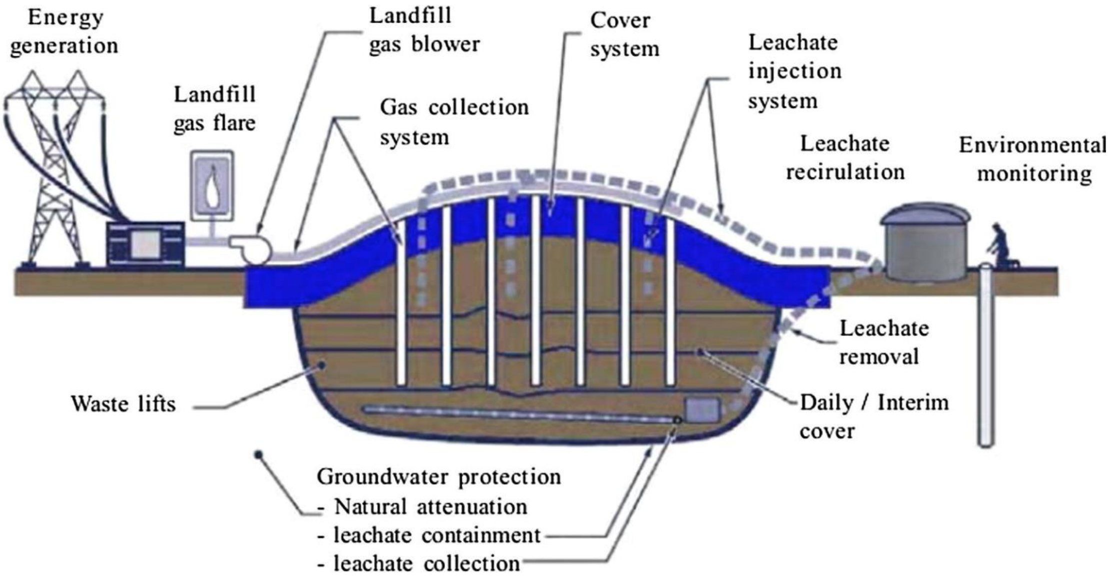

Figure 13. Landfilling with recovery system (Kumar & Samadder 2017)

Recycling can be defined as breaking down materials or products into pieces for its original or new use. Recycling of municipal waste can be done directly or after treatment. Recycling reports should not include (European Commission 2020; European Commission 2017):

- Energy recovery or processing of materials which later can serve as a fuel
- Direct recycling of waste at a place where it was generated
- Residues generated from other treatment which can be sent to recycling (for example, sand or metal from the bottom ash)

Composting and digestion mean returning biodegradable waste (food waste and bio-waste from garden/park) back into its biological cycle as a substance which it beneficial for agriculture or environment. Only separately collected biodegradable waste can be considered for composting and digestion. Mixed waste should be treated via incineration or landfilling. (European Commission 2020; European Commission 2017.)

According to European Commission (2017, 10), municipal mixed waste treatment is narrowed to incineration and landfilling. Sorted municipal waste should be recycled or recovered. Some countries practiced a composting and digestion of mixed municipal waste after mechanical separation which is not suitable due to a level of contaminants which might stay in the mass and harm the environment. Thus, even after a biological treatment, mixed municipal waste cannot be used for composting. (EC 2017, 8-9).

4.5 Sorting of municipal waste

Sorting of waste means separate collection of waste varying on its type and nature for a further treatment (recycling, energy recovery, composting and landfilling) and transformation into valuable resources (European Commission 2017; FCC environment 2021).

Waste sorting can be done in a different way (Futura-Sciences 2021; Rousta 2018):

- directly "at the source", meaning that producers of the waste separate the waste on their own before it is collected. It also involves end users, meaning that waste should be separated already at home by inhabitants with arranged waste sorting facilities nearby
- "voluntary sorting", meaning that producers of waste deliver waste to collectors or to place with special containers
- "sorting in the collectors", meaning that waste is sorted by employees or automatically by machines

Waste separation "at a source" is the most efficient way of waste sorting, which benefits to recycling and decreases landfilling. One of the crucial factors here is easy admission and close location to sorting infrastructure (Tchobanoglous, Theisen & Vigil 1993; Xevgenos, Papadaskalopoulou, Panaretou, Moustakas & Malamis 2015).

Standard scheme of municipal waste treatment includes incineration, landfilling, recycling and composting (figure 14). In some countries sorting for further recycling can be done at composting plants or at a landfill.

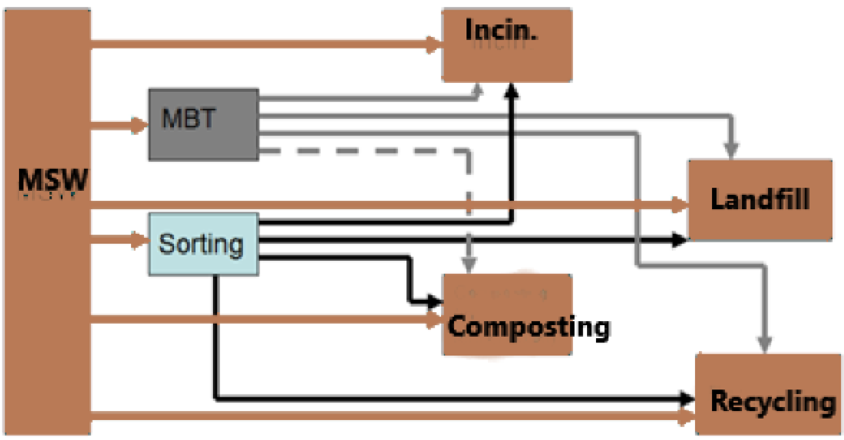

Figure 14. Municipal waste treatment (adapted from European Commission 2017; European Commission 2020)

Treating procedures for waste depends on its type, for example mixed waste and residues after sorting should be treated via incineration and landfilling, sorted waste should be recycled (figure 15).

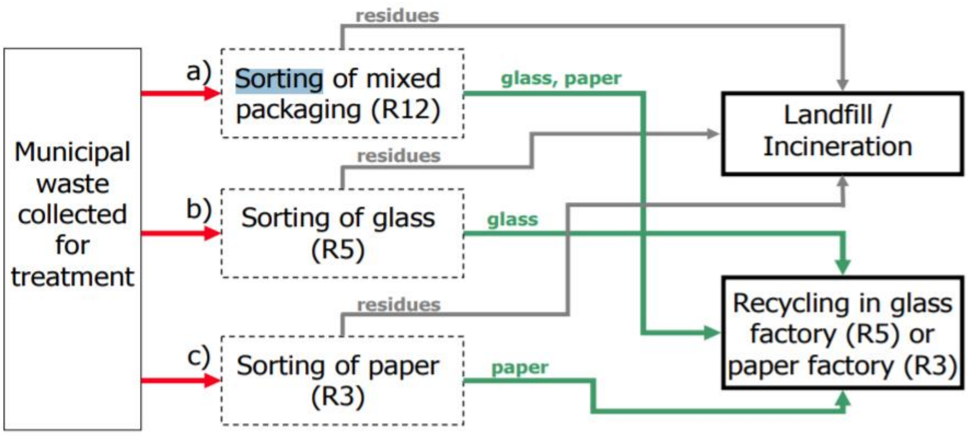

Figure 15. Municipal waste treating procedures (European Commission 2017; European Commission 2020)

4.6 Waste to energy technologies

Collected non-recyclable waste may be transferred into electricity, heat and fuel via different processes like incineration, gasification, pyrolysis, plasma gasification, anaerobic digestion and gas recovery from landfills. Traditionally, waste to energy means transformation of waste into valuable products like steam and electricity generated by steam. Usually, municipal solid waste (MSW) is used for the purposes of waste to energy. (Environmental Protection Agency (EPA) 2020; Miller 2021.)

Among the advantages of utilizing MSW for energy are the following ones (Miller 2021):

- Preventing the release of methane from landfills
- Reducing the amount of waste on landfills up to 90%
- Reducing the emission of CO_2 due to replacing coal use by waste
- Preservation of natural resources like natural gas, coal and oil

The choice of waste to energy technologies depends on many factors, for example, type of the waste and its amount, content of the waste and desired outcome (for example, electricity, heat or fuel), how clean is the waste stream and what is a moisture rate of the waste. Traditionally, waste to energy technologies can be divided into two categories - non-thermal technologies and thermal technologies.

4.6.1 Non-thermal technologies

Non-thermal technologies include anaerobic digestion and mechanical biological treatment.

Anaerobic digestion

Anaerobic digestion is used for organic and domestic sewage waste, not suitable for unsorted MSW. Treatment of such waste occurs without oxygen under the temperature of 55-75 C. One of the reason of choosing such method is a need to reduce quantity of sludge. The outcome of the treatment is a methane, which can be used to generate energy, and a residue in a way of stabilized organic substance which can be used for soil amendment. (Environmental Protection Agency (EPA) 2021; Waste to energy international 2021.)

Mechanical biological treatment

Mechanical biological treatment (MBT) suits for residual waste and usually involves mechanical process such as material recovery and biological treatment such as composting. MBT does not replace other waste treatment technologies like composting and recycling, but rather complements them. The result of MBT can be (Department for environment food and rural affairs 2013):

- Pre-treatment of waste before landfilling
- Mechanical sorting of MSW for further recycling or energy recovery
- Stabilization of waste for further output as a compost
- Conversion into a biogas through energy recovery process
- Conversion into a refuse derived fuel via energy recovery

4.6.2 Thermal technologies

Thermal technologies include incineration, pyrolysis, gasification and plasma gasification. The distinction is based on the amount of air used in a process, where incineration uses the most air (it is a combustion technology) and pyrolysis uses the least air (figure 16).

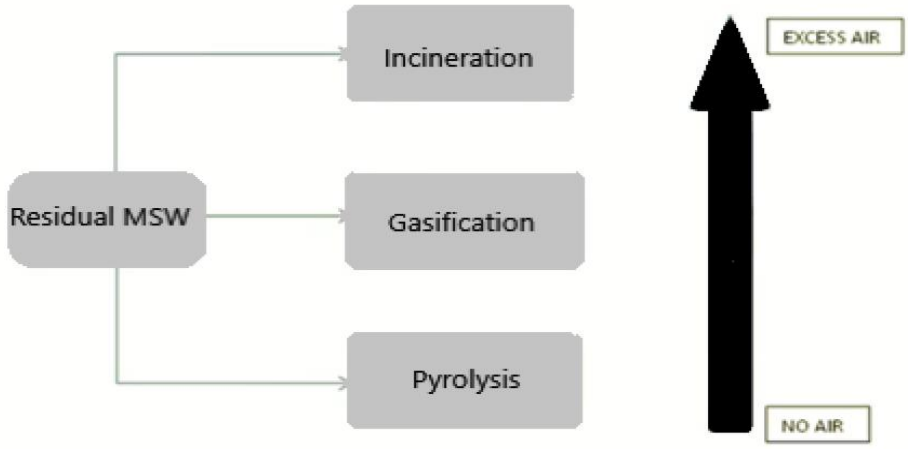

Figure 16. Advanced conversion technologies (adapted from waste to energy international 2021)

Incineration

Incineration of waste to energy is not a new concept. Albert Fryer was the person who created and patented the technology of the first incinerator, which was built in Nottingham, 1874. Back then, incinerators used to be called ‘’destructors’’, and the term was copyrighted by Manlove Elliot, the first large-scale manufacturer of incinerators. (Herbert 2007.) The purpose of incineration plants was to control the outbreak of disease and reduce the size of landfills, which was the result of rapid growth of population in big cities.

Oxford dictionary defines incineration as activity related with burning of something, usually waste, until it is fully destroyed (Oxford learner’s dictionaries 2021). Waste to energy incinerators burn waste with a help of oxygen, at temperatures of more than 850°C. The outcome of burning waste is heat and electricity, which is produced by spinning blades of a turbine generator due to a high-pressure steam (Liu, Nishiyama, Kawamoto & Sasaki 2020).

To get the same end products, incineration plants can equally use MSW or hazardous waste as a feedstock. The temperature of incinerator allows to break down molecules of waste, thus creating carbon dioxide (reaction between carbon and oxygen) and water vapor (reaction between hydrogen and oxygen), which after combustion go to boilers, leaving the incombustible parts known as” fly ash” behind. Pollutants, for example, acid gas, dioxins and mercury are filtered out, thus minimizing risks of being exposed outside. (National Research Council 2000.) Valuable products which can be produced through incineration process include heat, electricity, bottom ash and fly ash (figure 17).

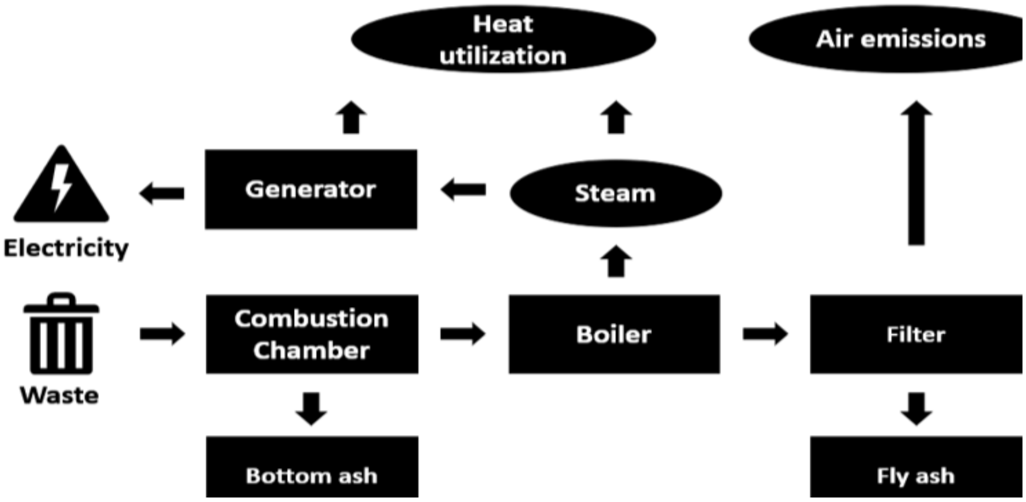

Figure 17. Waste to energy incineration process (adapted from Liu, Nishiyama, Kawamoto & Sasaki 2020)

Previously, bottom and fly ash were disposed because there were no technologies which could provide a use of them. Nowadays, bottom ash can be successfully used for road and construction building (Almeida, Carneiro & Lopes 2020), while from fly ash many valuable products can be recovered, for example, alumina, aluminium, iron, titanium, silicon and others (Ebben & Carlson 2021).

The incineration plants provide many benefits, for example, it provides alternative to fossil fuel energy source which results in decrease of CO_2 emissions, size of landfills and generated methane. In the beginning, incinerators used to have problems in meeting the environmental standards, since the plants caused air pollution by generating CO_2 and dust. Nowadays, due to technological advancements those issues have been minimized and the waste to energy plants can comply with environmental standards. (Liu, Nishiyama, Kawamoto & Sasaki 2020; National Research Council 2000.)

However, incineration of waste to energy has its drawbacks such as (Liu, Nishiyama, Kawamoto & Sasaki 2020; National Research Council 2000):

- it is very expensive to build the incinerators and maintain them
- it does not generate enough income to cover its operational costs
- requires huge amount of calorific waste to operate efficiently, otherwise if every time the facility is shut down and started up, risks of getting incomplete combustion products and increased emissions gets higher
- might cause health risks when filters or system do not have high standards

Gasification

Gasification process was discovered by Dean Clayton in 17th century, and it was widely used during 19th century, and back then gasification plants were powered mostly by coal and peat to produce gas for lighting and cooking (Fabry, Rehmet, Rehmet, Rohani & Fulcheri 2013). By the end of 19th century gasification had a big role on producing electricity by using gas. However, natural gas pipelines eventually replaced the gasification plants. During both world wars, gasification became popular once again, because of scarcity of the gasoline, and during the war gasification plants powered millions of vehicles. (Office of Fossil Energy 2021.)

Gasification process is between incineration and pyrolysis from the oxygen point of view, as it includes partial oxidization in small amounts but not full combustion. So that to initiate and sustain the process of gasification some heat is required. Gasification can be defined as a process of converting carbon-based materials into gas, known as syngas, via heating with temperature more than 700°C. Produced syngas mostly carries hydrogen and carbon monoxide, which can be used for energy production, transport fuels and many types of chemicals. Due to a high temperature, a by-product of gasification is not ash but slag, which has many potential markets, for example construction industry, asphalt paving filler, pipe bedding material. (National energy technology laboratory 2021; Office of energy efficiency & renewable energy 2021; Seo, Alam & Yang 2017.)

Gasification of MSW has a separation process, which separates glass, metal, and chemically inactive materials from the rest of the materials, and the produced syngas contains mainly carbon monoxide, hydrogen, and methane (Seo, Alam & Yang 2017).

The main difference between incineration and gasification is that incineration plants use waste as a fuel to produce CO_2 and heat, which later produces steam initiating generation of electricity. Gasifiers on the other hand does not use waste as a fuel but breaks it down into small molecules and converts them into syngas. (Woods 2015.) The production of syngas versus just heat gives more efficient way in production electricity, because syngas can actually run a generator opposed to just creating or being combusted for heat (Waste 2020).

Pyrolysis

Pyrolysis is a kind of thermal degradation of organic materials via use of indirect external sources of heat. The process runs under the temperature of 300-800° C in the absence of oxygen. It is important for successful cycle that there is a consistent process of heating the feedstock, which vaporise the inflammable parts. These vapours contain mostly hydrogen, methane, carbon monoxide, hydrocarbon gases, water vapour and carbon dioxide. Main products which can be received through pyrolysis are char, oil and syngas (figure 18). (Waste 2020; Breault 2010; Meier, Beld, Brodgwater & Elliot 2013.)

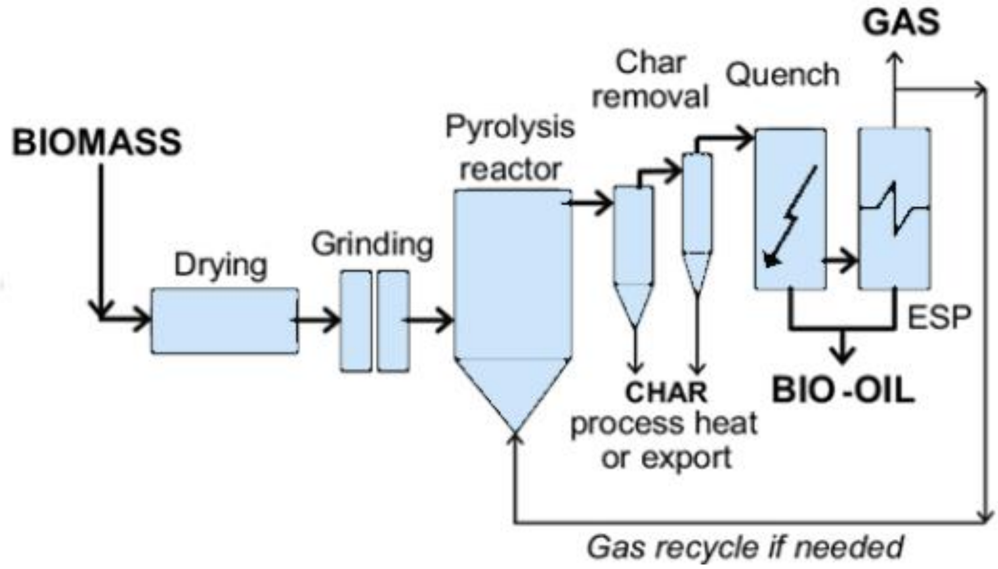

Figure 18. Pyrolysis process (adapted from Meier, Beld, Brodgwater & Elliot 2013)

Breault (2010) defines pyrolysis as one of the steps in gasification process, followed by combustion and cracking process, which further breaks down molecules with a help of additional heat. For example, hydrocarbons in the vapours are broken down into smaller molecules, and with higher temperatures fewer hydrocarbons will be remained. This process ensures that the large tar molecules are decomposed. After combustion and cracking, reduction process is coming which is the opposite of combustion. The purpose of reduction is to convert the combustion products into flammable gasses which could later be used as a fuel.

Plasma gasification

There are many different gasification technologies, however plasma gasification is the most popular gasification technology for the municipal waste. Plasma gasification can take any feedstock for conversion (Waste 2020):

- municipal waste and organic materials convert into syngas
- inorganic materials convert into inert glazed slag

The process uses electricity passed through graphite and carbon electrodes with steam (or oxygen/air injection) to produce electrically conducted gas known as plasma. By using high temperature over 3000 °C, plasma gasification plants can break down waste into molecules and turn them into syngas (figure 19). The gas which is produced by plasma gasifier can be converted later into valuable products such as fuel, electricity with the help of gas engine or turbine generator, chemicals (for example, carbon monoxide and hydrogen) and fertilizer. Plasma gasification produces less emissions than grate combustion, however since plasma technology use electricity to produce high-temperature gas, there is no advantage over combustion in energy production per material. (Dodge 2009; Waste 2020; Seo, Alam & Yang 2017.)

Figure 19. Plasma gasification (GSTC 2021)

Global Syngas Technologies Council (GSTC) (2021) highlights the following advantages of plasma gasification:

- High flexibility: can use e.g., coal, mining waste, hazardous waste, tires, biomass, and MSW to produce fuel
- High availability and over 99% conversion rate (matter into synthetic gas)
- Produces valuable glassy slag and syngas, which can be used to get electricity, transportation fuels, fertilizers
- Low CO_2 emissions, operational and maintenance costs
- Does not produce toxic bottom and fly ash, no methane and greenhouse gas, low environmental impact

E4tech (2009) explains that gasification technologies can vary depending on:

- How the feedstock is put into the gasifier

- Which type of oxidant is used
- How the heat of the gasifier is provided
- Temperature range
- Pressure of the gasifier

Some of the examples of different gasifiers according to E4Tech (2009):
Entrained flow: Feedstock (mainly wood products) and air intake is from the top of the gasifier, which operates under the high temperatures, producing high quality syngas (but not enough clean for tars), hydrogen and carbon monoxide. Ash melts onto the walls, which is called molten slag.

*Bubbling fluidised bed (*similar with circulating fluidised bed): Feedstock (wood, plastic, aluminium, MSW) is fed from the side of the gasifier, and the air is from the bottom. Operates at temperatures of under 900 C° degrees, which does not cause ash melting. Produces syngas (cleaning for tars is required), methane and hydrocarbons.

Dual fluidised bed: Has two chambers - gasifier and combustor. Feedstock (mostly wood) is fed in from the side and is turned into nitrogen-free gas and char with the help of steam. The char goes into the combustion chamber which operates at temperatures of under 900 °C degrees, resulting in heating of bed particles. Bed particles then are pushed back into the gasifier. This type of gasifier produces syngas which contains hydrogen and methane.

4.6.3 Synopsis

Analysis of waste to energy technologies can help to understand what products (energy sources) can be received (including by-products), what feedstock is required and how much of it is possible to supply from a landfill (table 2). Choice of approach should vary depending on the waste stream, as well as comply with needs and possible sources of revenue (Waste 2020):

- Heat – can be used for district heating and industrial purposes
- Metals- ferrous and non-ferrous metals can be recovered
- Aggregate- re-use of slug for building purposes or as additives
- Water- recovered water can be reused
- Electricity- power purchase agreements

Table 2. Synopsis of waste to energy technologies by products (adapted from Dodge 2009; Waste 2020; Seo, Alam & Yang 2017; GSTC 2021)

Process	Feedstock	Products (energy source)	By-products	Diversion from landfill MSW feedstock
Anaerobic digestion	organic waste; domestic sewage	methane		50 %
Incineration	MSW; ASR; RDF; C&I; CDW; medical waste	heat		70 %
Gasification	MSW(sorted); C&I; RDF	syngas; synthetic fuels; steam; combined cycle power		70 %
Pyrolysis	consistent feedstock	combustible tar or bio-oil	chars	70 %
Plasma Gasification	MSW; ASR; RDF; C&I; CDW; medical waste; hazardous waste (incl. asbestos)	syngas; synthetic fuels; steam cycle; cycle power (combined)	glassy silicate, metal drops, salt, sulpher, water,	98 %

4.7 Previous findings related to waste treatment

Some researchers report that combination of landfill gas recovery systems (LFG) and incineration of MMSW has the most economic benefits along with lowest greenhouse emissions and best energy potential. Moisture content of MMSW has a great impact on share of GHG emissions and generated energy, for example, 20 % increase in moisture in MMSW can increase GHG emissions up to 44% and reduce energy recovery to nearly 17%. Thus, pre-treatment (sorting and heating of waste) is very important, because it can reduce GHG emission and increase amount of generated energy (Tan, Hashim, Lim, Ho, Lee & Yan 2014).

According to Ouda & al. (2016), reuse and recycling are considered to be preferable methods for MSW reduction, compare to incineration (with energy recovery), because they provide low-carbon solutions along with reduced environmental impact.

There is a tendency that countries with high rate of recycling have also high rate for incineration (with energy recovery) from waste, while areas focusing on landfilling as a preferable method for waste treatment usually have a low recycling rate (Achillas, Vlachokostas, Muossiopoulus, Banias, Kafetzopoulus & Karagiannidis 2011).

There are lots of debates around the topic of MSW and the best treatment technology. However, it is necessary to take into account that, for example, anaerobic digestion is not suitable for MMSW but it is good for food and garden waste; incineration is the best option for a mixed MSW and can be efficiently used for energy recovery; pyrolysis and gasification are suitable for specific types of waste like wood waste, plastic, tyres, electronic waste; landfilling is good for inert wastes (Kumar & Samadder 2017).

The choice of MSW treatment also varies on the country. For instance, Netherlands, Denmark, Sweden and Switzerland mostly focus on recycling and composting option (Department for Environment food and rural affairs 2013, 5). In Germany, along with recycling, pyrolysis has been successfully implemented for MSW treatment in Burgau and Hamm (Lombardi, Carnevale & Corti 2015). At the same time using pyrolysis technology for a mixed MSW can be not efficient due to a composition of mixed MSW and moisture content (Luz & al. 2015). In UK, mixed MSW is treated via incineration with energy recovery, thus, providing 2.3 % electricity demand for the country and preventing of 2-2.6 mln. tonnes of GHG emissions annually (Jeswani & Azapagic 2016)

Before deciding about waste-to energy technologies it is essential to know two main indicators (Yadav & Samadder 2017; Aleluia & Ferrão 2016; Zaman 2010; Whiting & Azapagic 2014):

- composition and characteristics of waste, influencing on its heating value
- environmental impact (CO_2 emissions) of different waste treatment options (see table 3)

Table 3. CO_2 emissions for different waste treatment options (adapted from Zaman 2010; Whiting & Azapagic 2014)

Waste treatment technology	Global warming potential (1 kg of CO2 equivalent per 1 unit of MWh electricity)
Incineration	424
Pyrolysis	412
Gasification	412
Anaerobic digestion	222
Landfilling (without gas recovery)	746

Mixed MSW (unsorted residual waste) due to its characteristics and composition has limitations in the way of its treatment. European commission (2017) specify that mixed MSW should be allocated to incineration or landfilling, meaning that other options which are possible for MSW treatment like composting and digestion are not appropriate for mixed MSW (MMSW). Efficiency of MMSW treatment from incineration can be reached via energy recovery and mitigation of CO_2 emissions (compared to landfilling), thus, contributing in reduction of waste and raw resources consumption.

In Finland, share of municipal waste is only 2,5 % out of total waste, with approximate 500 kg. generated per person (Team Finland 2021). Out of municipal waste, share of separately collected waste is 46% and share of MMSW is 49% (figure 20), meaning that all this MMSW waste can be efficiently utilized for energy, for example, district heat and electricity (Circwaste 2020b).

Figure 20. MMSW share in Finland (adapted from Circwaste 2020b)

Within a period of 2003-2017, share of energy recovery in Finland has tremendously increased, while landfilling decreased, thus contributing to circular economy idea (figure 21).

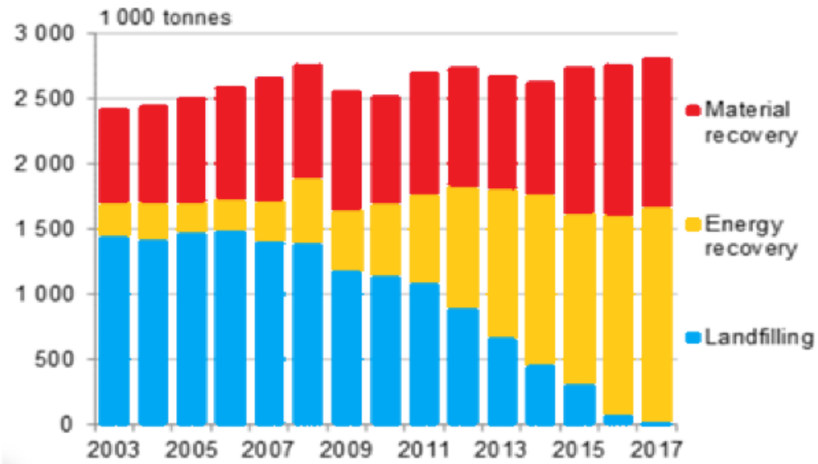

Figure 21. Municipal waste treatment 2003-2017 (adapted from Team Finland 2021)

Last years in Europe there is a tendency to achieve high rates of recovery and recycling of waste, where plastic represent a large share. It is proposed to focus on reuse and recycle of plastic (Ellen MacArthur Foundati on 2017b), thus minimizing share of plastic which ends up in MMSW and can be used for energy recovery. Reduction of plastic in MMSW can significantly affect on a calorific value of waste for energy recovery and some countries like Switzerland, Denmark, Netherlands, Belgium and Austria, where energy recovery can exceed 50%, should consider additional ways of energy compensation. In Finland nearly 140 000 tonnes of plastic out of MMSW successfully used for waste to energy solutions (CircHubs 2021). High heating value of plastic can be used so that to substitute fossil fuels and reduce consumption of natural resources, meaning, that in case when recycling is not possible or economically not sustainable, incineration can be considered as a best option to recover value out of waste via energy recovery. (Wasilewski & Siudyga 2013; Ioelovich 2018.)

Previous findings showed that mixed plastic waste, especially PP and HDPE, has a significant advantage compared to other waste types and leads to a better calorific value, which together with partial moisture removal provides higher heating value. Compared to coal heating value of only 28 MJ/kg, plastic heating value can exceed 40 MJ/k due to a high presence of hydrogen and carbon. Similar heating value can be received only from natural gas (48 MJ/kg) and oil (43 MJ/kg). (Wasilewski & Siudyga 2013.) Changes in MMSW composition and increase of recycling (sorting) can affect on a characteristic of MMSW for incineration and amount of energy produced (Gug, Cacciola & Sobkowicz 2015; Horttanainen, Teirasvuo, Kapustina, Hupponen & Luoranen 2013).

A large share of plastic in MMSW has a low quality and consist of already recycled plastic (for example, trash bags), thus making its further recycling economically inefficient but beneficial for energy recovery (McKinsey & Company 2016, 19). Recycling of only several types of plastic can be economically efficient, for example, PET bottles can yield high performing value via advanced and full type of recovery (bottle-to-bottle), whereas economic value of PET plastic for energy recovery is quite low (figure 22) (McKinsey & Company 2016, 13).

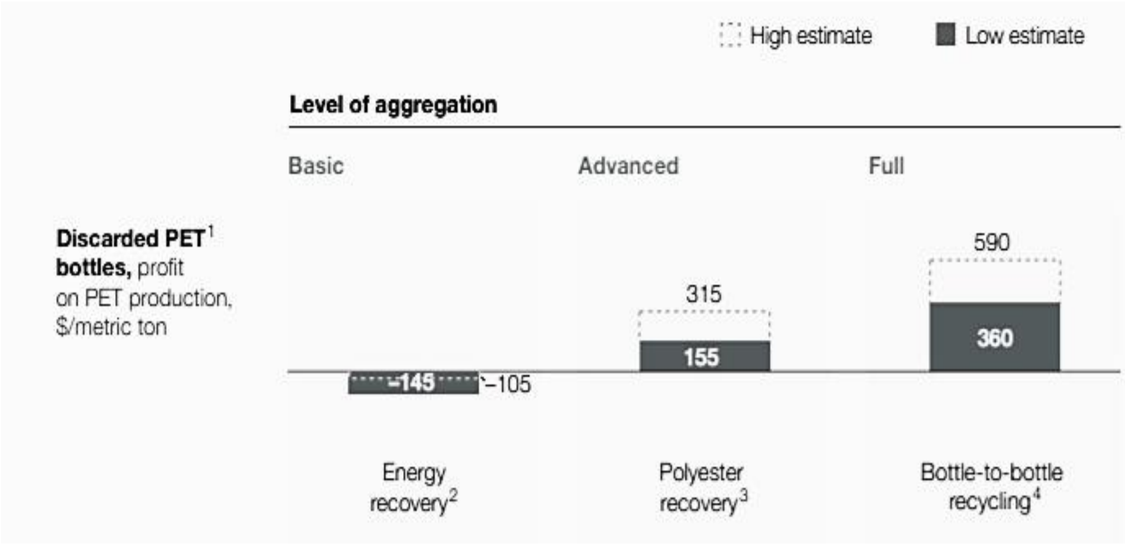

Figure 22. Value from discarded PET through level of aggregation (adapted from McKinsey & Company 2016, 13)

Recycling requires lots of investments and even high-quality recycled materials might be difficult to sell due to uncertainty of recycled plastic properties (McKinsey & Company 2016, 22). In Finland, it is expected to increase volume of recycling up to 65% by 2030, which is nearly 25 % more that now, meaning that the share of plastic in MMSW will gradually decrease (Team Finland 2021)

Among other concerns related to the topic of MMSW treatment via incineration with energy recovery are harmful emissions, including CO_2. In Finland, total GHG emissions from waste sector is nearly 3%, 85% of which comes from landfilling. Share of GHG emissions from incineration is only 0,6%. In 2018 total GHG emissions increased by 2 %, compared to 2017, as a result of increase in consumption of peat and natural gas (Statistics Finland 2019).

Some of previous findings showed associations between renewable energy and increase of CO_2 emissions (Zoundi 2017; Lee 2018), while others stated that in a long-run perspective recycling and energy recovery lead to decline of CO_2 and significantly contribute to sustainable environment through different processes (Danish, Baloch, Mahmood & Zhang 2019; Bayar, Gavriletea, Sauer & Paun 2021).

5 Methodology

Methodology justifies a usage of particular method. According to Rutberg & Bouikidis (2018), research can be either qualitative or quantitative. Qualitative research takes the human experience and perception into an account, while quantitative research focuses on numbers, on mathematical equations and statistics, providing results in numbers which can be considered as more objective (Moore 2016). Quantitative data provide generalized results with an attempt of researcher to remain objective and explain observed things, which are usually a large amount of cases (MacDonald & Headlam 2015, 9; MacDonald & Headlam2015, 8)

Cohen, Manion and Morrison (2007) argues that there also a third research method called experimental research, which is a scientific approach to experiment one or more independent variables, manipulating them by adding to one or more dependent variables thus testing their influence.

Creswell (2017, 6) states that in situations, when it is required to get a complete understanding of the problem, a mixed qualitative-quantitative method should be used. Mixed method will help to understand “how mechanics work” and connect together different parts of evaluation process (Creswell 2017, 7).

5.1 Qualitative method

Qualitative research method represents individual opinions of people about the phenomena in connection with a real life based on their expertise, experiences and knowledge. In a nutshell, it is a subjective perception of reality by individuals, based on their feelings and beliefs. Qualitative research often requires deep understanding of a topic, like why and how, and such information could be provided via free-form text responses from participants, their observation or interviewing (Rutberg & Bouikidis 2018). Qualitative strategy is usually the best option when a problem is not well understood, and there is a need to find out the reasons behind the problem.

Data collection has a significant role in any research, hence it requires a focused attention and there has to be a clear reason behind the data collection. According to Ajayi (2017) there are two types of data, secondary data, and primary data. Secondary data can be characterized as data which are already available from previous research, while primary data are data which are gathered from the main source (Ajayi 2017).

For our thesis, a qualitative research was chosen as a research method. Partially, it was a recommendation of our commissioner that current thesis should be conducted as a qualitative and explanatory research, because previously there have already been conducted many quantitative research (in a form of surveys) but there is still lack of qualitative research on a topic.

A qualitative method is used in this research because this is an exploratory research with a purpose to understand reasons and motivations behind why certain decisions are made for certain waste streams. Exploratory research is a type of interview with a participation of strategic representatives who are interviewed so that to identify priorities and future plans, test hypothesis and make connections between research subjects to progress the findings forward (MacDonald & Headlam 2015, 41).

There are number of statistics and data available about waste management, however, the available data are mostly in numerical forms and lack the reasoning behind them. For this research, opinions of experts in circular economy sphere, waste management and waste-to-energy industries are needed, hence, the size of research sample is quite limited. For data collection, both primary and secondary data will be used, since there are useful data available online which can serve our purposes, however, data from the main sources are required, due to focus of our thesis on a topic which has not been previously covered.

This thesis is qualitative and exploratory research, where data are collected with a help of a semi-structured instrument. Semi-structured interview can provide a possibility do not strictly follow with a list of open-ended questions but follow the topic of the conversation. It is possible to ask additional guiding questions when it is appropriate to direct the interviewees. Case study can be used for qualitative method.

5.2 Semi-structured interview as a data collection method

There are three main types of interviews - structured, semi-structured and unstructured. In a structured interview, pre-planned questions are asked in a previously arranged order, which helps to keep the interview highly focused on a topic, however, sometimes it might have lack of in-depth data due to a limited flexibility in the interview format (Alsaawi 2014, 149-150). In a semi-structured interview, which is a mix of a structured and an unstructured interviews, a respondent answers on a set of prior pre-planned questions by their own words, however, interviewee may be asked additional open-ended questions so that to explain some issues and get clarification. This type of interview is good for researchers who understand the topic and want to elaborate it via additional open-ended questions (Alsaawi

2014, 150). In an unstructured interview, which is useful when there is little information about the interviewee, the interviewer has no specific restrictions or prearranged questions, hence the interview is open and spontaneous (Easwaramoorthy & Zarinpoush 2021).

For this thesis a semi-structured interview is chosen because predetermined questions will be asked to enable interviewees to be focused and provide more information about the topic. Also, semi-structured interviews help the interviewees to go deep in the topic and give honest answers from their own perspective and experience. An unstructured interview was not considered for the purposes of this thesis because it is time consuming, requires proper skills from the interviewer, it generates lots of information which might be difficult to analyse and sometimes leads to unpredictable directions (Alsaawi 2014, 149 -151).

During the semi-structured interview open-ended questions will be asked which can potentially help the interviewer to find out more than anticipated, whereas close-ended questions might limit participants to give abstract or predicted answers (Farrell 2016). Therefore, open-ended questions will serve the purpose of this thesis by getting as much information as possible from participants, along with in-depth extensive answers and possible discussions. The interview questions will be divided under themes, which will make it easier to analyse the results and link them with theoretical framework and research questions.

Silverman (2013) points that in a qualitative research the focus of questions is on “How”, rather than “How many”. For the current thesis, among the others, the following questions are raised (full list of questions see in the Appendix 2):

- What are the main challenges to transit to circular economy?
- How successfully pre-sorting is implemented in Vantaa?
- What are alternatives for MMSW treatment rather than incineration?
- How do you think which one produce more CO_2 - recycling of recyclable part from MMSW or its incineration?
- What are the main challenges in removing recyclable and reusable materials out of MMSW?
- How do you utilize valuable products out of the bottom ash?
- What are the main challenges for households to sort waste properly?

5.3 Data collection

The data for the interview were collected from Vantaa City, Vantaa Energy, HSY and Waste Management Company X, as these organizations operate in the spheres related to implementation of circular economy, waste-to energy solutions and waste management, thus may provide the best insights for the purposes of the current research. Based on the competences, participants from aforementioned organizations were assigned and informed about the interview via emails. Before the initial interview, a set of questions was sent to interviewees to let them prepare and better understand what types of questions might be asked. Additionally, “Consent form for personal data processing” was attached to comply with GDPR and existing regulations. It was agreed with all interviewees that their names will not be visible in the final research. Some of the interviewees wished to generalize the name of the company and their job position.

Data collection (interviews) were held on the 12 and 13 weeks 2021. Initially, so that to raise discussions on a topic and save time for arrangement, interviews were planned to be conducted not individually but in groups of 2-3 people, in total 3 group-interviews with total participation of 6 people. Due to a different schedule of participants and impossibility to find in a short time a convenient day which would satisfy all members of each group, it was decided to conduct interviews individually according to a schedule (table 4).

Interviews were conducted in teams of two interviewers. Time required for each interview was between one-two hours; time required for data analysis – two weeks. All interviews were held online due to restrictions of Covid-19 for personal contacts. For the convenience of the interviewees, a power point presentation was created for a visual support of the questions.

Participants for the interview were chosen based on their skills and knowledge required to answer on main research questions. There was not any sampling based on gender or age of the participants, because the nature of the research did not require it.

Table 4. Interview schedule

Date	Interviewee	Organization	Role in the Organization
26.03.2021	Interviewee 1	Helsinki Region Environmental Services (HSY)	Logistics planner
26.03.2021	Interviewee 2	HSY	Project Manager in waste management
29.03.2021	Interviewee 3	HSY	Circular Economy Expert
01.04.2021	Interviewee 4	City of Vantaa, Environment Centre	Project coordinator
08.04.2021	Interviewee 5	Vantaan Energia OY	Development manager
06.04.2021	Interviewee 6	Waste Management Company X	Development Manager

5.4 Tools and data analysis

For current thesis, all interviews were conducted on-line via Zoom application. Information was recorded with a prior consent of the interviewees. Transcription of the records into text was performed manually and with a help of programmes like “happyscribe” (www.happyscribe.co), “sonix” (www.sonix.ai), “amberscript” (www.amberscript.com).

According to Perroni, Costa, Lime, Silva & Vosgerau (2021) the content analysis can be done by using set of techniques, like: Categorical, Evaluation, Enunciation, Discourse, Expression and Relations. In this research a categorical method was used to analyse the content. The content analysis was conducted with a focus on categories which were identified based on the research questions. The categorical analysis was based on the interviewees’ answers for interview questions in which interviewers were seeking to find similarities and differences about the topic of research.

For text analysis and its further coding, the Microsoft Word tool was used. According to Linneberg & Korsgaard (2019), coding is a process of labelling and organizing qualitative data, searching and identifying themes and relationships between them, structuring the data to establish a good overview and convenient access to it.

To analyse the interview answers, every line of transcript was read carefully, and the lines were double checked with the help of the recorded interview to ensure that no mistake was done in the transcript. After the transcript was read, we started the process of coding, which means that all relevant words, sentences and phrases were labelled and put in different categories. Categories were created by putting several codes together and names of the categories were based on the themes of the codes. Then categories were listed from most relevant to least relevant and decided how different categories were connected to each other by finding patterns between them. Later, the information from data was extracted and simplified and presented in a table form.

Microsoft Words was the chosen tool for the coding because it enables coding by using the comment system, which can be done by adding the code as a comment on the phrase, word, or sentence. Comments and codes were extracted in a separate Word file with a help of macros “Doctool” (www.thedoctools.com). Later, extracted information was analysed with a help of Microsoft Excel by filtering answers according to defined categories to see all differences and similarities in responses of the interviewees.

For the documentation of the results each code is presented and defined with a justification, and the relationship between the codes is justified thoroughly. According to Linneberg & Korsgaard (2019) the visual display minimizes the reading and makes the complicated topic easier to understand, therefore, to display the coding clearly a horizontal tree structure was used (Figures 23 and 24). A horizontal tree structure is a convenient way of displaying data by categories and showcasing the connection between the codes (Linneberg & Korsgaard 2019).

5.5 Reliability of the research

The terms' reliability is used to assess the quality of a study. According to Golafshani (2003), a qualitative research can be considered reliable if the result of the research is consistent, the sample is referred accurately, and the same results are found when a similar research is done later by someone else. Testing the quality of the qualitative research is the most important test of the research if the reason behind the testing is to elicit the information.

Stenbacka (2001) states, that the concept of reliability in a qualitative study is irrelevant and even misleading since the purpose of a qualitative research is to generate understanding. But, Patton (2001) argues that, reliability of a qualitative research should be considered when assessing the quality of the research, design of study and analysing the results. According to Healy & Perry (2000), the criteria for quality in a qualitative study are credibility, neutrality, consistency, and applicability. Seale (1999), states that to ensure the reliability of a qualitative research, the trustworthiness should be examined. In addition, the competence of the researcher should be taken into an account as a part of the reliability of the research (Patton 2001).

In this research, experts from different organizations within the waste, environmental and circular economy industries were interviewed to ensure the trustworthiness of data. Similar aspects from five main categories related to circular economy, MMSW treatment and sorting, CO_2 emissions and economic value were asked from experts to see repetitions and differences in answers. The purpose of the research was to understand a position of experts from different organizations in dealing with challenges and potentials in mentioned categories.

The answers from interviewees were trustworthy since it came from credible experts within the relevant industries. However, the research was done by university students with limited skills and knowledge related to power engineering, specifics of waste streams, material flows, value supply chain and waste to energy technologies which might affected the relevancy of research questions. Therefore, one could argue that the credibility of the researchers might be questionable, because of lack of experience, even though the source of data was credible.

All work and data processing were done remotely due to COVID-19 restrictions. Interviews and all communications, including communication between researchers were done online via Zoom and Microsoft Teams.

6 Results of the research

As it was previously mentioned in 5th chapter of this thesis, so that to answer on the main research questions, "What are potential and challenges in Vantaa's MMSW treatment from the perspective of circular economy" and "How MMSW treatment in Vantaa City can be improved from the perspective of CO_2 emissions and its economic value? - all interview answers were split into categories (codes) related to a circular economy, Vantaa's MMSW treatment and sorting, CO_2 emissions and economic value associated with Vantaa's MMSW. Interview analysis for each of the category finally led to answers on the main research questions. Below, in subchapters 6.1 - 6.5 interview results for the categories are provided and in subchapters 6.6 - 6.7 answers on the main research questions.

6.1 Potential and challenges of circular economy

All the candidates agree that the potential of circular economy is huge, both economically and environmentally. For example, it was mentioned that by transiting into circular economy, the GHG levels of EU could go down by 56%, and by reusing and recycling the problem of resource scarcity can be fixed, also the new economic model will create new jobs for people.

> As stated by Interviewee 3: ''The potential of circular economy is huge. Circular economy is given as a solution to the biggest challenges of today – climate change (-56 % GHG emissions in EU by 2050), biodiversity loss and resource scarcity, by reusing materials which are already on market and not digging for new virgin material, destroying habitats. It is also calculated that there is a lot of job potential in a circular economy (700 000 by 2030 in EU).''

According to Interviewee 4, about 10 percent of the world economy is circular, and it should be much higher than that. Therefore, they are promoting recycling and reusing along with looking forward for better ways of promoting a circular economy.

> Interviewee 4: "our strategy is to find already existing practices, which have been proven to work, and run pilot projects using the existing practices, gather data and make decisions based on the data, later if they conclude that those practices are sustainable and work, they can implement those practices in the city".

> Interviewee 6: "We actively promote circular economy by investing in sustainable services. We have invested in new services that promote the circular economy, increase customers' material, energy efficiency and reduce costs. Our goal is to further increase the use of secondary raw materials instead of virgin materials. In

> accordance with the order of priority in waste management, we primarily direct the generated material streams to be reused or recycled. In 2019, we opened a new plastic processing line which makes it possible to recycle even more difficult-to-recycle plastic sorts.''

It is very difficult to change the entire economic model into circular and there are many obstacles which must be overcome. When it comes to challenges of transition to a circular economy, answers of the interviewees vary.

According to Interviewee 3, some of the biggest challenges in transition towards a circular economy are the following ones: circular design, logistics, services, consumption, usage, recycling and waste management. In this situation, first step for big and real changes should be taken by laws and regulations which would set the framework. Secondly, focus on design, innovations and circular economy business models, where public authorities support the circular initiatives and business models, for example, by creating cooperation platforms and public procurement of circular solutions. Implementation of circular economy in reality faces multiple obstacles.

> Interviewee 3: "One huge issue is safety – how to get materials to circulate, but bad stuff in them, such as toxins, not to. Also, there is a need to have a market for recycled material, and a reliable supply of recyclable material that meets the quality standards, in order to be appealing for investments. Also, the material needs to be clean enough and separated from other materials in order to get the best results in the recycling process. There should be technical solution in order to recycle materials without decrease in value, and the next product needs also to be recyclable. Recycled materials should be safe to use and cheaper compared to virgin ones.''

According to Interviewee 6, challenges in transition towards circular economy also relate to creating demand for recycled materials and finding skilled workforce; current technologies do not allow a transition to renewable and CO_2 neutral energy production, that is why new sustainable methods for the market should be introduced; in Finland lots of recyclable materials are wasted, and it is mainly because municipal companies oversee the mixed waste.

> Interviewee 6: "we mainly focus on the B-to-B side, where waste management is not municipalized, and recycling opportunities are much greater. We do not treat mixed waste. Because in Finland it is mainly treatment by municipal companies. And it's not recycling or part of circular economy. And that's the reason, why it's very poorly done, and we waste lots of recycling materials in Finland".

Interviewee 5 sees the biggest challenge in lack of demand for the recycled products, while Interviewee 4 sees challenges in set standards for the procurement of recycled materials.

> Interviewee 5: "'Main challenge is the lack of markets and demand for recycled raw material or products made from recycled materials. This is more of a regulatory issue: recycled material should be used first for products".

> Interviewee 4: "Standards should be changed, city have to change the way they are doing business, for example, when we want to build a school there are standard materials that we use, there is no set criteria for a share of recyclable materials which need to be used, as a result companies do not provide it.''

6.2 Vantaa's MMSW sorting

All the candidates believe that sorting at a source is the best and most cost-efficient way of getting the most out of the waste. Candidates had different opinions about means to promote pre-sorting, so that people were eager to sort their waste before it ends up in a mixed bin container.

Interviewee 3 stated, that money is the most efficient way of motivating people to pre-sort waste.

> Interviewee 3: ''Money is the most efficient way- if you get some compensation for recycling and fee for not recycling, but it is difficult, because not everyone has cash, so we cannot make waste management price to be high, everyone should afford it. In Finland we implement this compensation system, and it is very effective. Also, people's mindset has changed for the last years - more people want to recycle and sort plastic out. It would be great that the same will be with a biowaste.''

However, Interviewee 6 and Interviewee 4 had a different opinion on the topic, believing that educating people about benefits of recycling is the best way of promoting recycling. Additionally, Interviewee 4 stated, that informing people about the carbon-neutrality can make people feel responsibility to put efforts to achieve this goal: "Carbon-neutrality goal and being resource wise can motivate people, so that they feel responsibility for their input to achieve this goal.''

Pre-sorting allows recycled materials to keep the quality and that makes the recycling process easier, especially considering that it is technically possible to sort mixed waste before incineration, as it was pointed by Interviewee 4.

> Interviewee 4: “The current system is based on a source operation, so we think if people can help us and sort their waste there will not be any mixed waste. There was some discussion that there should be some sorting before incineration in a current system, but it requires heavy investments. In other cities, for example, Riihimäki, they have facility that they can sort plastics and other materials before incineration, so it is technically possible.’’

Sorting of Vantaa’s MMSW before incineration is a very important stage which faces lots of difficulties, one of which is not efficient sorting at a source (by primer consumers), especially in terms of plastics and biowaste.

> Interviewee 3: “People do not like to sort out biowaste. Biowaste in mixed waste decreases the quality of other materials, as the rest of the material get wet and dirty. Bacteria, fungi and moisture make it hard to get out useful high-quality materials from the mixed waste”.

Large share of biowaste in MMSW increase a moisture content “Moisture content varies quite a lot, waste fractions are dirty, plastics are difficult to separate into different qualities” (Interviewee 5).

Not efficient MMSW sorting by consumers, lack of mechanical processing and viable solutions “existing solutions, such as optical sorting plants for household mixed waste are not a very cost-effective idea” (Interviewee 2) cause that “a large share of MMSW which can be recycled going directly to waste incineration” (Interviewee 3)

Nowadays, most of the apartment buildings with five or more apartments have access to separate containers for waste, at the same time there is still a challenge to provide proper sorting of waste at a source.

> Interviewee 3: “limitations of space in kitchen make it difficult to have a separate bins for each stream of waste. Many people still have lack of sorting skills and motivation to sort waste, have wrong attitude”.

Moreover, “Vantaa is a multicultural city and give a right message in different languages is a challenge” (Interviewee 4). There is still a problem with some apartment buildings and private houses which have only mixed waste bins, not separated containers.

> Interviewee 2: “Accessibility of different bins plays a big role – easy access is very important. In apartment buildings with 5 or more apartment there should be separate containers for waste”.

6.3 Vantaa’s MMSW treatment

Vantaan Energia waste incineration plant is the main treatment for mixed waste in the region. From a circular economy point, incineration is the last step, since the materials disappear and cannot be reused.

> Interviewee 2: “Material recycling from mixed waste is difficult, and while incineration produces energy which is good, it destroys materials, at least 80 % of which can be recycled and reused. What cities can do is to buy circular services and products via public procurement, invest in and promote recycling in all activities in order to reduce the amount of mixed waste”.

It is very important to increase recycling rate and reduce waste, but these goals face their challenges.

> Interviewee 4: “A challenge is which treatment is a best, because we think we have so efficient incineration plant in Vantaa, that it is challenging for material recovery. Currently, material recovery works quite well in metals, paper and carboard, but not with plastics. In plastics, material recovery is a bit difficult due to a difference in quality and it is often very dirty in MMSW. Getting the materials out of MMSW is hard, so cost efficiency should be considered as well as technical challenges. We have a plan to reach material recovery of 60% by 2025 (now it is 54%) and 70% by 2030, if I remember correct, but sometimes it is difficult to justify”.

Amid the main challenges identified in MMSW treatment are new technologies and their potential.

> Interviewee 5: “Reusing and recycling technologies are not mature enough yet to handle all waste fractions economically. So, grate fired incineration is most suitable for waste with varying content. Later, perhaps, pre-screening and much later full material recovery without burning will be possible”.

Logistic system also plays an important role in efficient Vantaa's MMSW treatment. HSY do not have own trucks but buy collection services from other companies. Collection of waste during rush traffic hours can be tricky and that is why extended collection hours being planned. Fast, quiet and low emissions trucks are important for waste management system. The transition to low or zero-emission waste transportation is slowly happening via procurement requirements. Also, electric vehicles are being planned for pilot testing. Electric cars produce zero CO_2, they are quiet, which is important for a city centre and for neighbourhoods, where people get angry for morning trash pickups.

> Interviewee 1: "We try to develop electric cars project for testing. Electric cars will provide zero-carbon emissions and they are very quiet, which is important for night shifts waste collection. We do not know how good it will be, how long it will last and is it possible in Finland, we do not know. Main obstacle is that all parts should be electrical, some of these things do not exist yet. Trucks need to get certification so that to be used. Not all cars should be electric in the future, it is not a best option, because they require lots of rare metals, and it is a huge problem to get all of them. A solution might be to recycle metals from already existing cars which are in the loop, then we do not have to excavate more".

Shifting towards electric cars is not a panacea and requires lots of further research.

> Interviewee 4: "There is need to have more information of how electric cars fit to circular economy, because there is a challenge of batteries and their treatment. Current batteries require rare metals and there is a waste treatment of those batteries after their life cycle, which is a downside of those cars".

Interests of public and private waste management companies in Vantaa do not always comply in terms of MMSW treatment.

> Interviewee 6: "In Finland, municipal waste is mainly treated by municipal companies and it's not recycling or part of circular economy. And that's the reason, why it's very poorly done, and we waste lots of recycling materials in Finland. Our company don't want burn and waste recyclable materials, we want to be a part of circular economy. MMSW needs more pre-treatment and efficient collection which plays a key role in the development of the recycling rate. When materials are diligently sorted at source, they can be recovered and utilized effectively. For example, in our company in 2019, 76% (74) of all materials were sorted at source, with only 24% (26) ending up in mixed waste".

Interviewee 5: **"**No pre-sorting or heating is done for the waste. Moisture content varies quite a lot, waste fractions are dirty. Plastics are difficult to separate into different qualities. As long as MSW incineration is replacing fossil fuels, burning has the highest value. As renewable energy grows, then the largest value should pivot to recycling of MSW for raw materials".

6.4 CO_2 emissions associated with Vantaa's MMSW treatment

There are different opinions related to CO_2 emissions associated with incineration of Vantaa's MMSW.

> Interviewee 3: "average emissions of incinerated mixed waste are 506 kg CO_2 /t (2018). A huge amount of mixed waste is plastic and biowaste, as a result amount of CO_2 is so high. At least 80 % of mixed waste can be recycled and reused".

> Interviewee 5 has a different point of view: "The energy content of Finnish waste is enough to sustain the process, so I would guess it does not affect the GHG. Also, flue gas condensers collect the energy from the moisture at the end of the process, so all heat is collected also".

Understanding of CO_2 emissions in association with full cycle of MMSW pre-sorting and its incineration requires in-depth research and analyses, thus at the current stage of Vantaa's MMSW treatment it is difficult to say what is more environmentally friendly and produce less CO_2 emissions – incineration or recycling.

> As stated by Interviewee 4: "It is not always easy to tell about the benefits of pre-sorting, because we don't always know is it actually a better way if think about CO_2 compare to incineration, which is highly efficient and can produce electricity and heat. So, we have to think about global goals, we need more calculations based on CO_2 and its potential if we do more sorting before incineration. For CO_2 related with recycling of recyclable part from MMSW or its incineration we don't have exact numbers, there should be a life-cycle analysis, it is not simple".

Another aspect relates to CO_2 emissions during Vantaa's MMSW transportation, which has some uncertainty in terms of CO_2 calculations and its reporting, which can be traced via different statements of interviewee 4, Interviewee 3 and Interviewee 6.

> Interviewee 4, regarding CO_2 emissions: "HSY makes these calculations, we just keep that information for our annual reporting. We report annually out total CO_2 as City of Vantaa".

As provided by Interviewee 3: “HSY do not collect waste itself, we procure this service, so these GHG are not calculated in the HSY CO_2 total. We do not have data. Our procurement of services set minimum requirements for example, emission levels of the transportation vehicles, and through this public procurement mechanisms we try to lower the emissions. We do not have any specific data for Vantaa or any other one city in our region. Sub-contractors provide information regarding CO_2 emissions they produce during transportation but not directly to us”.

In accordance with Interviewee 6: “HSY do not ask to provide any reports about CO2 relating with waste transportation for accessing or tracking CO_2 emissions”.

Vantaa City has a very ambitious goal to become a zero-carbon. So that to reach this goal all possible sources of CO_2 emissions should be analysed, measured and reported. One of such sources is associated with a Vantaa’s MMSW treatment.

Interviewee 3, regarding amount of CO_2 produced for Vantaa’s MMSW treatment: “Unfortunately, we do not have updated data on this. We had one project which was done over 10 years ago, where CO_2 emissions for different sort of waste including MMSW were investigated. But over 10 years ago incineration plant didn’t exist, so, it is really different numbers, and we don’t use them anymore, unfortunately. So, that research project has been done for over 10 years ago. It is not easy to do it again, so we do not do it every year, we need to find resources for this and unfortunately it has not been prioritized in the last years, even though we are asked about this every year”.

In general, a positive shift towards CO_2 reduction requires implementation of new technologies and innovations, collaboration of public and private waste management sectors. Modern technologies provide efficiency and contribute into CO_2 mitigation.

As provided by Interviewee 4, “usually, efficiency (and Vantaa Energy is very efficient) means that it is good for CO_2. We need to have more solutions for material recycling after that it may be more efficient than incineration in terms of CO_2”.

As stated by Interviewee 6 about potential of CO_2 mitigation in relation with MMSW: “By reduction of indirect emissions generated in our supply chain, 70% of our biggest suppliers and subcontractors can meet their goals to reduce their own emissions by 2025. Recyclable raw materials substitute virgin raw materials and waste derived fuels substitute fossil fuels in energy production, savings amounted total 1,2 Mton CO_2 in 2020. Low -emissions new vehicles (Euro 6 standard and gas fuelled heavy vehicles) and low-emissions fuels, as well as optimization of transport routes can help to reduce emissions. Use of waste -based Neste Renewable fuel instead of diesel enables to reduce transport-related GHG emissions. It also represents an example of how

> circular economy works in practice: waste is transported with a help of fuel made from waste".

6.5 Utilizing value from Vantaa's MMSW

Along with transition towards circular economy and goals about CO_2 reduction, economic feasibility and cost-efficiency play an important role when dealing with MMSW. It is very important to find a cost-effective way to increase recycling and reduce waste.

> As stated by Interviewee 4: "it is not so easy with MMSW. From incineration we can get energy, which has more or less fixed value. If we focus on getting new recyclable products out of MMSW it is more difficult to predict what the value would be. In the beginning the value might be not high, but in a long run the value might be higher but we need to have a functional market for this. Currently, for some materials, for example recyclable glass and plastics, there are not so much market at the moment, so the market should be developed as well as people's attitude should be changed. Cost efficiency is a huge challenge. It is cost efficient to incinerate the waste, so, we think how to do it the same cost effectively in material recovery. We have highly developed technology for incineration which makes it challenging to promote material recycling because we do it too efficiently by incinerating. Of course, Vantaa Energy will not say they do it too efficiently, there job is to do it as efficient as possible".

Position of different stakeholders regarding MMSW treatment vary depending on their role in the process and belonging to the public or private sector of waste management.

> Thus, according to Interviewee 5: "there is no economic way to recycle, for example, different dirty plastics. In general, the heat value would probably decrease if recycling would increase. Current method is probably the most economical way to treat waste since there is not a functioning market yet for recycled fractions which would make recycling profitable. Circular economy must increase, but regulations are needed to form a market. For example, valuable metals can be taken out of the bottom ash and would probably amount to millions in a country wide context from all MSW ashes, but there is not yet a profitable method for this material recovery. At the moment, ash is hazardous waste and is disposed".

Position of private sector in terms of Vantaa's MMSW handling emphasizes necessity to shift more towards recycling rather than incineration and provide wider options in waste management for private companies.

> As stated by Interviewee 6: "treatment of mixed waste is usually the most expensive. We want to create more demand for recycled raw material, increase the use of secondary raw materials instead of virgin ones, direct the generated material streams to be reused or recycled. We have invested in new services that promote the circular economy, increase our customers' materials, energy efficiency and reduce costs. For example, in 2019, we opened a new plastic processing line which makes it possible to recycle even more difficult-to-recycle plastic sorts. We are looking forward to handling the whole chain of waste management, transportation".

Current Vantaa's MMSW treatment via incineration does not comply with a circular economy and mostly can be justified from an economic point of view and cost-efficiency.

> According to Interviewee 3: "In incineration plant materials and nutrients are lost, but from waste is produced electricity and heat. The goal is to incinerate as little as possible, and only those materials, that cannot be recycled. In 2018 from Vantaa's household mixed waste recyclables materials were 76%. Waste incineration destroy materials, they are lost, the loop is broken, and it is not about a circular economy".

Utilizing value from MMSW treatment is a long process, which requires investments, innovative technology, collaboration of private and public sectors, stable market of supply and demand, clear regulation for all parties.

> As stated by Interviewee 3: "Increase of recycling from MMSW depends on a global market. It is possible to stimulate it via mechanism of carbon trades, with a help of taxes, regulations, economic incentives, increase prices for raw materials and reduction of price for recyclable products to make them more competitive".

Interviewee 4 adheres to a similar with Interviewee 2 position in terms of necessity to strengthen a market for recycled products from MMSW.

> Interviewee 4: "for recycled paper and metals selling has already been done successfully because there is a global market, so there are also possibilities for other materials, but it requires financial support. European Union ready to invest lots of money in activities related with circular economy. In the beginning it might not bring any profit, but in a long run it will pay off. Currently, Vantaa's MMSW value is heat and electricity which comes through incineration. Demand for electricity is higher than for heat, because it is easier to sell it. The situation in future with electricity will not change. Heat we cannot store or use it later, we cannot sell it to other cities, and it is not in a high demand all year around. It might be so, that heat will also become a

market product and thus, we will utilize everything. More information is available from Vantaa Energy, they have some plans related to heat storage".

From the perspective of Interviewee 5, heat production out of Vantaa's MMSW seems to be more economically profitable and has a better potential.

> Interviewee 5: "Heat consumption in Vantaa is about 1800GWh annually and this will probably be stable. Electricity production depends on Nordpool market prices. Looks like electricity prices will stay relatively low in the future, so heat production is probably more important. Currently, renewable share in MMSW is probably around 40%, but it will grow".

As opposed to Interviewees 5 and 4, Interviewee 6 heavily relies on recycling as the most valuable MMSW treatment and sees material recovery as a source of economic value providing sustainability and promotion of a circular economy.

> As stated by Interviewee 6: "Recycling is the most valuable. The market situation of our services remained relatively stable throughout the year. The demand for secondary raw materials was mostly good. The demand for wood chips and waste-based fuels increased as expected. The increasing sustainability requirements of our customers increased the demand for service solutions promoting circular economy".

Summary of all interview findings in a graphical way helps to understand the key points identified in each of the assigned categories: circular economy, MMSW treatment and sorting, CO_2 emission and economic value of MMSW (see in figure 23).

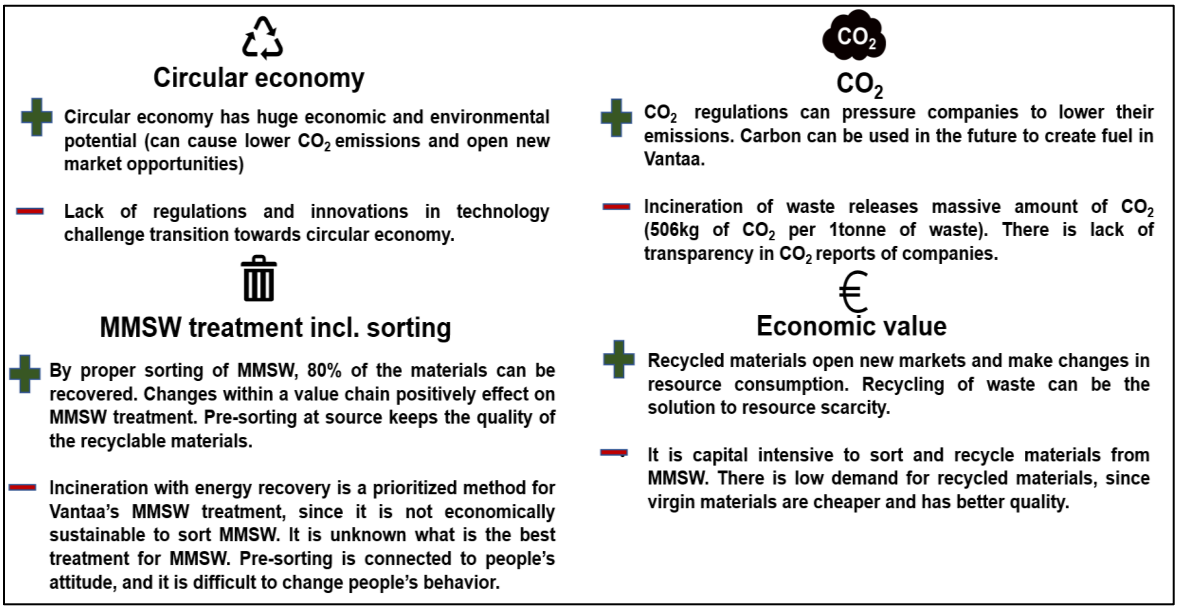

Figure 25. Synopsis of main interview findings (see also in Appendix 3)

Main challenges in Vantaa's MMSW treatment according to interview findings are lack of regulations, standards and technologies; lack of pre-sorting and cost-inefficiency of recycling compared to incineration; lack of global market for recycled materials (figure 24).

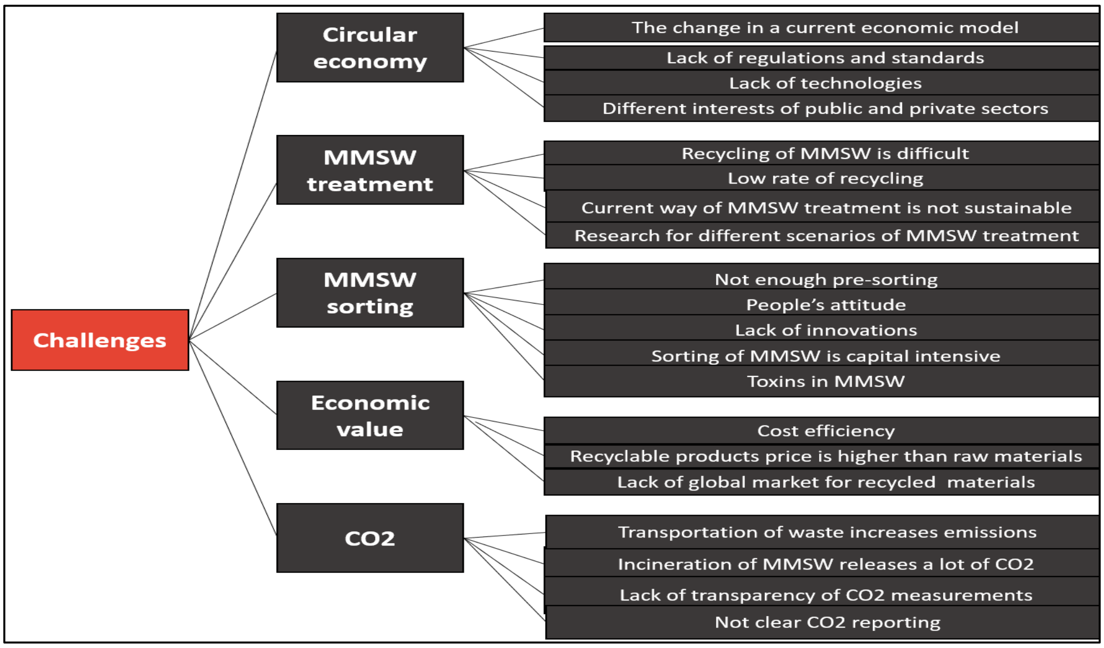

Figure 24. Summary of main challenges in MMSW treatment (see also in Appendix 4)

Potential of Vantaa's MMSW treatment according to interview findings lies in use of new technologies, implementation of precise sorting along with close collaboration between all stakeholders (figure 25).

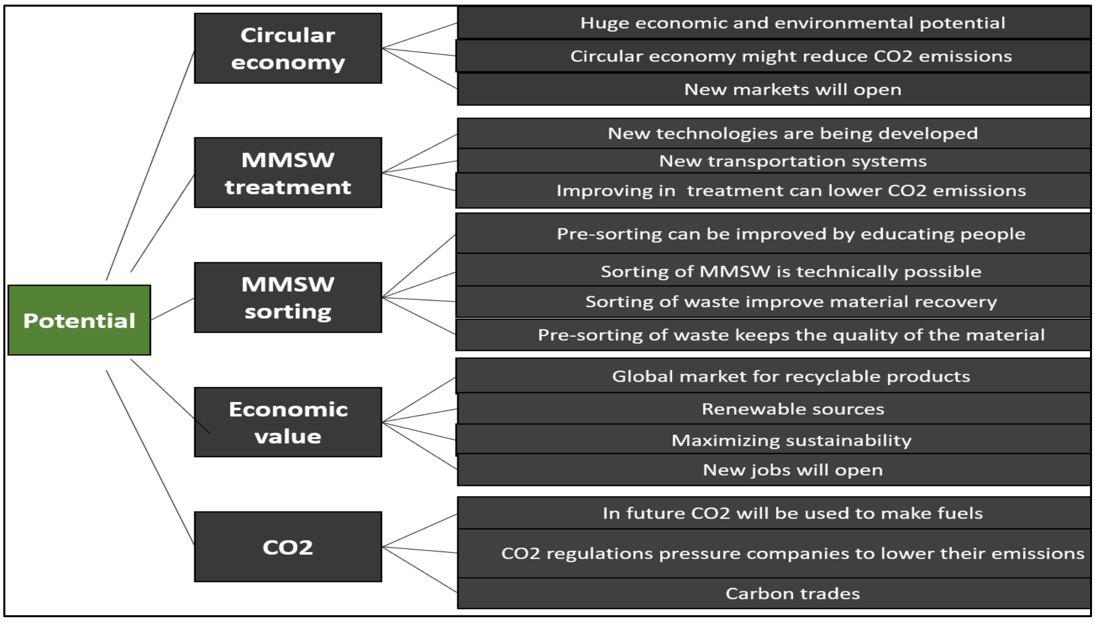

Figure 25. Summary of potential in MMSW treatment (see also in Appendix 5)

6.6 What are potential and challenges in Vantaa's MMSW treatment from the perspective of circular economy

The potential of circular economy is huge, and it could be the solution for the biggest challenges which we are facing today, like climate change and resource scarcity. One of the biggest challenges which is connected to a circular economy is waste treatment, which should be improved in Vantaa city. Solution for the treatment of waste should be profitable so that to be economically sustainable.

With a current way of MMSW treatment in Vantaa city, the waste is used only for incineration and all the potential recyclable materials are being destroyed. Being a better alternative to landfilling, waste incineration considered to be an easy and profitable way of utilization Vantaa's MMSW. In order to achieve circular economy, the recyclable materials should be extracted out of MMSW. However, there are many reasons, why recyclable materials in MMSW are not being recovered. The biggest reason for that is a fact that it is simply economically not sustainable to sort the waste and recycle materials, since the market for the recycled products is low. The reason behind non-functional market for recycled products is the price for virgin materials, which is lower than the price for recycled ones. By finding a solution to make the price of the recycled and virgin materials comparable, the demand for the recycled materials can potentially raise, and that would motivate waste management companies to recover recyclable materials from MMSW. The price of the recycled products should be lowered in order to find demand for them, however, if it cannot be lowered, then the price of the virgin materials should be raised, for example by taxation.

Another problem of MMSW treatment is its heterogeneous structure which includes different type of materials. For example, in Vantaa's MMSW share of biowaste is quite large, which leads to increase of toxins, bacteria and decrease in quality of recyclable materials. The solution for that is to promote pre-sorting at a source. By proper pre-sorting, recyclable materials will keep its quality which will make MMSW treatment easier and reduce total amount of Vantaa's MMSW. The biggest challenge of pre-sorting is people's attitude. It is hard to motivate people, that is why a message promoting the environmental benefits of circular economy should be consistent across all channels: social media, educational institutions, kindergartens, working places, etc. The other challenge in pre-sorting is that some of the private residential areas do not have separate bins for different types of waste, and residents should pay extra for each additional container if they want to sort waste. In this situation, if these areas are provided with separate recycling bins with a payment for service regardless of their amount, people will be motivated more to pre-sort since this option is available for them.

Sorting of Vantaa's MMSW is also a difficult task since there are no proper technologies which can do it cost-efficiently. Innovative technologies are needed to sort the waste properly and recover the recyclable materials without losing its quality. However, development of new technologies can be very capital intensive and may need lots of investments. In this way, it is possible for City of Vantaa to start with small steps by using already existing successful practices and participating in projects to get some data based on which it can be possible to make a decision about cost-efficient and sustainable sorting system. Additionally, a research for the best treatment of Vantaa's MMSW should be done from every standpoint, for example, economic and environmental.

The challenge is also noticeable in interests between Vantaa's private and public waste management companies leading to reduced efficiency in waste treatment. The difference of interests has to be minimized and there should be a cooperation based on transparent communication and mutual benefits between the public and private sectors to achieve better results in circular economy.

Hereby, by changing people's attitude, introducing new sorting technologies, finding a market for recycled materials and cooperation between waste management organizations, the value out of Vantaa's MMSW can be maximized and that would take a step closer to a circular economy. Maximizing value out of MMSW will help to open new markets and with them new job opportunities for people.

6.7 How MMSW treatment in Vantaa City can be improved from the perspective of CO_2 emissions and its economic value

Vantaa's MMSW characteristics play quite important role on amount of CO_2 emissions produced during its treatment. Large presence of biowaste in Vantaa's MMSW increase its moisture content leading to higher CO_2 emissions during incineration. Similar impact has presence of plastic in Vantaa's MMSW. Pre-sorting by households, as well as before incineration (removing biowaste, high/middle quality plastics) can significantly influence on a level of CO_2 during incineration process. Currently, without these activities the amount of CO_2 during incineration process is high, in general, 506 kg CO_2 per one ton of mixed waste (SYKE 14 March 2019). In this way, it might make sense for Vantaa Energy to invest in sorting technology, as it has already been done in Riihimäki, thus contributing into CO_2 mitigation by removing biowaste and plastic out of MMSW. Improvements might also be done with a help of waste pre-sorting by households through organizing compulsory biowaste separation out of mixed waste and providing containers for biowaste at each neighbourhood regardless of the number of residents.

Improvement of Vantaa's MMSW treatment requires new technologies and large investments, thus collaboration of all stakeholders is needed. Contribution to CO_2 mitigation also requires cooperation between all private and public sectors, more transparency and clear metrics what should be measured and how, what kind of reports should be provided and by whom. Additionally, during public procurement of waste management services from sub-contractors via tenders, it is good not only set limits for CO_2 emissions for vehicles but also get reports with exact numbers of CO_2 produced during the MMSW treatment (transportation).

It makes sense to develop efficient transportation routes for eliminating rush-hours, traffic jams and long roads leading to increase of CO_2 emissions. Also, during Vantaa's Energy service breaks instead of waste transportation to Ämmässuo (where it is packed in plastic bales and stored until it can be again transported back to the incineration plant), it is possible to elaborate the whole path and, for example, direct waste to a nearest waste management company for treatment, thus, reducing CO_2 emissions related with transportation back and forth, as well as avoid unnecessary plastic consumption relating with waste baling.

Vantaa's results of the projects and their expertise in CO_2 mitigation can speed up passing laws relating to compulsory biowaste sorting out of MMSW and providing separate biowaste containers regardless to the number of apartments in the neighbourhood. Further innovations and investments in technologies can significantly mitigate CO_2 emissions associated with MMSW treatment.

From economic point of view, improvements in Vantaa's MMSW treatment are quite challenging and require big changes in every step of the chain.

First of all, it is important to find a cost-effective way to increase a share of recycling and reduce waste. In a current situation, economic value comes from Vantaa's MMSW incineration resulting in energy production (heat and electricity), which has a fixed value and can be sold. Value of recycled products out of Vantaa's MMSW is basically unknown, which leads to hesitation and consideration about cost-effective Vantaa's MMSW treatment which brings value and fits to circular economy principles of maximum material recovery. This challenge originates from a global market demand and supply on recycled products. At the moment, there is no developed market for a large number of recycled materials, for example, glass and plastic, which makes it difficult to utilize and get value. Material recovery requires huge investments and should be cost-efficient so that to work. Moreover, a global market for recycled fractions should be developed and comply with proper regulations, standards for a share of recycled materials (renewable energy) in a final product, public procurement, taxes and financial incentives.

Secondly, prices for virgin materials should be higher and for recyclable ones lower, so that to create competitive advantage, stimulate demand and supply for recyclable products. With new technologies it is possible to significantly reduce costs of material recovery and speed up the whole process.

Taking into account all of the above, at the moment, from economic point of view it seems that incineration of Vantaa's MMSW is the most efficient way to utilize value, even though, one could argue that it contradicts to a circular economy idea and waste hierarchy framework. For Vantaa Energy, it can be recommended to invest in technology which will help with pre-sorting and heating waste before its incineration, thus maximizing value out of Vantaa's MMSW and contributing into CO_2 mitigation. Further on, with new innovations in the field of carbon capture, excessive heat storage and cost-efficient extraction metals out of the bottom ash, it will be possible not only get economic value out of Vantaa's MMSW but also in a full scale contribute to a circular economy.

7 Discussion

This chapter aims to provide suggestions about further research which might be done so that to comply Vantaa's MMSW treatment with circular economy, with a goal about CO_2 mitigation and cost-efficiency in waste management. Additionally, own reflections on learning process and development are represented, as well as challenges which were faced during the thesis process.

7.1 Development ideas for further research

As described in previous chapters, MMSW treatment is complicated and requires a complex approach so that to fit to circular economy, be cost-efficient and environmentally friendly. Even though MMSW is only a small part of overall waste volume in Finland (figure 26), improvements in households' treatment and services can be adopted by other waste streams.

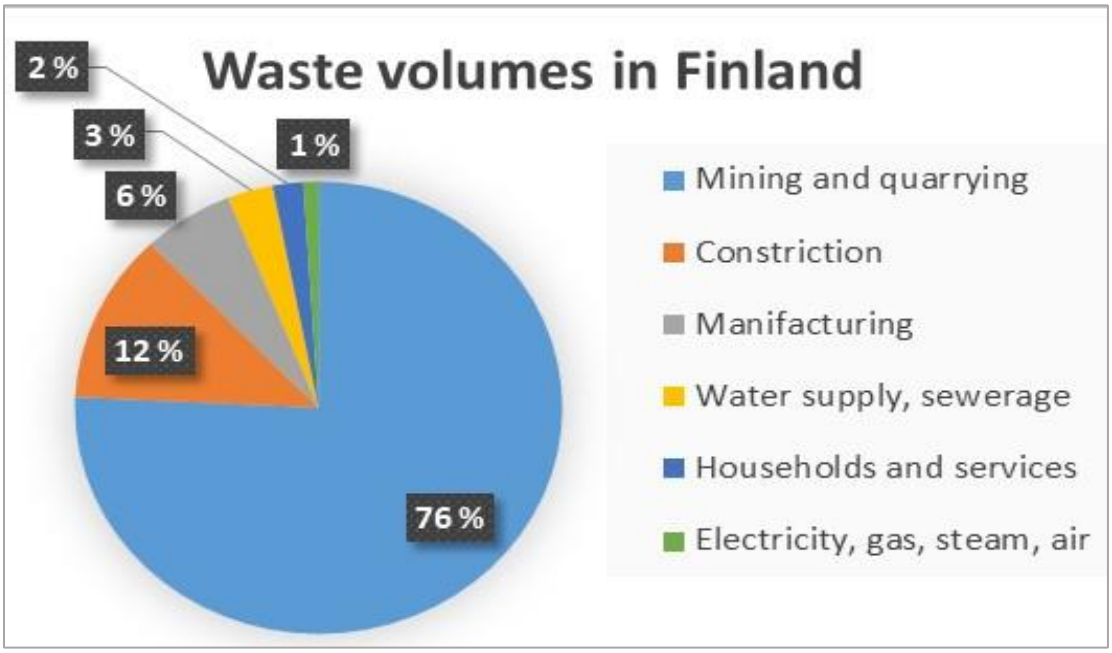

Figure 26. Waste volumes in Finland (SYKE 19 January 2021)

Results of the research showed that there is a common opinion about necessity to comply Vantaa's MMSW treatment with circular economy principles and Vantaa's goals for CO_2 reduction, but there are challenges how to do it in practice. Main obstacles with Vantaa's MMSW were lack of cost-efficient technologies, lack of investments in waste management sector, insufficient cooperation between private and public waste management companies, lack of people's awareness and education about benefits of circular economy, lack of availability of services for some of the areas.

It is important to remark, that many of stakeholders mentioned lack of proper research and clear results in MMSW treatment as one of the reasons which slow the processes of improvements. So that to gain more data, further steps might be recommended:

A preliminary analysis of what produce more CO_2 - an incineration of recyclable part of MMSW or its recycling (full cycle). Results of the research can provide insights for a level of emissions related with different options of Vantaa's MMSW treatment, can help to contribute into City of Vantaa goal of 215 ktCO_2e emissions by 2030 (City of Vantaa 2018, 5), as well as decide about cost-efficiency of the process and priority in investments.

Analysis of metals' value extracted out of the bottom ash after Vantaa's MMSW incineration can help to understand further potential of resources. Currently, in Europe, metals extraction out of the MMSW bottom ash after incineration is a viable option and already implemented in Netherlands, Germany, Belgium and Denmark (Sloot, Kosson, & Hjelmarc 2001). Moreover, improvement in ash quality will ensure that metals extracted out of the bottom ash can be a marketable product.

Benchmarking of Vantaa's MMSW treatment with other cities in Finland and similar in Europe can be beneficial so that to adopt best practices in MMSW treatment and later, run pilot projects directly on the spot. Moreover, it was admitted by stakeholders, that finding some already existing practices and performing a pilot project is a best way to make a decision.

Research and investigation of other options of MMSW treatment, rather than incineration, can be beneficial for City of Vantaa, aspiring for transition to a circular economy and zero-carbon footprint. As it was mentioned by most of the stakeholders involved in this research, Vantaa's MMSW incineration is a cost-efficient method to reduce waste and landfilling, get energy (heat and electricity) but at the same time this approach contradicts to a circular economy.

Because only sorted waste can be recycled and later used as secondary raw materials, pre-sorting considered to be as one of the most important factors influencing on the amount, characteristics and further treatment of Vantaa's MMSW. Since amount of waste generated depends on the consumers, it might be a good idea to provide marketing and educating campaigns for Vantaa citizens, because in most of the cases motivation to sort waste is driven by their will to contribute into changes and quality of lives.

Currently, Vantaa City implements procurement of recycled materials depending on the projects, because still there is no general directive which set the criteria for the use of recycled materials, which means that it is up to the level of ambition of the individual projects that define the required use of recycled materials. Public procurement of recycled materials is an important part of circular economy because it stimulates and supports companies involved in recycling to produce secondary raw materials. In this way, City of Vantaa have to be an example for other public and private companies which efficiently implements this practice.

In most of the cases the price of products impact on the choice of the consumers. At the moment, the price for recycled heat offered by Vantaa Energy is 1,90 €/MWh (0% VAT) higher than normal district heat price (Vantaan Energia 2021b), which makes it not too attractive for the final consumers. Finding solutions for lowering the price for recycled heat can make it more competitive and stimulate replacing fossil heat with a renewable energy.

Thus, results received during this thesis show that at the current stage, among recommendations for Vantaa's MMSW treatment can be sorting of waste before incineration; stimulation of waste pre-sorting by prior consumers; providing containers for waste separation in all neighbourhoods; close cooperation between private and public stakeholders involved in the process across the whole supply chain; clear reporting and measurement of CO_2 emissions; public procurement of recycled materials; adopting the best technologies and practices, regarding MMSW treatment, for example, sorting practices in Riihimäki; extraction metals out of the bottom ash after MMSW incineration in Germany, Netherlands and Denmark; conducting proper research of other options of MMSW treatment, rather than incineration with energy recovery (see in figure 27).

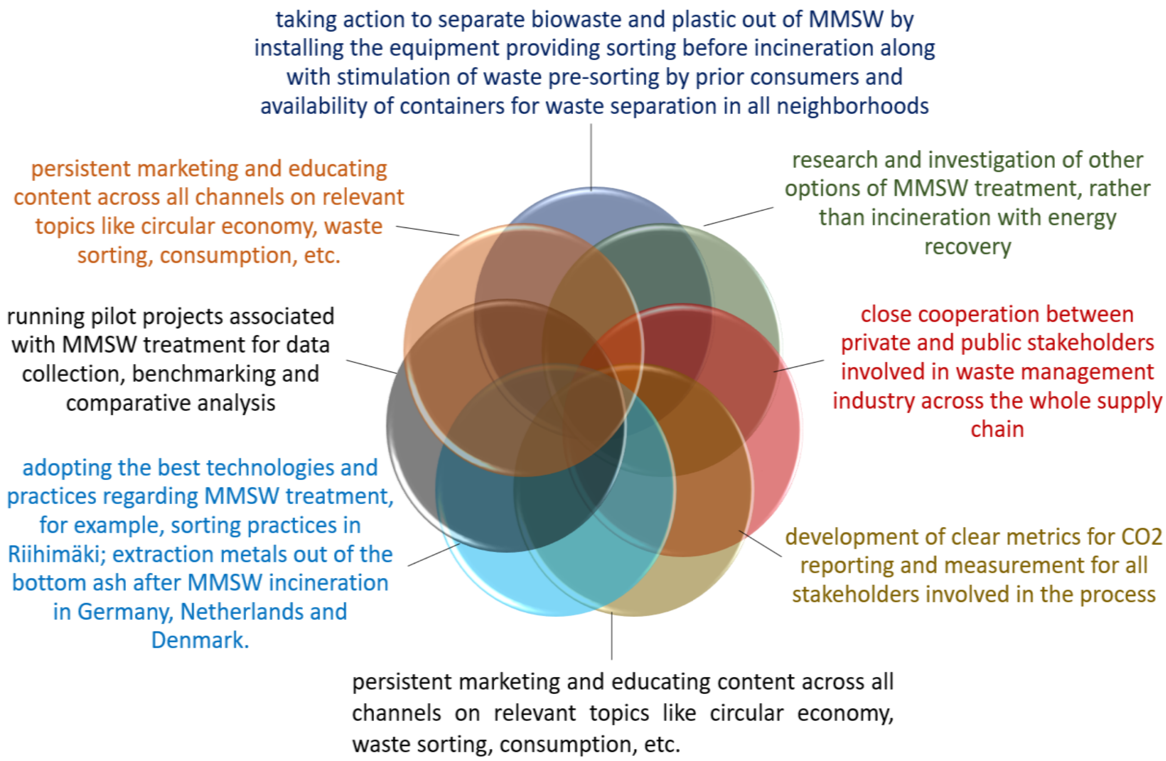

Figure 27. Recommendation for Vantaa's MMSW treatment

7.2 Reflection on own learning

During the thesis process, we managed to practice our researching skills and obtain knowledge about circular economy, Finland's and Vantaa's waste management system, concept of waste to energy, the future plans of Finland and EU regarding waste management and sustainability.

Topics like circular economy, waste to energy and waste management were completely new to us and we did not have much knowledge about them prior to this thesis. Our interest to the aforementioned topics helped us to conduct this research, thanks to which we managed to learn a lot about potential and challenges of circular economy, sustainability issues which we are facing, like resource scarcity and environmental problems, new business models and their influence on the transition towards a smart, sustainable, low-carbon system.

We realized that changes need to happen now, and every country must take place in it, since we are all living on the same planet and actions of some countries could potentially cause problems to everyone on Earth. If the world leaders cooperate and set rules and standards on how to manage waste and natural resources, that would smooth the transition to a circular economy. Without the cooperation of countries, it is not likely to achieve circular economy since companies can import goods and resources from other countries for much cheaper than buying recycled materials from their own countries. We also learned that rules and regulations are mandatory to achieve a circular economy, because if there is nothing to stop companies to buy and sell natural resources, then companies will always go on the most profitable direction. Rules and regulations will motivate or, in some cases, force companies to cooperate to achieve sustainability worldwide.

We expanded our knowledge and skills during the process of our thesis and managed to learn how to find relevant academic materials, conduct a qualitative research and keep efficient teamwork via online sources of communication. In the beginning, one of our challenges was that the concept of circular economy was alien to us, and we were introduced to the concept for the first time when our commissioner spoke about it. Due to lack of structure and theoretical knowledge about the topic, at first it was difficult to find relevant academic materials and previous research which would serve our purpose, since we had no idea about the direction which we had to go. However, by reading academic materials, talking with our commissioner and watching relevant webinars, we managed to learn enough to specify our thesis direction and focus on a specific topic.

This thesis was done during the pandemic and every process happened remotely, from meeting with our commissionaire and teacher to interviewing our candidates. While the remote process had its benefits, like saving time and accessibility of the stakeholders, it also had it downsides, for example, we could not visit the Vantaa Energy incineration plant. Since this thesis was done by two students, it made the process smoother and more efficient, because we managed to combine knowledge and skills of two of us by sharing information to successfully do a research on a complicated topic. By having two authors, we approached the thesis process more objectively and by constant communication we kept each other on alert and motivated.

Through our studies in Haaga-Helia we obtained knowledge how to conduct a qualitative research, thus, it helped us with an understanding of the main steps we should follow during this thesis. However, we faced some challenges while creating interview questions for our research candidates, since we had to interview experts from four different organizations and the interview questions should have been tailored differently for each of them. Since nowadays lots of resources and learning materials can be found online, it significantly helped us with studying, especially, during a remote mode of work. By reading relevant literature on research methods, consulting with our commissioner and teacher we got ideas how to go forward with interview analysis and interpretation of the results. Using a text coding with a help of Microsoft Word and codes filtering via Microsoft Excel we managed to structure all interview answers for further analysis of similarities and differences in the assigned categories. Thus, received results are totally based on the opinions of experts, none of the answers were missing.

In total, our work on thesis took a full four months of work and, of course, time management was a huge challenge for us, because even though working remotely helped us to save time, we still had other courses to attend to, other assignments to complete, our daily jobs and personal lives. Since we had a limited time and rarely had the entire day to work on the thesis, we reserved 3-4 hours on the thesis every day. Tight schedule limited our social life, we did not have enough time for our hobbies and some of other daily activities had to be minimized to maximize our time for the thesis. However, intensive reading and writing along with a daily work on thesis, helped us to learn a previously completely unfamiliar topic to us, increase our writing skills and English vocabulary, especially in our chosen subject. Since work on thesis required us to work together and constantly communicate online, our teamwork skills also significantly improved.

Summarizing, we are glad that the work is done, and the thesis is written. Of course, from the current point of view and knowledge, some things and parts of this thesis might have been done differently, but we consider this thesis is like a small step on the way before the main outcome - our desire to strengthen skills in the fields of circular economy, waste to energy and sustainability. Thus, our recommendations for universities and educational institutions would be to familiarize the concept of the circular economy to students. Many governments are aiming to achieve circular economy, and if the circular economy is going to be a new economic model, it would be wise and desirable for students to be familiar with the topic. Educating of students can contribute to new ideas and innovations which might be beneficial for a smooth transition from a linear economy. Finally, when students are more informed about the circular economy, they are likely to spread the awareness to others, and the knowledge about the topic itself might change the attitude of the people about production, consumption and utilization of resources.

8 Conclusion

Sustainable development is one of the urgent and difficult targets nowadays. According to European strategy 2020, smart and sustainable growth cannot be implemented without resource efficiency and positive climate actions (European Commission 2010). Furthermore, in the European strategy 2030 it is highlighted that sustainable development cannot be achieved without solving waste issues. Main concerns associated with waste are environmental problems like CO_2 and toxic emissions, increase of plastic in water and damage of natural resources (European Commission 2019).

Modern system of waste treatment offers different methods and some of them are more preferrable than others, for example reuse, recycling and combustion of the waste for energy are far better solutions than landfilling (Troschinetz & Mihelcic 2009). However, it is not ambiguous at all, because some of the preferred methods still produce pollutants, for instance, incineration residues (Dijkemaa, Reuterb & Verhoef 2000).

Currently, incineration of waste is applied as a main method for Vantaa's MMSW treatment, which has its pros and cons. The main arguments supporting this method, that it is technologically advanced, safe, economically efficient, can help to generate clean energy (heat and electricity), safe natural resources, minimize landfilling of mixed municipal waste and reduce GHG emissions. At the same time, it should be considered that this type of waste treatment is out of the loop of circular economy and has a negative impact on the environment. Apart from CO_2 emissions, which are nearly similar per one unit of energy as coal and twice more than natural gas (Environmental Protection Agency (EPA) 2014), waste incineration is associated with emissions of such harmful substances like lead, dioxins, cadmium and mercury; has negative public acceptance and eliminates the possibility to inject the materials back into economy as secondary raw materials. Moreover, instead of investing in new technologies for possible sustainable solutions like products redesign, pre-sorting, changes of consumers behaviour and reduce of consumption, financial incentives are provided for repackaging old solutions under a new name (Baptista 2018).

In Finland, the actual recycling rate of MMSW is 42 %, which is lower than MMSW incineration rate (55%). According to European Union targets, by 2025 recycling rate of MMSW should increase up to 55% and by 2035 up to 65% (Team Finland 2021). Such ambitious targets mean that actions should start to be already implemented now with regard to economic feasibility, environmental impact, circular economy approach, value of the products invested and received, technological possibilities and alternative solutions.

At the current stage, precise sorting mechanism along with diversion of waste streams towards recycling and reuse, in combination with energy recovery solutions, can help City of Vantaa to approach closed-loop cycle of circular economy and meet EU goals for increase of recycling and reduce of CO_2 emissions. Later, introduction of new legislation supporting sustainable materials and producers' responsibility for the extended life cycle of materials, new technologies and markets for recycled materials will allow to use recycled materials and by-products of waste treatment as valuable resources, thus utilizing maximum value out of Vantaa's MMSW treatment and contributing to CO_2 mitigation.

Declaration of Competing Interest

We declare no conflict of interest

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Appendices

Appendix 1. Terminology

GHG - greenhouse gas

CO_2 equivalent - the number of tons of CO_2 emissions which has the same warming potential as 1 metric ton of another GHG

MSW - municipal solid waste

MMSW - mixed municipal solid waste

ASR - automotive shredder residue (consists of glass, fiber, rubber, automobile liquids, plastics and dirt). ASR quite often includes hazardous substances, for example, lead, cadmium

RDF - refuse derived fuel, which comes from domestic and business waste, and include biodegradable material along with plastics

C&I - commercial and industrial waste

CDW - Construction and demolition waste

LFG - landfill gas recovery systems

Appendix 2. Interview questions

Questions for a semi-structured interview

Research questions:

1. What are potential and challenges in Vantaa's MMSW treatment from the perspective of circular economy?
2. How MMSW treatment in Vantaa City can be improved from the perspective of CO_2 emissions and its economic value?

Categories for data analysis from the perspective of potential and challenges:

- Circular economy
- MMSW sorting
- MMSW treatment
- CO_2
- Economic value

Vantaa City:

Circular economy:

1. What are the main challenges to transit to circular economy? How this challenges affect on transition towards circular-economy. What are the important steps to start with?
2. What is a potential of circular economy?
3. If do not think about CO_2, what is more valuable- energy from recyclable share of MMSW or recycled products for Vantaa City?
4. Can a MMSW be reused or recycled, and which share?

MMSW sorting:

1. How successfully pre-sorting is implemented in Vantaa? How city can make pre-sorting to be more efficient? What are the main challenges to do that?
2. Should a mixed waste be sorted before further treatment?

- Yes - WHY? How do you think, what produce more CO_2 - actions related with sorting or energy recovery out of it?
- No - Why not?

MMSW treatment:

1. What are the challenges with MMSW treatment? How this challenges affect on transition towards circular economy? What are the important steps to start with?
2. What is plan related to reduction of MMSW? How are you going to reach it?
3. What are alternatives for MMSW treatment rather than incineration? Which alternative is better? What challenges prevent you from doing it?
4. What are the future plans for MMSW treatment?

CO_2:

1. How do you think which one produce more CO_2- recycling of recyclable part from MMSW or its incineration?
2. What is a City plan related to electric cars for transportation of MMSW to reach low-carbon targets?
3. How Vantaa City track CO_2 emissions related with MMSW transportation?

Economic value:

1. If not think about environment and circular economy, what is the most profitable way of Vantaa's MMSW treatment? What would be a win-win way of treatment MMSW of Vantaa
2. How do you prioritize between transition towards circular economy and economic profit?
3. What is in higher demand, electricity or heat? How will it change by 2030, 2050?

EXCEL:

- Is there any share of MMSW which goes to landfills? What is that share?

Vantaa Energy

Circular economy:

1. What are the main challenges to transit to circular economy. What are the important steps to start with?
2. What is a potential of circular economy?
3. How reduction of MMSW can be compensated for energy recovery from the perspective of circular economy?
4. From your side what could be the best treatment for MMSW from the perspective of circular economy to get maximum value out of it?
5. What is the best technology for treating Vantaa's MMSW from the perspective of circular economy?
6. How do you utilize value from carbon capture? What is a potential for further usage of this carbon?

MMSW treatment:

1. How much waste out of MMSW is recyclable? How removing of all recyclable waste out of MMSW will affect on energy production and how much %? How to compensate it from the perspective of circular economy?
2. What is a moisture share in MMSW, how do you treat it (pre-sort, heating)?
3. What are the future plans for MMSW treatment?

MMSW Sorting:

1. What are the main challenges in removing recyclable and reusable materials out of MMSW?
2. Do you sort MMSW before incineration?

   Yes -What type of waste do you sort out? Why?
   No - What could be a good reason to install a sorting system at a spot and what it would take?

CO_2:

1. How do you think which one produce more CO_2- recycling of recyclable part from MMSW or its incineration
2. How moisture affect on energy production and GHG?
3. How do you treat and utilize this CO_2?

Economic value:

1. If not think about environment and circular economy, what is the most profitable way of Vantaa's MMSW treatment? What would be a win-win way of treatment MMSW of Vantaa
2. How do you prioritize between transition towards circular economy and economic profit?
3. Is there way which can make the incineration business more profitable, bring more money?
4. What are the main valuable products which can be taken out from the bottom ash and how much (%)? How do you utilize valuable products out of the bottom ash and where does the rest part go? (If not, why). What is their potential for other industries?
5. What is in higher demand, electricity and heat for Vantaa. How will it change by 2030, 2050? What share of total energy production come from incineration of MMSW? How much of it heat and electricity?

EXCEL:

- What is a share of recyclable products in MMSW? (paper, glass, plastic, metal). Specify types of them.
- What is a share of reusable waste in MMSW?
- What is a price per 1 unit of renewable energy from MMSW vs 1 unit of energy from fossils?
- What share of renewable energy of Vantaa City comes from Vantaa Energy incineration? What share of renewable energy from Vantaa Energy incineration plant comes from MMSW?
- What is a limit for CO_2 emission for Vantaa Energy? How much of it comes from MMSW?
- CO_2 emissions from MMSW incineration for the last 5 years

HSY

Circular economy:

1. What are the main challenges to transit to circular economy? What are the important steps to start with?
2. What is a potential of circular economy?
3. How ban on disposable plastic (from April 2021) will it affect on the amount of MMSW?

MMSW treatment:

1. How Vantaa city can help with MMSW treatment?
2. What are the future plans for MMSW treatment?
3. What are the challenges with mixed waste treatment?
4. What are the challenges relating to transportation of MSW/MMSW?

MMSW Sorting:

1. What are steps from collecting MMSW to delivering it into Vantaa Energy? How can the process be shorten?
2. What are the main challenges for households to sort waste properly
3. What are the main challenges in removing recyclable and reusable materials out of MMSW

CO_2:

1. How characteristics of MMSW affect on GHG? (for example, moisture)
2. How much CO_2 do you produce for MMSW treatment (from collection to final delivery) - how to minimize it?

Economic value:

1. If not think about environment and circular economy, what is the most profitable way of Vantaa's MMSW treatment? What would be a win-win way of treatment MMSW of Vantaa?
2. Which part of MMSW treatment cost the most?
3. Is there scenario how to make more money out of MMSW treatment?

EXCEL:

- What is a share of recyclable products in MMSW?
- What is a share of reusable waste in MMSW?
- How many tons is Vantaa's MMSW in 2020? What is a specification of MMSW?
- MMSW characteristics for the last 5 years (decrease, increase)
- Is there any share of MMSW which goes to landfills? What is that share?
- How much CO_2 do you produce for MMSW treatment
- How much of total CO_2 the company produce related with transportation? How much of it come from MMSW?

<u>Private Waste Management Company X</u>

Circular economy:

1. What are the main challenges to transit to circular economy? What are the important steps to start with?
2. What is a potential of circular economy?
3. Municipal mixed waste vs mixed waste you treat – which treatment match more with circular economy and why?

Waste treatment:

1. How do you think what are the future of mixed waste treatment?
2. How do you think what are the challenges with mixed waste treatment?
3. What are the challenges relating to transportation of waste?
4. How do you utilize materials which cannot be recycled?

Waste Sorting:

1. What are the main challenges with sorting the waste?
2. What are the main challenges in removing recyclable and reusable materials out of waste?
3. How sorting of the waste can be improved?

CO_2:

1. What is you input into CO_2 reduction? How are you doing it?
2. Which part of waste treatment connected with most of CO_2 emissions?

Economic value:

1. If not think about environment and circular economy, what is the most profitable way of treating waste?
2. Which part of waste treatment cost the most?

Appendix 3. Synopsis of main interview findings

Circular economy

\+ Circular economy has huge economic and environmental potential (can cause lower CO_2 emissions and open new market opportunities)

− Lack of regulations and innovations in technology challenge transition towards circular economy.

MMSW treatment incl. sorting

\+ By proper sorting of MMSW, 80% of the materials can be recovered. Changes within a value chain positively effect on MMSW treatment. Pre-sorting at source keeps the quality of the recyclable materials.

− Incineration with energy recovery is a prioritized method for Vantaa's MMSW treatment, since it is not economically sustainable to sort MMSW. It is unknown what is the best treatment for MMSW. Pre-sorting is connected to people's attitude, and it is difficult to change people's behavior.

CO_2

\+ CO_2 regulations can pressure companies to lower their emissions. Carbon can be used in the future to create fuel in Vantaa.

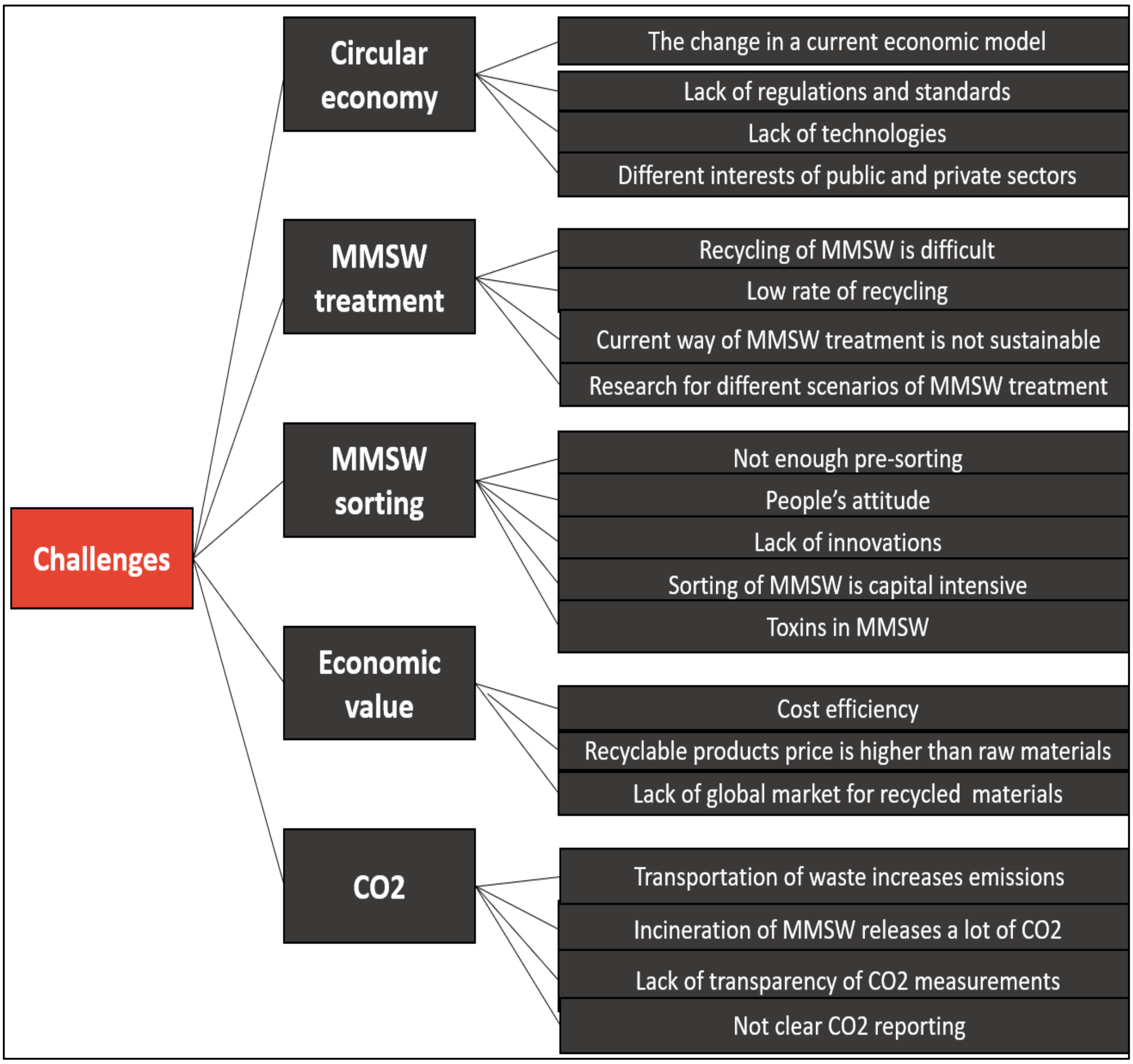
− Incineration of waste releases massive amount of CO_2 (506kg of CO_2 per 1tonne of waste). There is lack of transparency in CO_2 reports of companies.

Economic value

\+ Recycled materials open new markets and make changes in resource consumption. Recycling of waste can be the solution to resource scarcity.

− It is capital intensive to sort and recycle materials from MMSW. There is low demand for recycled materials, since virgin materials are cheaper and has better quality.

Appendix 4. Summary of main challenges in MMSW treatment



Appendix 5. Summary of potential in MMSW treatment