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Deliverable 3.1.2

best
Sustainable Bioenergy
Solutions for Tomorrow

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Summary

Development of smart urban biomaterial and energy system requires accurate and open data regarding resources. The objective of this study was to evaluate feedstock potential especially for energy, but also for nutrient and material, recovery in integrated urban biomaterial management system. The present quantity and quality of municipal waste (MSW) fractions generated in two EU countries, Finland and Germany, was analyzed. Municipal waste generation is 611 kg/capita/a in Germany and 506 kg/capita/a in Finland. In the both studied countries, share of main MSW fractions is similar. Organic fraction is largest (ca. 30%) followed by paper and cardboard (21-22 %) and plastic (12-14%). In addition, future prospects in waste generation were reviewed. Consumption patterns and other factors such as city and ICT development have a great impact on future waste generation and there is a variety of scenarios projecting waste flows in 2020. It can be assumed that in high income countries waste generation growth has stopped to the current level. In 2020 MSW non-recyclable plastic and organics can contribute to ca. 2 % of total energy consumption in Germany and ca. 1% in Finland. Municipal wastewater contain ca. 6 kg N and 1 kg P per capita/a and municipal solid waste contains about half of that. Nutrient recycling could be considered not only in biowaste chain, but also when processing other waste fractions. In addition, chemical energy of municipal wastewater corresponds to ca. 0.7% (DE) and 0.3% (FI) of the nations' energy demand. EU policies and targets are guiding Europe towards circular economy where role of waste prevention and recycling may increase and role of incineration may decrease. Biorefinery concepts, which enable integrated production of e.g. chemicals and fuels using biomaterials instead of fossil feedstock, are currently widely studied and developed.

Tampere, September 2014

Contents

1 Introduction

It is anticipated that one path towards sustainable urban development is increased self-sufficiency of the cities, meaning that economic activity is matched with the population size and urban infrastructure. In waste management, aim is to turn linear urban metabolism into urban harvest (Agudelo-Vera et al. 2012) which recognizes waste as a resource and as a symbol of unsustainability. In the urban context, waste materials compose a significant material flow that has potential for recovery.

In EU, policies and targets are guiding Europe towards circular economy. In EU waste hierarchy waste prevention and recycling are higher than waste-to-energy (WTE). However, materials can be reused only to the certain extent and recycling of harmful compounds must be avoided. WTE seems to have its role in urban waste management and energy system. It has been pointed out that the main goal of waste management is to protect people and environment, and some present waste fractions cannot be safely or feasibly recycled. WTE is considered as safe option for disposal of harmful compounds and some energy can be recovered in the process. (Brunner & Rechberger 2014.) Over the last decades, WTE has meant incineration, but recently new technologies such as gasification and pyrolysis have come on the market.

In energy systems waste is considered as biomass alongside agricultural and forestry residues, herbaceous crops, aquatic and marine biomass. Waste based biomass includes municipal solid waste (MSW), municipal sewage sludge, animal waste, industrial waste, etc. (Panwar et al. 2012.) Biomass can be solid, gaseous or liquid, and it can be used for heating, producing electricity and for transport biofuels (EC 2014). Knowledge of biomass properties and fuel characteristics is essential for bioenergy and chemical conversion processes (Song et al. 2012). Today's WTE plants typically work continuously providing base load electricity and district heating. In future renewable energy systems, energy recovery from waste is likely to provide electricity when wind is not blowing. (Munster et al. 2013.)

Urban symbiosis where resources from urban refuse are transferred directly to industrial applications improve the overall eco-efficiency of the city. However, identifying the best symbiosis method for each city requires understanding and information exchange on background conditions and local policies. (Geng et al. 2010.) Key question in waste management optimization is how best to interact with adjoining production for energy, materials and chemicals (Munster et al. 2013). Ranking between material and energy recovery depends on several factors including energy recovery efficiency of WTE, pollutions costs, energy price and profit of material recovery (Chen & Chen 2013). Evaluation of WTE is highly dependent on assumed values for lower heating value (LHV) of the waste, biomethane potential (BMP) in the anaerobic digestion process, and fuel efficiency in transportation (Hung & Solli 2012).

Development of smart urban biomaterial and energy system requires accurate and open data regarding resources. The objective of this study was to evaluate MSW feedstock potential for integrated urban biomaterial management and energy system. In addition to Finland, another forward-looking European country (Germany) was selected as a case area of the study. Quantity and quality (LHV, BMP and nutrients) of MSW fractions including sort separated fractions and those collected as mixed MSW generated in Finland (FI) and in Germany (DE) were analyzed. In addition, future prospects in waste generation were reviewed. Also potential of municipal wastewater was introduced shortly. Based on current waste data and future prospects in waste generation and countries' energy plans, potential of waste based feedstock in future urban energy mix was assessed.

2 Materials and methods

2.1 Municipal solid waste in focus

MSW is defined as household waste and some part of similar type wastes generated by small businesses and public institutions and collected by the municipality (Eurostat 2014). In this study, MSW was assumed to represent city waste generated by people or "consumers" in their daily life. It was supposed that when a person is not at home, he/she is e.g. at day-care, school, work or hospital and eats in restaurant/canteen. In other words, he/she generates waste somewhere else than home, but the whole waste generation does not change considerably. Similarly municipal wastewater MWW is assumed to represent urban wastewater flow generated by inhabitants of the city.

2.2 Data collection: waste generation and properties

MSW generation in Germany and in Finland was calculated using the national waste statistics (Federal Statistical Office 2013 and Official Statistics of Finland 2013) and studies on regional mixed MSW separation (Horttanainen et al. 2013, HSY 2013, Mikkonen 2013, Wagner & Hung Anh 2010). MSW generation was calculated as a sum of sort separated fractions and those fractions in mixed MSW. Calculations were made for 15 waste fractions. MSW waste properties relevant for energy recovery (LHV and BMP) and nutrient (nitrogen, phosphorous) recovery were compiled from literature (Horttanainen et al. 2013, HSY 2011, HSY 2012, Pommier et al. 2010, Riber et al. 2009, Sokka et al. 2004) and energy and nutrient content calculations (per capita/a) for main MSW fractions were made. Same energy and nutrient potential data from literature was applied to both countries MSW generation data.

Examples of energy content calculations based on LHV (1) and BMP (2) as well as nutrient calculations (3) are presented below.

Energy content (MWh/capita/a) = Waste fraction generation FI/DE (kg/capita/a) * LHV (MJ/kg waste) * $0.2778 \cdot 10^{-3}$ (MWh/MJ) (1)

Energy content (MWh/capita/a) = Waste fraction generation FI/DE (t/capita/a) * BMP (m^3 CH_4/t waste) * 10^{-2} (MWh/m^3 CH_4) (2)

Nutrient content (mg P/N/capita/a) = Waste fraction generation FI/DE (kg/capita/a) * TS % waste fraction * P/N (mg/kg dry fraction) (3)

Similarly MWW potential was analysed using generation data (Destatis 2012, Säylä & Vilpas 2012), energy potential data (Heidrich et al. 2011) and nutrient content data (Säylä& Vilpas 2012, DWA-benchmarking 2010 (according to Barjenbruch 2011).

2.3 Future prospects

In this study, the future prospects in waste generation were evaluated by reviewing scenarios from literature as well as compiling and evaluating drivers for waste generation trends. Among the variety of forecast and scenario tools to predict future prospects, foresight approach has recently raised its status in research due to increasing complexities and rapidly changing operating environment that are related to globalization, climate change, energy questions and advances in ICT (Hurmekoski & Hetemäki 2013). According to Munster et al. (2013) explorative scenarios are suitable for long term considerations when uncertainties about future development are large. It is necessary that scenarios reflect important, uncertain and quite different assumptions taking external background systems into account, since they have great impact on results.

3 Results and discussion

3.1 Waste and wastewater generation

Urban waste material flows in Finland and in Germany were studied based on statistics and scientific articles. In 2012, 506 kg/capita municipal solid waste (MSW) was generated in Finland and 611 kg/capita in Germany. EU-28 average was 492 kg/capita/a. (Eurostat 2014.) In Finland little over half (257 kg/capita, 54 %) of the MSW is collected as mixed MSW and another half as source separated waste fractions (Official Statistics of Finland 2013). In Germany source separation rate is higher, separated fractions contributing to 64% of the MSW while about 36 % (227 kg per capita) of MSW is collected as mixed MSW (Federal Statistical Office 2013). Organics and paper/cardboard and have the highest share of the separated fractions in both countries. In Finland 67 kg/capita/a organics and 67 kg/capita/a paper/cardboard is source separate while corresponding quantities in Germany are 122 and 101 kg/capita/a, respectively (Table 1). In Germany plastic/light packing is also effectively (67 kg/capita/a) sort separated. In Finland only 7 kg/capita/a plastic is source separated.

Municipal waste water generation is 103 m^3/capita/a in Finland (Säylä & Vilpas 2012) and 128 m^3/capita/a in Germany (Destatis 2012).

3.1.1 Generation of mixed MSW

Three recent (2013) MSW sorting studies from Finland were used to evaluate mixed MSW composition (Figure 1). Studies show consistent shares of biowaste (average 29.7 %), plastics (20.6 %), paper and cardboard (15.4 %), diapers (6.6 %) and textiles (5.9 %) in the mixed MSW. Different classifications in the three studies cause variation especially in the shares of landfill waste and combustibles.

3.1.2 Generation of MSW total

Generation of total MSW fractions was calculated by summing the source segregated wastes and the mixed MSW. The amounts were elaborated based on national statistics and waste sorting studies and using classification used in the MSW sorting studies (Figure 1, Table 1). For comparison MSW composition analyses from the studies covering different case cities and countries are presented (Table 1).

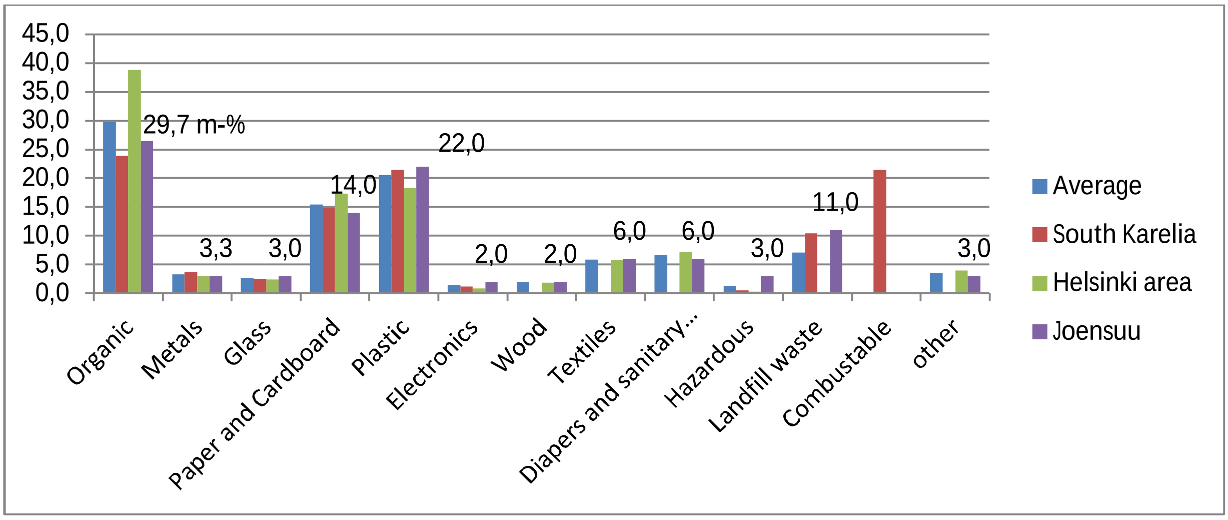

Figure 1. *The composition of the mixed MSW in three different sorting studies. Mixed MSW is defined as MSW that is left after source segregation* (Horttanainen et al. 2013, HSY 2013, Mikkonen 2013)

The largest MSW fractions in Germany and Finland are organic (ca. 30%), paper and cardboard (21-22 %) and plastic (12-14%) (Table 1). Smaller fractions potential for energy recovery are wood (FI 4 %, DE 1%), textiles (2-3%) and diapers (FI 4%). Same main fractions are found also in other studies (Ionescu et al. 2013, Luoranen et al. 2009, Chen & Chen 2013, Consonni & Viganò 2011, Hoornweg & Bhada-Tata 2012). For smaller MSW fractions, other studies gives ratios: wood 4-4.6 % (Ionescu et al. 2013, Chen & Chen 2013), textiles 2.5-6 % (Luoranen et al. 2009, Ionescu et al. 2013) and diapers 1.7-15 % (Colon et al. 2013, SEMARNAT 2010 according to Espinosa-Valdemar et al. 2011).

MSW composition is similar in Finland and in Germany. Some differences are due to variation in compilation of statistics and classification in separation studies. These differences originate to different waste management traditions of the countries and different research questions and methods of the sorting studies. For example in Germany landfilling is a marginal waste management method (0.5 % of MSW 2012) while in Finland it is still widely used (33% of MSW 2012) (Eurostat 2014). Thus landfill waste is a relevant class for waste separation study in Finland but not in Germany. In Germany partly corresponding class is fines. In Germany light packaging/plastic is collected separately and all packaging except glass is included, e.g. milk cartons, metal tins and plastic packaging. In this study all German packaging/plastic waste was assumed to be plastic which leads to overestimates in DE plastic amounts and underestimates in e.g. cardboard and metal amounts. In Finland source separated milk cartons end up to paper and cardboard fraction, and metal tins to metals. Collection of plastics is not widely available for households in Finland and most of the household plastics are discarded as mixed MSW. In Finland kitchen waste and garden waste are collected together and in Germany they are collected separately. Variation in waste data is notified also in other studies. According to Ott & Rechberger (2012) harmonized method to measure or estimate the amount of biodegradable municipal waste does not exist and data concerning waste is not homogeneous.

Regardless of heterogeneous data sources, it can be concluded that the largest fractions of Finnish and German MSW are organic (approx. 30%), paper and cardboard (21-22 %) and plastic (12-14%). Similar distribution applies to the other high income countries. When income level of the country rises, share of organic waste tends to decrease and paper to increase. Share of plastic does not depend on income level as clearly. Average urban municipal solid waste generation in low income countries is 219 (kg/capita/a) and 777 (kg/capita/a) in high income countries. (Hoornweg & Bhada-Tata 2012.)

Table 1. *Amount and composition of the MSW in Finland and in Germany (mixed MSW and source separated waste fractions)*

	MSW Finland						MSW Germany						MSW other studies						
	Source separated[1]		Mixed MSW[2]		Total		Source separated[3]		Mixed MSW		Total		Cent. Europe[12]	Lithuania[7]	Italy[9]	Taiwan[8]	High income[10] a	Low income[10] b	Other
	kg/cap./a	%	kg/cap./a	%	kg/cap./a	%	kg/cap./a	%	kg/cap./a	%[4]	kg/cap./a	%	%	%	%	%	%	%	%
Organic	67	14	76	16	143	30	122	19	64	10	186	30	31	44	30.5	37.4	28	64	30[11]
Paper/ cardboard	67	14	40	8	107	22	101	16	27	4	129	21	22	14	25.8	39.6	31	5	
Plastic/ packaging	7	1	53	11	60	12	67	11	23	4	90	14	9	9	14.6	16.6	11	8	
Metal	23	5	8	2	31	7			7	1	7	1	3	3	2.7		6	3	
Wood	14	3	5	1	19	4			5	1	5	1	4		4.6				
Electronics	13	3	4	1	16	3	7	1			7	1							
Textiles			15	3	15	3			11	2	11	2	6	2.5					
Landfill waste			18	4	18	4													
Diapers			17	4	17	4													5-15[5] 1.7[6]
Glass	6	1	7	1	12	3	32	5	11	2	44	7	12	11	5.8		7	3	
Hazardous			3	1	3	1													
Minerals, soil,stones							12	2	11	2	24	4	4	2					
Bulky waste							30	5			30	5							
Fines									32	5	32	5			12.9				
Other	26	5	9	2	35	7	26	4	36	6	62	10					17	17	
Total	222	47	255	53	477	100	398	64	227	36	625	100							

[1] Official Statistics of Finland: Municipal waste in 2012
[2] Horttanainen et al. 2013, HSY 2013, Mikkonen 2013
[3] Federal statistical office (Waste balance 2011)
[4] Wagner & Hung Anh 2010
[5] SEMARNAT 2010 Urban Solid Waste (USW) according to Espinosa-Valdemar et al. (2011) (Mexico, USW)
[6] Colon et al. (2013) (EU-27)
[7] Luoranen et al. (2009) (Kaunas, Lithuania, household waste)
[8] Chen & Chen (2013) (Taiwan, mixed MSW)
[9] Consonni & Viganò (2011) (Italy, gross waste)
[10] Hoornweg & Bhada-Tata (2012) (a high income countries, b low income countries)
[11] Ott & Rechberger (2012) (EU-15)
[12] Ionescu et al. (2013) (Central Europe)

3.1.3 Other waste generated in cities

In addition to municipal solid waste, there are other significant waste streams that have recovery potential. Generation of waste excluding major mineral wastes was reported to be 1713 and 4517 kg/capita/a in Germany and in Finland, respectively (EUROSTAT 2014b). In Figure 2, waste generation by different economical activities in Germany, in Finland and EU is presented. The presentation covers hazardous and non-hazardous waste from all economic sectors and from households, including secondary waste from waste treatment, but excluding mineral waste and soil. Other than municipal waste varies from one city to another and depends on e.g. economic structure of the city. Part of this type of waste is generated outside the cities.

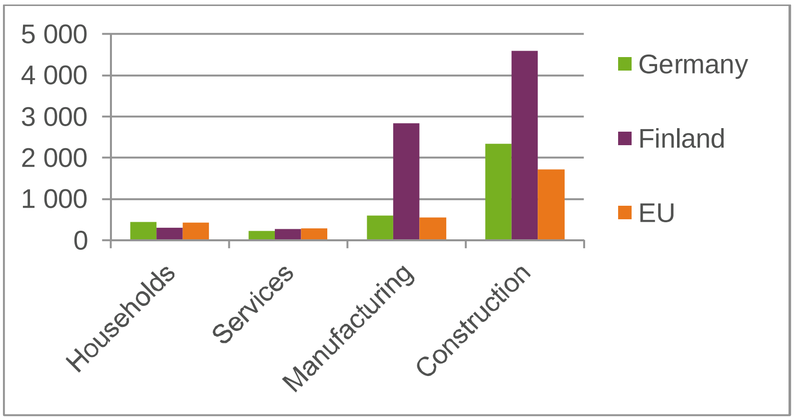

Figure 2. *Waste generation by different economical activities in Germany, Finland and EU average (kg/capita/a 2010)* (EUROSTAT 2014b).

MSW includes household waste and some of the service sector waste (Figure 2). In a UK preliminary study, commercial and industrial waste (C&IW) potential total national electrical output using incineration coupled with steam turbine was detemined to be 6TWh, contributing to 1.9% of the national electricity demand. Due to heterogenousity, C&IW is more challenging feedstock for WTE solutions than MSW. (Lupa et al. 2011.)

3.2 MSW and MWW potential for energy recovery

3.2.1 Energy content of the main municipal solid waste (MSW) fractions

In Table 2 energy content of the main MSW fractions and smaller fractions potential for energy recovery (textiles, diapers, wood) in Germany and Finland is presented. Other waste fractions are not taken into account. There are inert materials such as glass, metals, ceramics and minerals, and materials not suitable for energy recovery (electronics) among other fractions. There are also uncertainties concerning content of other waste fractions and therefore their energy content calculations are assumed unreliable.

Energy content values are based on LHV and/or BMP of each fraction. Sum of main fractions (paper/cardboard, plastic, organic) energy content is 0.8-1.5 MWh/capita/a for Germany and 0.5-1.1 MWh/capita/a for Finland. Plastic fraction energy potential is highest (DE 0.5-0.7 and FI 0.3-0.5 MWh/capita/a) followed by paper/cardboard (DE 0.5 and FI 0.4 MWh/capita/a) and organic fraction (DE 0.1-0.3 and FI 0.1-0.2 MWh/capita/a). Most of the MSW plastic energy content originates to non-recyclable plastics (DE 0.5 and FI 0.4 MWh/capita/a). LHV and

BMP based energy contents of organic waste are consistent.

When MSW share of the city energy consumption is estimated, efficiencies of different WTE technologies need to be taken into account. Wondwossen & Federico (2014) reported a net LHV efficiency of 33.19 % for highly efficient WTE plants. Cucchiella et al. (2014) reported unit efficiencies of 25-30 % for energy recovery from MSW and 25-60 for biomass energy source. Typical efficiency of combustion system without CHP is in range of 25 and 50 percent. System efficiency with CHP is typically in range of 70 to 85 percent. (Tchobanoglous et al. 2014.) To give a rough estimate of WTE contribution to urban energy mix, 80% combined heat and power (CHP) efficiency and current per capita waste generation is used in following calculations.

With 80% WTE efficiency, MSW plastic can contribute to 0.4-0.6 MWh/capita/a DE and 0.3-0.4 MWh/capita/a FI and out of that, non-recyclable plastic contains 0.4 MWh/capita/a DE and 0.3 MWh/capita/a FI. MSW organics contain 0.1-0.2 MWh/capita/a DE and 0.1-0.2 MWh/capita/a FI and MSW paper/cardboard contains ca. 0.4 MWh/capita/a DE and 0.3-0.4 MWh/capita/a FI. Based on population 2020 projections FI 5.6 million (Official Statistic of Finland 2012) and DE 80 million (relatively old population, Federal Statistical Office 2009) and total energy consumptions 2020 FI 327 TWh and DE 2293 TWh from the National Renewable Energy Action Plans (EC 2010), per capita energy consumptions in 2020 are estimated to be 29 and 58 MWh/a in Germany and in Finland, respectively. In conclusion, in 2020 MSW plastic, organics and paper/cardboard can contribute to 3-4 % of total energy consumption in Germany and 1-2% in Finland. If only non-recyclable plastic and organics are taken into account, shares of ca. 2% in Germany and ca. 1 % in Finland are achieved.

Small share of MSW-to-energy in total energy mix calculated above is in accordance with Brunner & Rechberger (2014) who report that MSW and other wastes in modern countries contribute to ca. 5% of the total energy demand. For more accurate estimations of MSW potential in urban energy mix, data recarding city characteristics and intergrated waste management and energy systems is needed.

Table 2. *Energy content of main MSW fractions in Germany and in Finland based on lower heating value (LHV) and/or biomethane potential (BMP).*

	Energy content (MWh/capita/a)			
	Germany		Finland	
	Based on LHV	Based on BMP	Based on LHV	Based on BMP
Paper and cardboard	0.5	0.2	0.4	0.1
Organic	0.2-0.3	0.1-0.3	0.2	0.1-0.2
Plastic	0.5-0.7		0.3-0.5	
Non-recyclable plastic	0.5		0.4	
Textiles	0.06		0.08	
Diapers			0.05	0.007
Wood	0.02		0.08	

Source: Own elaboration based on the Table 1 data and HSY (2011), Horttanainen et al. (2013), Pommier et al. (2010), Riber et al. (2009), Torrijos et al. 2014.

3.2.2 Municipal wastewater (MWW) energy content

There are three different types of energy stored in wastewater, which are chemical energy, thermal energy and hydraulic energy. Chemical energy is the energy that can be released by chemical reactions from compounds such as organic molecules. Thermal energy is the heat contained in wastewater. Hydraulic energy is the sum of potential energy (caused by height difference), kinetic energy (caused by velocity of the flow) and energy depending on the pressure head. (Tchobanoglous et al. 2014)

In a study from UK, internal chemical energy potential of domestic wastewater was reported to be 7.6 kJ/l (Heidrich et al. 2011). When this is multiplied by MWW generated in Germany and in Finland, energy potential of 0.27 MWh/capita/a in Germany and 0.22 MWh/capita/a in Finland is obtained. Using 80 % combined heat and power (CHP) efficiency and current per capita MWW generation, it is calculated that approximately 0.22 and 0.17 MWh/capita/a could be produced from municipal wastewater in Germany and in Finland, respectively. To estimate the share of the urban energy demand potentially met with MWW feedstock, energy consumptions projections of DE 29 and FI 58 MWh/capita/a are used as described in the context of the MSW above. This corresponds to 0.7% (DE) and 0.3% (FI) of the total energy consumption in 2020.

3.2.3 MSW fractions applicability to WTE

Plastic fraction is one of the largest MSW fractions. In terms of energy content, plastic fraction is suitable for energy recovery. One disadvantage of waste plastic fuel is high chloride concentration. Chloride in the untreated gas corrodes the furnace and boiler, chloride in treated gas contributes to acidification, and chloride in bottom ash may leach in high concentrations (Riber et al. 2009). 86 % of the chloride entering the WTE plant passes to air pollution control and 12 % to bottom ash (Consonni & Viganò 2011). Different life cycle analyses (LCA) suggest different processes for plastic waste management. According to Luoranen et al. (2009), city plastics and composites should be recycled instead of combusting in Kaunas. Chen & Chen (2013) suggest energy recovery for plastic bags/films. Plastic bags/films consists inhomogeneous materials of PE, OPP films, hard plastic and laminated materials from households. For PVC and PET material recovery is recommendable in case of low WTE efficiency and high carbon taxes. According to Riber et al. (2009), ca. 74% of household plastic waste in non-recyclable.

Paper and cardboard fraction contains almost as much energy as plastics. Paper and cardboard should be combusted instead of recycling in Kaunas (Luoranen et al. 2009), whereas Chen & Chen (2013) suggest material recovery for paper in case of low WTE efficiency and high carbon taxes.

Organic waste contains ca. 50 % less energy than the plastic fraction. According to Luoranen et al. (2009), biowaste should be combusted instead of composting. On the other hand, heating value of the mixed MSW so low that is not suitable for combustion or it is a poor fuel (Mikkonen 2013). The main reason for that is biowaste, which increases liquid content of mixed MSW. Low share of biowaste and high share of plastics increase the heating value of mixed MSW. (Horttanainen et al. 2013.) Chen & Chen (2013) suggest recycling for food waste. According to Bernstad & la Cour Jansen (2011), anaerobic digestion (AD) with biogas used as vehicle fuel and digestate used as fertilizer result in greater avoidance of global warming and avoidance of O_3 formation compared to composting or incineration of food waste. AD and aerobic biological treatment increase nutrient enrichment and acidification compared to incineration. Substitution of fossil car fuel by biogas avoids more GHG-emissions than using biogas for electricity generation, while the latter leads to better energy balance.

Analyses presented above don't offer clear answers to optimal treatment of the MSW fractions. Bernstad & la Cour Jansen (2011) point out that major contribution to uncertainty in LCA is related to the choice between substitutions of marginal or average energy production and they depend on e.g. future policy decisions and technology development. For example high manure biogas targets can create need for use of biowaste as a co-substrate. If avoided marginal is energy crop, environmental and economic benefit of separating biowaste streams may change. (Munster et al. 2013.) WTE technical possibilities are not reviewed here. Panwar et al. (2012) evaluate pyrolysis the most suitable for conversion of biomass into liquid fuel. Hydrogen generated during pyrolysis can be utilized in fuel cell. Integrated process, where part of the biomass is used to produce valuable materials and chemicals and only residual fractions are used for H_2 generation, can be feasible.

3.2.4 Effect of separation and collection on quantity and quality of MSW fractions

Bing et al. 2014 discussed source separation and post-separation of plastic waste. Results showed that with post separation more plastic waste was collected. However, source separation had lower costs and the contamination level for collected plastics was lower than for post separation. Rigamonti et al. 2009 determined an optimum level of source separation to be 60 %. With higher separation efficiencies, the quality of collected waste was lower. Rada & Ragazzi (2014) studied whether source separation could function as a pre-treatment process for incineration while the use of other waste management processes could be reduced. After all, the suitability of source separation to pre-treatment depends on cultural and local circumstances in the waste collection area.

Several studies have compared curbside collection and drop-off collection in terms of distance to the collection bins and the convenience to the citizens (Bing et al. 2014, Gallardo et al. 2010, Gallardo et al. 2012, Dahlén & Lagerkvist 2010a, Gonzalez-Torre & Adenso-Diaz 2005). For plastic waste, Bing et al. 2014 concluded that curbside collection gave a better response rate from the citizens than drop-off collection. Gallardo et al. 2010 and Gallardo et al. 2012 found similar results in recyclables collection as the smaller distance to bins correlated to the amount of waste separated in different fractions and the quality of waste. In addition, if the mixed waste container was not close to recyclable bins, the better quality of recyclables was achieved. Similarly, in a study by Gonzalez-Torre & Adenso-Diaz 2005, convenience, easy access and short distance to bins were found to affect positively on the number of waste fractions separated.

Collection frequency can have an impact on the citizens' participation in source separation. Reduced collection frequency could result in higher separation rates and higher participation rate by citizens (Williams & Cole 2013), but low collection frequency might also lead to overflows of collection bins and thus have a negative effect on separation rate (Gallardo et al. 2012). Related to the collection frequency and convenience of sorting, Lane & Wagner 2013 compared different collection containers following a conclusion that larger recycling containers and wheeled bins would affect positively on source separation and recycling. However, the suitable container attributes were culturally related and a single container type would not be the best option for everyone.

Weight-based billing in waste collection has been discussed as a possible solution to reduce the amount of mixed waste and increase recycling. Dahlén & Lagerkvist 2010b studied the impact of waste-based billing in waste collection. The amount of collected waste was reduced compared to collection areas where weight-based billing was not used. However, they showed that the separation rate of recyclables was not higher even though less mixed waste was collected.

3.3 Municipal solid waste and wastewater potential for nutrient recovery

Nutrient recovery potential of MSW fractions and MWW was calculated based on Table 1 data and Riber et al. 2009, Sokka et al. 2004 and HSY 2012. Elaboration show that within MSW, N is mainly in organic fraction (0.78-1.59 kg/capita/a DE, 0.60-1.22 kg/capita/a FI). However, considerable amount of N is also in plastics (0.5 kg/capita/a DE, 0.3 kg/capita/a FI), textiles (0.34 kg/capita/a DE, 0.45 kg/capita/a FI) and paper/cardboard (0.23 kg/capita/a DE, 0.19 kg/capita/a FI). In Finland, diapers contain 0.08 kg/capita/a N and wood 0.13 kg/capita/a. Most of the MSW phosphorous is included in organics (0.10-0.21 kg/capita/a DE, 0.08-0.16 kg/capita/a FI). Smaller amounts are in textiles (0.02 kg/capita/a DE, 0.03 kg/capita/a FI) and paper/cardboard (0.01 kg/capita/a DE and FI). For plastic waste phosphorous content, there are contradictory values in the literature. Sokka et al. (2004) assume it neglible, but Riber et al. (2009) measured considerable concentration for especially non-recyclable plastic. Using nutrient measurements of Riber et al. (2009) P flows as high as 0.3 kg/capita/a DE, 0.2 kg/capita/a FI in MSW plastic were calculated. High concentrations can be due to plastic containing P based flame retardants (source) and e.g. food contamination in plastic waste fraction. Even if plastic itself does not contain that much P, it should be taken into account that MSW plastic such as food packaging is contaminated with e.g. food waste witch enters to WTE if not pretreated.

Total MSW N flow is 1.7 kg/capita/a in Finland (Sokka et al. 2004). Total MSW P flow is reported to be 0.45 kg/capita/a in EU-15 (Ott & Rechberger 2012), 0.6 kg/capita/a in Austria (Egle et al. 2013) and 0.2 kg/capita/a in Finland (Sokka et al. 2004). To give an overall city nutrient flow picture, MWW contains at least twice as much nutrients as MSW (N 6.3 kg/capita/a DE, 5.7 kg/capita/a FI and P 1.0 kg/capita/a DE, 0.9 kg/capita/a FI) (own elaboration based on DWA-benchmarking 2010 (according Barjenbruch 2011), Destatis 2012, Säylä & Vilpas 2012). Depending on waste management system, considerable amounts of nutrient are stored in waste management. Egle et al. (2013) have estimated that in Austria 1.1 kg /cap/a P is stored in waste management.

New technologies enable combining material recycling and resource conservation to WTE (Brunner & Rechberger 2014). For integrated energy and nutrient recovery systems, nutrient flows in different systems are relevant. According to Tonini et al. (2014) in incineration all the entering N evaporates to flue gas and nearly 90 % of P enters to bottom ashes, ca. 10 %

enters to air pollution control residue. After AD nearly 90 % of entering N is in digestate and rest in biogas. All the P is in digestate.

3.4 Future prospects for waste and waste water generation and characteristics

Future waste generation can be approached with STEEP framework presented in Figure 3. Aim of the framework is to cover external aspects, namely Social, Technical, Environmental, Economical and Political, that will impact development of the studied phenomenon. Factors presented in Figure 3 have an impact on MSW quantity and quality in future.

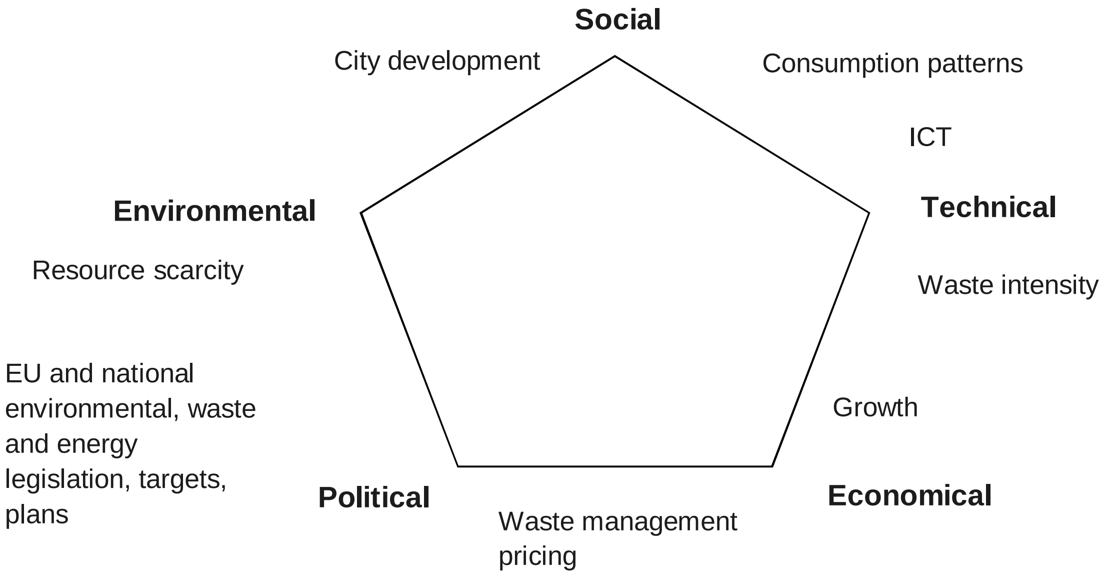

Figure 3. *STEEP framework: Drivers for MSW quantity and quality development*

Urban development and its relation to waste generation have been described by Dixon et al. (2013) with three 2050 visions: Smart-Networked City, Compact City and Self Reliant-Green City. For waste and resource use the first vision foresees novel materials and growth in consumption that require high level waste management. ICT facilitates the development of market based mechanisms for resource recovery. The second vision foresees system integration, where advanced energy recovery technologies are highlighted. The third vision foresees decreased consumption and small scale, low cost solutions for waste treatment. Focus is on optimizing use of renewable resources and local materials.

Waste generation can decouple from economic growth if growth turns from waste-intensive production towards non-waste-intensive production. To make this happen, strong political measures are needed in EU in future. (Östblom et al. 2010.) According to Sokka et al. (2007) decoupling of MSW generation and gross domestic product took place in Finland in the 1990’s indicating that waste prevention policy measures such as introduction of waste management hierarchy were successful. Recent statistics (Eurostat 2014) evidence little increase in per/capita waste generation over last decade. In Hoornweg & Bhada-Tata (2012) projections for 2025, total per capita waste generation in high income countries is estimated to stay in current level. Also Sokka et al. (2007) conclude that waste generation in Finland can be stabilized to the current level or even decreased by 2020.

Moliis et al. (2009) have studied waste generation trends in waste fraction level (Table 3). Scenarios are based on IPAT-model, I=P*A*T, where I is environmental impact, P is population, A is wealth and T is technology. Scenarios agree that plastic/packaging waste stream is increasing. Specialists have also assumed that organic waste stream is increasing more than the historical data indicates. Waste flows are assumed to be increasingly complex including highly compounded materials and sometimes hazardous substances of organic origin and trace elements (Brunner & Rechberger 2014).

Table 3. *Municipal solid waste generation estimations in Finland 2007-2030 (%) (Moliis et. al 2009.)*

Waste amount in Finland (Mt/a)	Scenario 1: Business as usual	Scenario 2: Business as usual adjusted by specialists	Scenario 3: Succesful waste prevention policy measures
Paper, cardboard	- 16.2	+ 3.5	- 39.4
Organic	+ 13.2	+24.2	- 26
Glass	+ 19.5	-9.9	-38.9
Metal	+ 5.6	+7.9	-36.9
Plastic	+ 14.5	+31.9	+ 6.5
Textile	+ 26.7	+24.5	-3.5
Other	+ 31.1	+18	+ 1.8
Total	+9.9	+16	-21.9

In Finland specific water consumption has decreased since 1970's and has now stabilized to the level of 250-260 l/day/capita. Considerable changes in the consumption are not expected. However, alternative sanitation solutions are a weak trend that can affect water management sector. (Silfverberg 2007.) In old parts of Helsinki, storm waters are led to the same sewer than municipal waste waters, which causes peak flows to the wastewater treatment plants. In new areas, storm waters are collected separately and led to the water bodies untreated. Recent trend in storm water management is natural solutions such as wetlands used for purification and utilization in irrigation. (Helsinki 2013.)

4 Conclusions

When integrated waste management and energy systems are planned, it is necessary to know the quantity and quality of waste flows. However, waste data available is poor because statistics are either in general level, not harmonized or classification does not meet the needs of the users. There is also uncertainty concerning environmental impacts of different waste management systems. Currently EU is promoting circular economy, which may lead to greater importance of recycling and decreasing role of waste incineration. However, certain waste fractions such as non-recyclable or harmful materials and waste streams from recycling processes and biorefineries are available for WTE in future.

In both studied countries, Finland and Germany, share on main MSW fractions is similar. Organic fraction is largest (ca. 30%) followed by paper and cardboard (21-22 %) and plastic (12-14%). MSW generation is higher in Germany (611 kg/capita/a) than in Finland (506 kg/capita/a) and in both countries it is below an average high income country MSW generation (777 kg/capita/a). Future MSW generation depends on a variety of factors including resource scarcity, consumption patterns, product design, ICT development, city development and policy measures. In high income countries waste generation is assumed to stay in current level or even decrease in 2020-30 projections. Packaging/plastic waste stream is expected to increase as well as amount of complex and composite materials. If policy measures are expected to prevent waste generation and facilitate recycling, they should be directed to consumption and product design instead of end-of-pipe solutions.

When urban waste material potential is compared to the energy demand in 2020, it can be concluded that:

- MSW plastic, organics and paper/cardboard can contribute to about 3-4 % of total energy consumption in Germany and 1-2% in Finland.
- If recyclable plastics and paper/cardboard are assumed to be recycled and only non-recyclable plastic and organics are taken into account, shares of ca. 2% and 1% of the total energy consumption in Germany and in Finland, respectively, are achieved.
- Chemical energy of municipal wastewater corresponds to ca. 0.7% (DE) and 0.3% (FI) of the nations' energy demand.
- In addition commercial and industrial waste (C&IW) is estimated to fulfill 1.9% of the national electricity demand in UK.
- Municipal wastewater contain ca. 6 kg N and 1 kg P per capita/a and municipal solid waste contains about half of that. Nutrient recycling could be considered not only in biowaste chain, but also when processing other waste fractions.

Urban wastematerial flow data gathered in this deliverable will be used in the final deliverable 3.1.4 of the Task 3.1. “Plan for bioenergy and biomaterial loops in the future cities” together with future city energy system data (deliverable 3.1.1) and best urban bioenergy solutions data (deliverable 3.1.3).

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