Sustainability of Waste Management System: Waste Generation and Collection

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Sustainability of Waste Management System - Waste Generation & Collection

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Description

Waste means any substance or object, which the holder discards or intends or is required to discard. Waste generation begins at the point in time when it is being discarded. After that, generation cannot be prevented or reduced. Solid waste includes, among others, municipal, agricultural, mining, industrial, commercial solid waste, construction and demolition waste, electronic waste, and sludge generated during wastewater treatment.

Solid waste is generated in all the stages of the life cycles of different products and materials. The largest volumes of waste are usually generated during mining and quarrying of raw materials, as well as from construction and demolition activities. Municipal solid waste (MSW) is the most commonly known, very heterogeneous waste which is defined as solid waste originating from households and similar kind of waste generated in commerce, offices, public institutes and municipal services. Generation rate of waste from different business fields is varying according the volume of the business activities and specific waste generation of producing a unit of each product. Municipal solid waste generation rate is affected mostly by the population and gross domestic product (GDP) per capita.

Waste collection systems consist of the waste collection bins on the yards of the houses or enterprises, loading of the waste to the collection vehicles and further transportation to the waste treatment or disposal facilities. Waste can be collected as separate fractions or mixed waste straight from the households or other

sources, or from regional collection points. If waste is not being collected, it is considered as littering, which should be avoided. Collection systems are commonly not working properly in developing counties.

Waste generation phase defines the amount and composition of waste that has to be treated, recovered and disposed. Waste collection phase has good potential to separate recyclables and recoverables from disposable waste. Thus, these phases are very important for the sustainability of waste management.

Introduction

Waste management refers in the context of this entry and four other entries of this encyclopedia to the management of solid waste materials. Solid waste means all waste, rubbish or litter collected and treated which is solid in nature even if its moisture content is high, such as sewage sludge. Solid waste includes municipal, agricultural, mining, industrial, commercial solid waste, construction and demolition waste, electronic waste and sludge separated from different wastewater treatment processes. In the legislation of the European Union, waste is defined as following: “waste means any substance or object, which the holder discards or intends or is required to discard” (Directive 2008/98/EC).

Waste management is widely related to different sustainability aspects. The original reasons for waste management are preventing and reducing environmental impacts and health hazards related to solid waste. Waste, especially biodegradable waste, is a good growing media for pathogens, which can then spread to humans via air, water or food. Waste material can cause pollution to air, water and soil, also in other forms like landfill gases, toxic leachates, toxic gases from inappropriate waste incineration and littering. Apart from direct environmental impacts, waste is also related to resource efficiency, diminishing natural resources and fossil materials, and rare-earth elements. It is also important for land use issues in form of landfilling and illegal dumping. On the other hand, waste management is an important factor in municipal economy. In some developing countries the costs of waste management can be several tens of percent from the whole municipal costs. Socially, waste management is related for example to business possibilities and employment. One problematic issue of employment in waste management sector is scavengers, who collect waste having some monetary value and who sometimes are even living on the dump sites.

Solid waste generation is a key factor for the environmental impacts of waste management. Generation rate defines how much waste enters to the collection, treatment, recovery and disposal systems, and it sets the basis for the extent of environmental impacts from each of these phases. Information on waste generation rates and its composition are vital for designing the waste management systems. Internationally, widely spread waste hierarchy (or priority order) defines prevention of waste generation as the highest priority

option in waste management followed by preparing for re-use, recycling (use as material for manufacture), other recovery (e.g. energy recovery) and safe disposal, in this order (Directive 2008/98/EC). Waste generation phase determines also the composition of the waste directed to the waste management system.

Waste collection defines how large share of the generated waste is directed to controlled and official treatment and disposal. Waste can be dumped or incinerated illegally, instead of collection with official systems, which usually leads to much worse environmental impacts than any legal waste management operations. Waste treatment and recovery and their sustainability can be affected with collection system by applying separate collection of different waste fractions.

Waste generation

Waste generation term refers to the moment when the object or material is discarded, like defined in the EU directive on waste (2008/98/EC). This means that waste generation cannot be reduced with different waste treatments or utilization operations. It can be reduced only before the waste has generated.

Solid waste generation

Solid waste generation sources can be divided to different economic activities. In the statistics of the European Union, rough categories of economic activities are: mining and quarrying, manufacturing, energy, construction and demolition, households and other economic activities. Waste generation from different economic activities depends strongly on the volume and intensity of each activity. Mining and quarrying forms often one of the largest shares of the total waste generation because the volumes needed for metal refining and construction purposes are large and the densities of the soil and rock materials are high. Construction and demolition waste makes also large share of the total waste generation in most of the countries, because the construction sites also handle great volumes of materials and large share of the waste materials are mineral waste (concrete, soil) which has high density. Manufacturing waste generation is totally dependent on the industrial structure of the country or region, its natural resources, labour price and knowledge level. Energy conversion produces mainly ashes and flue gas treatment residues and their amount depends on the sources of energy used for electricity and heat generation.

In European Union (28 member countries), the total waste generation in 2016 was approximately 2 500 million (metric) tonnes (Mt) including all the economic activities. This means, that on average about 5 tonnes of waste per inhabitant. The shares of different economic activities in waste generation were the following (Eurostat, Waste statistics, 2019):

- mining and quarrying 25 %,
- manufacturing 10 %,
- energy 3 %,
- construction and demolition 36 %,
- households 8 % and
- other economic activities 16 % (including waste water sludge 10 %, services 4.6 %, wholesale of waste and scrap 1 % and agriculture, forestry and fishing 0.8 %).

When using the waste generation statistics, it is important to understand how the statistics were formed. If the statistical system works well, there are certain rules on what shall be included to the statistics and what is to be excluded. These rules differ across countries making direct comparison of the statistics difficult in some cases. For example, in European Union waste statistics, the rejects which have been recycled internally at the site where waste was generated, is not included to statistics. This means that for example in agricultural waste the manure used on the own fields of the farms, is not included in the statistics. Manure is however commonly the largest waste fraction of agricultural waste, and it can be treated for example with anaerobic digestion to produce biogas and still be used as fertilizer for the fields. Manure is one of the largest waste flows for biogas production. Still it is not included in the statistics and the numbers in statistics cannot be used e.g. for estimating the biogas potential from agriculture. For example in Finland, the generated amount of manure is about 14 Mt and the amount of agricultural, forestry and fishing waste in statistics is about 3 Mt. (Luostarinen et al., 2017)

The most well-known and monitored waste material is municipal solid waste (MSW), which is defined commonly as solid waste originating from households and similar kind of waste generated in commerce, offices, public institutes and selected municipal services, such as schools and health care centres. Yet, municipal sewage sludge and construction and demolition waste are excluded from MSW. For MSW there is the most information available from all waste categories. The aspects of MSW generation are introduced here as one example category of different waste materials. MSW has been selected here, because there is plenty of information available from MSW generation, and on the other hand, the data related to waste generation in other branches of economy is less available and more difficult to define so that it would be comparable with each other.

Globally the generation of MSW is estimated to be approximately 2 billion metric tonnes per year and it has been forecasted to grow to 3.4 billion tonnes per year by 2050. Final disposal represents still about 70 % of the treatment of MSW globally. Most of the greenhouse gas emissions of waste management sector,

about 1.6 billion tonnes or 4-5 % of the global GHG emissions, originate from landfills, where the biological degradation of waste produces methane and carbon dioxide. (What a Waste 2.0, 2018)

MSW generation rate varies in a wide range in different countries and regions. The most important factors influencing the generation rate are population and its density and wealth (measured e.g. with gross national income (GNI) per capita or gross domestic product (GDP) per capita). Figure 1 presents the variation of MSW generation rate per capita in relation to GDP per capita. It is clear that growing incomes increase MSW generation though the variation in different wealthy levels is large. It hast to be taken also into account that the statistics of waste management are often very inaccurate. They are often rough estimates especially in such countries where infrastructure is poor and GDP per capita is low.

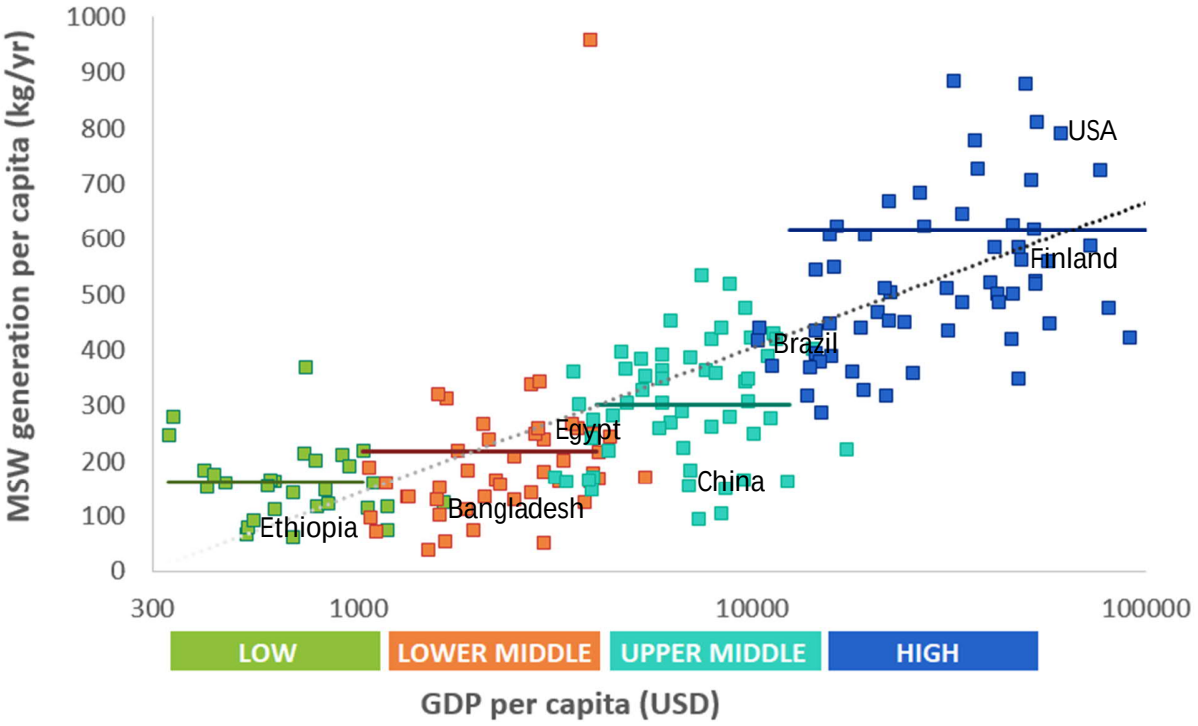

Figure 1. Annual generation of municipal solid waste (MSW) per capita in different countries having different gross domestic product (GDP) per capita. (Global waste outlook, 2015)

Several studies have been carried out to make models for forecasting of MSW generation (Daskalopoulos et al., 1998; Dyson and Chang, 2005; Beigl et al., 2008; Kolekar et al., 2016). Daskalopoulos (1998) has

presented simple correlation equations for MSW generation in country level in Europe (1) and USA (2) using GDP and population as variables:

$$MSW = 0.1292 \cdot GDP^{0.4412} \cdot Population^{0.4855} \quad (1)$$

$$MSW = 4.08413 \cdot GDP^{0.458} \cdot Population^{1.24075} \quad (2)$$

where GDP is gross domestic product expressed in billion US dollars,
MSW is municipal solid waste generation, million tonnes per year.

Composition and properties of waste

Waste generation phase determines also the composition of waste. It is possible to affect the composition of treated waste materials significantly with the collection and separation systems and especially with separate collection of recyclables. Composition of industrial, construction or mining waste can be influenced with the processes. The more effective the processes are, the less utilizable waste material is produced. Also these business lines can use many of their own by-products in their own production before they are discarded and convert to waste.

Composition of the generated MSW is affected by consumption habits and abilities. It means that the income level of people is affecting also the composition of waste. We can see from the results of Global Waste Outlook (2015) in Figure 2, that the share of organic waste is higher when income level of the country is lower. In the low income countries people are consuming less different products. Food waste forms higher share of all the waste, when the total amount of waste is much lower than in high income countries, and still the people have to prepare their food and eat. On the other hand, food products in high income countries are more often pre-manufactured. For that reason they don't produce as much waste at homes as the less prepared food materials. Pre-manufactured food is usually also packed more carefully, which also increases packaging waste in high income countries.

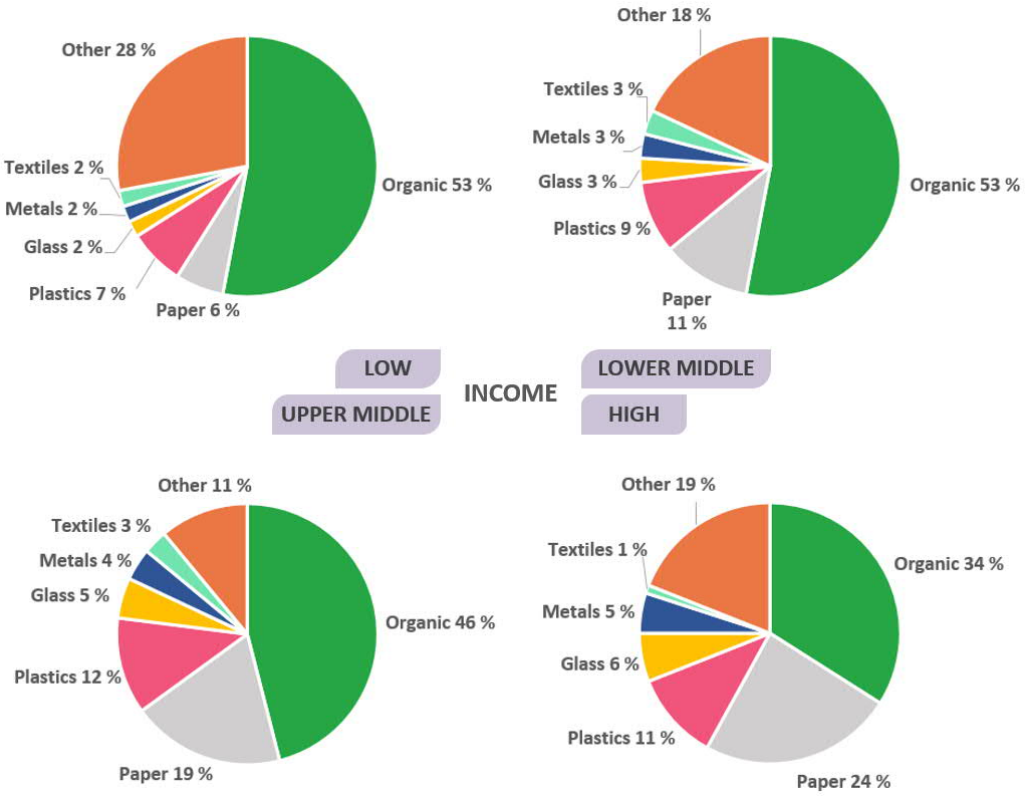

Figure 2. Rough compositions of MSW in different income level countries. (Global waste outlook 2015)

Figure 3 presents analysed MSW compositions in example regions of different countries. Finland (South Kareli region) represents high income country. It can be seen that the contents of biowaste (organic waste) is significantly lower than in Brazil (Sao Paulo) and China (Hangzhou), which both represent higher middle income countries. The composition of Finnish waste does however not contain all the MSW materials because there is a well operating separate collection system in the case region. Large share of biowaste has been separated at source in biowaste bins for composting purpose. Thus, it is important to understand from the used data, how and from which phase of waste management the composition has been determined.

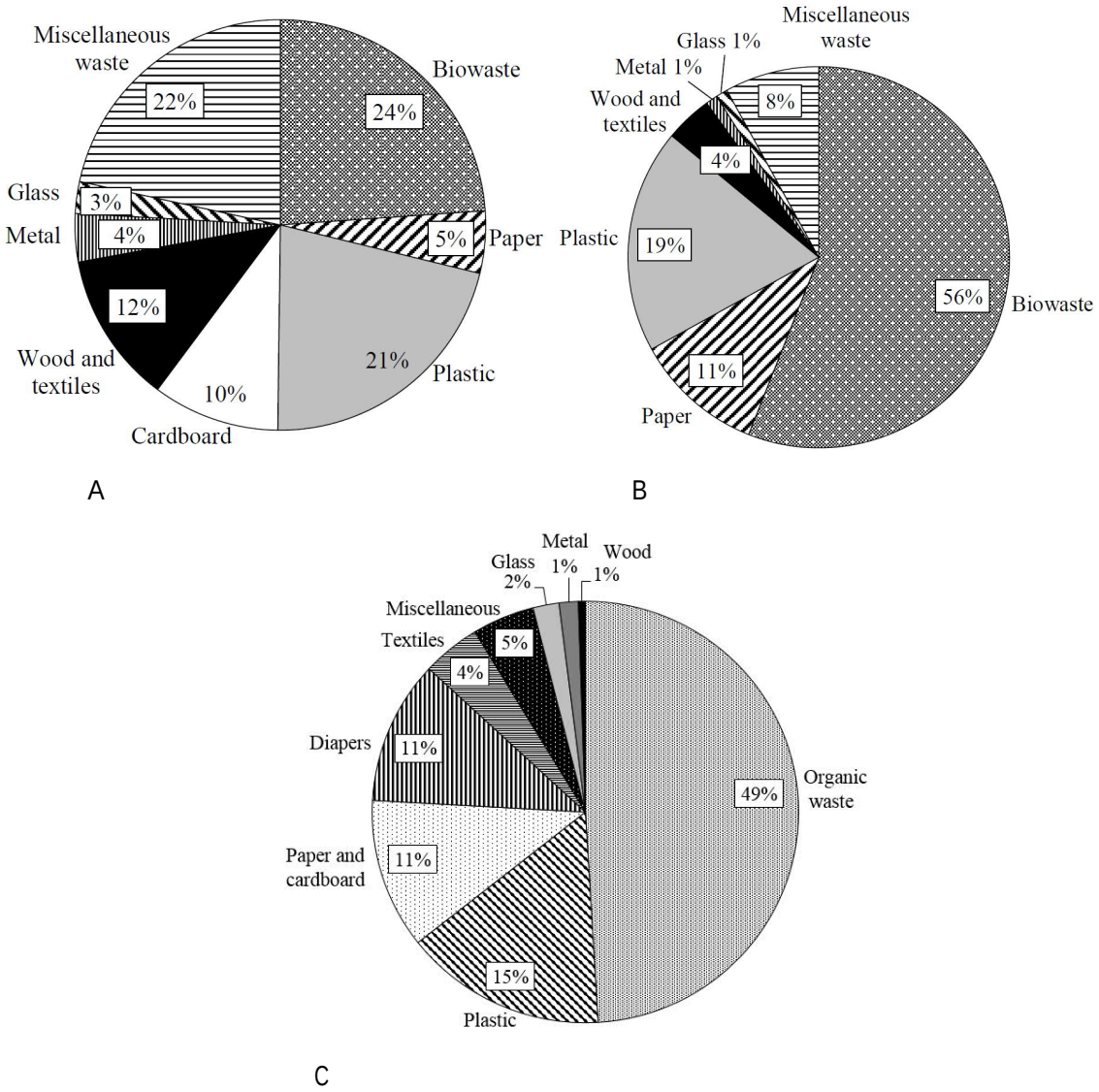

Figure 3. Compositions of MSW: A) Mixed residual MSW in South-Karelia, Finland (Horttanainen et al., 2013), B) Mixed MSW in Hangzhou, China (Havukainen et al., 2017), C) Mixed MSW in Sao Paulo (Liikanen et al., 2018)

Waste collection

Waste collection includes 1) the waste collection bins on the yards of the houses or enterprises, 2) loading the waste from the bins to the collection vehicles and 3) transportation of the waste to the first discharging place, which can be a waste treatment or disposal site or a transfer station before longer transportation. The last phase can be separated also from collection to belong in a separate transportation phase.

Waste collection is one of the key steps in the waste management systems both economically and environmentally. Waste collection from scattered generation places, especially households, forms the large share of the total costs of waste management. In developing countries it can form almost the whole cost of waste management if there is no other treatment than final disposal on non-sanitary landfills or unofficial dumps. In developed countries, other treatment costs are significant, but also collection costs increase when there are several different waste fractions to be collected.

It is not self-evident that all the waste is collected and directed to the official waste management system which has legally and environmentally justified permissions for waste treatment and disposal. World Bank has done surveys on the collection rate of MSW in different parts of world and found that the collection rate can vary between 44 and 100 %. In the developing countries the waste management and collection infrastructure is often inadequate. Significant part of waste is dumped illegally in street sides and rivers or incinerated on backyards. (Fig. 4)

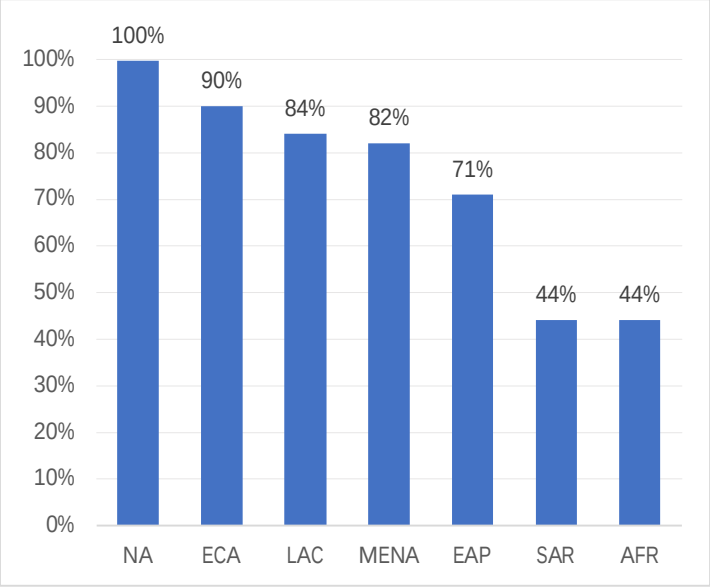

Figure 4. Collection rate of waste (MSW) in different regions (North America (NA), Europe and Central Asia (ECA), Latin America and Caribbean (LAC), Middle East and North Africa (MENA), East Asia and Pacific (EAP), South Asia Region (SAR) and Sub-Saharan Africa (AFR). (What a waste 2.0, 2018)

Purposes and aims of waste collection

The main purpose of waste collection is to deliver waste from its generation location to appropriate treatment or disposal and in such a way to avoid harmful environmental impacts both in the location of

generation and in the subsequent phases of waste management. Simultaneously, collection makes it possible to get waste materials recovered, and it also enables collection of data related to waste generation and treatment.

Waste collection phase includes short term storage of waste in the waste bins. They should be planned so that they protect the environment and people from the possible harmful impacts of waste. Such impacts are for example odours released from decomposing organic waste and noxious animals, like rodents, birds and flies, attracted by the potential nutrition in the waste. Bins should also protect the waste material from spoiling before possible recycling and recovery purposes. Rain water for example, can lower the quality of waste transported to energy recovery as well as increase the transportation costs.

Waste collection is an effective phase of waste management for separation of different waste materials. People have, in principle, a better ability for correct and accurate waste separation than any machines. It is possible to get better quality recoverables with well working source separation system than with mechanical separation.

Different waste collection systems

The collection bins should be designed so that it is easy to recognize the correct bin for a waste fraction brought to the bin. Citizens should be informed properly about the separate collection system, its purposes and separation instructions at the collection sites and through different media. Figure 5 presents examples of separate collection bins of a regional collection point on the yard of a grocery store. Figure 6 presents source separation on the yard of a row house. It is also important to make source separation easy inside homes with different well organized collection systems like the one presented in Figure 7.

Figure 5. A regional collection point of recyclables on the yard of a grocery store in Finland. Series of collection bins, a bin for cardboard and instructions in the bin of metals.

Figure 6. A waste collection shelter for recyclables and residual waste on the yard of a row house in Finland. Paper and organic waste (biowaste) collection bins in one side of the shelter. Two shelters include bins for residual waste, paper, plastic packages, biowaste, cardboard, metal and glass.

Figure 7. A sink with a waste cupboard including 4 buckets for different waste fractions.

Waste can be collected from the source locations with different systems. Collection bins can be located on the yards (e.g. in shelters like in Figure 5), where the collection truck enters and the bins are picked and emptied by the vehicle driver or an assisting person. In some countries the collection bins are brought in certain days and daytimes to the street side to be emptied. In some regions the trash bags (different colours for different fractions) are brought to the street side to be picked from there to the waste trucks. The waste management fee is usually paid for the waste management company according to the size, number and frequency of emptying of different waste bins. Some modern tightly populated city districts have pneumatic collection system which transports the trash bags in a pipeline network to a collection point where the truck empties or changes the container. This kind of a collection system can include also such source separation possibility, that the user can select which waste he/she has placed to the system and according to that selection the system transports the bag into a correct container.

Waste can be collected also with regional collection points. In European countries this system is often used for recyclables so that people can bring their source separated recyclables materials to the collection point for example when they go to a grocery store or to a gasoline filling station. The collection points are meant for those citizens who don't have separate bins for all the recyclables on their home yards, like often is the case with detached houses. The recyclable fractions can be left to these points without payment. The waste management cost is then often covered by extended producer responsibility system (including the waste management cost into the prize of a product). Some countries and regions are collecting some of the recyclables with so-called co-mingled waste system, where several recyclable materials are collected in the

same bin. These different fractions have to be such that they can easily be separated from each other mechanically with a good separation rate and purity.

Waste is collected often with changeable containers from such sources where the generation of waste is large. This kind of waste sources can be e.g. large department stores, construction sites and factories. Different metal containers are used for different waste fractions. They can be open or covered. An empty container is left to the place when a full one is picked and transported to the treatment. The containers can be equipped with a compression system, when the waste has low bulk density like packaging waste.

When planning the waste collection system, the routes should be designed so that the driving distances are minimized and moving between the collection points would be smooth. Different computational systems are used for the optimization of the routes like geographical information system (GIS). Also geographic positioning systems (GPS) are used for follow up and documentation of the collection, and navigation systems for helping especially the new drivers of the vehicles. It is also possible to equip at least larger waste bins with sensors, which follow the filling level of the bins and send the information (via internet) to the collection company. The information of the filling levels is then used for on-line route planning of the collection trucks. This kind of technology has been observed to save 30 % in the number of emptying times in a pilot project in Finland. (Uusio Uutiset, 2013)

Waste collection systems are very diverse in different parts of world. In the developing countries, the collection is more based on manual work compared to developed countries. Waste is often collected from densely populated city districts with small vehicles or carriages. Recyclables are collected by waste pickers door to door or from the waste bins and containers. In some countries, the private poor waste pickers are used as unofficial waste management personnel for the cities.

Sustainability aspects in waste generation and collection

Waste generation and type of collection determine the composition of waste fractions directed to different treatments. If the waste directed to energy recovery contains a lot wet organic waste, it has deteriorating impact on the energy production and its environmental sustainability. If the heating value of waste is very low, there can be need to add higher energy content fuels (often fossil fuels like coal) to the incineration process to raise the combustion temperatures to the levels demanded in legislation (usually at least 850 °C) and needed to destroy the toxic organic compounds. Fossil fuel addition increases both greenhouse gas emissions and costs of the incineration. This kind of case and possibilities for improvements of the situation have been introduced and analysed in Havukainen et al. (2017) for the city of Hangzhou in China. When

the problem of wet MSW would be solved by mechanical preparation of refuse derived fuel (RDF) in the case study, one consequence was generation of a wet mixed reject material from the process. It was shown in the life cycle assessment for the scenarios, that a rational treatment and utilization (like anaerobic digestion) should be implemented for the organics containing reject to prevent its landfilling and the methane emissions caused by that, and so to make the RDF using system environmentally sustainable. (Havukainen et al., 2017)

Development of commercial (hypermarket) waste collection and treatment was studied in Hupponen et al. (2018). There was a source separation system already in the baseline scenario which was the existing collection when the study was carried out. The collected fractions, their mass shares and treatment methods were the following: cardboard (49 %, recycling), biowaste (24 %, anaerobic digestion), energy waste (11 %, combustion and heat and power production), PE-plastics (2.4 %, recycling), small shares of paper, metal and glass to recycling and mixed residual waste (13 %, landfilling). The residual mixed waste contained 50 % biowaste, 19 % energy waste, 13 % cardboard, 6 % paper and small share of glass and metal. So it would be realistic to improve the source separation and get one third of the mixed waste mainly to biowaste and energy waste fractions. With these measures it was possible to reduce the greenhouse gas (GHG) emissions of the system by 5 %. The most effective realistic measure for GHG emission reduction was directing the mixed residual waste to energy recovery (heat and power production with annual total efficiency of 63 %), which reduced the net emissions of GHG by 93 % from the baseline situation. This study, with many others concentrating on waste materials containing mainly packaging waste, shows that collection and transportation of the waste do not form significant proportion of the GHG emissions of the total waste management system. (Hupponen et al., 2018)

Summary

Waste is defined as any substance or object, which the holder discards or intends or is required to discard. Waste can be generated in every phase of the life cycle of the products, materials and services. Even the waste treatment, separation, recycling and recovery processes often produce secondary waste.

Waste generation rate can be affected before the waste is generated (substance or material is discarded). The rate of generation is affected by the complicity of the refining and manufacturing phases in the waste materials of different business lines. MSW generation increases with increase of population and wealthy. Waste generation defines both the amount and composition of waste materials. Production processes and consumption should be developed to reduce generation of waste and to improve sustainable recycling and recovery of the waste which cannot be prevented.

The statistics and other data, concerning waste generation, are often rather inaccurate and sometimes even unreliable. Data quality usually improves with the technical level of waste management but also in the well-developed countries where waste is mostly treated according to high standard legislation, there are significant deficiencies in the accuracy of waste generation data.

Waste collection phase of waste management secures the directing of waste materials to correct treatment and reduces environmental impacts of waste storing and spreading in the surroundings of the waste sources. From sustainability point of view, it is most important that all the waste is collected systematically by stakeholders who obey the legislation. Most of the litter in the nature, including the plastic marine litter, originates from such cities where the waste collection system does not work properly.

Separate collection of different waste fractions makes it possible to receive good quality material for recycling and recovery purposes, if the people are aware and motivated to source separation. It is however important to understand in the planning of waste management system, that it is unrealistic to expect even nearly all recoverables to be placed in the correct separate collection bins. So there is usually always some residual waste containing still recoverable materials. Also, there are always some impurities in the separately collected recyclables which have to be removed mechanically or manually or/and there has to be tolerance in the production processes and products utilizing the waste materials.

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