Comparative Analysis of Reverse Logistics Activities and Incineration for Greening Waste Management

Stankeric, Oliver

UNIVERSITY OF ZAGREB

FACULTY OF TRANSPORT AND TRAFFIC SCIENCE

Oliver Stankeric

COMPARATIVE ANALYSIS OF REVERSE LOGISTIC ACTIVITIES AND INCINERATION FOR GREENING WASTE MANAGEMENT

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Student: **Oliver Stankeric (0135222937)**
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Title: **Comparative Analysis of Reverse Logistics Activities and Incineration for Greening Waste Management**

Description:

Thesis will define basic processes of reverse logistics and outline benefits of using reverse logistics activities. Comparative analysis will be provided for waste management systems of chosen EU country and Republic of Croatia. Possibility of incineration will be observed with comparison of implementing incineration systems in Republic of Croatia. Benefits will be outlined and optimal solution chosen.

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Mentor: Committee Chair:

Ivona Bajor, PhD

University of Zagreb

Faculty of Transport and Traffic Sciences

University of Pardubice

Jan Perner Transport Faculty

Topic:

Comparative Analysis of Reverse Logistics Activities and Incineration for Greening Waste Management

Komparativna analiza aktivnosti povratne logistike i spaljivanja sirovina u sustavu upravljanja otpadom

Primary mentor: dr. sc. Ivona Bajor **Student:** Oliver Stankeric

Secondary mentor: doc. Ing. Petr Průša, Ph.D.

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SUMMARY

Due to intensive development of technology and a large increase of population at a global level, as well as a continuing deruralisation, the concentration of urban population increased the amount of waste disposed of and the need for its systematic management. As a result of increasing amounts of waste, additional types of waste appeared that did not previously exist. Consequently, diverse infrastructure has been developed for waste management and its disposal, some of which – primarily incineration infrastructure - has been comprehensively described in the paper. The amount of waste disposed in the Czech Republic has stagnated, whilst Croatia has seen upwards trends and waste management has not reached a satisfactory level. This paper will analyse the waste management systems in these two countries, examining both the advantages and the disadvantages of the systems and providing a proposal for an optimisation solution concerning waste management in the Republic of Croatia with an emphasis on waste incineration. The optimal waste management infrastructure will be highlighted based on cost-benefit analysis.

KEY WORDS: Green logistics, reverse logistics, waste management, incineration, waste.

Content

1. INTRODUCTION

Throughout history waste was considered simply as waste and in the Middle Ages it was disposed of on the streets and on landfills. Waste is being disposed of on landfills even in modern days despite all the available technologies, mechanisation and the processes of recycling and recovery. Upon intense development of industrialisation over the past decade urbanisation rate increased, which led to consumerism causing problems with waste management. If global population continues increasing, consumption will also increase in the future and the main problem will escalate further. Therefore, waste management is a strategic concern and an obligation for the entire world. Developed countries are faced with ecological problems and they have been developing waste management systems during the last twenty years. The Croatian waste management law is coordinated with European Union directives, but the main problem is its implementation in practice.

In order to really do something on the subject of landfills it is necessary to consider different solutions. There are two solutions that are frequently mentioned, the first one is incinerators whilst the second is recycling. It is necessary to evaluate the need and the efficiency of both methods of waste disposal and the possibility that the solution could be a combination of both. One thing is certain, incinerators should be avoided as much as possible. Throughout this paper, the operating system of an incinerator will be displayed, as well as its technology and impact on the environment.

First incinerators started their operations in Europe around the 20th century. Currently, the developed European countries of Europe incinerate most of their municipal waste so they can use the thermal and electric energy that was produced through incineration and in order to avoid waste disposal in landfills. The Republic of Croatia has to learn from all the other countries that developed a global awareness of the extent of the pollution of the environment and the extent of energy that is being wasted. Moreover, throughout this paper, the system of waste management in the Czech Republic was analysed and from that analysis some conclusions were reached e.g. in what way and in what direction should this system be improved and whether a new one needs to be built.

Through the system of reverse logistics in the waste management sector a conclusion was reached that there can be more savings that contribute to the entire society and are suitable for the environment. Against the backdrop of this philosophy and practices a survey will be conducted amongst the general public, in order to establish the current level of satisfaction with waste management services, as well as the potential acceptance of the proposed system.

among the population so the current level of satisfaction by the waste management service can be shown as well as potential acceptance of the proposed system.

2. REVERSE LOGISTIC

This chapter will explain theoretical guidelines of green and reverse logistics and hence present their relation to the process of waste management. Subsequently, definitions of reverse and green logistics, activities and groups of activities such as hierarchical structure based on priorities of waste management will be presented.

2.1 Green logistic

Development of globalisation and decentralisation of manufacturing encouraged proportional development of logistics especially after the second half of the twentieth century. Hence, logistics has been present at all levels such as regional, national and international. It is currently really hard to imagine any system without logistic support. However, it is a well-known fact that the performance of core logistics activities conflicts with the laws for protection of the living environment. Against the backdrop of philosophy and consciousness aimed at improvement of the processes and striving to preserve what is important, knowledge is gained about implementing green logistics as an ecological and accepted way of doing business.

Green Logistics is concerned with producing and distributing goods in a sustainable way, taking account of environmental and social factors. Thus the objectives are not only concerned with the economic impact of logistics policies on the organisation implementing them, but also with the wider effects on the society, such as the effects of pollution on the environment. [1]

In addition, green logistics activities include measuring the environmental impact of different distribution strategies, reducing the energy use in logistics activities, reducing waste and managing its treatment.

Moreover, green logistics is defined as the “concept that includes strategies whose aims are to reduce the influence of supply chain on environmental pollution and to reduce the energy-related impact of freight transport. Green logistics includes areas that are connected with material management, waste management, packaging and transport.” [1]

Green logistics is the concept that performs its tasks in an efficient way, and points out the issue of the living environment. Green logistics today incorporates the following areas of operations:

- City logistics,
- Reducing freight transport externalities,
- Reverse logistics,
- Logistics in corporate environmental strategies,
- Green supply chain management. [1]

Sustainable logistics is a set of logistic activities to ensure the synergy of economic and environmental objectives in accordance with increasingly stricter environmental laws and the laws on consumer protection. It is aimed at ensuring the greatest possible difference between positive and negative external effects of the logistic phenomenon. The concept of sustainable logistics is usually interpreted as a balance of inter-related social, economic and environmental dimensions. The visual representation of the mentioned above can be seen in Figure 1. [2]

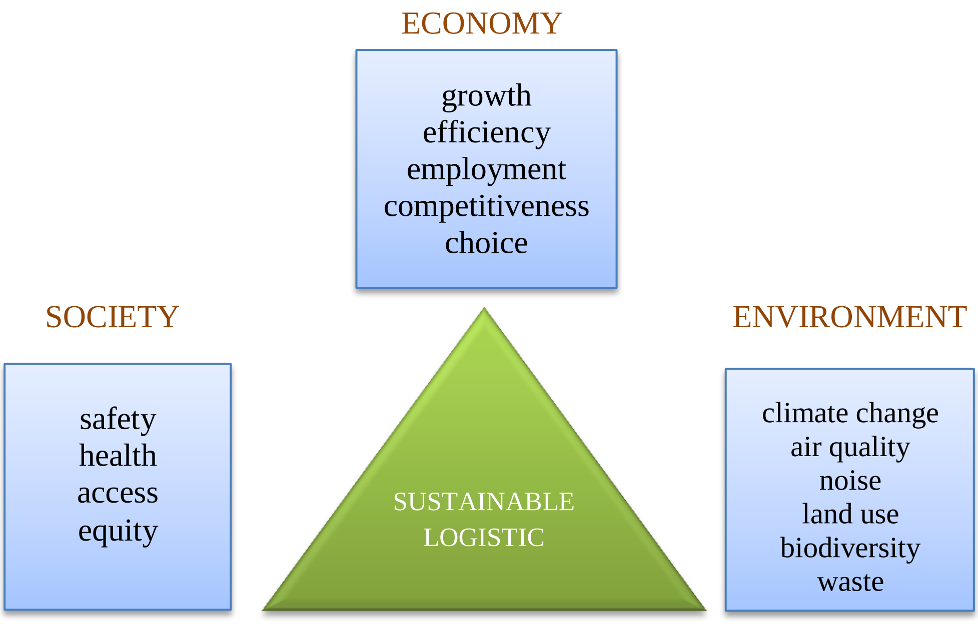

Figure 1: Description of bonds between society, economy and environment through sustainable logistics

Source: [3] made by the author

The vision of logistics is developing logistic sustainable growth as a set of logistic activities which simultaneously ensure synergic substations of economic and ecological goals complying with increasingly stringent environmental laws and those of consumer protection. The strategic aim is to ensure the greatest possible difference between positive and negative external effects of logistics phenomenon. The awareness on the environmental protection is becoming more significant and measurements commenced in order to avoid further pollution of the planet. The greatest burden will be incurred through the implementation of the core logistics processes (transportation, manipulation, storing) because of the fact that these processes are in major confrontation with basics codecs of living environment.

2.2. Reverse logistics activities

Reverse logistics in the research area mainly refer to damaged goods that should be returned to the manufacturers or distributors. Terms such as return logistics, retro logistics or reverse distribution are all used throughout the references to imply reverse logistics. [4]

Logistics is defined by The Council of Logistics Management as “The process of planning, implementing, and controlling the efficient, cost effective flow of raw materials, in-process inventory, finished goods and related information from the point of origin to the point of consumption for the purpose of conforming to customer requirements” [5]

During the time of globalisation and liberalisation of world trade increasing attention has been paid to reverse logistics. Great importance is given to reverse logistics partly because of increasing recognition of the value of products and technologies that are created in the supply chain and due to the increasing influence of the green laws in Europe. Disposal of waste materials and waste in general is always a burning issue when it comes to urbanisation and increasing population density in urban areas. Following the industrial revolution problems intensified as a repercussion of production and great amounts of waste and dangerous materials negatively influenced the environment. This led to the development of a systematic control and an attempt to find new solutions that aim to protect the citizens and their health.

Reverse logistics is focused on the management of those products from which have a potential to retrieve value that could be again implemented in supply chain and it greatly differs from the term green logistics.

Decision making about transport of recycled materials has a great importance because costs of transportation could exceed their actual value and invalidate all the financial benefits of the program of returned used products. It is currently rather difficult to imagine any system without logistic support. However, realisation of core logistic processes is often in collision with environmental protection requirements.

Reverse logistics activities are all the processes that a company uses for the purpose of collecting used, damaged or unwanted goods and products whose expiration date has been reached, including the packaging of end users or suppliers. Once the product has been returned to the company, there are various possibilities for its management. The management activities implemented in such cases will be described hereinafter. If the product can be returned to the supplier as full return, the company should primarily decide in favour of this option. [6]
Subsequently, there are many activities that could fall under the heading of reverse logistics, as it has been defined. Concerning all the supply chain duties within a company, the question has been posed as to which activities qualify as reverse logistics. The survey respondents indicated that they are involve the following functions as reverse logistics activities:

- Remanufacturing,
- Refurbishing,
- Recycling,
- Landfill,
- Repackaging,
- Returns processing,
- Reclaim Materials,
- Recondition,
- Salvage. [4]

Efficient manipulation of goods that are in the process of return is essential because of the constant decline in price of products and in the functionality of the supply chain; with the exception of a small percentage of returned goods, this ensures a faster circulation of goods.

When the product has been returned it can be redistributed, aiming to achieve the biggest value:

- Product can be returned to the producer with return of whole value,
- Unused product return to sales,
- Redirected to outlet stores,
- Directed on secondary markets,
- Processing and product recovery ,
- Recycling,
- Disposal on landfills. [4]

Activities of reverse logistics that are applied by the recovery of useful waste:

- Collection,
- Review,
- Sorting,
- Repairing,
- Cleaning,
- Processing. [5]

Collection - the first and compulsory activity of reverse logistics include processes related to the collection of used, damaged or unwanted products or packaging. In addition to the collection, this activity also includes packaging and transport of goods from the end user or the level of the supply chain which initiates the return. The earnings usually depend on the type of product and the material of which it had been made. It also depends on the way the supply chain is doing business and business contracts. [5]

Verification / selection / sorting - after the arrival of returned goods at each level of the supply chain, the checking is performed and it takes place at a predetermined location. After checking the documentation of the status of an approved returned good, based on the established quality and condition of products, the selection and sorting of products or packaging is performed. Sorting products for return is one of the most complex activities in the logistics systems. Concerning the sorting of waste, door-to-door sorted waste is a well-organized system, or in waste management centers additional checks are performed and then waste is processed further. [5]

Storage - storage of returned goods, in this case, waste undergoes further processing or routing to the location of the implementation of activities of reverse logistics. [5]

Routing channels into reverse logistics - trained employees value the products in the return process and are directed into channels which will achieve the highest possible market value or direct them to the landfill. [5]

Recondition - is a process in which worn or dysfunctional components of the product or packaging are replaced with new ones in order to re-use. This activity does not include the production process. [5]

Refurbishing - is a process in which the products or packaging is returned to its original state by performing activities such as cleaning, polishing and painting, to name a few. In this process the structural components remain unchanged. [5]

Re-process – is a process of manufacturing that is repeated exclusively due to the failure of the original process. [5]

Remanufacture – is a process of manufacturing intended to make a product out of new and used materials. [5]

Reuse – an activity which the returned object (packaging and finished products) is slightly modified or not at all. [5]

Recovery - according to the European Environmental Protection Agency, it is defined as an operation of waste management in which certain activities of reverse logistics reduce the amount of waste intended for landfills in order to obtain raw materials and energy (energetic and material recovery), for the purpose of economic and /or environmental benefits. It is important to point out that recovery and recycling are not the same terms and that the recovery has a broader meaning than recycling. Recycling is a process that involves processing of waste materials in order to obtain raw materials (material recovery) for reuse in the production process aiming to reduce the amount of waste that is directed to the landfills. Moreover, as it has been previously mentioned, some authors consider recovery as a group of previously mentioned activities. For the purpose of this work recovery will be referred to as an independent activity. [5]

Disposal - is the final activity of reverse logistics, which needs to be avoided as much as possible. Waste disposal represents an organised activity of permanent disposal of waste in landfills. [5]. A landfill is defined as a deposit of waste into or onto land; it includes specially engineered landfills and temporary storage for over one year on permanent sites. The definition includes both landfill in internal sites (i.e. where a generator of waste performs its own waste disposal at the place of generation) and in external sites.

With the following picture the backward process will be shown and how to make raw material out of waste and thus transform it into the final product. Individual waste has to be separated on the point of produce at the door and distributed to the centre for waste management were it will be additionally separated and processed. Upon waste processing and separation, useful raw materials can be generated that can be used by producers for manufacturing of new products.

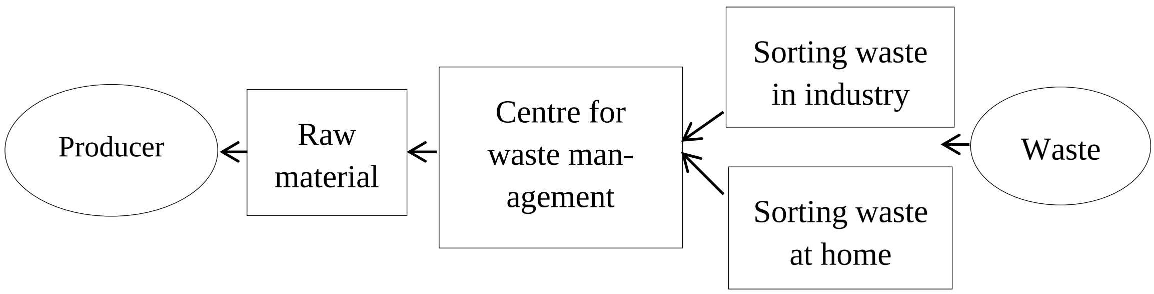

Figure 2: Backflow, of waste to the raw material

Source: author source

Efficient systems of waste management have well organised and arrangement operations processing residual and its maximum use for getting energy and recovery materials in the system of production, and some of the operations performed are: recycling, waste to energy, organised sorting, incineration and finally disposal. All these operations have their schedule by rule of priority for waste management as shown in *Figure 3*.

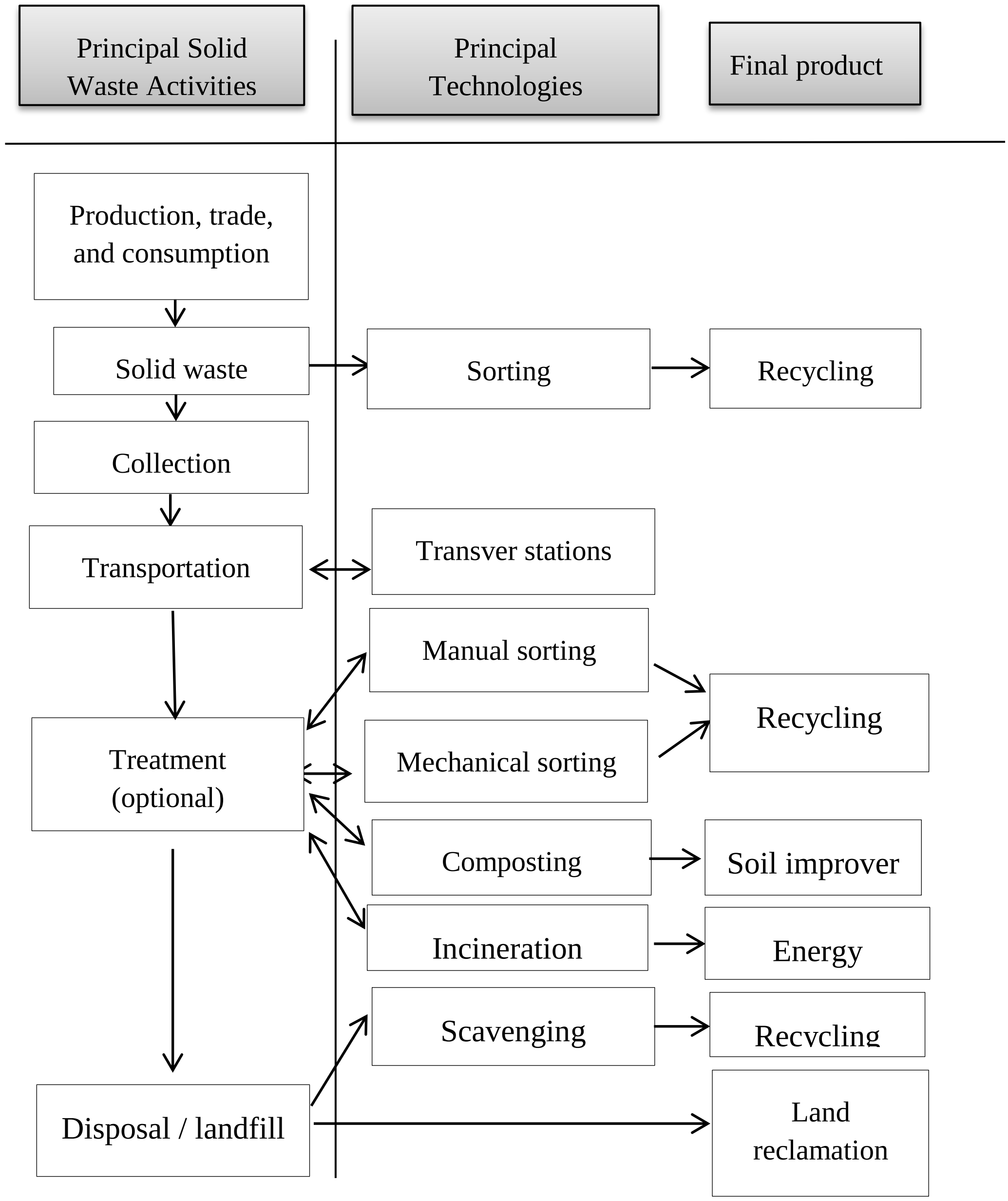

Figure 3: Solid waste handling and treatment system components

Source: [6] made by the author

Figure 4 clearly shows the basic traditional reverse logistics of waste management dealing in the return of unwanted products to a central location for processing and hence they are stored, recycled and reused into different streams in new markets.

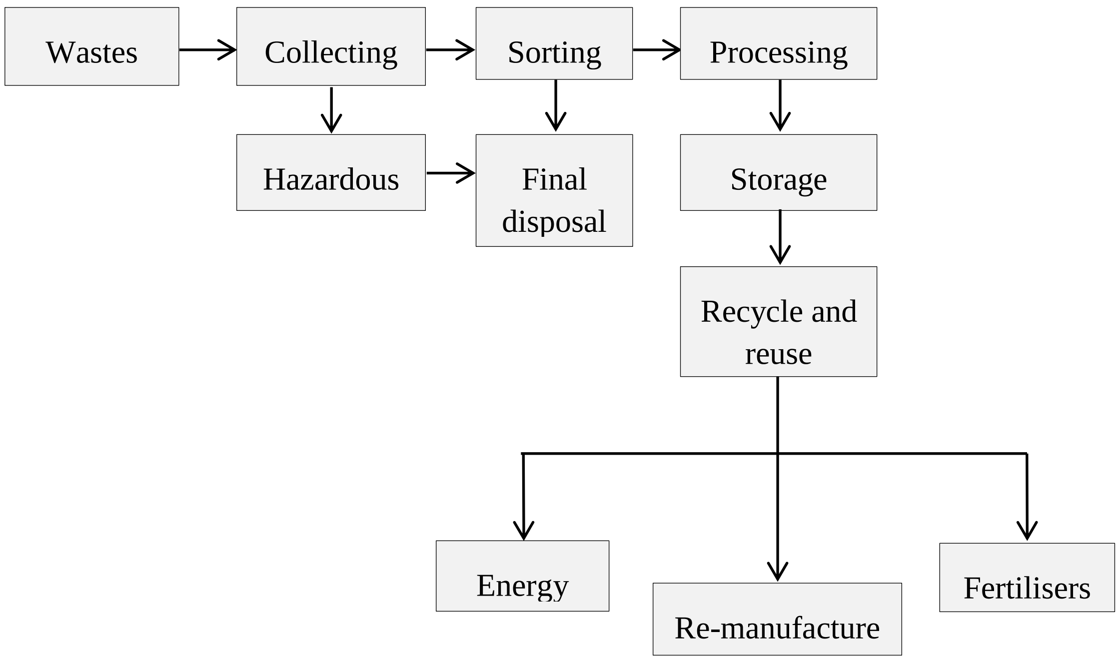

Figure 4: Integration of waste management and reverse logistics

Source: [7] made by the author

2.3 The principle of waste management hierarchy

In 1975, The European Union's Waste Framework Directive (1975/442/EEC) introduced for the first time the waste hierarchy concept into European waste policy. It emphasised the importance of waste minimisation, and protection of the environment and human health as a priority. Following the 1975 Directive, European Union policy and legislation adapted to the principles of the waste hierarchy. [8]

The waste hierarchy (as defined in Article 3 of the Waste Framework Directive 2008/98/EC) ranks waste management options in terms of their environmental impact. The waste management hierarchy is used as an over-riding principle in respect to waste management strategy and policy development. This hierarchy is widely accepted and used at an international level, and is represented in the figure below.

The waste hierarchy is a process that indicates an order of preference for action to reduce and manage waste. Its aims are to protect the environment, conserve resources and to minimise waste generation. It is often presented in the form of a pyramid, although several marginally different versions are in use. The waste hierarchy gives top priority to preventing waste; when waste is generated, it gives precedence to direct re-use, recycling, recovery methods (such as energy recovery) and finally all disposal.

Figure 5: European Union waste hierarchy

Source: [9] made by the author

Prevention

Preventing waste means reducing the amount of waste generated, reducing the hazardous content of that waste and reducing its environmental impact. It is based on a simple concept: if one produces less waste, one consumes fewer resources and one does not have to spend as much money on recycling or disposal of one's waste. For instance, repairing one's old bicycle instead of buying a new one is a perfect way to reduce waste. [10]

Re-use

The principle of reuse is one that is well applied in the developing country context. Re-use implies re-utilising waste material without making substantial changes to its form. Repair goes hand in hand with reuse, revitalising the utility value of the product through applying skills and labour. Reuse can also be applied to using a waste product for a new purpose. For example, making seedling pots from plastic bottles or liquid paperboard cartons. Re-use is a principle that tends to be overlooked as affluence and consumerism grows. [50]

Recycling

Recycling is a process that utilises waste materials and applies various technologies to change the material into useful feed stocks for industrial or manufacturing processes. Recycling is further down the hierarchy due to the higher costs involved in collection, transport and reprocessing.

The recycling industry can sometimes be volatile, with market fluctuations creating uncertainty within the industry. Recycled materials usually compete with virgin products, which are often relatively cheap. Virgin materials do not have the environmental costs of their product included into the price, making it difficult for recycled resources to compete. This is particularly the case for low value plastics and recycled paper. However, in many cases, recycling makes good environmental and economic sense. [50]

Energy recvery

Recovery of energy from waste incineration or the combustion of landfill gas. Many types of waste, including municipal solid waste, sewage sludge and scrap tyres, contain an organic fraction which can be burnt in an incinerator. The energy is recovered via a boiler to provide hot water for district heating of buildings or high temperature steam for electricity generation. The incinerator installation represents high initial capital cost and sophisticated emissions control measures are required to clean-up the flue gases. [51]

Disposal

Looking at hierarchy disposal is the least desirable option, also known as "burying it". This is the last resort method for waste disposal and the least favoured (in waste reduction terms), although still the most common. Mostly it is the least favoured because there are no benefits from what has been buried in the ground. Once something is at a landfill and buried (provided the landfill is set up and lined properly) there is no real harm the waste can do as it degrades naturally - although this can take thousands of years. [52]

The European Union, through the Waste Landfill Directive (Council Directive 1999/31/EC 1999) [11] has set targets for the reduction of biodegradable waste going to landfill, to encourage more recycling and to reduce emissions of the greenhouse gases. Where disposal to landfill occurs, the process is controlled, ensuring that human health is not endangered or harm to the environment does not occur.

3. INCINERATION

Incineration is a method of waste disposal that involves the combustion of waste. It may refer to incineration on land or at sea. Incineration with energy recovery refers to incineration processes where the energy created in the combustion process is harnessed for re-use, for example for power generation. Incineration without energy recovery means the heat generated by combustion is dissipated in the environment.

Incineration or burning of non-recyclable solid waste helps to reduce the volume and the health risks related to the waste fraction to dispose. Incineration is waste treatment process involving combustion of organic substances in waste materials. Incineration and other high temperature processes for waste treatment are called “thermal treatments”. Incineration reduces the volume of waste (previously compressed into trucks for waste removal) by 95% to 96%. This means that the replacement of waste disposal for incineration of waste significantly reduces the space required for waste disposal. Trucks for waste disposal often have a built-in compressor which reduces the volume of waste before delivery to incineration plants. Alternatively, in landfills the uncompressed volume of waste can be reduced by about 70% with compression by static steel method, but implying a significant cost of energy. [12]

The Waste incineration directive (WID) makes specific reference to facilities for the incineration and co-incineration of waste and provides the following definitions for these terms in Article 3 of DIRECTIVE 2000/76/EC of the European Parliament and of the Council of 4 December 2000 on the incineration of waste. [13]

“*Incineration plant*” means any stationary or mobile technical unit and equipment dedicated to the thermal treatment of waste with or without recovery of the combustion heat generated. This includes the incineration by oxidation of waste, as well as other thermal treatment processes such as pyrolysis, gasification or plasma processes in so far as the substances resulting from the treatment are subsequently incinerated. [13]

This definition covers the site and the entire incineration plant including all incineration lines, waste reception, storage, on site pre-treatment facilities, waste-fuel and air-supply systems, boiler, facilities for the treatment of exhaust gases, on-site facilities for treatment or storage of residues and waste water, stack, devices and systems for controlling incineration operations, recording and monitoring incineration conditions.

‘Co-incineration plant’ implies any stationary or mobile plant whose main purpose is the generation of energy or production of material products and: [13]

- which uses waste as a regular or additional fuel; or
- in which waste is thermally treated for the purpose of disposal.

If co-incineration takes place in such a way that the main purpose of the plant is not the generation of energy or production of material products but rather the thermal treatment of waste, the plant shall be regarded as an incineration plant within the meaning. [13]

The advantages of incineration:

- A substantial reduction of the volume of the rest of the treatment (over 90%),
- A low environmental impact in relation to the disposal of untreated waste and in relation to biological treatment
- A partial compensation of expenses through energy production [53]

The disadvantages of incineration:

- Relatively high investment costs
- 25%-30% of solid residues in the form of ash
- Emission of pollutants through gas into the atmosphere [53]

3.1 Directive of the EU parlament on the incineration of waste

The Waste Incineration Directive (WID) implies the achievement of significant savings considering the environment, human and animal health, air, surface and ground water by incineration and co-incineration of waste. Savings are achieved through compliance with strict conditions for emission of exhaust gases and the amount of waste produced by incineration system. The Waste Incineration Directive was designed so that the same operative and technical limitations for thermal treatment of waste in energy facilities should be in force throughout the European Union. The WID was replaced by the Industrial Emissions Directive 2010/75/EU, which came into force on 6^{th}January 2011.

The Industrial Emissions Directive (IED) is a recast of the WID alongside six other European Directives. The objectives of the IED are to “reduce emissions into air, soil, water and land

and to prevent the generation of waste, in order to achieve a high level of protection of the environment taken as a whole”. Operator’s combusting waste would need to comply with Annex VI of the IED. [14]

Waste incineration is a waste management tool. It is, therefore, important to note that all Community waste legislation has a direct relevance to the Directive 2000/76/EC, whether this aims to reduce waste generation or address alternative management options.

The Directive covers some types of waste that had not previously been covered by the Directives on municipal incineration (Directives 89/369/EEC and 89/429/EEC) and hazardous waste incineration (Directive 94/67/EC), which are repealed by Directive 2000/76/EC. [15]

Directive 2000/76/EC has a clear relationship with those Directives which it replaced – those on municipal incineration (Directives 89/369/EEC and 89/429/EEC) and hazardous waste incineration (Directive 94/67/EC). As noted above, permitting for incinerators under Directive 2000/76/EC is to undertake within the procedures set out under the IPPC Directive 2008/1/EC. [15]

The Directive sets out the limit values for emission to air for a whole range of toxic gases including:

- total organic carbon
- heavy metals such as
    - mercury,
    - cadmium,
    - chromium and
    - lead,
- dioxins and furans,
- carbon monoxide,
- dust/ particulates,
- hydrogen chloride,
- hydrogen fluoride,
- sulphur dioxide,
- nitrogen oxides and

- gaseous organic compounds (expressed as The Total Organic Carbon-TOC). [16]

Table 1 sets out the emission limits to air (EC Waste Incineration Directive 2000). The measurement of nitrogen oxides, carbon monoxide, dust, TOC, hydrogen chloride, hydrogen fluoride and sulphur dioxide are required on a continuous basis. Heavy metal concentrations and concentrations of dioxins and furans, because of the complexity of the analytical process, need to to be reported twice per year.

Table 1: Air emission limit values for incinerators

Daily average values	
Total dust	10 mg/m3
Gaseous and vaporous organic substances, expressed as total organic carbon	10 mg/m3
Hydrogen chloride (HCl)	10 mg/m3
Hydrogen fluoride (HF)	1 mg/m3
Sulphur dioxide (SO2)	50 mg/m3
Nitrogen monoxide (NO) and nitrogen dioxide (NO2) expressed as nitrogen dioxide for existing incineration plants with a nominal capacity exceeding 6 tonnes per hour or new incineration plants	200 mg/m3 (*)
Nitrogen monoxide (NO) and nitrogen dioxide (NO2), expressed as nitrogen dioxide for existing incineration plants with a nominal capacity of 6 tonnes per hour or less	400 mg/m3 (*)
(*) Until 1 January 2007 and without prejudice to relevant (Community) legislation the emission limit value for NOx does not apply to plants only incinerating hazardous waste.	

Source: [17] made by the author

There are, however, some notable exemptions from WID under Article 2 for treatment of plants concerning exclusively the following types of waste:

- vegetable waste from agriculture and forestry;
- vegetable waste from the food processing industry, if the heat generated is recovered;
- fibrous vegetable waste from virgin pulp production and from production of paper from pulp, if it is co-incinerated at the place of production and the heat generated is recovered;

- wood waste, with the exception of wood waste which may contain halogenated organic compounds or heavy metals as a result of treatment with wood preservatives or coating, and which includes in particular such wood waste originating from construction and demolition waste;
- cork waste;
- radioactive waste;
- animal carcasses as regulated by Directive 90/667/EEC without prejudice to its future amendments; and
- the waste resulting from the exploration for, and the exploitation of, oil and gas resources from off-shore installations and incinerated on board the installation. [13]

3.2 Types of incinerators

Incineration system, with the exception of large municipal system, can be small-scale, “batch” incineration. Examples of that type of incineration are: incineration of animal waste (waste of animal origins such as waste from butchery or dead animals from farms, etc.) incineration of medical waste (infectious or generally medical), incineration of industrial waste, etc. The advantage of these types of incineration is that the waste (especially potentially infectious waste such as animal or medical waste) is disposed at sight, without delay, without a need for risky and expensive transport. Consequently, the risk of spreading infectious diseases is decreased and waste disposal costs are reduced.

Incineration is primarily divided into:

- Mere thermal treatment
- Thermal treatment with energy recovery and
- Thermal treatment combined with energy and heat recovery (combined heat and power - ‘CHP’). [7]

The first generation of incinerators was set up in the first half of 20th century and all the following generations advanced parallel with the development of technology and knowledge: Development of incineration was influenced also by stricter directives for the preservation of the environment and human health. Benefits of different generations can be seen below.

I –st generation (1950-1965)

- major objectives: reduction of volume of waste and maximum burning,
- development of furnaces waste burning (mainly grates),
- usually lack of heat utilisation,
- lack of flue gas cleaning.

II-nd generation (1960-1975)

- dedusting of flue gas,
- utilisation of waste heat (heat utilisation boilers).

III-rd generation (1975-1990)

- reduction of gaseous pollutant emissions (mainly sulfur, chlorine and fluor compounds,
- reduction of heavy metals,
- problems with safety of storage of solid residues,
- improvement of waste heat utilisation.

IV-th generation (1990-)

- improvement of effectiveness of flue gas cleaning, mainly from NOx, dioxins and furans,
- improvement of parameters of solid aside products of waste utilization (ash) to safety storage: - cement blocks, - vitrification. [18]

Modern incinerators include pollution mitigation equipment such as flue gas cleaning. There are various types of incinerator plant design: moving grate, fixed grate, rotary-kiln, and fluidised bed. Modern incineration produces energy and reduces waste in inert residual with minimal pollution. Incineration of waste can be classified by exact criteria such as capacity, kind of waste that is processed, kind of system for burning waste.

There are 3 main classes of technologies used to combust MSW: mass burn, refuse-derived fuel (RDF), and modular combustors. This section provides a general description of these 3 classes of combustors. [7]

The data about the number of incinerations throughout Europe will be provided hereinafter. The incinerations presented belong to the group of municipal solid waste incineration (MSWI) with a capacity of more than 15 tonnes per day or 10,000 tonnes per year. Special plants for hazardous waste, sludge, agricultural, hospital waste and similar have not been included. The types of incineration which are included in the statistics are Waste to Energy. [7]

Information for 483 European Waste to Energy plants for 2014 has been provided in the full report by CEWEP. The following graph 1 shows all the countries in Europe with Waste to Energy plants. [19]

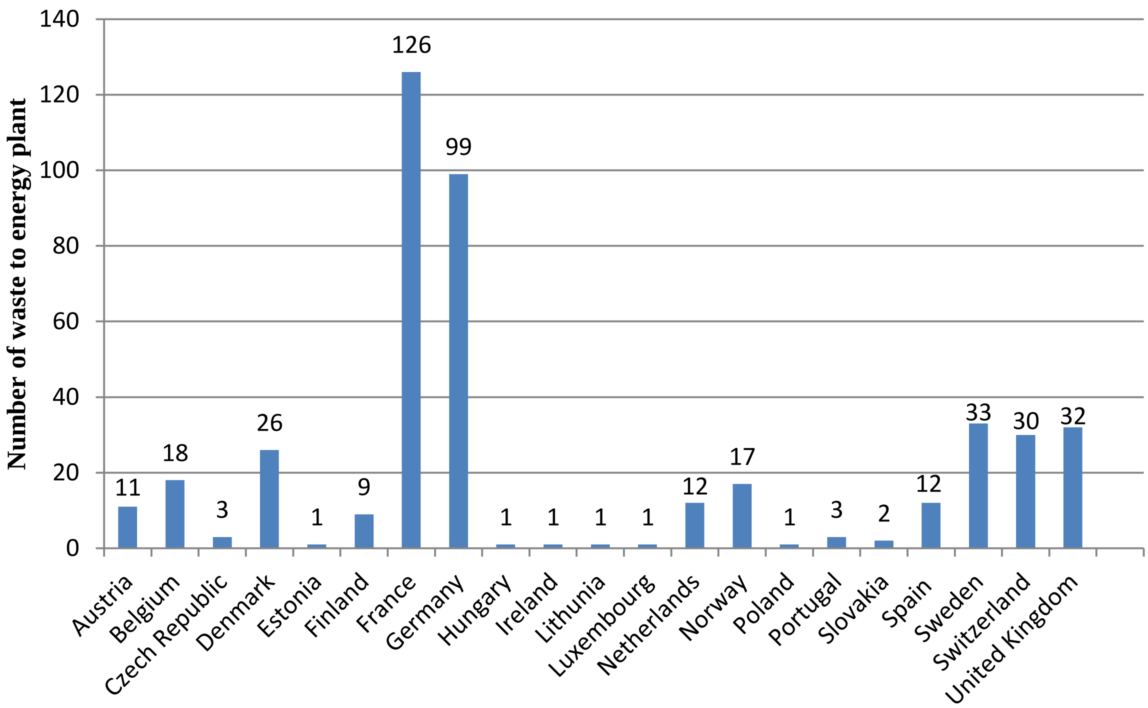

Chart 1: Waste to Energy Plants in Europe 2014

Source: [19] made by the author

3.2.1. Mass burn incineration

Concerning the issue of mass burn incineration, large-scale incineration of municipal solid waste is performed in one chamber in one stage where the complete combustion and oxidation will happen. Usually there are 10 to 15 tonnes per hour (tph) or 50 to 1,000 tonnes per day (tpd). [20] This kind of incineration belongs in the group of combustion incinerators. [16]

These incinerators are the biggest facilities where waste can be ignited at great temperatures. When these facilities were created, they were very simple with simple waste burning and ash transport to landfills for disposal. Their popularity subsequently increased, as well as their complexity for big loads of waste to generate energy. Most of them are still in use today and are credited as waste-to-waste facilities.

The core of the plant is its combustion system, which can be split in 2 large groups: the burning of "as-received" and inhomogeneous waste and pre-treated and homogenized waste. These schemes are usually based on a moving grate and are widely used and tested with new technologies. Its benefits are technical performance and large variations in waste composition and calorific value. A rare mass burning substitute is the rotary kiln. [6]

Figure 6 shows normal modern municipal incineration plant with energy recovery. It can be split into five big fields:

1. waste delivery, bunker and feeding system;
2. furnace;
3. heat recovery;
4. emissions control;
5. energy recovery via district heating and electricity generation [16]

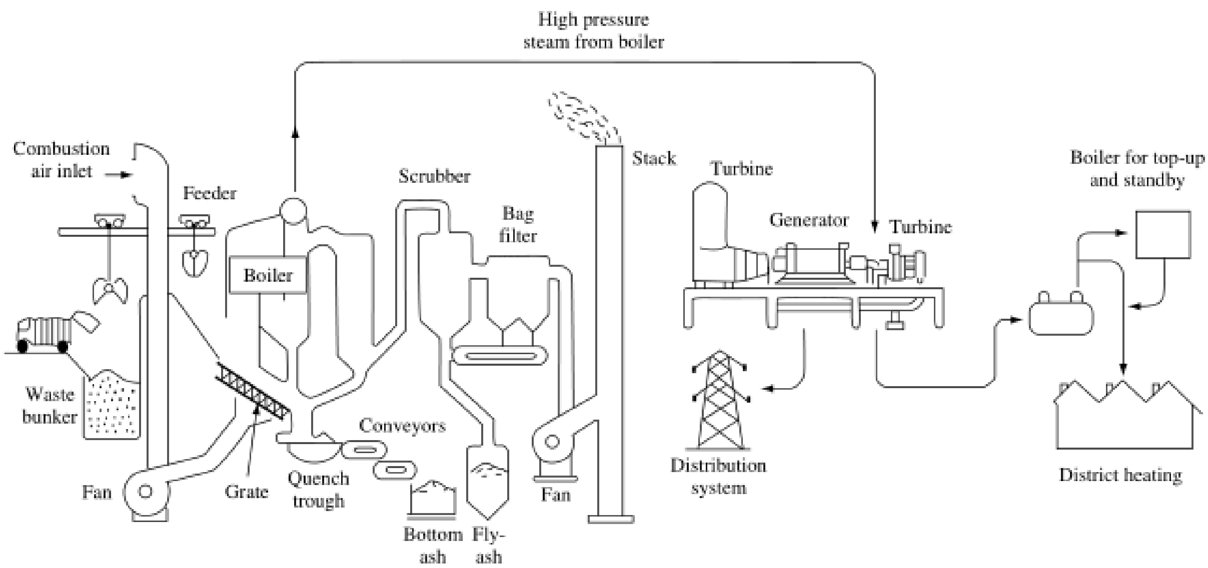

Figure 6: Schematic diagram of a typical mass burn municipal solid waste incinerator

Source: [16]

The mass burn combustor category can be divided into there principal subcategories of the mass burn technology:

- **Mass burn refractory-walled (MB-REF)-** energy is recovered by a waste heat boiler located after the combustion chamber
- **Mass burn water wall (MB-WW)-** Energy is recovered by steel tubes filled with water which line the combustion chamber
- **Mass burn rotary kiln (MB-RK)** similar to a refractory furnace, but uses a rotating combustion chamber [21]

The advantages of this incineration technology:

- Efficient and cost-effective for medium capacities,
- Flexibility in the drive,
- Relatively easier regulation of temperature. [54]

The disadvantages:

- Not applicable for bigger plants,
- Requires relatively complicated system for pre-treatment of waste,
- Relatively big drive expenses. [54]

3.3. Fuel from waste

Fuel from waste is produced in waste management plants from non-hazardous and unsorted municipal waste in accordance with the hierarchy of waste management of the European Union. The process which is performed by processing waste into fuel from waste is called Mechanical Biological Treatment (MBT). MBT technology combines two key processes: mechanical (M) and biological (B) treatment of waste which is the main objective of reducing the volume of waste that ends up in the landfill. The experience of more developed European countries shows that with MBT implementation the need for landfill volume can be reduceed by 40% to 60%, and landfill gas emissions to 80%-90% [46]. Various elements of M and B processes may be configured in different ways to provide a wide range of specific objectives such as:

- Maximising the amount of renewable fuels (glass, metal, plastic, paper, etc.)
- Composting

- Production of high quality solid fuel from waste – RDF and SRF properties
- Production of bio-stablilised materials (with a biodegradable component)
- Production of biogas for the production of heat and/or electric energy [55]

In order to be classified as a fuel from waste, such fuel must be processed, homogeneous and it needs to correspond with its composition to certain criteria such as moisture content, calorific value, ash content and content of heavy metals, to name a few. Fuel from waste is produced in a controlled environment and according to strict quality control and regulation.

Fuel from waste consists of paper, cardboard, wood, textiles and small plastics, dry, stable and free of odors. Due to the high calorific value it is used as a fuel throughout the European Union in different plants, from cement kilns to power and heating plants. [56]

Use of fuel from waste implies the following benefits:

- Reduction in the proportion of fossil fuel use
- Reduction in the amount of waste that has to be disposed of at landfills
- Reduction in the costs of energy
- Reduction in the emisson of greenhouse gas or carbon monoxide
- Opening of new possibilities for development of local bussinses [56]

3.3.1. SRF- solid recovered fuel

Amongst all the known MBT processes for the production of waste from fuel the most commonly used process is bio-drying, which provides fuel known as SRF (solid recovered fuel). SRF is prepared from non-hazardous waste to be utilised for energy recovery and incineration and coincineration plants and meeting the classification and specification requirements laid down in EN15359 (Standard from the European Standardisation Committee).

SRF is produced by waste treatment, shredding, separation of biogenic fraction (paper, organic mater, textiles, wood, organic fine fraction, other fossil fuels and plastic) and its chemical properties are similar to fossil fuels such as stone coal. Fuel from waste is an alternative energy source that is used to produce energy and that meets the criteria laid down in European standards CEN/TC 343 - Solid Recovered Fuels. [57]

Furthermore, the use of SRF in the cement industry, where it can be found in the largest application, is considered "Best Available Technology" and is explained in the section "1.2.4. Use of waste " in the document of the European Commission. *(Source: European Commission (ed) (May 2010) Reference Document on Best Available Techniques in the Cement, Lime and Magnesium Oxide Manufacturing Industries*)

Cement industries increasingly appreciate SRF due to its composition and its higher quality concerning its composition from RDF which will subsequently be explained, also SRF has to comply with CEN/TC343 standard with respect to its composition. The composition of SRF with raw materials that it includes can be seen in the chart on number 2. All those raw materials have to be ensured by MBT plants while collecting and sorting the waste because unless this has been done, the expenses can be significantly higher. [58]

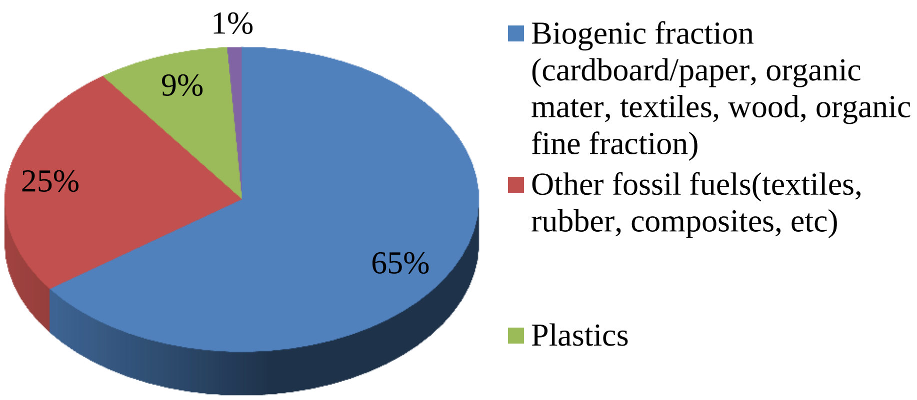

Chart 2: A view of all the present materials that make up SRF

Source: [55]

In the European cement industry an average rate of fossil fuel replacement by using fuel from waste was 30% in 2010 and in some countries even exceeding 60%. Austria leads in SRF/RDF fuel from waste exploitation, while it is the least used in Italy with 8.63%, all of the countries listed and their percentages of RDF/RDF use have been presented in the Chart 3. [47]

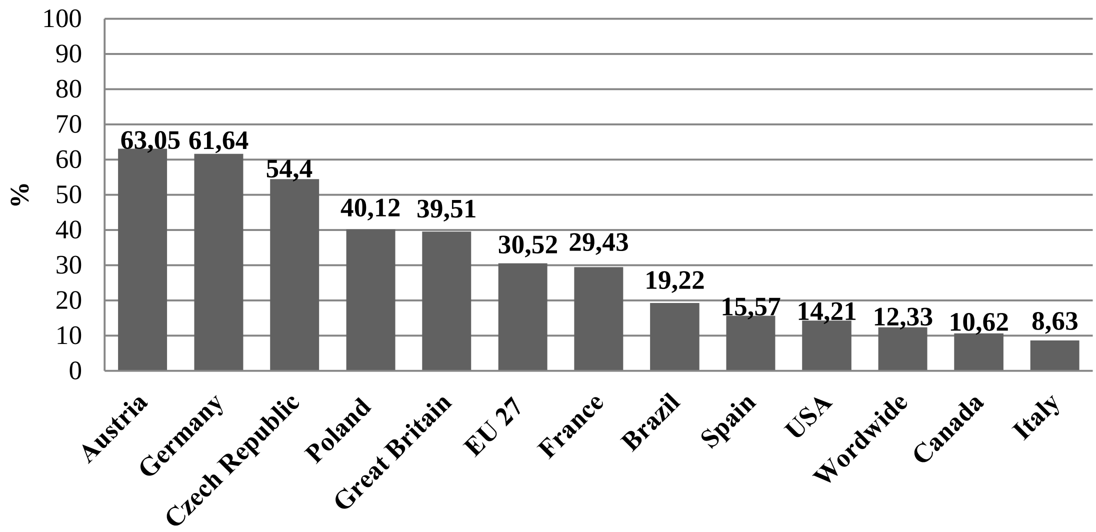

Chart 3: rate of fossil fuels replacement by SRF usage

Source: [47]

From 1 tone of non-hazardous waste can be made from 230 to 500 kg of fuel (SRF/RDF), depending on its composition. [58]

3.3.2. RDF-Refuse Derived Fuel

Lower quality fuel is produced using other technologies that are usually obtained from coarse waste which is removed from the material before entering the stage of biological treatment and it is called RDF (refuse derived fuel). Therefore this fraction, in addition to having significantly lower calorific value, is not fully biologically stable and if it has to be disposed it represents a significant level of share disposal. RDF entails light and suitable fractions that have the required composition and energy value that can be used as a supplement or alternative to regular fuels (mainly fossil) in our case in factories for the production of cement they have a key number of 19 12 10 combustible waste (fuel derived from waste) and don't have properties of hazardous waste. [58]

The main difference between RDF and SRF is that for the RDF Classification according to EN 15359: 2012 is not applicable, so the cement industry has to exactly specify when ordering certain features that correspond to the technological process. With SRF a well-defined system of classification according to EN 15359: 2012 is applied, so that the cement when ordering must specify the class of SRF's particular economic feature (heating value), technological feature (chlorine) and environmental characteristics (live). [48]

All of these cement plants, incinerators, power plants, thermal power plants that use SRF and RDF fuel must be certified for the usage of this type of fuel in its plants. The permits are issued by government institutions with the previously performed control activities and analysis of the impact on human health and the environment in the areas where the plants are located.

4. ANALYSIS OF WASTE MANAGEMENT IN CZECH REPUBLIC AND REPUBLIC OF CROATIA

4.1. Analysis of Czech Republic waste management system

The Czech Republic is a country located in Central Europe, covering an area of 78 866 km2. Its population is 10 553 843 (as of December 31, 2015) and the number of its inhabitants is expected to increase in the future. The country is divided in 14 regions, including the capital – the city of Prague - which forms one region. In the Czech Republic there are 206 municipalities with extended responsibility for waste management and a total 6258 municipalities. The current situation in the Czech Republic concerning waste management has been improving and waste management is a dynamically growing sector of the national economy. [24] [25]

4.1.1. Waste Legislation in the Czech Republic

The Waste Act in the Czech Republic was first adopted in 1991. Before adopting the Waste Act, there was no legislative control or no rules concerning waste handling in the Czech Republic and waste management was not governed by any sectorial rules with the exception of so-called secondary raw materials. [26]

Waste Act no. 185/2001 was adopted in 2001 and it emphasised waste prevention, defined the hierarchy of waste handling, and promoted the fundamental principles of environmental and health protection in waste handling.

Following this Waste Act, a large number of decrees have been adopted, and it is important to highlight as follows: [26]

- Decree No. 381/2001 Coll., List of Waste
- Decree No. 383/2001 Coll., on waste management
- Decree No. 376/2001 Coll., on classification of hazardous waste properties
- Decree No. 294/2005 Coll., conditions of landfilling and use of waste on the surface

In June 2003 the Government of the Czech Republic adopted a new waste management regulation on the waste management plan (2003 – 2013). This constitutes a far-reaching planning document which is deemed to enforce EU strategies in the Czech regulatory framework, and will develop minimisation, recycling and treatment of waste. Particularly important provisions are those concerning source separation of bio waste, composting, as well as mechanical-biological treatment of municipal solid waste. Today the Czech legislative framework is compatible with EU norms and regulations for waste management. [27]

The latest revision to Waste Act No. 185/2001 Coll. entitled Revision No. 229/2014 Coll. The revision was aiming to ban landfilling of mixed household waste, recyclable and recoverable waste until 2024 and introduce obligatory separation of metal, bio, paper and glass waste in all the municipalities commencing from 2015. [27]

Currently a plan of waste management is new CZ Waste Management Plan 2015 – 2024. The government adopted a plan 22/ 12/ 2014 through the Government Decision No. 1080 and the Regulation No. 352/2014 Coll on the same day. The strategic aims of plan are: waste prevention, minimisation of environmental impact and health, maximal recovery and reuse of the Czech sources, secondary raw materials to replace primary sources. [27]

The Ministry of Environment is responsible for waste management and the waste strategy is covered by the State Environmental Policy and Implementation Plan, which set goals for 2012 - 2020. The goals cover the main regulations as reducing waste to the disposal in landfills and better reuse process for an improved and sustainable waste management system.

4.1.2. Institutional organization of waste management in the Czech Republic

Waste management system in the Czech Republic functions through the local government competency in waste management that is executed by the municipalities and the regions. Waste Act generally determines effective public administration in waste management. In terms of vertical organisation system it is divided into state administration and local governments (regional distribution of regions) in these terms power and responsibilities are included. On the other hand, horizontal organization is divided into individual institutions of public administration in the area of waste management, thus corresponding to their territorial jurisdiction and the associated hierarchy. Czech waste management authorities in hierarchical order have been listed hereinafter:

Ministry of Environment (MoE or the Ministry) has the highest level of competency, this is the central government administration authority in the field of waste management for the entire country, the regions and the municipalities. The MoE has developed the national WMP, the current WMP of the Czech Republic for the period 2015–2020, currently in force. Other bodies at the state level in the waste management field are: The Ministry of Interior (MoI), The Ministry of Agriculture (MoA), The Ministry Health (MoH) and The Ministry of Finance (MoF). [28]

Regional governments are the next level of bodies within the state administration in waste management, including 13 regions plus Prague as the capital city and a separate region. Regional governments are obligated by the law to commission and approve in the form of an obligatory ordinance their management plans. The plans of the regions must be based on and respect the Waste Management Plan of the Czech Republic and comply with all the rules and the laws. [28]

Municipalities (communal environmental offices) produce municipal waste and have a direct responsibility for the physical management of waste on their territory. Each municipality has the obligation to create a system of collection, removal and other waste management that is usually embedded in a municipal ordinance. In terms of financing the waste management system, it is a mandatory expenditure of municipal budgets. Municipalities have to make an annual report of the amount of waste to keep statistic data for regional governments and the Ministry. [28]

Czech Environmental Inspectorates execute monitoring and control and the inspection can impose fines. Institution has 10 local inspection offices in charge of control.

Other government entities have been listed below that implement the laws and fulfil the regulations in the field of waste management:

- Central Institute for Supervising and Testing in Agriculture (CISTA)
- Public Health Protection Authorities
- Czech Trade Inspection Authority (CTIA)

- Customs authorities
- Police of the Czech Republic
- Other entities and institutions in waste management
- Other organizations (e.g. CENIA, the Czech Environmental Information Agency, to name a few) [28]

4.1.3. Waste management in the Czech Republic

In the Czech Republic each inhabitant is provided door-to-door waste collection service for mixed municipal waste. In 2014, 32 million tonnes of waste was produced in the Czech Republic, of which 1.6 million tonnes was hazardous waste and 30.5 million tonnes other waste. 3043 kg / year of waste was produced per inhabitant. Out of 32 million tonnes of waste 83% has been reused, of which 79.5% was for materials and 3.5% used for energy recovery. 10.3% of all waste ended at the landfill. Over half (51%) of the total waste production consists of construction and demolition waste. However, it was almost fully utilised (almost 98%). [29]

An important group of total waste is municipal waste. The inhabitants of the Czech Republic in 2014 produced 5.3 million tonnes, implying a share of 506 kg of waste per each citizen of the Czech Republic. The share of municipal waste in total waste was below 17%. 2014 saw 46.5% of municipal waste produced of which 34.8% was used to produce material (in 2013 the share was 30%) and 11.8% was used for energy recovery (in 2013 also 12%). 48.3% of municipal waste was removed through landfilling (in 2013 it was 52%). [29]

From 2012-2014 the collection of separated municipal waste increased. The percentage of collected municipal waste in 2014 was 16%, whilst that percentage in 2012 totalled 17%. [29]

Waste management facility network

Some detailed information about facilities in waste management system is fundamental for strategic management of the waste management sector in the country and in some regions. The network of facilities for waste management comprises of various facilities subdivided by species and capacity. New European directives suggest separated waste collection at both national and regional level because of improved use of materials and the entire system. Development of new modern technologies is also imperative. New types of facilities are being provided and the existing ones require recostrution and expansion.

In 2013 the Czech Republic had 1,530 functional waste collection sites which were open for both companies and citizens, as well as over 1,480 locations for disposal of electric and electronic equipment and over 17,000 locations for disposal of portable batteries and accumulators. [28]

In 2014 the Czech Republic had 479 operational waste separation facilities, whereas the most important types of facilities for waste management system currently operating are systems for separating waste, especially for municipal waste for recovery. The waste that has greater value and is focused on is glass, paper, plastic and metal. 116 facilities for final waste separation are currently in function in the Czech Republic. [28]

In 2014 there were 178 landfills in function in the Czech Republic. The waste from the category “other waste” and “hazardous” can be disposed on waste disposal sites labelled as S-IO, S-OO, S-NE in accordance with the provision number 383/2011 COLL. In 2014 the waste in the category “other waste” could be disposed at a total of 152 landfills with free capacity exceeding 30 million m3. There were 39 landfills for inert waste with label (S-OI) and 25 landfills capable for hazardous waste. [28]

In the Czech Republic three incineration facilities are currently operating intended for energy recovery from municial solid waste in process for combining heat and power generation, they are called WTEI and the annual capacity of those incinerations is 654,000 tons. [28]

Table 2 shows incinerators of municipal waste and hazardous waste, with listed company names, the headquarters, the capacity and the capability of heat recovery process. Moreover, it provides the incinerators which work as energy recovery for hazardous waste (category is N) and alternative fuels which are produced from waste are used in facilities for co-incineration in cement producing process (cement plants). The number of this type of facilities for cement production in the Czech Republic is five with a capacity of 250,000 t/year, compared with hazardous waste incinerators whose capacity is 60,658 t/year on the territory of the entire country. [28]

Table 2: Selected waste incinerators including cement plants utilising waste in a technological process in 2010

Operator	Operator's registered office	NUTS	Management site	Designed capacity t.year–1	Heat recovery
Incinerators of municipal waste					
PRAŽSKÉ SLUŽBY, a. s.	Prague 9	CZ010	Prague 10	310 000	Yes
SPALOVNA A KOMUNÁLNÍ ODPADY Brno, akciová společnost; Zkratka: SAKO Brno, a. s.	Brno	CZ064	Brno	240 000	Yes
TERMIZO, a. s.	Liberec	CZ051	Liberec	96 000	Yes
Incinerators of hazardous waste					
AVE Kralupy, s. r. o.	Kralupy nad Vltavou	CZ020	Kralupy nad Vltavou	10 000	Yes
SITA CZ, a. s.	Prague 2	CZ080	Ostrava-Marianske Hory	18 400	Yes
DEZA, a. s.	Valašské meziřiči	CZ072	Valašské meziřiči	10 000	Yes
SITA CZ, a. s.	Prague 2	CZ042	Usti nad Labem	16 000	Yes
MEGAWASTE-EKOTERM, s. r.	Prostejov	CZ071	Prostejov	4 000	Yes
SPOLEK PRO CHEMICKOU A HUTNÍ VÝROBU, a. s.	Usti nad Labem City	CZ042	Usti nad Labem City	5 000	Yes

Source: [32] made by the author

It is important to mention also incineration facilities for medical waste. At end of 2013, 27 incinerators for medical waste operated throughout the Czech Republic. All the facilities have the required permissions for undisturbed work. [28]

The following picture provides all the types and locations of incineration systems on the territory of the Czech Republic. It can be noted that most incineration systems are located in the central Bohemian region because this region has the largest number of inhabitants when compared with other regions. Hence, it produces the largest amount of waste which needs to be managed in compliance with the law.

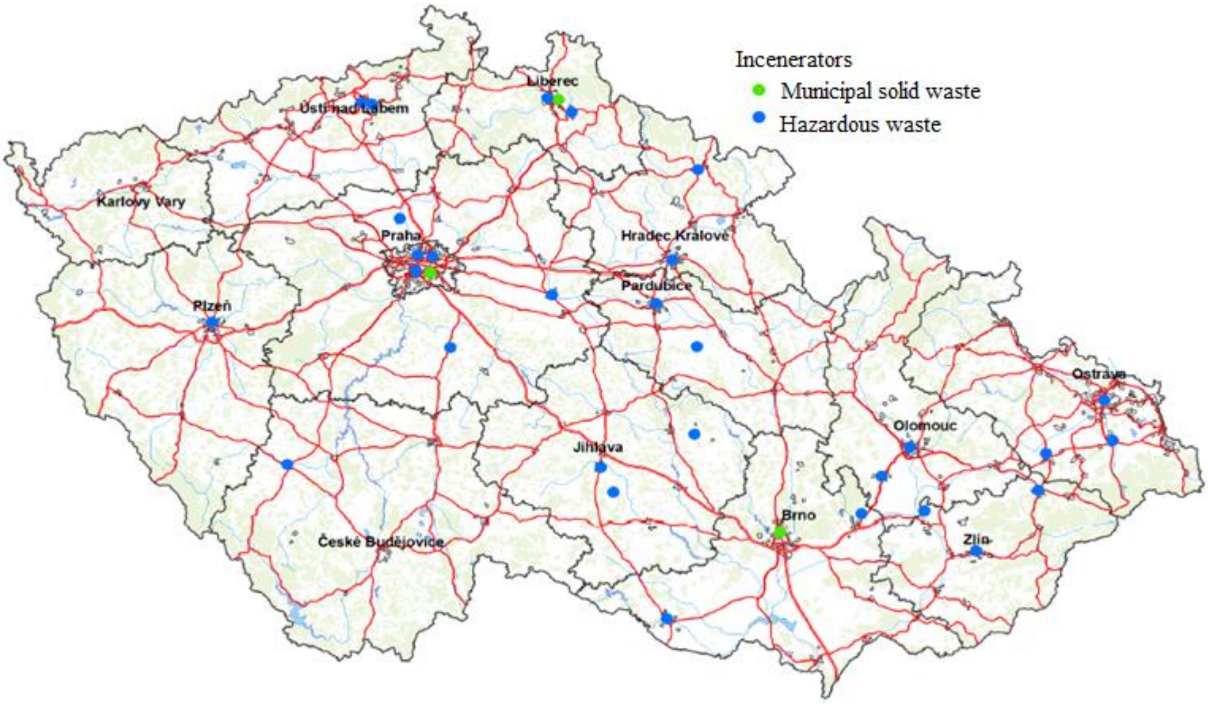

Figure 7: Locations of incinerators managing the waste in a technological process in 2010

Source: [32]

The operation of all the previously mentioned facilities is in compliance with the current regulations without any violations in their system.

In the table 3 all 14 regions on the territory of the Czech Republic are shown with the values of the total waste produced per each region in 2014. Moreover, it provides the values of generated hazardous and municipal waste for each region. [28]

Table 3: The amount of waste divided by categories in all the regions of the Czech Republic

Regions	Total waste production (1000 tons)	Total production of hazardous waste (1000 tons)	Total municipal waste production (1000 tons)
Prague region	4569	234	712
Central Bohemia region	4275	220	707
South Bohemia region	4054	193	664
Pilsen region	3404	153	531
Carlsbad region	3050	100	408
Usti region	2126	97	389
Liberec region	1856	94	297
Hradec region	1824	88	281
Pardubice region	1504	86	269
Jihlava region	1420	82	247
Brno region	1202	72	245
Zlin region	1143	72	239
Olomouc region	919	51	204
Ostrava region	682	25	132
Total	32028	1567	5325

Source: [30], made by the author

Waste treatment methods are defined by codes described in Act No. 185/2001 Coll., on waste, and Decree No. 383/2001 Coll. Methods for waste management process can be for material recovery as reuse, recycling and other methods. The benefits of waste management process are energy recovery, waste incineration and disposal of waste by landfilling (depositions on landfills and other). [31]

Since 2009, a positive trend has been recorded of an increasing share of recovered waste. Some of the reasons for this increase are changes in waste processing technology or due to replacement of primary materials with waste substitute materials.

A positive trend in the use of waste for material recovery can be also seen. From 2009 to 2014 the share of waste for these purposes increased from 72.5% to 79.5%. Between 2013 and 2014 the amount of waste that was used for material recovery was up by 25,466.9 tonnes. This has been illustrated on Chart 2. [31]

The most frequently used method of waste disposal is depositing on ground or beneath the ground on designated landfills. Generally, this method of waste disposal is characteristic of the Czech Republic. Over the recent years the situation started improving. Between 2009 and

2014 the share of disposed waste in the total waste generation dropped from 14.6% to 10.3%. From 2013 to 2014 the comparison of data shows a decreasing value of disposal of waste by 169.4 tonnes to 3,293.5 tonnes. t (Chart 4) [31]

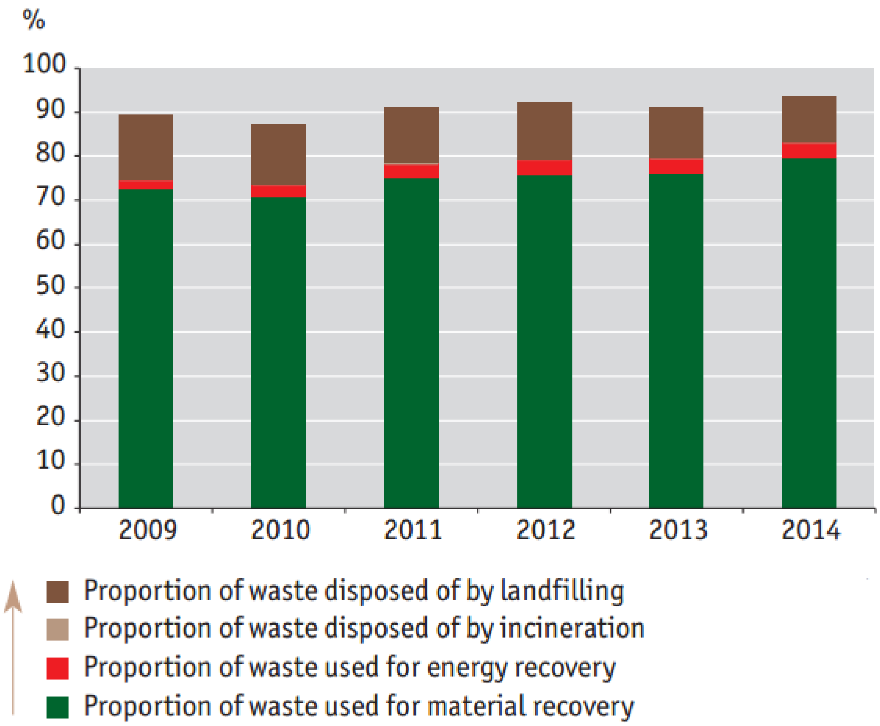

Chart 4: Proportions of selected waste treatment methods in the total waste generation in the Czech Republic [%], 2009–2014

Source: [31]

Only a small part of the total waste generation is used for energy recovery, in the long run, using waste for producing energy is more or less stagnating because European Union sets rules and strategies which member countries need to comply with, so they are turning to method of circular economy with zero waste system which provides greater efficiency and lesser loss of all benefits that waste could provide. Between 2009 and 2014 the percentage of waste which is used for energy recovery increased from 2.2% to 3.5%. A slightly increased amount of waste that was used for this purpose between 2013 and 2014 has been shown, by 68.3 tonnes to reach 1,110.4 tonnes. (Chart 2). [31]

Table 4 presents the amounts of waste that were processed in incinerations. It can be noticed that the amount of waste increased from year to year as the amount of recycling waste. The total amount of waste which was recovered, hazardous and non-hazardous waste, has been shown.

Waste recovery is a process whose main result is using waste for a good purpose, and this means situations when waste replaces materials which should be implemented in products or waste is used as fuel in factories or in a broader economic sense. [32]

The codes of list management methods/operations according to Decree of the Ministry of the Environment No. 383/2001 Coll. Pointed out are codes R1, R4, R4 D1-D5 and D10:

- R1- Utilisation of waste in a manner similar to fuel or in some other manner that produces energy. Covers the incineration and co-incineration of waste in power stations and industrial facilities such as cement kilns so that the resultant energy can be used to generate heat or electricity.
- R2 Solvent reclamation/regeneration
- R3 Organic substance recycling/reclamation
- R4 Recycling/recovery of metals and metal compounds
- R5 Recycling/recovery of other inorganic materials
- R6 Regeneration of acids or bases
- R7 Recovery of components used for pollution abatement
- R8 Recovery of components from catalysts
- R9 Oil re-refining or other reuses of oil
- R10 Land treatment resulting in benefit to agriculture or ecological improvement
- R11 Use of waste obtained from any of the operations numbered R1 to R10
- R12* Exchange of waste for submission to any of the operations numbered R1 to R11
- R13* Storage of waste pending any of the operations numbered R1 to R12 (excluding temporary storage, pending collection, on the site where the waste is produced) [32] [40]

* These codes (R12, R13) refer to pre-treatment operations, which must be followed by one of the remaining recovery operations.

Waste disposal is any operation which is not represented as recovery, including operations where energy or renewable material is generated as a secondary product of waste.

- D1- Depositing on or under the ground (landfilling)
- D2- Treatment by soil processes
- D3- Deep injection D4 Storage in surface reservoirs D5 Depositing in special technically controlled landfills
- D4- Storage in surface reservoirs
- D5- Depositing in special technically controlled landfills
- D6- Release into a water body except seas/oceans
- D7- Release to seas/oceans including sea-bed insertion
- D8- Biological treatment not specified elsewhere in this Annex which results in final compounds or mixtures which are discarded by means of any of the operations numbered D1 to D12
- D9- Physico-chemical treatment not specified elsewhere in this Annex
- D10- Incineration on land- Covers the incineration of waste where the main purpose of the incineration is the thermal treatment of waste in order to reduce the volume and the hazardousness of the waste, and to obtain an inert product that can be disposed of.
- D11- Incineration at sea
- D12 Permanent storage (e.g. emplacement of containers in a mine, etc.)
- D13* Blending or mixing prior to submission to any of the operations numbered D1 to D12
- D14* Repackaging prior to submission to any of the operations numbered D1 to D13
- D15* Storage pending any of the operations numbered D1 to D14 (excluding temporary storage, pending collection, on the site where the waste is produced) [32] [40]

* These codes (i.e. D8, D9, D13, D14 and D15) refer to pre-treatment operations, which must be followed by one of the other disposal operations. [32]

Table 4: The amount of total, recycling, landfill and incinerated waste for the period from 2010-2014

Tonnes

Code	Indicator	2010	2011	2012	2013	2014
	Waste management, total 1)	**27 952 975**	**30 506 667**	**30 237 544**	**28 994 027**	**30 876 896**
	Hazardous waste	2 092 432	2 055 452	2 053 153	1 725 276	1 758 332
	Non-hazardous waste	25 860 544	28 451 214	28 184 392	27 268 751	29 118 564
R4, R5	**Recycling**	**4 515 307**	**5 211 842**	**5 726 180**	**5 780 053**	**6 239 170**
	Hazardous waste	182 808	178 766	147 225	78 190	79 076
	Non-hazardous waste	4 332 499	5 033 076	5 578 955	5 701 863	6 160 095
D1-D5	**Deposit onto or into land (e.g. landfill)**	**4 169 356**	**4 990 482**	**3 668 271**	**3 608 189**	**3 433 885**
	Hazardous waste	60 289	53 285	36 717	35 161	35 403
	Non-hazardous waste	4 109 067	4 937 196	3 631 554	3 573 027	3 398 483
R1, D10	**Incineration**	**822 781**	**1 007 266**	**1 035 220**	**1 018 640**	**1 018 640**
	Hazardous waste	91 434	107 918	109 336	113 076	124 806
	Non-hazardous waste	731 347	899 348	925 883	905 564	970 738

*) Includes all waste produced, transferred from other companies, and taken from the warehouse; due to an amendment to the Act on Waste, not all waste management methods can be included in time series.
1) Includes waste from enterprises and municipalities.

Source: [33], made by the author

Second method for disposal waste is incineration. In the long term, only a share of 0.3% of the total waste generated is incinerated at an annualised level in the Czech Republic. Speaking from a broader perspective, a share of 0.3% of incinerated waste compared with the waste disposed on landfills is insignificant. [33]

Landfill and incineration tax in the Czech Republic

Incineration tax in the Czech Republic is not in place yet. The government still has not provided the required legislation for quotas and tariffs of one tonne of incinerated waste. Waste collectors have to pay on average €46 /t for incineration of municipal waste, whilst the fees usually range from €36 to €56. To this day the incentives of "energy to waste" and regulations have not been defined. In the Czech Republic, the renewable energy feed-in tariffs and premiums are provided; the tariff for the usage of landfills and sewage gas is €121.2 /MWh (feed-in) and €55.3/MWh (premium). [34]

Regarding the Czech law concerning the tax rates for waste disposal or landfill tax there is a strong correlation between raising taxes for landfill and restrictions on tax for the declining amount of the landfilled MSW. The data was provided for the period from 2001 to 2010 where the tax on waste disposal was raised ten times while the amount of landfilled waste was reduced by only 15% in the given period. From the presented values the percentage was not that significant when it is divided by a longer period of time and the reduction of the amount of waste depends on other factors and not only on landfill tax. [35]

Nevertheless, a limited impact on MSW incineration was detected by the adoption of the tax on waste disposal. Moreover, through a significant raise in taxes, a limited influence on MSW incineration was also detected. By raising taxes, no significant changes were accomplished concerning the incineration of MSW. There can be many reasons for that, all the waste that was redirected from landfills in other channels did not end up in the incinerator, some of the possibilities are sorting, recycling, biological processing, composting and reuse. The increase in MSW increased from 12.8% in 2001 to 14.9% in 2010 which can be seen in the Chart 5 [35]

Disposal in the Czech Republic still dominates as the first solution for waste disposal. The reason for this is that this solution is economically greatly appealing, because dumping is still a cheaper option than recycling and incineration, for specified activities the investment in the infrastructure is much greater than landfills and disposal considerations. Although the situation has started changing over recent years because of the EU laws that have to be complied with. This refers to the gradual increase of infrastructure and the capacity for waste disposal activities other than landfilling. The reason being the increased awareness of waste and support through EU funds for the development of the waste management sector. It is this system with accompanying infrastructure that has the ability to compete with the activities of waste disposal.

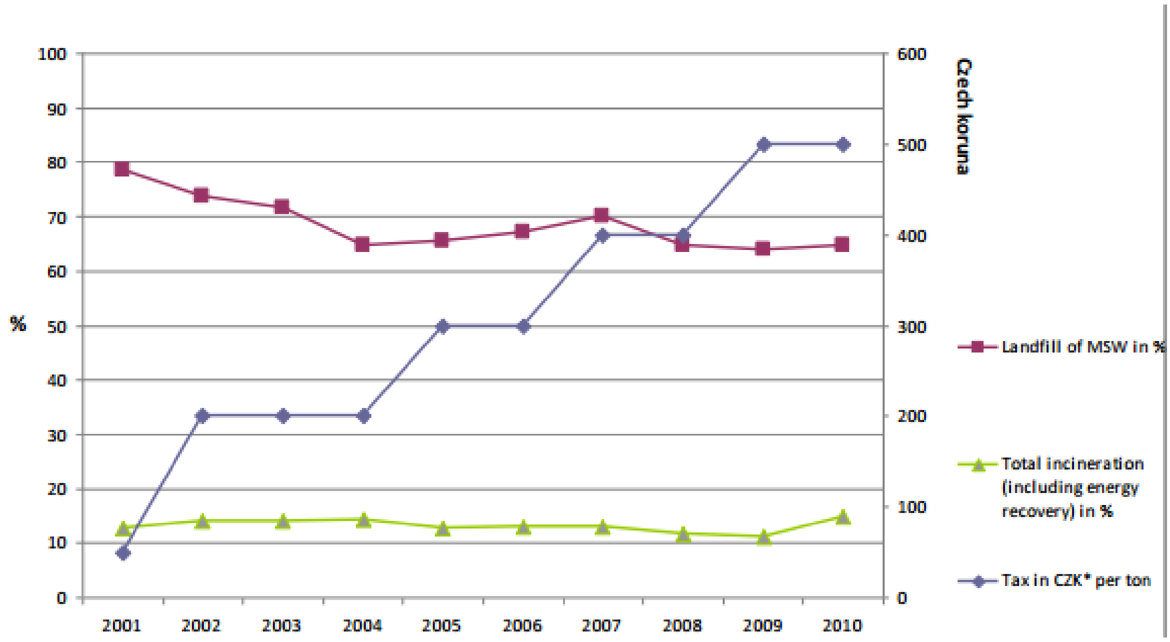

Chart 5: Development of landfilling and incineration of MSW and landfill tax in the Czech Republic

Source: [35]

4.1.3.1. Incineration and energy recovery from municipal waste in the Czech Republic

SAKO Brno a.s.

As has been previously stated, in the Czech Republic there are three incineration plants for municipal waste from which useful energy is received such as thermal and electrical energy. The first plant that started working was in Brno in 1904 and it was the first incineration plant in the former Austro-Hungarian Empire. During the Second World War the plant was destroyed and it was built again in Czechoslovakia in 1989. The total annual capacity of the plant is 240,000 t with 3 ČKD Dukla boilers with cylindrical grates. Since 1998 the incineration plant has been generating electricity with the capacity of 400 kW of electrical energy where mixed municipal waste is transformed into electricity and heat and these processes rank amongst the most modern ones in Europe. It has also undergone a substantial reconstruction of the facilities following investment worth €72 million. During the reconstruction 2 new lines for waste incinerations were built. Each incineration line consists of a steam boiler with a rated output of 45 TPH of steam. After the reconstruction which lasted from 2008 to 2011 the capacity increased to 248,000 t/year. The plant is managed by the SAKO Brno joint-stock company which is one hundred percent owned by the Statutory City of Brno. This is one of the leading waste management companies that operates in South Moravian region and is in compliance with ISO 9001 standard. It provides services in the field of waste management for cities, municipalities, businesses and the citzens. The incineration plant of Brno can meet the demands of the entire city of Brno with 30% of steam from the plant. The plant works on lower limits of exhaust gases than stated in the legislation concerning the protection of air quality. [37] SAKO Brno provides services for both businesses entities and the citizens, such as:

- Collecting waste
- Waste to energy- incineration
- Collection of bulky items
- Sales and rental of garbage bins and dumpsters
- Scrapping
- Illegal dumping removal [38]

Figure 8 shows all 36 collection centres operating in the city of Brno in the Czech Republic. All locations are shown as yellow stars and yellow star with red asterisks mark shows the location of SAKO Brno where there are also incinerators. It may be noted that waste collection centres on the map are well-distributed throughout the city, which implies a better management of transport costs in waste collection. Each location is an enclosed area and equipped with dumpsters equipment for waste collection that should not be disposed in standard waste bins. All these locations are available to citizens and businesses for collection of the following types of waste: [39]

- sorted waste,
- hazardous waste and
- bulky waste.

The waste in these collection centres is collected free of charge, the only thing that is subject to the collection of items such as tires and construction rubble without admixtures. Tyres - subject to a fee: CZK30 / pc without discs, CZK55 / pc with discs. On these locations diverse types of waste are collected such as: paper and cardboard, plastics, aluminium packaging, glass, textile clean, biological waste of plant origin from gardens and households, fluorescent tubes and energy saving light bulbs, bulky waste (furniture, flooring, textile products, mattresses, wood), car batteries, monocells, storage batteries, el. appliances past their service life, hazardous waste (paints, oils, acids, alkalis, dissolvents, pesticides), bathroom renovation waste.

Some terms and conditions that need to be complied with in waste collection centres have been listed hereinafter which are important for the smooth and proper running and management of the centre:

- A waste collection centre can receive vehicles of a maximum weight of 3.5 t
- Instructions of the waste collection centres must be respected and strictly obeyed.
- Instructions for waste disposal in containers needed to be obeyed which implies proper disposal of waste
- Operators in the centre are obligated to perform a visual check of the driveway waste received
- In case the centre does not have sufficient capacity, the operator may refuse to accept delivered waste and recommend a visitor to submit it to the nearest suitable site
- Treat bulky waste in advance in order to efficiently use the containers
- During the delivery of waste to be charged, such waste is disposed of in a container after an agreement on the amount of financial compensation for the received waste.
- If the collected waste is subject to payment, the operator of the center is obliged to issue the required accounting documents with a seal and the name of Statutory City of Brno, including the name of the physical entity, waste catalogue number, waste type and the total amount of the received waste. [39]

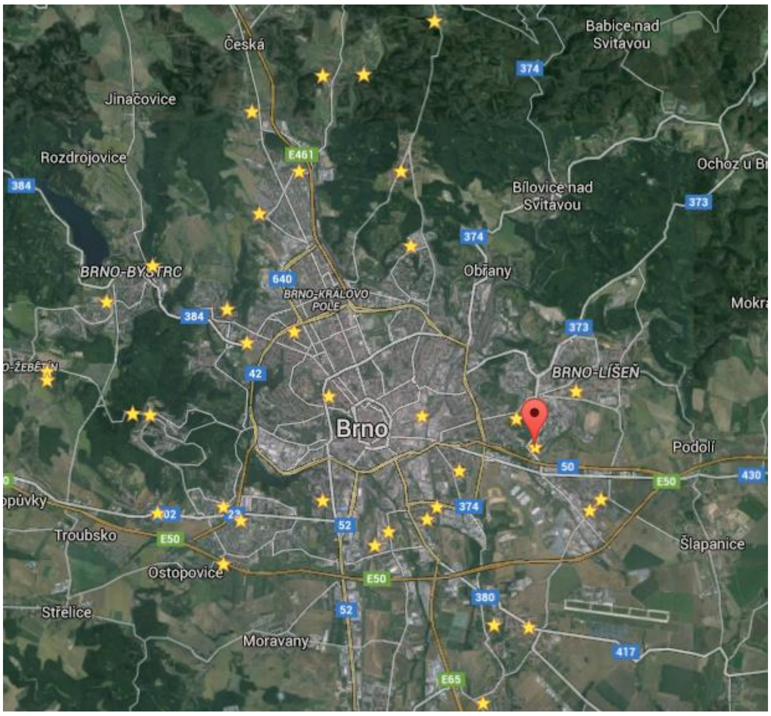

Figure 8: Waste collection centres in Brno which are owned by SAKO company

Source: [39] made by the author

There are considerable differences between the cases in which the company co-operates with businesses and the cases in which waste collection is organised for citizens and the waste collected in this way is fed to the incinerator. A special attention is paid regarding relations with businesses, due to the differences concerning sometimes larger quantities of waste of a small number of users and big administration complex that must be respected in the handover of waste and its processing procedure. There are specific rules when it comes to co-operation with businesses:

- Minimum weight of waste for transport in a truck is 1.5 t
- The price of a ton of waste disposal is CZK850 or €31
- Payment for waste disposal is in cash or on the basis of the account in case of contractual-relationship
- The waste producer is obligated to provide a basic written description of the waste, which they shall submit at the point of weighing at the entrance to the plant.

ZEVO Prague Malešice

The second oldest incineration was built in Prague in the late 1970's with a formal name ZEVO Malešice. It was intended for incineration of municipal waste and upgraded with new technologies in 1998 so it was capable of producing energy from waste. The capacity of the incineration works on 310,000 tonnes of waste/year which makes it the biggest incineration plant concerning its capacity in the entire Czech Republic. The reason is that the majority of the population lives in the central Bohemian region compared with the other 13 regions in the country. In the incineration there are 4 steam boilers with the capacity of 15 tonnes per hour for every boiler. [39]

TERMIZO Liberec

The last incineration plant for municipal waste that started operating is situated in the city Liberec and operates under the name TERMIZO a.s. Its construction work lasted for 3 years and testing operations started in 1999. Finally, it started operating in 2000. The plant works at the capacity of 96,000 t/year of MSW. It has one line for incineration with a moving grate and the capacity of 12 t/hour. Gaining steam from the work process, the water is supplied to the citizens of Liberec whose number stands at 102,000 according to the census conducted in 2013. [39]

This table shows the capacity of all municipal waste plants. Their percentages of utilisation of waste like electrical or thermal energy throughout the Check region has also been provided. Theoretical capacities of all the three plants for energy production from waste stand at 654,000 tonnes which accounted for 12.6% out of all the total municipal waste production in the Czech Republic in 2013. In that year there was 5.2 million tonnes of municipal waste. [37]

Table 5: Municipal waste incinerators in the Czech Republic

	Theoretical capacity in t / year	Energy recovery in 2014	Capacity utilization%	Quantities produced el. energy in MWh / 2014	The supplied amount of heat as steam GJ / 2014
ZEVO Prague Malešice	310 000	311 900	100,6	45 000	850 000
TERMIZO Liberec	96 000	93 541	97,4	24 400	672 696
SAKO Brno, Inc.	248 000	237 367	95,7	63 408	1 112 475
Total	**654 000**	**642 808**	**98,3**	**132 808**	**2 635 171**

Source: [36] made by the author

Disposal of waste and recycling can be done in various ways that have been described and listed in this paper. Table 6 shows methods of processing and the amount of waste that has been recovered, disposed or other ways of export of waste, composting and other similar processes. Concerning each type of waste and processing method total amounts have been provided with a special emphasis on the amounts of hazardous and non-hazardous waste.

Table 6: Methods of waste management in 2014*)

Tonnes

Code	Indicator	Total	Non-hazardous	Hazardous waste
	Waste management, total 1)	**30 876 896**	**1 758 332**	**29 118 564**
R	**Waste recovery, total**	**12 803 542**	**295 101**	**12 508 441**
R1	Use as a fuel or other means to generate energy	1 016 414	51 433	964 981
R2-R6	Recycling, regeneration	6 918 559	100 654	6 817 905
R12	Treatment of waste prior to recovery	2 741 359	108 739	2 632 620
D	**Waste disposal, total**	**4 601 284**	**660 305**	**3 940 979**
D1-D5	Deposit onto or into land (e.g. landfill)	3 433 885	35 403	3 398 483
D8	Biological treatment	449 877	194 009	255 868
D10	Incineration	79 130	73 373	5 757
D14	Treatment of waste prior to disposal	264 060	24 171	239 889
D15	Storage of waste pending any of disposal operations	385	i.d.	i.d.
N	**Other ways, total**	**13 472 070**	**802 926**	**12 669 144**
N5	Warehouse balance residuum as at 31 December	3 676 910	345 344	3 331 566
N7	Waste exports to the EU Member States	2 871 551	29 446	2 842 105
N17	Waste exports to non-EU states	73 468	i.d.	i.d.
N10	Sale of waste as a raw material	396 659	2 689	393 970
N12	Landfilling of waste as technology material securing landfills	1 164 969	107 265	1 057 704
N13	Composting	300 019	i. d.	i. d.

*) Includes all waste managed during the year (i.e. waste produced, transferred from other companies, and taken from the warehouse). 1) Includes waste from enterprises and municipalities.

Source: [33] made by the author

4.2. Analysis of waste management system in the Republic of Croatia

The Republic of Croatia is a Mediterranean country in the Southeast Europe. Croatia is bordered by Slovenia in the West, Hungary in the North, Serbia in the East and Bosnia and Herzegovina in the Southeast. Croatian coast is the Adriatic Sea, and it is the longest coastline in Southeast Europe on the Adriatic Sea. The country covers an area of 56,594 km^2 concerning its continental part and 87,661 km^2 implying its land and sea together. The country is divided in counties, Croatia has 20 counties and the City of Zagreb has the status of a separate county and it is also the capital of Croatia. The country has 4,284,889 inhabitants and the number of inhabitants is expected to decrease in the forthcoming future. [59]

4.2.1 The framework for waste management in Republic of Croatia

The legislation of waste management in the Republic of Croatia still has not reached a satisfactory level and the waste usually ends up on unregulated landfills, which in the extreme cases adversely affects both the environment and the population. The control of the amount of waste and the system of waste disposal is not precise enough in all the areas of regional and local authority so the problem of the forecast of the movement of waste can cause difficulties in planning the required capacities. Insufficient compliance with the legislation is present, utility charges in certain areas are insufficient to covering all the expenses. The citizens are not sufficiently informed concerning the requirement of classification and adequate waste disposal. Local and regional governments are not sufficiently encouraged to become involved in joint problem-solving at a regional level. The situation has recently begun to improve because the time limits set by the European Commission are expiring as the Republic of Croatia is a member of the European Union, but these results are not even near the specific goals and the system works with a lot of shortcomings, which will be shown hereinafter. [44]

Strategic planning documents:

- Strategy for Sustainable Development of the Republic of Croatia (NN 30/09)
- National Environmental Strategy (NN 46/02)
- National Environmental Action Plan (NN 46/02)
- Waste Management Strategy of the Republic of Croatia (NN 130/05)

- Waste Management Plan in the Republic of Croatia for the period 2007 to 2015 (NN 85/07, 126/10, 31 / 11, 46 / 15) [41]

General regulations for the area of waste are:

- Law on Ratification of the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal (NN MU 3/94);
- Act on the Environmental Protection and Energy Efficiency (NN 107/03, 144/12);
- Environmental Protection Act (NN 80/13, 153/13, 78/15);
- Law on Sustainable Waste Management (NN 94/13);
- Regulation on Categories, Types and Classification of Waste with a Waste Catalogue and List of Hazardous Waste (NN 50/05, 39/09);
- Regulation on the Control of Transboundary Movements of waste (NN 69/06, 17/07, 39/09);
- Decree on Border Crossing on the Croatian Territory over which the import of waste in the European Union and the export of waste from the European Union is permitted (OG 6/14);
- Rules on Waste Management (NN 23/14, 51/14);
- Ordinance on the Methods and Conditions for Thermal Treatment of Waste (NN 45/07);
- Ordinance on the Methods and Conditions of Waste Disposal, Categories and Operational Requirements for Waste Landfills (NN 117/07, 111/11, 17/13, 62/13) and
- Ordinance on By-Products and the Cancellation of the Status of Waste (NN 117/14). [41]

4.2.2. Institutional organization of waste management in the Republic of Croatia

The waste management system involves all the levels of the government: the national, the regional, the local and the municipal level, as well as all the areas of the economy of production, consumption and everyday life, and it includes a large number of participants.

The following administrative structures need to be mentioned at the national level:

The Parliament as the highest level in the hierarchical structure of the waste management system that makes the laws on waste and other relevant regulations of the strategy on waste management. [60]

The Croatian Government that makes plans on waste management, regulations, and mandatory sitting of buildings in the waste management system. [60]

Government bodies are the Environmental Protection Agency and the Environmental Protection and Energy Efficiency Fund. [60]

Environmental Protection Agency has the task of preparing reports about waste management, as well as of development and coordination of a unified information system of environmental protection and the development of indicators for monitoring the situation in waste department. [60]

Environmental Protection and Energy Efficiency Fund has the task of collecting fees (fees for motor vehicles, environmental impacts of hazardous and non-hazardous industrial waste management), project financing and determining conditions for funds (rehabilitation of landfills, encouraging avoidance and reduction of waste, waste treatment and utilisation of valuable waste, encouraging cleaner production and avoiding emissions in the manufacturing process). [60]

Regional Level Waste Management

According to regulations the regional authority shall adopt waste management plans county wise and the City of Zagreb for a period of eight years. Legal regulations prescribe that waste management plans for the counties and the City of Zagreb must be in line with the Strategy and Waste Management Plan of the Republic of Croatia, Sustainable Development Strategy of the Republic of Croatia, Environmental Protection Plan of the Republic of Croatia and the County Enviromental Programme and Environmental Protection Programme of the City of Zagreb. The county is required, in their respective areas, to ensure the implementation of the prescribed measures for the disposal of hazardous waste and waste incineration. The county needs to cooperate with local governments during the implementation of measures for the management of such waste. Moreover, several counties can opt for a joint implementation of measures for the management of such waste. Buildings intended for the storage, recovery and

/ or disposal of waste must be planned in a way to meet the requirements at the national level. In this way, it is an attempt to ensure compliance of planning and action in the field of waste management at a national and a regional level. [61]

In accordance with the regulations, the local government shall adopt waste management plans and determine the location of the physical plans of municipalities and cities for the period of eight years. Legal regulations require that waste management plans of municipalities and cities must comply with the county waste management plan and county programmes of environmental protection. They are obligated to implement waste management measures and for the collection and dissemination of data.

Other pariticpants in the organisational structure:

Manufacturers and importers of products and waste, legal and physical entities, activities that generate waste (household, economy and the public sector) participate in the waste management at the state, regional and local governments, depending on the method and degree of organisation and knowledge, awareness and information. It is their responsibility to make waste management plans, and provide data to the competent authorities. [61]

Waste management companies - the main task is the collection and transport of waste and management of facilities and installations for waste management, as well as to provide data to the competent authorities. [61]

Consulting companies, professional organisations and associations- implement activities to improve practice, awareness and encourage participation in the organised system of waste collection and its improved utilisation. [61]

All these structures are responsible in their area of work for the functioning of the system. Field data are prepared by the state administration offices in the counties on the basis of statements made by the departments of environmental protection in cities and municipalities. The scheme of the organisational structure and interconnectivity has been shown in Figure 9.

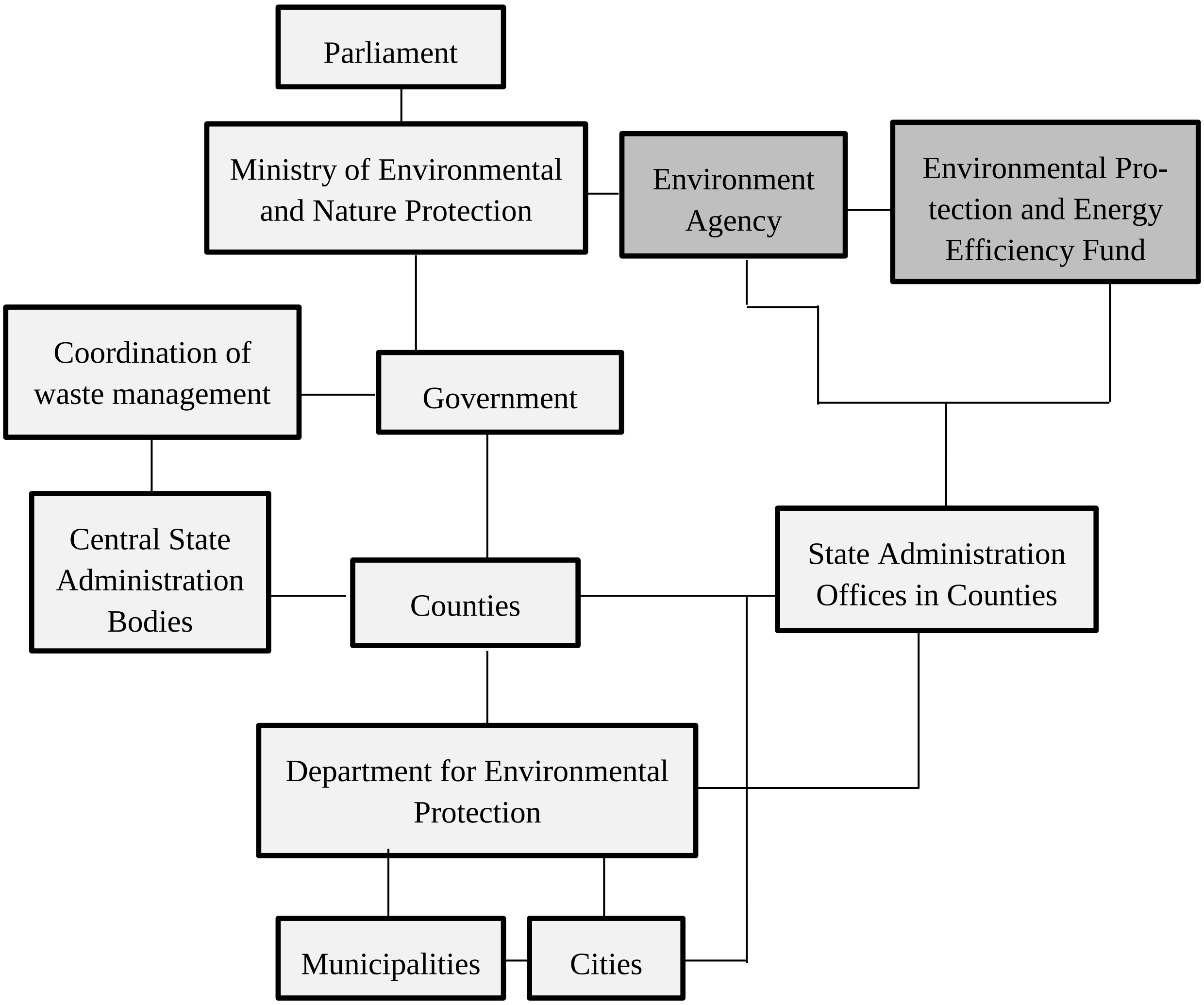

Figure 9: The organizational structure of Croatian institutions in the Waste Management

Source: [42] made by the author

4.2.3. Waste Management in the Republic of Croatia

In 2014, the total registered amount of waste (municipal and manufacturing) was about 3.5 million tonnes, what is 4.5% up compared with 2012. Considering the origin of the waste, the largest share was generated by households, as much as 33%, including different types of waste produced by the citizens. Concerning the economic activities, the largest waste producers are the service sector and the construction sector with the share of 18%, followed the manufacturing sector accounting for 13%, the collecting, processing, waste disposal and recycling of the materials services with a share of 12%. The remaining economic sectors accounted for 6.5% of the total amount of waste. [43]

Public service of municipal waste collection in 2014 covered 99% of Croatian population, and it was not available in one municipality. The total amount of municipal waste that was produced on the territory of Croatia in 2014 was 1,637,371 tonnes or 382 kg per capita. From 2010 to 2014 there was an increase of separately collected waste types from municipal waste. 2014 saw 396,594 tons of separately collected municipal waste (24% of the total amount of municipal waste) which was 8% up in relation to 2011, or an increase of 10% compared with 2010. [43]

Although the number of local governments that perform the primary selection of waste has been increasing, there is still a large number of JLS, two-thirds and currently useful types of waste and municipal waste are not collected separately. The highest rates of municipal waste sent for recovery in 2014 was recorded in Međimurje County (36%), Koprivnica - Križevci County (21.1%) and the lowest in the Split - Dalmatia County (1.8%) and the County of Zadar (2%) [44]

Furthermore, during the period from 2010 to 2013 there was an increase in the share of municipal waste sent directly to recovery. The share of municipal waste directly addressed to recovery in 2010 was 68,947 tons (4% of the total amount of municipal waste) and in 2013 it was 258,056 tonnes (15% of total volume), including 8,728 tons of mixed comunal waste sent to mechanical and biological treatment. Consequently, a conclusion can be reached that the national rate of municipal waste sent for recovery in 2013 was 15%. The remaining amount of municipal waste was temporarily stored or forwarded to landfills where, usable components were isloated and forwarded for recovery (eg. bulk waste). The rate of recycling of paper, plastic, metal and glass from municipal waste in 2013 was 26.6%. [62]

The amount of landfilled waste that the landfills reported decreased in the period from 2010 to 2013 by almost 12%. In 2013 therewere 1,413,113 tons of communal wated reported for disposal, or 82% of total produced waste. [62]

The report on municipal waste for 2014 is based on data reported by collectors / transporters of municipal waste through forms PL-SKO (Registration form for the collector / carrier of municipal waste). From a total of 208 companies that in 2014 performed the activity of collecting mixed municipal waste, 206 submitted the data (in the forms PL-SKO) for 2014.

The biggest problem in the Republic of Croatia currently are excessively high rates of municipal waste sent to landfills, which still exceed 82%. This is partly due to the fact that there is no tax for waste disposal and this option appears to be the least expensive, also the entire system for waste disposal is not developed nor sufficiently invested in. One can compare this for example with the Czech Republic, where the government has set a tax of €20 / t, Italy €10-25 / t depending on the region, the United Kingdom €3-97 / t, Austria €87 / t whilst the EU average ranges around €80 / t. The local governments pay state taxes and the Republic of Croatia possesses the legal framework for the implementation of this tax on waste disposal and it only needs to be implemented. [63]

4.2.3.1. Buildings and facilities for waste management

Categories of waste management facilities in terms of spatial planning documents are waste management facilities at the level of the state, the county or at a local level.

Waste management facilities are defined by the decree that determines the structure and other interventions in the area of state and local (regional) importance and hence buildings of national significance have been listed:

- regional and county waste management centers,
- hazardous waste landfill,
- green islands and recycling centres,
- temporary hazardous waste landfill,
- facilities for treatment, storage and disposal of radioactive waste,
- incineration of waste [45]

Waste management centers in counties or regions are a type of industrial facilites intended for safekeeping (storage) or waste treatment for the purpose of the reuse and disposal of the remaining (unusable) amounts of waste in a safe way for the environment and human health. Those industrial facilities usually consist of a plant for mechanical-biological waste treatment (MBT plant). The plan envisages construction of modern facilities for recycling and recovery of electrical and electronic waste, scrap tires, old vehicles, waste oil packaging, car batteries, so that most hazardous waste is processed through these systems. Moreover, the plan envisages the establishment of a center for several counties in case of counties with a smaller area and a smaller number of citizens. [43]

Transfer stations are facilities for the preparation and handling of waste for shipment to a waste management centres (WMC) treatment and disposal (and possibly for a temporary storage) together with large capacity vehicles for the transport of waste over larger distances. Transfer stations are, in fact, dislocated entrance through which WMC receives waste collected at remote locations. [43]

In order to fulfill the negotiating positions, as well as strategic and planning documents from the scope of waste management, it was necessary to accelerate the preparation and construction of waste management centers and at the same time execute remediation and closure of existing landfills. Subsequently, we started with the construction of thirteen county waste management centers, hereinafter CWMC. Hence, diverse environmental organisations in the Republic of Croatia requested that the waste management centers were not built in this way because they are expensive, economically inefficient, technologically outdated and environmentally unacceptable. The associations believe that this is a destructive concept of waste management in Croatia because we are talking about harmful plants for mechanical - biological treatment (MBT) that will be implemented in ten of the planned 16 CWMC, and the price of these facilities will be €220 million. It has been suggested that one plant needs to be built per 1.3 million inhabitants. Hence, there is the issue of why should Croatia with 4.29 million citizens build ten plants for biological treatment of waste (1 plant per 429,000 inhabitants). Environmental organisations claim that these CCE facilities will be built near drinking water sources. They also launched a constitutional court proceedings to review the constitutionality of some specific regulations and seek involvement of experts in this area. [43]

As explained in the previous section, in the MBT plant unsorted municipal solid waste would be delivered and after treatment, from which only 30% of the recycling material would be used, the rest of the materials for recycling would undergo mechanical-biological treatment and bio-drying from which alternative fuel waste RDF would be formed with the final amount of 36%. [64]

In 2015, 21 facilities for energy recovery of waste were registered - 13 companies / small businesses obtained a certificate of registration in the Register, whilst their number in 2016 has increased to 15 companies / crafts energy waste recovery, and 6 companies in 8 locations have obtained permits for waste management for R1 process (using waste as a fuel or in other way to generate energy). We are primarily talking about plants for biomass and these plants do not use municipal waste as fuel. The information was obtained by contacting all 15 companies listed in the Register. In order to perform energy recovery certain types and amounts of plant waste are exempted from the requirement of obtaining a permit for waste management. Most of the energy recovery of waste is carried out in facilities that are not on the territory of the Croatia. A review of plant locations for energy recovery and waste incineration in 2016 has been provided in Figure 10. [43]

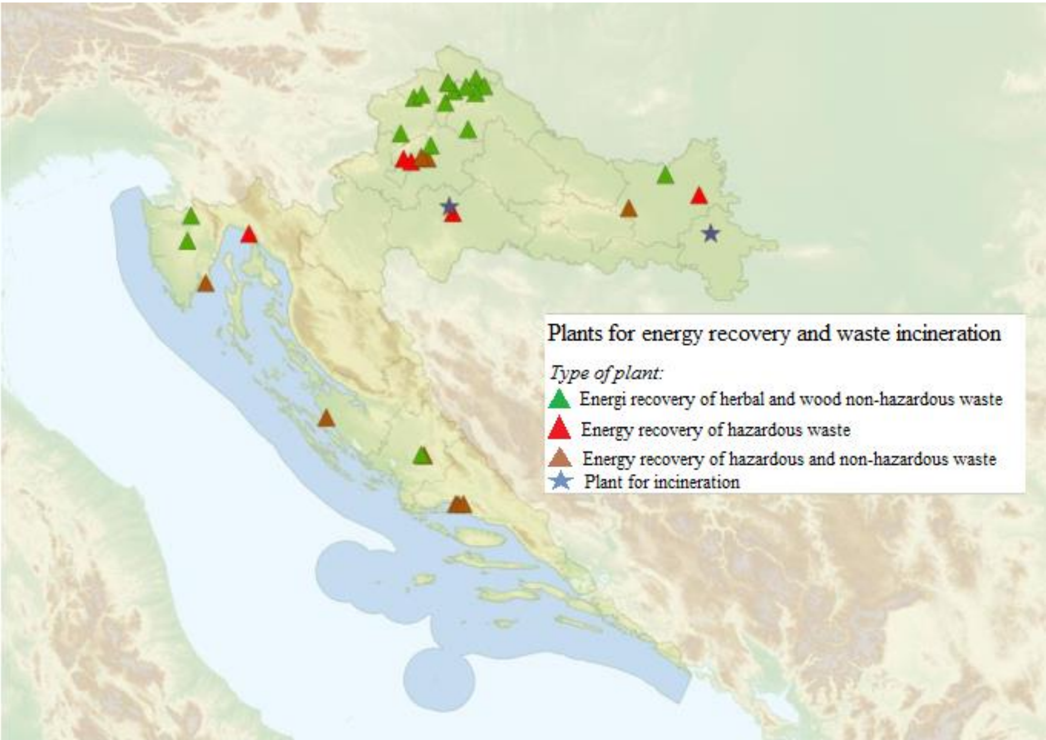

Figure 10: A review of plant locations for energy recovery and waste incineration in 2016

Sourse: [62]

Waste management facilities of at the county level

These are landfills that have not been registered as waste management facilities of national importance and cassettes for the disposal of asbestos. In Croatia the largest quantities of generated waste still end up in landfills.

Throughout 2015 waste was deposited at 146 landfills. In 136 landfill sites only municipal waste was disposed of, whilst at 10 locations exclusively industrial waste was disposed. By the end of 2015 172 landfills were closed and 83 locations of former landfills were displaced. From 2008 to the end of 2015 the number of rehabilitated landfills increased from 63 to 171 and 134 locations are in preparation or their rehabilitation is underway. [43]

The dynamics of landfill remediation was provided in the Waste Management Plan for the Republic of Croatia.

The period ranging from 2007 to 2015 was not satisfactory. Laws regulating waste disposal do not regulate waste management, especially the waste which is produced during research, treatment and storage of mineral resources of the continental shelf or seabed and subsoil. There are no conditions that restrict sinking waste on the seabed or its burial in the subsoil by a vessel or aircraft. No criteria have been provided about the type of substances that are allowed to soak in the sea based on a permit for waste management.

Concerning the disposal of asbestos waste generated in the construction owned by physical persons, a system of collection and disposal on special surfaces at landfills (casettes) was provided. The estimated remaining capacity of cassettes for asbestos waste at the end of 2015 was about 56,373 tonnes, or 35,233 m3. Although some opened capacities have been underused (17 casettes constructed whose total capacity is 121,470 tonnes), most of the construction waste containing asbestos is exported. [43]

Aerobic biological treatment of biowaste composting is performed in 11 compost plants with a total capacity of around 103,397 tonnes / year, of which 7 in 2016 have the permit for waste management. In 2016, only 6 out of a total of 10 biogas plants were holders of permits for anaerobic biological treatment of biowaste and their capacity is 234,800 t / year. [43]

Waste management facilities of local importance

Local units use local landfills for non-hazardous waste. These landfills need to be rehabilitated, yet the major problem is the lack of funding for rehabilitation. The local government has the task to address the issue of waste management facilities that are neither of national nor of county importance. [43]

4.2.3.2. Centers for waste management and mechanical-biological treatment

The process of mechanical biological treatment in the context of the entire system of waste management in the Republic of Croatia has been integrated in the main planning documents. The strategy of waste management of the Republic of Croatia (»Official Gazette«, No. 130/05) and Waste Management Plan of the Republic of Croatia from 2007 to 2015 (»Official Gazette«, No. 85/07) consists of the following phases:

1) Pre-treatement of waste
2) Mechanical biological treatment of biodegradable parts of municipal waste
3) Sorting parts of waste suitable for consumption
4) Producing alternative fuel from waste (RDF) [65]

It is important to highlight he fact that the centers for waste management in the Republic of Croatia are not intended for waste separation or recycling, but rather as pre-conditioning of waste for incineration in cement kilns. The obligations of the Republic of Croatia concerning the separation and the recycling of waste cannot be met by waste disposal in the centers. The waste that a waste management centre prepares for incineration in the cement plants is not considered as fuel and there are extra charges for the disposal of such waste. The current price per tonne for SRF and RDF fuel is €30/t that the utilities i.e. waste disposal centres pay to the cement plants for the disposal of the abovementioned waste. [66]

Concerning the costs of MBT plants, firstly investment costs regarding the construction of the abovementioned need to be analysed. The average construction costs are high, as has been shown in Table 7. In addition to the abovementioned construction costs, the costs of municipal waste treatment per tonne need to be analysed. It has been presented in the table and this shows an average for the centres in the Republic of Croatia, since the real costs should range from HRK 600 to HRK 1,000 which is on average from €80 to €133. If the amount of waste on the market is lower than it had been planned for a specific region, which is the case in the Republic of Croatia, the costs of production can be rather high. In that case, the final costs are incurred by the waste producers (citizens).[67]

Table 7: General in general of the MBT plant

Capacity, tpa	Technology	Investment Cost, milion €	Investment Cost, €/tpa	Operational Cost, €/ton
25 000	MBT	12,2	488	24 - 81
60 000	MBT	13,5	225	24 - 81
100 000	MBT	56	560	24 - 81
120 000	MBT	42	350	55
200 000	MBT	40,5	203	24 - 81

Source: [68]

The remaining waste for waste disposal - up to one tonne of municipal waste - is sent to MBT plants after processing and it is from 20% to 25%. Furthermore, it makes the investment more expensive concerning the operating expences. The second disadvantage is that a very small amount of separated materials such as plastic, cardboard, glass and paper have their market value, so they can be cost effective, too. These separated materials account for 10% of the total amount of the separated waste. [69]

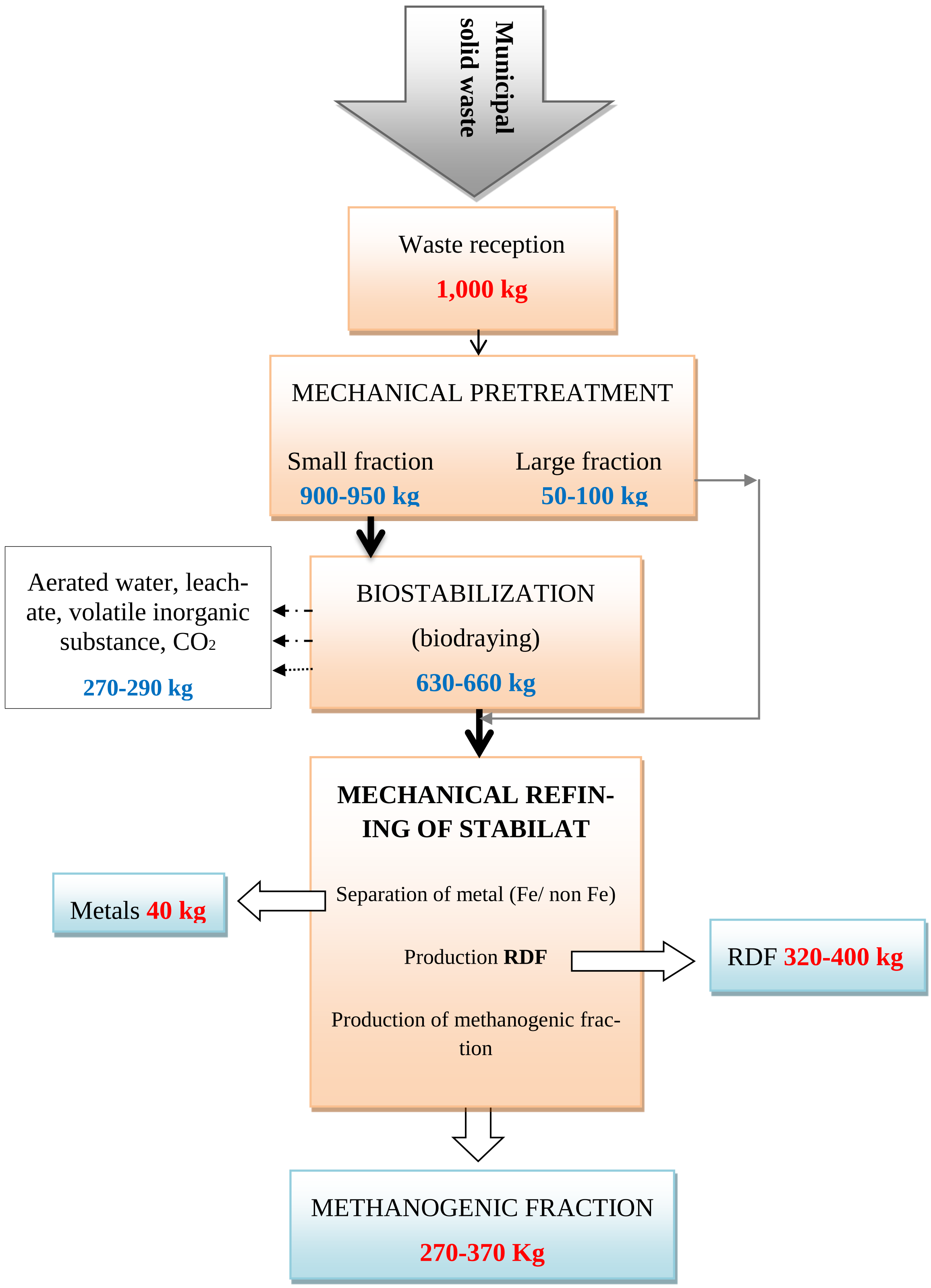

Figure 11: Schematic representation of the waste stream in the biomechanical waste treatment with output fractions

Source: [70]

4.2.3.3. Profitability of an incinerator in the city of Zagreb

There is a lot of public contention currently on whether to build an energy plant for municipal solid waste or not and this section will provide an economic analysis of construction and the work of an incineration plant for the territory of Croatia. The construction was planned to be located in Resnik in the Zagreb County. Taking into consideration the amount of waste which needs to be managed when the landfill Prudinec in the neighborhood Jakuševac closes in 2018 on a monthly basis, there are 222,000 tonnes/year of mixed municipal waste that come from the Zagreb area and a permanent system of municipal waste management needs to be created. Pursuant to the decision of the city of Zagreb which is defined in the waste management plan in Zagreb by 2015, the planned technology for solving this problem is thermal treatment of waste and this paper is, consequently, based on that type of plants. Most of the plants that are going to be reviewed in this paper will be at the level of about 230,000 tonnes of mixed municipal waste per year. [70] The waste that is intended for burning is primarily mixed municipal waste. Investment costs of incineration are estimated at around the amount of the reimbursement for waste disposal in the EU which specifically ranges from €46 / t up to € 174 / t and for the requirements of this work the average of €110/ t was considered. [72]

In table 8 the total investments costs are shown that make up for the construction costs of the entire plant for which the funds need to be provided. Some costs are amortized over twenty years which brings this investment into question.

Table 8: The structure of the investment costs and the amortization period for incinerator

	The share of the investment costs	Amount	Amortization [as]
Total investment costs [€]:	100.00%	155,563,718.22	
Infrastructure and storage of waste [€]:	8.17%	12,548,187.21	20
Components plant [€]:	56.31%	86,473,377.09	15
Designing [€]:	3.55%	5,455,733.57	5
Building [€]:	12.43%	19,095,067.50	20
Electro-mechanical installations [€]:	8.88%	13,639,333.93	15
Other investment costs [€]:	10.66%	16,367,200.71	15

Source: [73]

In Table 9 the required technological and economic data have been defined for plants with the capacity of 230 000 t per year in full operating mode.

Table 9: Technological and economic data for the plants

	WtE plant
Capacity [t/a]	230.000,00
Net overall efficiency, total	42,54
Electricity/ heat production ratio ®	0,40
Net heat efficiency %	30,37
Net electrical efficiency %	12,16
Working hours per year (h/a)	7.500,00
Net heat production [MWh/a]	219.668,54
Net electric production [MWh/a]	87.951,55
Production of secondary iron [t/a]	5.520,00
Production of secondary aluminium [t/a]	920,00
Investments [€]	155.563.718,22
Fixed costs [€/a]	6.143.156,00
Variable costs [€/a]	4.417.658,24
Personnel cost [€/a]	1.456.919,06

Source: [73]

Table 10: Review of prices, revenues and expenditures for the incinerator

Costs:	
Operation and maintenance costs [€ / a]:	12017733,3
Total investment costs [€]:	155563718,2
Revenues:	
The amount of treated waste [t / a]:	185 979,48
The fee for waste disposal [€ / t]:	110
Income from fees for waste disposal [€ / a]:	20457742,25
The yield of secondary iron [t / totpada]:	0,024
The yield of secondary aluminum [t / totpada]:	0,004
The amount of secondary iron [t / year]:	5520
The amount of secondary aluminum [t / year]:	920
Price of secondary iron [€ / t]:	105,26
Price secondary aluminum [€ / t]:	657,89
Revenue from the sale of secondary iron [€ / year]:	581052,63
Revenue from the sale of secondary aluminum [€ / year]:	605263,16
Electricity generated [MWh / a]:	73 642,18
Produced thermal energy [MWh / a]:	184 079,89
The selling price of electricity [€ / kWh]:	0,0693
Sale price of thermal energy [€ / kWh]:	0,0281
Revenue from electricity sales [€ / a]:	5104960,35
Revenue from the sale of thermal energy [€ / a]:	5167334,01
Total revenue [€/a]	**31916352,4**
Total costs [€/a]	**167581451,5**

Source: [73]

The attached Table 10 shows that the calculated costs and revenues that the incinerator would generate, which are at the bottom of the table, are 31,916,352. 2 [€ / year]. This amount mainly depends on the entry fee, which is 110 [€ / t] and it is not fixed. The second total cost of the plant, which concerns the construction costs, operating costs and maintenance costs, stands at 167,581,451.5 [€ / a]. The total cost reduces at an annualised basis because it is amortised through the income generated by the incinerator. The period ranging from 10 to 20 years of waiting for an investment is on the verge of profitability. Lifetime of the incinerator is 30 years. Rates and fees also affect the total cost of investment return. The highest fee is for waste disposal, which accounts for the greatest share of the revenue and its changes can have a substantial effect on the profitability of the investment. Practices have shown that a raise of fees by 30% can greatly threaten the profitability of the overall investment. [74]

It is estimated that after the heat treatment there are 33,000 tonnes of ash from the bottom of the boiler, 60,000 tonnes of solidified flying ash and from 8,000 to 16,000 tonnes of ash with radioactive material that could be accommodated at the landfill of hazardous waste. What would certainly additionally increase the price of the entire process of transport of residual ash to the landfill are various fees for air pollution and landfill maintenance. On average, the work costs 25% from the input of the amount of waste in the incinerator, which is a considerable percentage that generates additional expenses of disposal. [75]

4.2.3.4. System of separate collection of municipal waste in the Republic of Croatia

In Croatia there are currently 71 recycling yards, which are distributed through the whole Croatian territory. 16 Nevertheless, it is obvious that this number is still insufficient, because it does not bring all the separate waste at recycling yards. In order to make the system more effective it is necessary to establish door to door collecting and raise awareness amongst the citizens regarding the separation of useful waste.

The share of separately collected municipal waste, shown in Graph 4 in orange (including mixed waste such as bulky waste, waste from street cleaning, etc.) was 24% in 2013 and in 2014.

Chart 6 presents the total amount of municipal waste generated in 2014 shown in green. A slight decrease of 4.8% compared with 2013 can be seen which can be attributed to an increase in the separate collection of waste. [76]

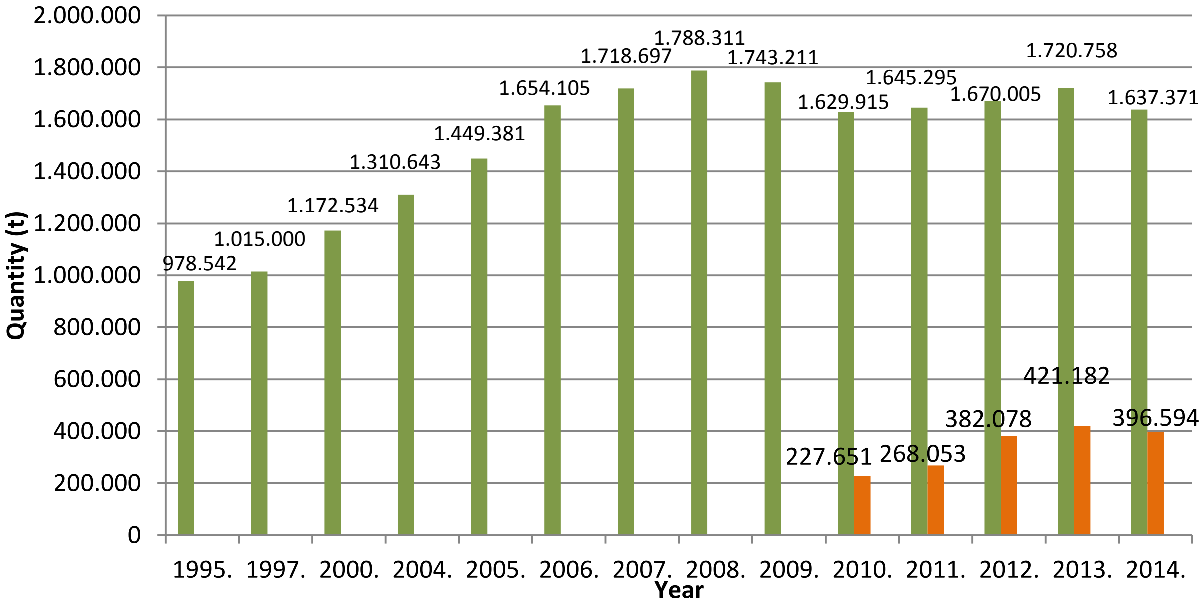

Chart 6: Quantities of total and separate collection of municipal solid waste production in Republic of Croatia 2014.

Source: [76]

Also in the period from 2010 to 2014 the amount of municipal waste sent directly to recovery has increased. The share of municipal waste directly addressed to the recovery in 2010 was 4%, in 2013 it was 15% and in 2014 it stood at 17% as it has been shown in the Chart no. 7. The remaining quantities of separately collected municipal waste are temporarily stored or forwarded to landfills where they are eventually usable components and are allocated and forwarded for recovery (e.g. bulky waste) and that information is not visible from the registration of taxpayers. [76]

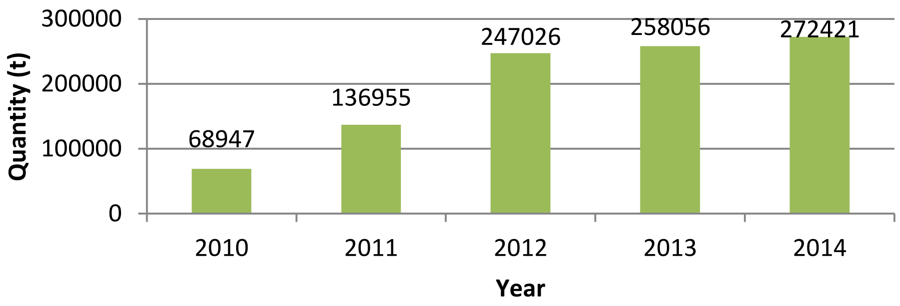

Chart 7: Quantities of municipal waste sent directly to the recovery in the period from 2010. to 2014.
Source: [76]

Pursuant to Article 55 of the Act on Sustainable Waste Management (OG No. 94/13), which states the provisions of the Waste Framework Directive, the Republic of Croatia, with the support provided by competent authorities, is obligated to ensure the preparation for reuse and recycling of the following waste materials: paper metal, plastic and glass from households and possibly from other sources if these waste streams are similar to household waste, at the minimum share of 50% by weight of waste. All of this should be accomplished by 1st January 2020.

Recycling rates 4 types of materials - metal, glass, plastic and paper from municipal waste (recycled amount versus the amount of waste that is produced using these materials) - is 22%. In 2014 still a large number of local governments did not perform separate collection of useful waste from municipal waste. [76]

4.2.3.4.1. Potential of revenue from recyclable materials in city of Zagreb

Setting new and refurbishing used pots in households as well as collecting and organised waste disposal from households and waste from the Zagreb area is under the jurisdiction of “Zagrebački holding l.t.d. – Čistoća Subsidiary”. [71]

Currently in the city of Zagreb there are 98 special waste collection vehicles that are in charge of collection of mixed municipal waste. In addition, there is a certain number of special vehicles that transport mixed municipal waste for companies. Non-hazardous waste is collected in

other systems such as containers in public spaces, recycling yards, various collection sites and buying centers. [71] Collection and disposal of municipal waste has been organised throughout the City of Zagreb. Municipal waste is collected in 17 urban districts.
Following a rough analysis of profitability of the incinerator in Zagreb conducted in the previous chapter, this chapter will present data on the percentage and the amount of municipal waste in the city of Zagreb, from which all the valuable raw material can be used to show the comparison of the most cost-effective systems. Chart 8 shows the amount of waste by individual materials that make waste, and from which added value on the market can be provided.
The economic definition of subsystems for the separate collection of waste generated by households, four bags are provided (paper and cardboard, plastics, bio-waste, other wastes), while the non-refundable glass packaging is continually gathered at common places for waste collection (waste collection points called green islands). The filled bags would then be deposited at waste collection points and they would vary by colour, type of material and similar. Collection in this way would use the door to door method.

The share of the total amount of collected municipal waste in the city of Zagreb in 2014 was 269,139.52 kg and from this amount there was even further separation with approximately 17% of valuable components from waste. [76]

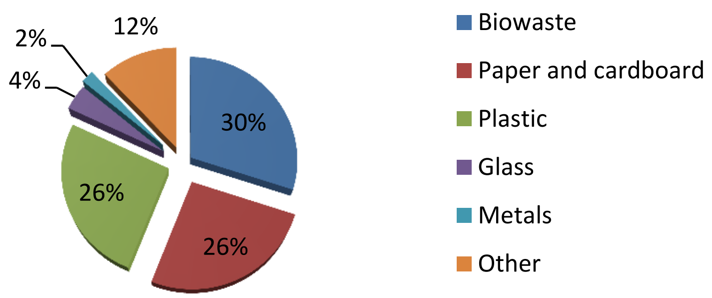

Chart 8: The composition of mixed municipal waste in Zagreb
Source: [76]

Percentage listed in Chart 6 is multiplied with the total amount of collected mixed waste in 2014 and the result is 80,741 t/year of bio-waste. In this way the calculation was made for the remaining materials in mixed municipal waste (glass, metal, plastic, paper). Hence, Table 11 shows the amount of bio-waste and its cubic amount as well as the market value from €28 to

€80 per compost ton. From this price scale the least possible value was taken, 28 [€ / m3]. [77]

Table 11: Potential revenue of biowaste

Biowaste	From	To	
Quantity/a	40.000	80.741	t/a
Volume	16.621	33.550	m3/a
Price	28	28	€/m3
The potential value [€]	**465.388**	**939.400**	

Biodegradable waste is processed in compost plants (Markuševec I Prudinec) that are under "Zagrebački holding l.t.d. – Zrinjevac Subsidiary" and it is not necessary to look for a new location or invest in the infrastructure. [71]

The prices for different types of paper and cardboard have been provided by the Zagreb-based company Green Point that buys scrap paper (several types) and board, prices and quantities have been shown in Table 12.

Table 12: Potential revenue from paper / cardboard

Paper/cardboard				
Quantity/a	70.000,00	t		
	Share in paper / cardboard	**Mass, t**	**Unit prices €/t**	**Potential value**
Cardboard	40%	28.000	73,5	2.058.000
Office paper	13%	9.100	93,5	850.850
Newsprint	22%	15.400	80,2	1.235.080
Mixed paper	25%	17.500	40,1	701.750
			Total [€]	**4.845.680**

From the following source a conclusion can be reached that during the calculation two plants in the Zagreb area for paper and cardboard processing were necessary. [78] In the Zagreb Area there are two plants for sorting paper and plastic and they are located at Žitnjak and Sesvete.

Table 13 shows the prices that are determined on the international market of raw materials for plastics and polymers, as well as their quantity by species. [77]

Table 13: The potential revenue of polymer/ plastic

Polymers, plastics				
Quantity/ a	70.000,0	t		
	Share of plastic waste	**Mass, t**	**The unit price €/t**	**The potential value in €**
Mixed solid plastics, HDPE and others	20,0%	14.000,0	40,0	560.000,0
PET	20,0%	14.000,0	107,0	1.498.000,0
PE film	30,0%	782,0	200,0	156.401,6
Others	20,0%	14.000,0	13,0	182.000,0
			Total [€]	**2.396.401,6**

From the following source it can be noted that during the calculation five plants in the Zagreb area for plastic processing were required. [78] In the Zagreb Area there are two plants for sorting plastic and they are located at Žitnjak and Sesvete. [71]

Table 14 shows the quantity and the price per tonne for glass packaging. The price at which Vetropack buys glass waste today, which is then cleaned of impurities, is €15.4 per tonne for coloured and €20 for a tonne of colorless glass waste. Vetropack is the only company in the Republic of Croatia that manufactures and purchases glass packaging. Since there are two defined prices for the two types of glass and the data for collected glass provides no information about the composition of glass, the average of these two prices was considered and it is €17.7. [79]

Table 14: The potential revenue of glass

Glass		
The quantity / a	10.765,0	t
Price	17,7	€
Potential value	**190.540,5**	€

The following source shows that during the calculation one plant in the Zagreb area for glass processing was necessary. In the Zagreb Area glass waste is processed at a plant that is located in Sesvetski Kraljevac. [71] [77]

Selling metal can generate revenue both on domestic or international market of raw goods and hence the overviews of the amount and type of metal in municipal waste and its price have been shown in table 15. [75]

Table 15: The potential revenues from metal

Metals				
Quantity/a	5382	t		
		Mass, t	**The unit price €/t**	**Potential value €**
Waste non-ferrous metals	10%	538,20	935	503.217,0
Al cans	10%	538,20	267	143.699,4
Fe cans	25%	1.345,50	80	107.640,0
Waste iron	20%	1.076,40	160	172.224,0
Various cables	3%	161,46	200	32.292,0
Wrecks and household appliances	30%	1.614,60	53	85.573,8
Accumulators	2%	107,64	200	21.528,0
			Total [€]	**1.066.174,2**

The following source shows that during the calculation one plant in the Zagreb area for metal processing was necessary. [77] Metal waste is processed mechanically on the machine for separating metal and non-metal waste. The plant for this type of processing is located at Jankomir. [71]

Table 16 shows the total revenue from sales of recyclable materials that generate added value.

Table 16: The total potential revenue from recyclable municipal solid waste

Types of separately collected waste	The potential revenues €/a
Paper / Cardboard	4.845.680,0
Polymers / Plastics	2.396.401,6
Compost	702.394,0
Glass	190.540,5
Metals	1.066.174,2
Total [€]	**9.201.190,3**

4.2.3.4.2. Investment costs for waste collection system

During defining of this waste the costs of transport to the recycling yards will be observed, expenses for the newly employed in the recycling yards, as well as the costs of waste separation of the collected waste. Transport costs are fairly same, so they even out.

Table 17 shows the investment costs concering bags for separate waste collection ment for recycling. In the calculation there are 3 types of bags – biowaste, plastics and paper and car-board.

Table 17: Total cost of bags

	Costs for bags €	Number of households	Garbage	Price for the entire month
Bags for plastic	0,0615		twice per mounth	37.475,76
Bags for paper and cardboard	0,1016	304.681,00	twice per mounth	61.911,18
Biowaste bags	0,294		one per week	358.304,86
			Total per mounth €	**457.691,80**
			Total per year €	**5.492.301,58**

Source: [80]

Locations of these plants are determined in accordance with the exsisting locations for waste management in the City of Zagreb. Plants for sorting plastic are intended as an extension of recycling yards. The plants for sorting paper and cardboard are planned on already existing locations Žitnjak and Sesvete, as well as metal sorting plants in Jankomir and glass sorting in Sesvetski Kraljvec. The costs of these plants are estimated based on the prices of equipment used in these plants.

Table 18: Costs of diferent plants

	Dimensions, m2	Unit price €	The number of plants	Price €
Sorting plastic	3.000	420.000	5	2.100.000
Sorting paper and cardboard	2.500	133.333	2	266.667
Sorting metals	2.500	133.333	1	133.333
Sorting glass	3.000	133.333	1	133.333
			Total €	**2.633.333**

Table 19 describes the costs of investment into a compost plant. A compost plant is already built on the planned location, but this investment enables capacity expansion.

Table 19: Invesments cost in composting site

Composting site	Unit	Number of unit	Unit price €	Price €
Land	m2	2.500		
Landscaping and paving	m2	2.500	25	62.500
Closed warehouse for maturing compos	m2	1.250	130	162.500
Warehouse, packing, laboratory	m2	800	160	128.000
Other				6.500
			Total €	**359.500**

In the following Table 20 the salaries of the total number of employes in separate waste collection system have been shown. For gross salary, the amount of €1,100 has been taken and for each sector the minimum number of workers has been taken while keeping in mind that in this system should be working regularly.

Table 20: The salaries of employees

Total number of employees	Number of employees	Gross salary €	Salary for all employees
Recycling centers	50	1.100	55.000
Composting sites	5	1.100	5.500
The transport system	40	1.100	44.000
Other staff	20	1.100	22.000
Total of employees	115	**Total €**	**126.500**

In Table 21 the operative costs of the plant are shown and later they will be included in the total cost.

Table 21: Operative costs of all plants and other equipment

	Unit	Number of units	Unit price €	Price
Sorting line	pieces	9	2.671	24.039
Press high pressure and baler	pieces	2	4.000	8.000
Forklift trucks with equipment	pieces	12	670	8.040
Support vehicle	pieces	4	530	2.120
Equipment recycling yard	pieces	1	16.000	16.000
Packer	pieces	7	6.000	42.000
Loader	pieces	2	3.000	6.000
The movable rotary sieve	pieces	1	1.300	1.300
Chopper green waste	pieces	1	2.000	2.000
Other			33.000	33.000
			Total €	**142.499**

Table 20: The total cost of investment in infrastructure of recycling center and other costs

Infrastructure	Price
Total prices of sorting plants	2.633.333
The salaries of employees	126.500
All operating costs	142.499
Total cost of bags	5.492.302
Composting site	359.500
Total €	8.754.134

Chart 9 shows the expenses and revenues of the incinerator, whilst the system for separate waste collection in the City of Zagreb will be shown separately, so the difference between these two different water management systems could be spotted more easily.

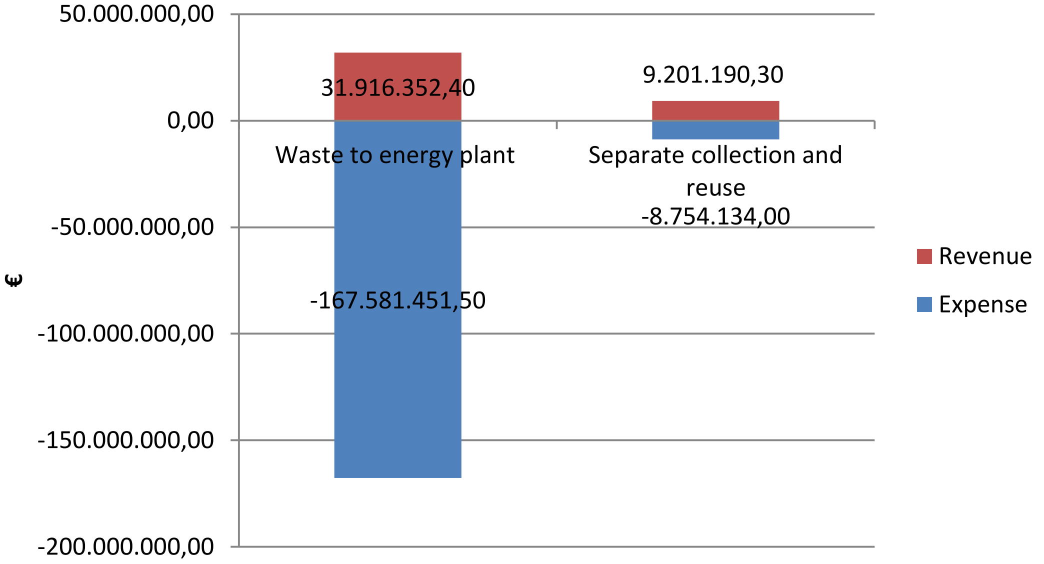

Chart 9: A graphic representation of the structure of expenses and revenues considered variants

Chart 10 will present the total result of the expenses and revenues. From the chart it can be concluded that the costs of the incinerator for the City of Zagreb is considerably higher compared with the system for separate waste collection and it is not self-sustainable.

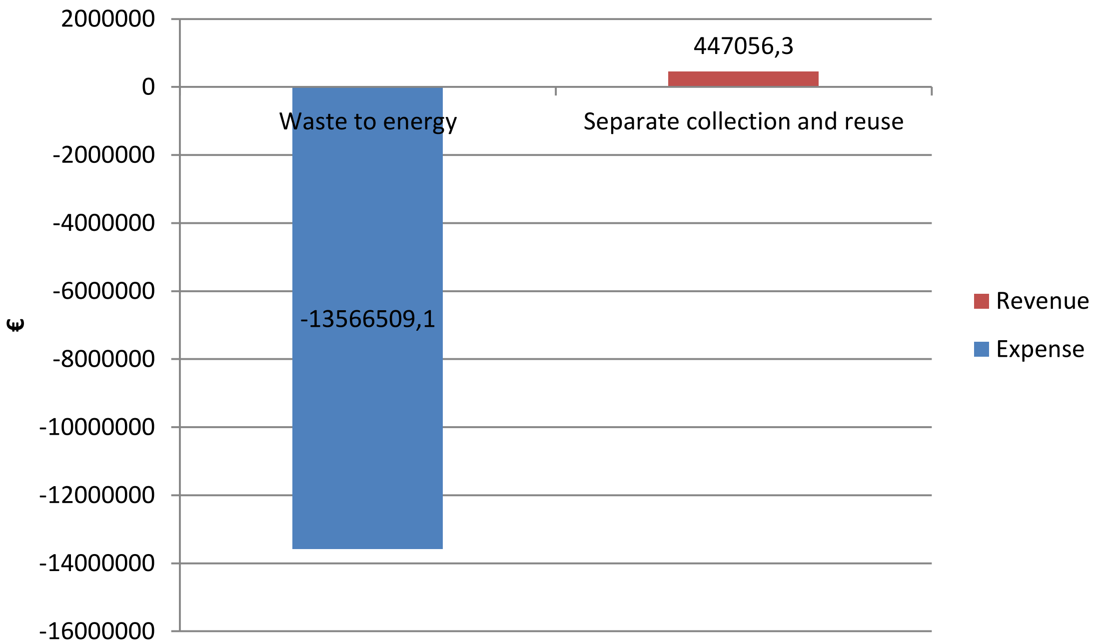

Chart 10: Graphic representation of the sum of all the expenses and revenues variants

Chart 8 shows that the price of the incineration plant deviates significantly from others. In addition to being very expensive, these plants for thermal processing in other developed countries have been increasingly closing (in this paper some shortcomings of these plants have been stated). If a thermal plant in Zagreb is constructed the question is how to log will it stay open? Namely, it is possible that Zagreb will follow other developed cities and give up on the plant in question when it has already been finished (wich would have very serious financial repercussions).

The following source states that with intensive waste separation and its reuse creation of additional jobs would result at a local level which has sociological and economic advantages for the population. The recycling 10,000 tonnes of waste creates 240 jobs, but incineration creates only 40. [81] Regarding the ecological benefits, every tonne of recycled or composted waste creates an environmental benefit higher than treatment options. Although the incineration option produces a certain amount of energy, studies show that the energy saved by recycling in the lifecycle of material is significantly higher for each material. [82]

5. MODELLING OF EXISTING SYSTEMS WITH AIM OF GREENING AND SUSTAINABILLITY

Following the conducted study, an analysis was conducted for the systems of waste management in the Czech Republic and the Republic of Croatia and using scientific literature for waste management. It can be seen that the system in the Republic in Croatia is still not at a satisfactory level and that urgent changes are required, as well as system upgrades. The proposal for the waste management system improvement in the Republic of Croatia is based on scientific literature from the area of research and the practice of waste management in the EU, the Czech Republic and the Republic of Croatia. The model has been made according to the criteria listed further in the text.

Important criteria in scientific projects in the area of research are:

- The system of waste management has to be ecologically acceptable, which means more waste has to be directed to consumption;
- The system of waste management ensures content to the consumers [83]

In accordance with the listed criteria, a model of waste management improvement in the Republic of Croatia has proposed hereinafter. According to the analisys in the Republic of Croatia it can be noted that waste management plans and the legislation have taken the wrong directions and are not in compliance with the waste management hierarchy, from the top of the pyramid to the bottom. The last alternative is the disposal of unprocessed waste and in the Republic of Croatia its share is at 82% of the total municipal waste amount. The plans of waste management are imposing new MBT technology that is slowly becoming outdated since it is not following the circular economy that is advocated by the EU with the system of separate collection and recycling of waste. Whilst MBT technology does not follow the stated demands and hence the goals of circular economy are not being adhered to.

Following the comparative analysis conducted for the incinerator in the previous chapter compared to a system of separate waste disposal it was established that the system of separate waste disposal was economically and sociologically much more acceptable than building a new incinerator. The following flow chart gives a proposal for some other solutions of separate waste disposal for the Republic of Croatia in which the rate of separated municipal waste has been increased, since that is the task the Republic of Croatia has to accomplish following its EU accession. The system is also applicable for some local and regional self-governments.

The flow chart 11 of municipal waste clearly shows that the priority is the collection of separated municipal waste. After the delivery of the collected waste in the sorting center the utility vehicle that brings mixed municipal waste and wastes are collected in different bags separately. In the sorting center, the waste is sorted by type and value and is sent to the market of raw materials in order to achieve economic value. Whilst the second part of the waste that is unsorted can be further sorted and sent to the center for waste management where a mechanic-cal biological treatment will bed one to get the RDF that can later be used in a waste incinerator or the cement industry, as well as biogas through the bio-drying process.

The reason for prioritising the preventive separation of waste collection is the conclusion that was reached following the analysis conducted in this paper. The conclusion was that the incinerators and MBT in the final calculation create a higher cost of production, but this does not follow the hierarchy of waste management which is very important in order to comply with the rules, as well as whilst caring for the environment. Following the examination of the waste management system in the Czech Republic, which has three incinerators for municipal waste, and the increasing legislation on environmental pollution, the ultimate profitability of the entire system can be questioned. The awareness of the economic benefits of other waste management systems is slowly beginning to raise, as well as the awareness of the importance of environmental protection and the protection of the health of the population. Chart 9 shows a model of waste management in the Republic of Croatia.

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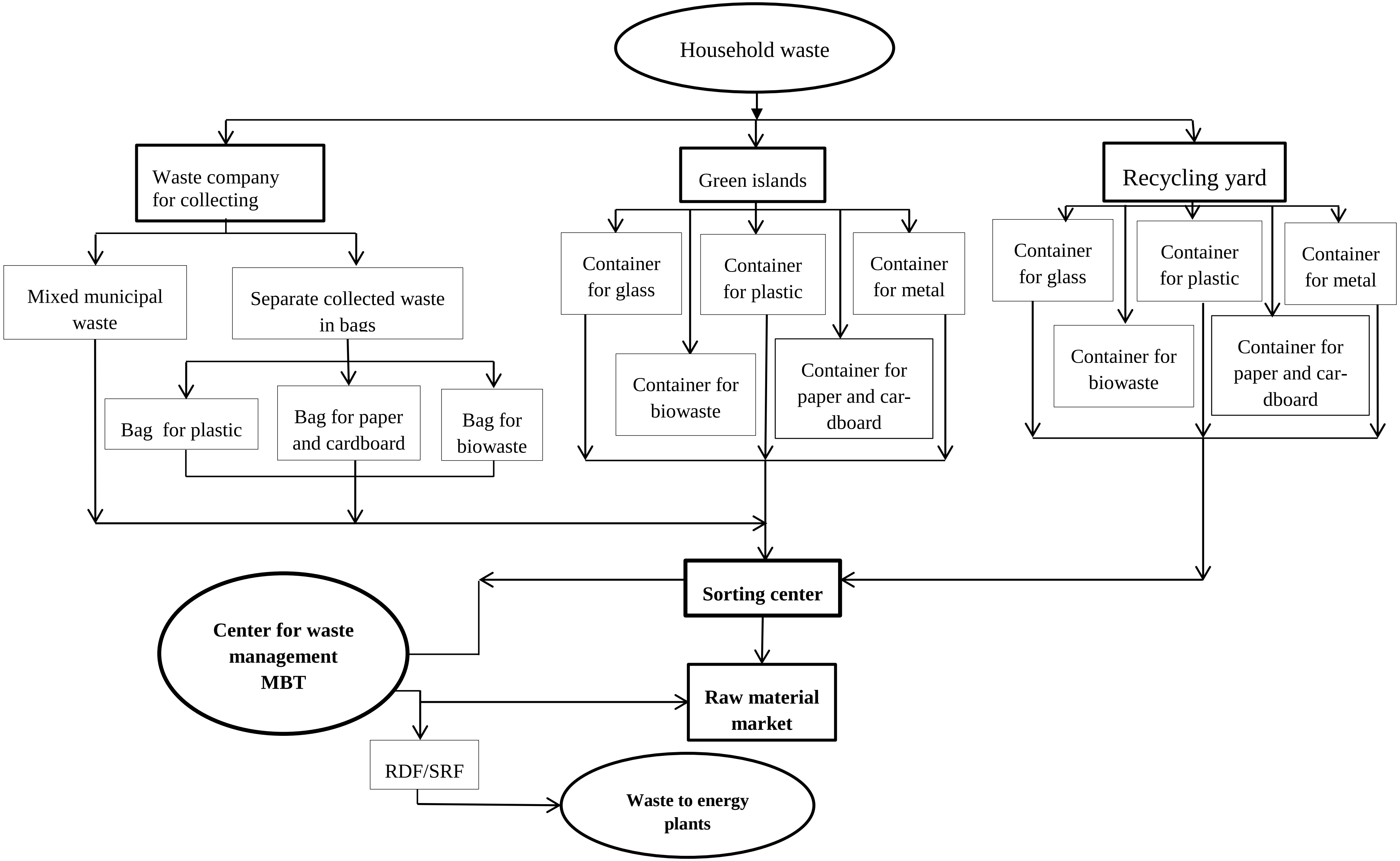

Chart 11: Model for waste management of the Republic of Croatia

As has been shown in the diagram, there is a possibility to separate useful raw materials using a doorstep collection scheme, as well as of municipal waste disposal. One of the incentive measures for reducing mixed municipal waste is certainly utility charges which would be charged by volume or mass of mixed municipal waste and not by square footage or the number of people in the household which is the current practice. This system of separate waste disposal generates more costs in the transport area, but they were not calculated due to a lack of information. All the collected waste is sent to the sorting facility where its selection, storage, and packing in bales is performed and in which they are delivered to the market of raw goods or are directly processed. The remaining mixed municipal waste is sent to the waste management center with MBT technology from which electricity is generated by producing bio-gas, separating iron and 20% of recyclable materials that are sent again to the market of raw foods. The remainder, on average 40%, is processed in RDF/SRF which serves as a fuel for plants for waste, thermal plants, and cement plants.

Through this proposed solution all the produced waste can be processed and only some of the waste is disposed after processing in MBT facility and goes to the landfill. It is important to highlight that the previously mentioned waste is processed and less harmful for the environment.

5.1 A survey on waste management conducted amongst the citizens of the Republic of Croatia

Regarding the third criteria that the authors are pointing out in their scientific papers and concerning waste management in the Republic of Croatia a survey was conducted in order to provide information about how the population is satisfied with waste management system and the specific objective was to see how informed the general public is regarding this issue and concerning their morals in case of waste separation. The ultimate goal of the survey was to collect information from the general public on whether they are in favour of the construction of incinerators in their place of residence and what they think of the ways it affects human health and the environment.

The survey was not aimed at a specific region since all the citizens of the Republic of Croatia participated in it. 569 people participated in the survey. Most of them were from Zagreb area (40.8%). The age group of the respondents was from 16 to 25 – accounting for 71.5% and from 26 to 35 with a share of of 20.3%.

Following the final analysis of the survey a conclusion can be reached:

- Citizens are aware of the importance of waste disposal and are interested in waste separation, yet the system is mostly disorganized and does not have the required infrastructure
- A large number of citizens knows what recycling is, which raw goods can be recycled and why they should be recycled
- A large amount of local government entities has not introduced a financial penalty system for not separating municipal waste and hence citizens do not fear substantial fines for utility charges
- Education level amongst municipal firms and local communities is, on average, rather low
- Citizens are against the construction of incineration plants since they think that they are harmful for the environment and that they are not economically efficient, which has been shown by a large number of studies
- Although the citizens are against the construction of an incineration plant, they do not separate waste

Following this survey a conclusion can be reached that permanent education of citizens is necessary starting from young age and throughout educational system an awareness of the importance of waste management needs to be built. Along with education, continous investment in waste management infrastructure is imperative, since there is an increasing number of energy independence philosophies and waste management is one segment of this system and needs to be considered thoughtfully. A graphical representation of survey results has been provided below.

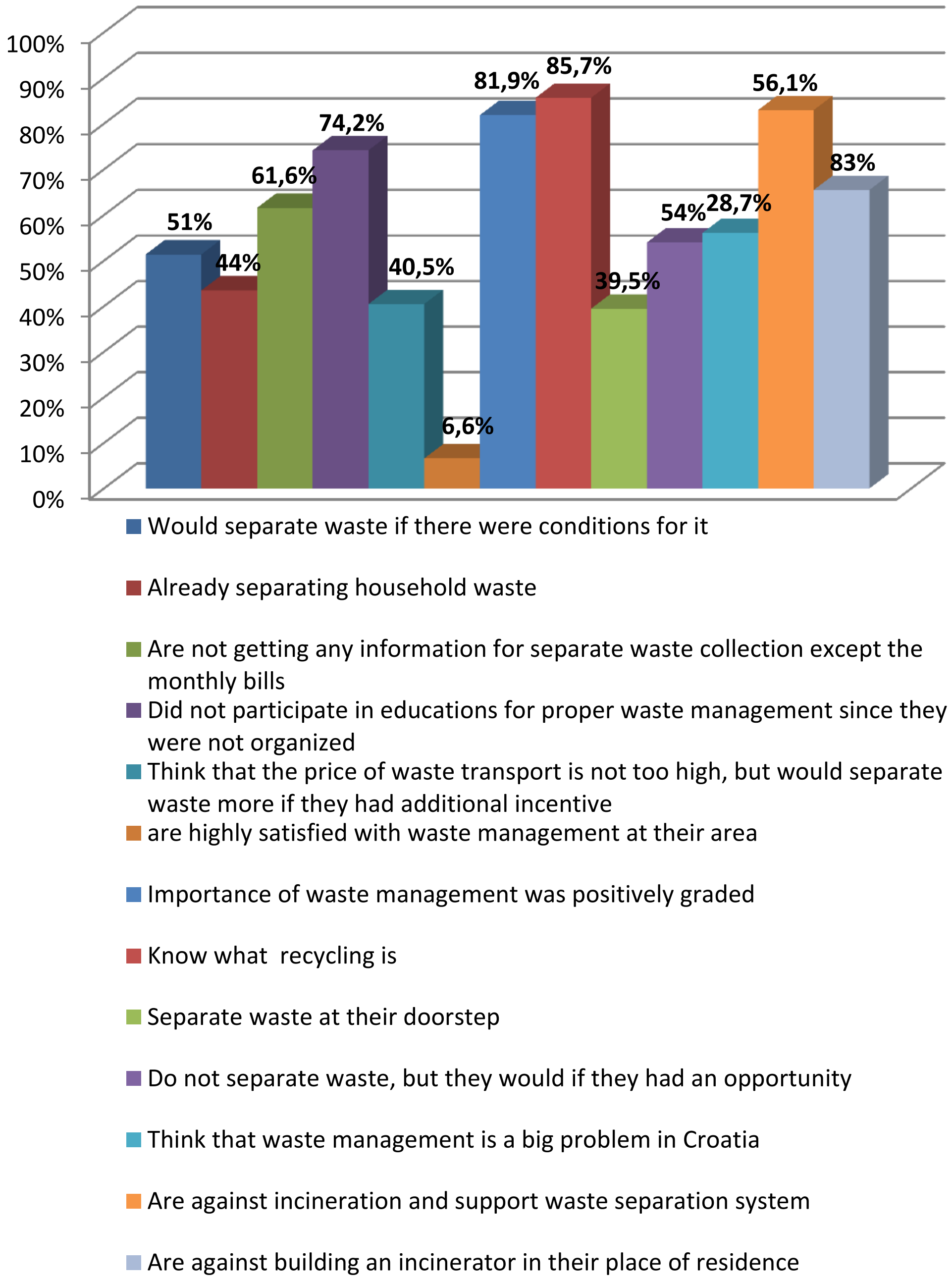

Chart 12: The results of poll

6. CONCLUSION

Sustainable waste management is an important social tool. Waste must be reduced starting from transport all the way to sales, consumption, use and disposal, and one should not create garbage during this process. Useful components must be separated from waste from recycling and production. Monitoring measures, information, management, regulation, education and communication with the public are important tools for a successful waste management. Th eawareness of the waste problem must be general. It is essential that all of the state structures, from the manufacturer, to the consumer understand the core of the problem and find a common path for the realisation of an integrated system of sustainable waste management.

Waste disposal is banned in some European countries, such as Germany, for example. In the Czech Republic, the problem of waste is being addressed through the introduction of tax per tonne of deposited waste, which yielded some results of reduced waste disposal. Landfills do harm to the environment, the whole bio-system, ground water, as well as man. It is important to note that with waste disposal considerably economic funds are lost. The Republic of Croatia has a time limit by which the number of landfills and the amount of waste collected must be controlled by legislation, planning and waste management strategy and EU regulations and laws.

Waste to energy is a topic that permeates this paper. The plants are physically big and economically they imply considerable investment, which is accompanied with huge operating costs and a need for a high amount of waste so that the energy could be used, whilst the waste should not be separated because it has to be in large amounts. When the combustion of waste happens gasses are released, such as dioxin, which further pollute the environment and the atmosphere. However, the problem is with the waste that remains after the combustion in the form of slag and ash, which can be toxic in certain percentages and this further increases the price of the entire process. An increasing number of developed countries has been opting for closure of the plants for thermal treatment of waste or for a gradual increase in separate waste collection.

Waste management in the Czech Republic has a long tradition, the waste incineration plant in the Czech city of Brno is one of the pioneers in entire Europe. The Czech Republic has three plants operating at a fairly full capacity. Since Czech Republic is an EU member state it is committed to increasing the amount of separated waste collection and, compared with Croatia, it has attracted more investment from European funds and started building a sustainable system.

Inadequate waste management is a problem with the environmental protection in the Republic of Croatia. Waste is increasing and the infrastructure that should dispose of it is insufficient. Waste management is not functioning as it should be because the regulations are not fully implemented and this has a negative impact on diverse features of the environment and human health, but it also affects the economic issues since this system is not self-sustainable and those who suffer the most are people who pay high waste management bills.

The Republic of Croatia has launched a major project of building 13 major waste management centres, two of which have been built. Following the analysis conducted, a conclusion can be reached that MBT technology installed in them is not in accordance with the current EU strategy and they imply investment and operating costs. Other solutions need to be considered. Recyclable waste fractions can be sold on the market. Hence, from a social stance, waste can become its re-source. It is necessary to sort waste for these recyclable fractions to be sorted.

Since it is impossible to conduct an analysis of the waste management system with the costs for the entire Republic of Croatia, an economic analysis was conducted for an incinerator for the city of Zagreb, as well as waste which would be collected for incineration throughout the areas of the city. It was found that the incinerator requires a high initial investment, but also the running costs are excessive. An additional problem is the issue of management of the remaining waste after combustion, since it accounts for 30% of the original amount of waste. The percentage of electricity and heat generated is rather small. These are the main reasons why at this point a waste incinerator needs to be ruled out as an option. Thus, an alternative to the initial idea needs to be found and the system of separate collection of municipal waste for the city of Zagreb is to be considered. The results of the analysis are positive and they show a sustainability of the system through income from the sale of secondary raw materials which also protects the environment and human health because they do not end up in the nature.

A model of waste management in the Republic of Croatia is based on the separate waste collection, its sorting and sending the residual part of mixed municipal waste to MBT plants that will produce biogas and RDF fuel for the cement industry.

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SUPPLEMENT

A survey regarding waste management in the Republic of Croatia

1. Which age group are you?

   a) 16 to 25

   b) 26 to 35

   c) 36 to 45

   d) over 46

2. Level of education

   a) High school education

   b) College education

   c) University degree

3. Which Croatian region do you belog to?

   a) Continental Croatia

   b) North Croatia

   c) Slavonia

   d) Dalmatia

   e) Istria and Kvarner

   f) Lika and Gorski Kotar

   g) The city of Zagreb and the surrounding cities

4. Are you willing to separate waste?

   a) I separate all the household waste

   b) I would separate waste if I had an oppurtuninty.

   c) I consider it pointless.

4. Do you think you are sufficiently informed about waste management by the companies involved in it?

   a) They inform and educate us about waste management on a regular basis

b) They occasionally inform and educate us about waste management

c) We do not get any information exept the monthly bill for waste disposal

5. Have you participated in any training about waste management or waste separation at school, faculty or in other institutions?

a) Yes, I have.

b) I have not, since it has not been organised

c) Training was provided, but I was not interested.

6. Do you think waste disposal fees are excessive?

a) Yes, I think the fees are excessive and that is why I separate only some types of waste.

b) No, I think the fees are in accordance with service quality

c) They are not too excessive, but I would separate waste more if I got some incentives.

7. Are you satisfied with waste management in your area?

a) Very satisfied

b) Partly satisfied

c) Partly dissatisfied

d) Absolutely dissatisfied

8. How important is proper waste management?

a) Environmental preservation is very important

b) It is important, but some other institutions are responsible for that

c) Other problems are much more important

9. What is recycling?

a) Recycling is separate waste collection and disposal

b) Recycling is using waste as a raw material for production of something else

c) I have heard the term, but I do not know what it means

10. What type of waste can be recycled?

a) All the household waste

b) Exclusively organic waste

c) Paper, glass, plastic, metal

11. Do you separate waste in your household?

a) Yes, regularly

b) No, but I would if the system were organised more adequately

c) No, it would take up too much of my time

12. How do you rate the problem of waste disposal in Croatia?

a) It is a huge problem in Croatia

b) As far as I know, waste is not a huge problem in Croatia

c) Things can always get better

13. Do you think waste inceneration is a good solution for Croatia?

a) Yes, I think waste incineration is a good idea

b) No, I am against waste inceneration and I support waste recycling

c) I did not know that waste can be incinerated

14. Would you object to an incinerator being built at your place of residence?

a) I would not mind, it is important to solve the problem of waste disposal

b) I am absolutely against waste incinerators

c) I am indifferent to this issue

15. If you are against the building of an incinerator, could you provide reasons?

16. Would you separate waste more if there were more incentives for it and what would be a good encouragement for you to separate your waste?

17. If you were provided an opportunity to change something about waste management in your area, what would you do?

METADATA

Title: **Comparative Analysis of Reverse Logistics Activities and Incineration for Greening Waste Management**

Student: **Oliver Stankeric**

Mentor: dr. sc. Ivona Bajor, doc. Ing. Petr Průša, Ph.D.

Title in Croatian:

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- ____________prof. dr. sc. Kristijan Rogić___________chairperson
- __dr.sc. Ivona Bajor and doc. Ing. Petr Průša, Ph.D.__ mentor
- ____________prof.dr.sc. Mario Šafran_____________member
- ____________doc. dr. sc. Darko Babić ____________ substitute

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University of Zagreb
Faculty of Transport and Traffic Sciences
10000 Zagreb
Vukelićeva 4

DECLARATION OF ACADEMIC INTEGRITY AND CONSENT

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