D.T3.3.5

FEASIBILITY STUDY

PILOT - ZAGREB AGGLOMERATION

Submission Date: 11.2019

Content

1. INTRODUCTION

Current energy transition and increased focus on renewable energy has exploit energy-saving potential of the solid waste and wastewater sector. Wastewater treatment plants (WWTPs) are large consumers of energy and make key contributions to the carbon footprint of municipalities and urban governments.

Their energy consumption usually accounts for the bulk of operational costs of wastewater utilities, sometimes up to 60 per cent. However, despite being a large source of electricity and heat, sewage is generally overlooked. In fact, the amount of energy it contains can be 10 times bigger than that is required to treat it. The increased number of utilities have also deployed their possibility to treat biowaste in order to produce renewable energy.

The project REEF2W recognizes that wastewater is an integral part of the water-energy nexus. The project is funded by the European Development Bank's Interreg Central Europe Programme and is carried out through 11 research institutes and wastewater utilities from Italy, Czech Republic, Germany, Croatia, and Austria.

The projects main objective is to drive up energy efficiency and renewable energy production of wastewater treatment plants. Project REEF 2W is funded by the European Regional Development Fund Interreg Central Europe Programme and is carried out through 11 research institutes and wastewater utilities from Italy, Czech Republic, Germany, Croatia, and Austria. The project's main objective is to drive up energy efficiency and renewable energy production in solid waste and wastewater facilities. It focuses on solutions that integrate organic waste and wastewater streams and the development of new infrastructures.

Figure 1. The REEF2W project consortium

1.1. Aim of the study

The main purpose of this deliverable is to analyse the energy efficiency and the potential to produce renewable energy in the project's five pilots. Implementing the first part of the feasibility study will allow to understand base scenario of the proposed WWTP, and to propose upgrade according to the feasible solutions. Furthermore it will provide a quantitative understanding about the potential to increase energy outputs. In the (fictive) technological upgrades defined for each pilot, these include measures to optimise existing processes and to install new technologies that produce renewable energy.

Biowaste will be used to enrich the organic content of sewage sludge, helping to elevate outputs of heat and electricity in a process called co-digestion. To prove that the new technologies can be technically feasible and make economic viable, project partners will develop a comprehensive assessment tool in close collaboration with utility operators in- a series of workshops. Another key task of REEF 2W is to investigate the legal and policy framework conditions and to advocate for policy alternatives that spur the large-scale use of wastewater-to-energy solutions.

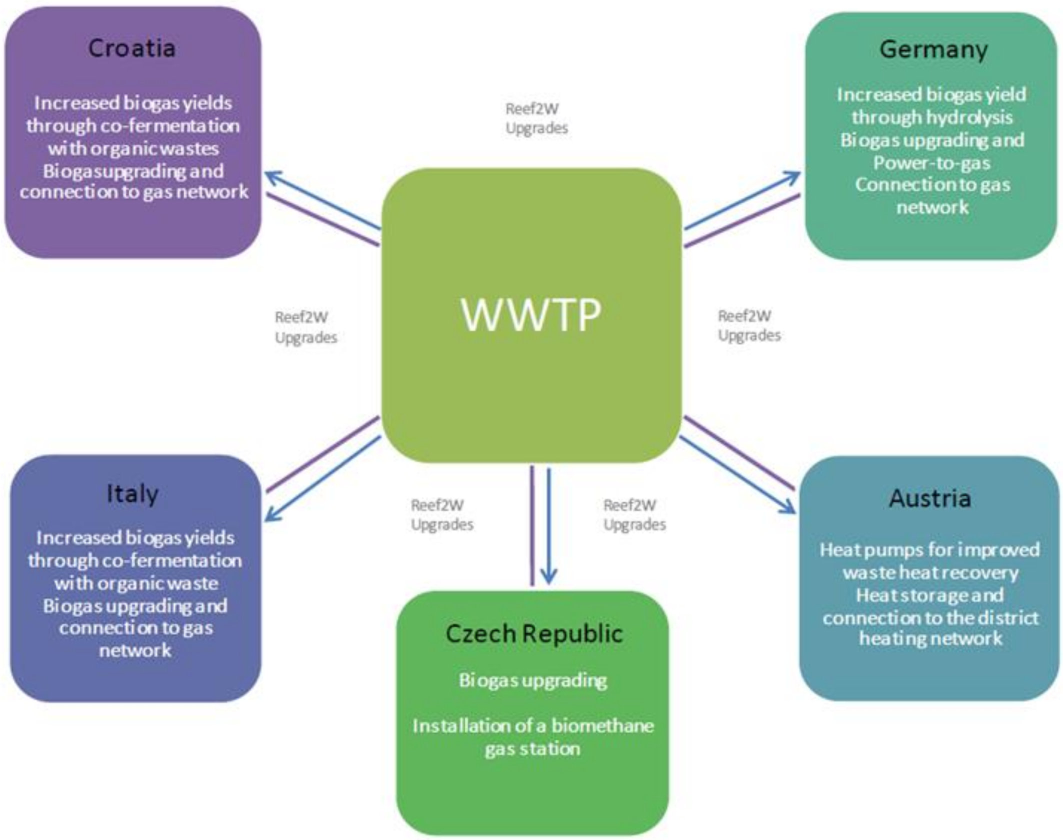

Figure 2. Involved countries in the REEF2W project

1.2. The expected benefits

This project provides an innovative approach in integrating organic waste and wastewater streams and infrastructures. Where beneficial, biowaste will be used to enrich sewage sludge, helping to elevate outputs of heat and electricity in a process called co-fermentation. To prove that the new technologies can be technically feasible and make economic viable, project partners will develop a comprehensive assessment tool in close collaboration with utility operators in- a series of workshops. Another key task of REEF2W is to investigate the legal and policy framework conditions and to advocate for policy alternatives that spur the large-scale use of wastewater-to-energy solutions.

The cultivation of energy crops will help meet the European criteria for reducing greenhouse gas emissions, production of renewable energy sources and closure of a whole range of development opportunities and investments in agricultural production. It will contribute to Croatia's energy and economic development and increase the security of supplies by using additional national energy sources. Rural development will be enhanced by promoting local economic activity, using additional agricultural and forest land production potential. The implementation of REEF2W technologies entails several advantages from an energetic, economic and environmental point of view. The overview of most important benefits is presented in the table 1.

Table 1. Overview of the energy, economic and environmental benefits

Energy optimization	Economic feasibility	Environmental sustainability
Additional process steps such as thermal hydrolysis or co-fermentation with organic substances increase biogas yields.	Energy savings and self-supply of energy and heat lead to a **reduction in operating costs.**	Energy savings and reduced use of fossil fuels result in a **lower CO_2-footprint** of WWTPs.
Additional heat production is achieved by heat pumps in the sewer.	Sales of excess heat, electricity and biomethane allows for **additional revenues.**	Biogas obtained from sewage is a **more environmentally friendly biogas** compared to crop-based feedstock.
A more efficient utilization of biogas is achieved by Combined Heat and Power or biogas upgrading.	Reduced sewage sludge volumes **reduce disposal costs**, especially where cost-intensive waste incineration is the only option.	Recycling of organic waste in sewage treatment plants **replaces the CO_2-intensive disposal on landfills.**
More efficient energy consumption, increased energy yields and the production of storable biomethane increase system security and flexibility.	Optimized economics of wastewater treatment plants lead to **financial savings for municipalities.**	The wastewater sector increases its **contributions to a sustainable energy transition** and **climate protection.**

1.3. Description of the stating postion (EU and national level)

In Croatia, it is necessary to encourage the construction of sewage treatment plants involving equal treatment of water flow lines and sludge flow lines. The sludge management policy was not specifically considered as a separate issue but was taken as part of the overall waste management policy, resulting in a lack of regulation and documents issued by various state and local government bodies. All this has led to the problem of implementing regulations in practice and slowing down, even stopping the realization of projects, and thus delays in the realization of plans.

Local community in Croatia has a big problem with sludge. The treated sludge (stabilized and dehydrated) can be used for landfill coverage, but it is classified as transitional and unsustainable due to the loss of phosphorus and energy that could be used for gas production and cogeneration. In Croatia there is almost no solution to discard sludge and is yet to be developed, by then feasibility studies should be developed, which are valid for projects in the 2014-2020 program period; and the solutions should include: a satisfactory solution for sludge disposal in Cohesion Fund applications, cost calculation, acceptable ways of disposal without any change in wastewater treatment processes.

The main reason for the increase of the generated waste amounts is population growth, lifestyle changes, development and consumption of products with materials that are less biodegradable, which created diverse challenges for municipal solid waste management in various cities of the world, especially in the urban areas. In that sense, main objective of the future EU policies are:

- Reduction of waste generation per capita
- Waste recycling and reuse at highest rate feasible
- Gradual phasing out landfilling practices, and
- Limited incineration of non-recyclable waste

The main purpose of these objectives is to increase recycling of municipal waste, phase out landfilling by 2025 of any recyclable materials, reduce food waste generation, extend producers responsibility, simplify the reporting obligations, and trim down the obligations that affect small and medium enterprises. Accepting the circular economy would help to, as in any natural cycle, reduce the amount of landfilled waste to a minimum and would be instrumental in creating new "green jobs". It has been more evident than ever that Europe must transform its economic model from a “take-make-use-dispose” pattern of growth into one that is based on reusing, repairing, refurbishing and recycling existing materials and products. For this reasons the EU today addresses the waste and water sector not only as an important environmental issue but also as a major opportunity for green jobs.

Figure 3. Waste management hierarchy

The improved waste management also helps to reduce health and environmental problems, reduce greenhouse gas emissions (directly by cutting emissions from landfills and indirectly by recycling materials which would otherwise be extracted and processed), and avoid negative impacts at local level such as landscape deterioration due to landfilling, local water and air pollution, as well as littering. In line with this, the European Commission (EC) has recently adopted Circular Economy Package[1], which includes revised legislative proposals on waste to stimulate Europe's transition towards a circular economy that will boost global competitiveness, foster sustainable economic growth and generate new jobs. Key elements of the revised waste proposal include:

- EU target for recycling 65% of municipal waste by 2030;
- EU target for recycling 75% of packaging waste by 2030;
- A binding landfill target to reduce landfill to maximum of 10% of all waste by 2030;
- A ban on landfilling of separately collected waste;

In recent years EC has also made significant efforts in order to improve current biowaste (foodwaste) management in EU, and divert it from being landfilled. Through different initiatives and actions potential environmental, economic and social benefits of biowaste and its energy utilization has been identified, and also recognized as a key instrument for new environmental policies. Currently the main environmental threat from biowaste (and other biodegradable waste) is the production of methane during the degradation at the landfills, which accounted for 2.6% of total greenhouse gas emissions in the EU in 2007. The Member States are obliged to significantly reduce the amount of biodegradable municipal waste that they landfill which will significantly reduce total gas emissions. The mentioned obligation does not prescribe specific treatment options for the diverted waste, but the most significant benefits of proper biowaste management, besides avoided emissions of greenhouse gases, would be the production of good quality compost and biogas that contribute to enhanced soil quality and resource efficiency, as well as a higher level of renewable energy production. In practice some Member States have not chosen biogas production and composting (process of anaerobic digestion) as a solution for certain biodegradable waste fractions, but instead choose the seemingly easiest and cheapest option such as incineration or landfilling and disregarding the actual environmental benefits and costs.

The problem of sludge management dates back to the very beginning of sludge production. Continuous improvement of purification technology and applying increasingly rigorous regulations on purification has resulted in a global increase in the number of municipal wastewater treatment plants. Consequently, produced sludge quantity steadily increase. It is clear that sludge production is inevitable and although it represents only about 1% of the total purified water, sludge disposal (utilization) represents up to 50% of the total cost of the device. Uses of the sludge varied with changes in technology and standards, as well as possibilities of individual countries. At first, agriculture and landfills had a leading place, while the combustion took a very small share in its final use. The adoption of the Directive which limits, and then prohibits disposal to landfills, has led to the application of other solutions to the sludge use.

The disposal of sludge on landfills is not permitted, it is further stated that landfill sites are forbidden to accept, among other things, "municipal waste if it’s mass of biodegradable component exceeds 35% of total mass". Therefore, in most countries, agriculture has become the leading way for the final disposal of sludge from municipal wastewater treatment plants. However, this way of using sludge is being reconsidered today, from a practical and economic point of view, as more demanding standards are required for quality sludge as well as for a safe environment.

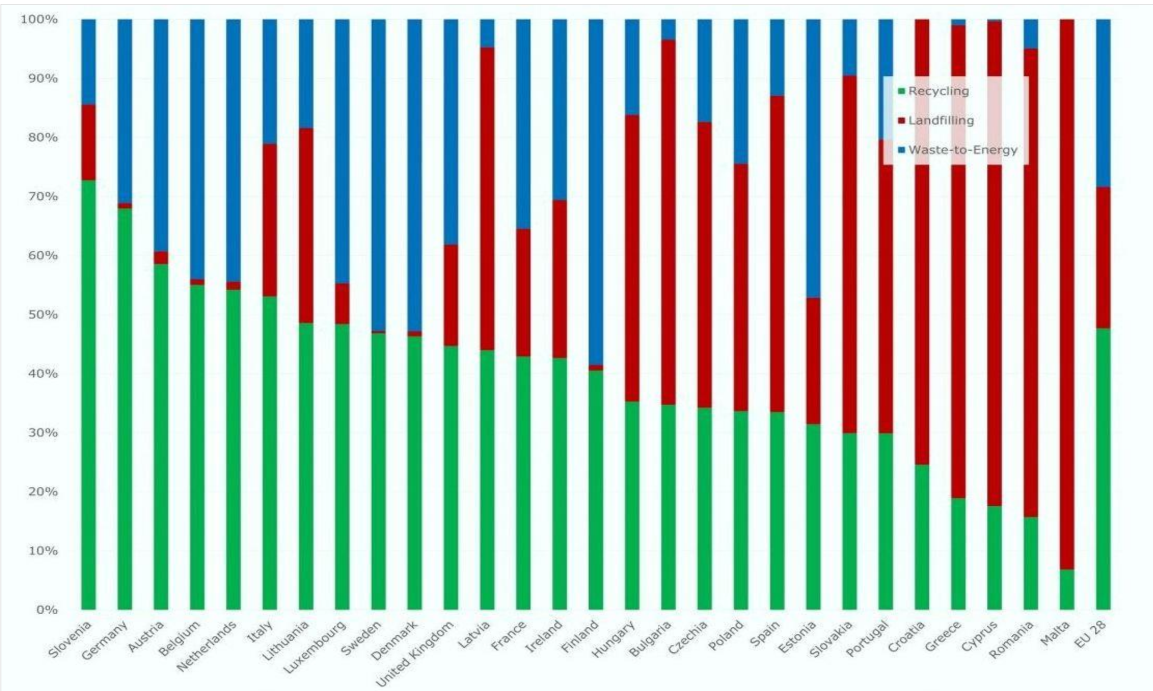

Figure 4. Waste treatment in EU for 2017(source: Eurostat)

1.4. Legal framework

1.4.1 Waste management

The main directives that regulate waste management sector in EU are Landfill directive[2] and Waste Framework Directive (WFD)[3]. The Landfill directive is defining biodegradable waste as a type of waste capable of ongoing anaerobic or aerobic composition, such as food and garden waste or paper. The Directive sets objectives for the reduction of biodegradable waste sent to landfills, with the following target: “biodegradable municipal waste going to landfills must be reduced to 35 % of the total amount (by weight) of biodegradable municipal waste produced in 1995”. It is likely that coming Directives will progressively ban the landfilling of biodegradable waste.

The WFD sets definitions for several waste-related terms and lays general principles for the organisation of waste management. In this directive biowaste is defined as a “biodegradable garden and park waste, food and kitchen waste from households, restaurants, caterers and retail premises, and comparable waste from food processing plants”. It does not include forestry or agricultural residues, manure, sewage sludge, or other biodegradable waste such as natural textiles, paper or processed wood.

It also excludes those by-products of food production that never become waste. It is a step forward to more precise definition of biowaste comparing with the Landfill directive. Among the principles set by the WFD, the most important one is the above mentioned waste management hierarchy that establishes a priority order for waste management. The hierarchy is presented in the table 2.

Table 2. Waste management hierarchy and management options for organic residues

Step in the hierarchy	Example of actions (treatments)
Prevention	• Direct avoidance (modification of processes…) • Redistribution of non-compliant products to food banks
Preparation for reuse	• This concerns mainly by-products used as animal feed, sent to rendering or used in other industrial uses
Recycling	• Composting; • Anaerobic digestion; • Deconditioning; • Land spreading;
Other recovery	• Incineration with energy recovery • Co-incineration
Disposal	• Incineration without energy recovery; • Landfilling.

The Directive also states that Member States must encourage the separate collection of biowaste for composting or anaerobic digestion and ensure the use of environmentally sage material produced from biowaste. The above mentioned Circular Economy Package, adopted by the European Commission in December 2015, includes revised legislative proposals on waste, amongst which is the WFD. Among the main elements of the proposals to amend EU waste legislation are:

- gradual limitation of the landfilling of municipal waste to 10% by 2030;
- greater harmonisation and simplification of the legal framework on by-products and end-of-waste status;
- new measures to promote prevention, including food waste, and its re-use;
- decrease the amount of generated waste;

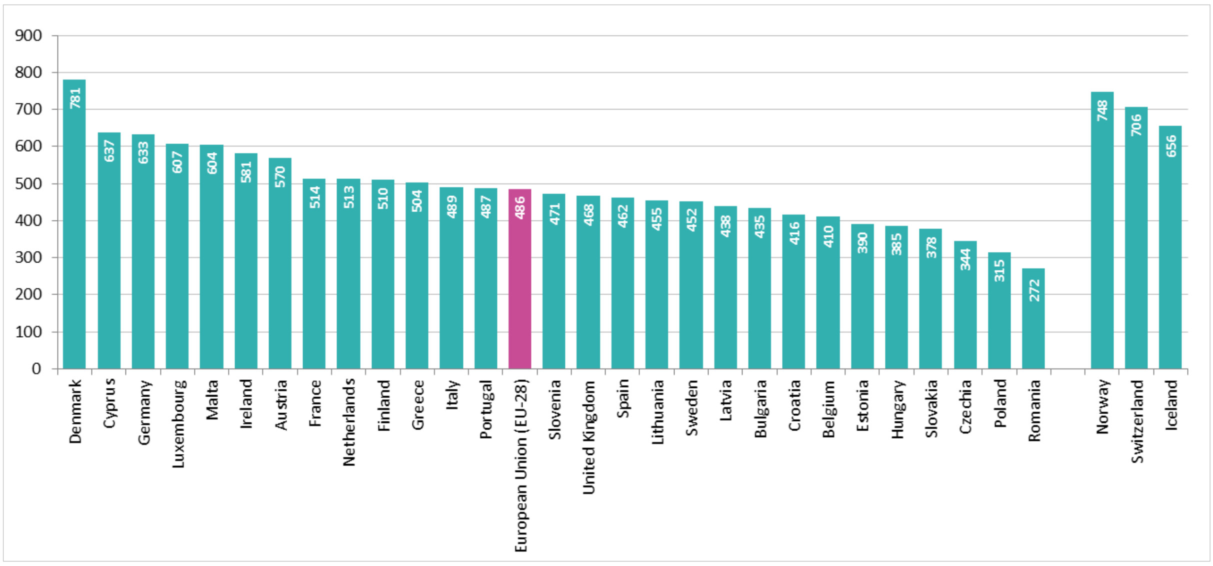

Figure 5. Municipal waste generation per capita in EU for 2017(source: Eurostat)

The governing legislation for the waste management in Croatia is the following:

- Act on Sustainable Waste Management[4]
- Waste Management Strategy of the Republic of Croatia[5]
- Waste Management Plan in the Republic of Croatia for the period 2017-2022[6]

The Republic of Croatia has to divert 65% of biodegradable municipal waste of the total amount (by weight) of biodegradable municipal waste produced in 1997 from landfills by the end of 2020 according to EU legislation. Therefore, the main objectives defined in the Waste Management Plan are to reduce the share of biodegradable waste in the municipal waste.

According to the Act on Sustainable Waste Management and in order to reduce gaseous effluents emitted into the environment resulting from the disposal of waste containing a high share of biodegradable components, the following objectives are set:

- by 2012 the share of biodegradable municipal waste deposited to landfills must be reduced to 75% of the mass share of biodegradable municipal waste generated in 1997;
- by 2015 it must be reduced to 50% of the mass share generated in 1997;
- by 2020 it must be reduced to 35% of the mass share generated in 1997.

The law also stipulated the obligation of separate collection of biowaste in order to be used in composting, anaerobic digestion and incineration with energy recovery. The law defines the order of priority of waste management with the advantage primarily on the prevention of waste generation. Implementation of the measures arising from the provisions of national legislation in the field of biodegradable waste is likely to affect the cost of waste disposal and to assume that in order to rationalize costs one should intensely consider the possibility of preventing its occurrence. Plans for waste management for the 2007-2015 period specially define the following:

- First selection – managements of special waste categories (example is very well developed recycling system in Croatia),
- Building of waste management centres at county/regional level ,
- Remediation of landfill (out of 303 landfills in Croatia, remediation is finished for 118, started on 47 and in preparation for 134 of them – data at the end of 2013),
- Remediation of black spots;

Currently the main environmental concern about food waste is its reduction and its deviation from landfilling to more suitable conversion, such as AD. The waste management hierarchy generally lays down a priority order of best environmental options in waste legislation and policies. Even though strong effort has been made in this direction, food waste is still being produced along the whole food supply chain: from the farm, to the processing and manufacturing, sales in shops, and consumption in restaurants, canteens and households. The main groups of food waste types are shown in figure 6.

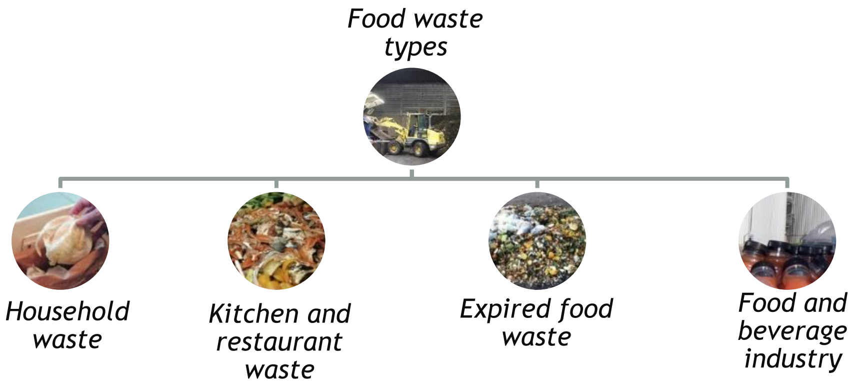

Figure 6. Different food waste types

The most common waste producers of food waste in urban areas are: households, restaurants and canteens (kitchen waste), market places and retail stores (expired food waste), and also waste from food and beverage industry. Sometimes, types of food wastes are mixed with other waste fractions (e.g. packaged products) so they have to be sent to deconditioning units before being treated. Foodwaste is usually from following sectors: meat and fish industry, fruit and vegetable industry, dairy industry, baking industry, milling and sugar industry, distilleries and wine production, etc.

Considering all waste producers, the hardest challenge for municipalities or the waste management companies is the introduction of separate waste collection from households, which consists large amount of foodwaste. The presence of contaminants in this waste requires a sophisticated process to receive a high-quality digestate at the end of the process.

Therefore, it is important to increase the public acceptance about the separate waste collection and to control the process. If random samples show high level of contaminations, the introduction of fines should be considered. In order to fully assess the existing waste flows in the Zagreb agglomeration, it has to be considered that the waste management depends, besides on the national and local framework conditions, on the characteristics of the waste management procedure. The main characteristic of each waste flow is presented in the table 3.

The treatment of biowaste can be done by several means, such as: anaerobic digestion (AD) (most favourable), composting, incineration, and landfill (least favourable). Their descriptions are shown in the table 4.

Table 3. Examples and characteristics of different waste flows

Waste type	Examples	Collection options
Processing waste	Wastes from: • Meat and fish industry, • Fruit and vegetable industry • Dairy and baking industry • Milling and sugar industry • Distilleries and wine production • Breweries and malt production	• Collection and treatment of the waste depends largely on the industry and waste type • Often, the waste is a very good co-substrate for AD
Spoiled food	• Wastes from process changes • Perishable goods	• Direct collection from wholesalers or retailers
Expired food	• Packed food from supermarkets that have passed or are close to the expiration date	• Direct collection from wholesalers or retailers
Kitchen waste from catering services	Wastes from catering services: • Restaurants, food stalls • Canteens • Hospitals, retirement homes • Kindergartens, Schools, etc.	• Collection of the waste depends on the size of the catering service • Direct collection from larger catering services in dedicated bins • Collection in bio-waste bins or mixed household waste bins
Kitchen waste from households	Wastes from households • In single houses • Multi-story buildings • In rural settlements • Cities or towns	• Food wastes can be collected in a dedicated bio-waste bin • Food wastes can be collected with the overall household waste • Food waste can be collected in dedicated plastic bags in the general

Table 4. Different treatment option for biowaste

Waste treatment	Description
Landfilling	All organic waste goes to landfilling which recovers the landfill gas and uses it in a combined heat and power (CHP) unit.
Incineration	All organic waste is incinerated (together with the mixed waste). Ash is dumped in a landfill site. The energy is used to generate power.
Composting	All organic waste is collected separately at source and then composted in a large-scale composting facility. No energy recovery is made. The compost is used as fertilizer and substrate substitute. MBT derived organic waste is not considered here as recycled material due to the high contaminations.
Anaerobic Digestion (AD)	All organic waste is collected separately at source and then digested. The biogas is upgraded to biomethane and used to substitute transport fuels. The digestate is used as fertiliser and substrate substitute. MBT derived organic waste is not considered here as recycled material as the use of the output is usually very limited due to high contaminations.

Figure 7. Usage of biogas as a transportation fuel (source: *UrbanBiogas project*)

The largest advantage of AD is that it recycles nutrients and generates energy. Disposal is the last option and should be avoided. Nevertheless, it should be mentioned that not all types of various biodegradable waste is suitable for AD, as shown in the table 5. Even though the benefits of AD or composting of biowaste is more than evident, still 40% of this waste is landfilled. The use of municipal biowaste for energy utilization has two main advantages: protection of the environment by avoiding the waste deposit and the production of energy from the renewable energy sources.

Table 5. Suitability of different biowaste treatments

Waste type	Combustion	Composting	Anaerobic digestion
Liquid manure	no	partially	yes
Sewage sludge	partially	partially	yes
Biowaste	partially	yes	yes
Grass from lawns	no	yes	yes
Sewage sludge	yes	partially	yes
Waste grease	partially	no	yes
Wood	yes	yes	no
Excrement	no	yes	yes
Straw	partially	yes	partially

1.4.2 Waste water treatment and sludge management

The sludge treatment and disposal processes are monitored by a number of EU directives that prescribe principles, targets, limitations, as well as monitoring the impact of sludge disposal on all environmental constituents. Wastewater and purification equipment are covered by the European Council Directive on the treatment of urban wastewater (91/271/EC) and the European Parliament and Council Directive on establishing a framework for Community action in the field of water policy (2000/60/EC). The purpose of their Directive is the establishment of a framework for the protection of surface water, trans-boundary, coastal waters, and groundwater. The directive requires management of the water price policy on the principle of cost recovery from water services, what has an impact on the water price which should also cover the cost of handling sludge from the wastewater treatment plants.

The problem of sludge management in Croatia has been elaborated in the Water Act[7] where is stated that the sludge generated in the wastewater treatment process can be used in accordance with a special regulation and that its disposal in water is prohibited in the Water Management Plan 2016-2021[8]. During the transitional period, disposal of stabilized and dehydrated sludge (with 25-30% DM) on waste landfills was permitted, according to the Waste Management Plan for the period 2007-2015. The current approach to sludge disposal is assessed individually, where each agglomeration and plant monitors its needs and capabilities within which it is defined by the regulations.

Underground water is the largest and most vulnerable water body of freshwater in the European Union, and also the main source of public water supply in many regions. That's why its protection is regulated by the Directive of on the protection of underground water against pollution and deterioration[9]. High concentrations of harmful pollutants in groundwater should be avoided, prevented or reduced for sake of the environment and human health protection. Specific measures are established to prevent and control underground water pollution.

The directive on Wastewater Treatment[10] states that recycle of sewage treatment sludge should be encouraged and its disposal in surface waters should be gradually abolished (which is forbidden since the end of 1998). According to the Directive disposal of sludge is in the function of environmental protection from the harmful impacts of wastewater discharge. A well-known fact is contained in the Directive, where it's stated that sludge that is produced by purifying sewage must be re-used whenever possible. However, processing and disposal procedures must have a minimal adverse impact on the environment. The directive on the protection of waters against pollution caused by nitrates from agricultural sources[11] aims to reduce water pollution caused or induced by nitrates from agricultural sources, and prevention of further contamination.

The Waste Management Plan stated that it is necessary to improve the management system for special categories of waste, and one of the tasks also relates to the establishment of a sludge management system from wastewater treatment plants. With the establishment of sludge management according to the Waste Management Plan, priorities of waste management should be taken into account: prevention of waste generation, (1) reuse preparation, (2) recycling, (3) other recovery procedures, and (4) waste disposal. First of all, material recovery and application on surfaces suitable for sludge application must be considered. Referring to the Act on Sustainable Waste Management, the Plan, handled sludge from wastewater treatment plants as a special category of waste.

It is important to note that projects for the construction of wastewater treatment plants that do not address the final disposal of sludge as a by-product of wastewater treatment are not considered fully completed, because they do not include technological solutions related to the costs and technology of sludge disposal. For this reason, costs that are based solely on the public drainage system and wastewater purification, i.e., only within the wastewater treatment plant itself, can´t be considered as complete. Namely, the total costs of sludge disposal are not negligible and can reach up to 50% of the total business[12], and in some cases may be significantly higher with the addition of other socio-economic-ecological parameters. Given the expected increase in annual production of sludge with 7,840,795,000 tons in 1995 to 12,986,620,000 tons in 2020, sludge management is a challenge for all utility companies, local governments, and the whole countries.

Figure 8. Waste water treatment in the City of Zagreb

1.4.3 Renewable energy production

The EU needs to implement energy strategy in order to secure energy supply, ensure low cost and to protect climate and environment. In this sense, one of the largest potentials lies in the renewable energy production from organic matter, such as biowaste. Its usage is very versatile: biogas for electric and heat energy production, or upgrade to biomethane and utilization as a biofuel.

The main focus of this study is on energy utilization of organic matter and the production of renewable energy. In this case, biogas is being produced. Biogas is a mixture of methane and carbon dioxide produced when organic material decomposes. Today, the majority of biogas produced in Europe is utilized in cogeneration plants, where electricity and heat are produced simultaneously. Hence, the profitability of these plants is directly dependent on a continuous disposal of the heat produced.

From today's perspective biogas is considered as an essential source of energy in a future energy systems. This is mainly due to the fact that biogas plants usually have an integrated storage system that gives them the flexibility to balance fluctuating power generation from sun and wind. On the other hand, biogas can also be injected into the existing gas networks or it can be used as a biofuel for CNG vehicles. The energy utilization of waste is presented in the figure 9.

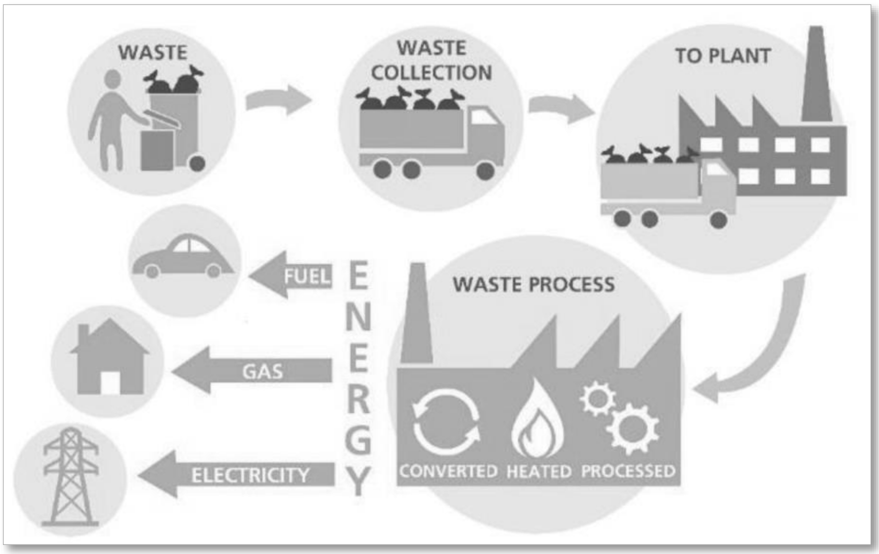

Figure 9. Diagram of the waste-to-energy-cycle (source: www.regenwaste.com)

The biogas sector in Croatia has been constantly growing in the past decade and is currently among the most important renewable energy sources with the 35 operating plants. Concerning the feedstock being used in these plants, it is mostly of agricultural origin, with the high shares of corn silage. The subsidies has been defined in the tariff system for power production from renewable energy sources and cogeneration (feed-in). The same system also defines the quota for subsidized biogas plants until 2020, being set at 70 MW.

However, at the beginning of 2016, the new Renewable Energy Sources and Highly Efficient Cogeneration Act[13] has been passed, which led to the abolition of previously valid regulations for subsidizing RES projects. This did not affect the already existing contracts and the ones which were in the process of being signed. The new act envisages new rules for signing the electricity purchase contract for RES projects. This includes the implementation of public tenders for feed in premium and signing the contracts with the guaranteed purchase price, all based on a selection of the best bidder and feed-in tariffs have been cancelled. Nevertheless, no necessary regulations have been passed up until now and therefore no new contracts have been signed in the past two years, which significantly slowed down the development of the renewable energy sector in Croatia. Regarding the current framework for the advanced biogas utilisation strategies in Croatia, it can be concluded that heat utilisation and electricity market have the most developed framework at this point.

Figure 10. Biogas plant in Germany

In the EU there are some national directives to produce biogas/biomethane and inject into the public natural gas grid. Most of these regulations on EU and national level. These Directives set out minimum requirements for the building-up of alternative fuels infrastructure, including recharging points for electric vehicles and refuelling points for natural gas (LNG and CNG) and hydrogen, to be implemented by means of Member States' national policy frameworks, as well as common technical specifications for such recharging and refuelling points, and user information requirements[14].

In Croatia there is overarching legal framework for the production of biomethane from biogas and its injection into the natural gas network in compliance with applicable rules stemming from the gas market. The established rules and regulations are applicable to biogas, gas from biomass and other types of gas if these types of gases can be safely transported through the gas system. There are no legal barriers for biomethane injection in the grid system, neither through the origin of feedstock for biogas production, neither for the mixture of biogas outside of the prescribed specifications (purified, but with large concentration of CO_2) with natural gas in the grid, if the mixture satisfies the requirements prescribed for natural gas. For injection in the grid and use as a vehicle fuel there is no additional standards.

The network Gas Distribution System permits blending of the biogas, gas from biomass and other types of gas with natural gas, but only if these types of gases can be safely added to the flow, and if the resulting gas mixtures can technically and safely be distributed through the distribution system. Biogas or gas mixtures shall meet the standard quality of natural gas and gas blending is approved by the Distribution System Operator. Implementing regulations to provide a simple and transparent way to the consumer, such as biomethane technical requirements for biomethane injection, positive discrimination towards the use and / or injection of biomethane into the natural gas network, payment terminal, etc. are currently lacking. By the end of 2012 in eleven European countries biogas was upgraded to biomethane. In nine countries thereof biomethane was injected into the grid. Sweden and Switzerland have the longest experience which started back in the early 90s. All of the biomethane countries developed standards for injection.

Figure 11. Biogas pipeline

1.4.4 Agriculture sector

The application of sludge on the soil is subject to a series of regulatory obligations, such as the Directive on the protection of the environment, and in particular of the soil, when sewage sludge is used in agriculture[15], Directive on the protection of waters against pollution caused by nitrates from agricultural sources[16], Directive on establishing a framework for Community action in the field of water policy[17], and Directive on environmental quality standards in the field of water policy[18].

The disposal of sludge within the global practice is carried out in several ways. There is no singular strategy nor unique guidelines for the disposal of sludge at the global level. Each country addresses the problem of sludge disposal in its individual way. Even at the EU level, there are present significant differences in the manner of sludge disposal among countries. The data of 2013 and 2015, identify certain changes in the sludge disposal in some countries, by increased usage of thermal treatment (combustion) and consequent reduction in the use of sludge on agricultural and non-agricultural lands. However, certain countries (e.g., Bulgaria, the Czech Republic, and Sweden) show an increasing share of sludge disposal on agricultural land. According to official data for 2015, sludge disposal in agriculture is the most widespread in Portugal, Ireland, the United Kingdom, Spain, Denmark, Bulgaria, and Iceland with a share of over 50%. Disposal of sludge on the soil of non-agricultural areas is the dominant way of disposal in Estonia, Slovakia, Finland, Hungary, and Lithuania. Sludge combustion is the primary way of disposal in the Netherlands, Switzerland, Belgium, Germany, Austria, and Slovenia. Although, restricted and almost deserted way in accordance with European directives, sludge disposal at landfills is still dominant in Romania and Italy, and in Malta, it is practically the only way of disposal of the sludge[19].

Currently, Croatia hasn't proper solution for management of sludge from the wastewater treatment plant, which is primarily related to the necessary processing infrastructure. Sludge is mostly temporarily stored or disposed on landfills, exported to neighbouring countries or fewer quantities are used for agricultural purposes or undergo composting. The current practice of sludge disposal in Croatia is referred to landfills, which is in direct conflict with Landfill directive and the implementation of this to Croatian legislation. Although landfill disposal continues to be practiced in Croatia, also in some other recent EU members, this practice is not sustainable in the long term and should be avoided as such.

According to the Waste Management, an adequate management of the sludge from wastewater treatment plants disposal isn't established in Croatia, which is primarily related to the required infrastructure. Waste Management Plan sets targets for waste management, which should be achieved by 2022 compared to 2015. It is necessary to improve the management system for special categories of waste and to establish waste sludge management system from wastewater treatment plants. Document Treatment and disposal of waste and sludge generated by the treatment of wastewater on public wastewater systems of towns and municipalities in Croatian counties[20] has estimated that existing wastewater treatment plants produce about 35,000 to 40,000 tons of sludge on dry basis annually per year. About 50% of that sludge is produced by the Central Wastewater Treatment Plant of the City of Zagreb, which is located at the plant location. At the national level, approximately 2.000 tons of sludge is used for agricultural purposes and 1,000 tons of sludge is composted annually.

Figure 12. Utilization of sludge as a fertilizer in agriculture

The remaining sludge is mainly disposed of at landfills. Waste producers reported 65.976 tons of waste sludge from industrial and municipal wastewater treatment plants for 2015, which corresponds to about 20.452 tons of dry sludge. In accordance with the Ordinance on the management of sludge from sewage treatment plants, sludge can be used in agriculture, and for the year 2015, 1.174 tons of sludge was reported on agricultural land. More than 70% of that amount was used as compost, after mixing with public waste (leaves, grass, and branches). Of the total of 7 sludge users in agriculture, 2 used sludge after composting. Also, in accordance with the Ordinance[21], the sludge must be used in a way to take into account the nutritional needs of plants, also to preserve soil quality (maintain or improve its physical and biological properties), and to preserve quality of surface and groundwater, in particular taking into account the limitations of the Ordinance. This ordinance limits the use of an unstable sludge in which no pathogenic organisms, potential pathogens, have been destroyed.

Conventional processes (condensation, biological stabilization, dehydration) do not remove pathogenic microorganisms from the sludge of wastewater treatment plants. Only certain sludge treatment processes (thermal treatments) remove them. The same Ordinance prohibits usage of treated sludge on grasslands and pastures used for livestock grazing, areas where food is grown at least two months before harvest, soil for growing fruit and vegetables, with the exception of fruit trees, then ground for feed and vegetables which may be in direct contact with the soil and which may be eaten raw in the period of at least 10 months before the date of harvest, a ground where there is a risk of sludge being washed into surface water, a soil having a pH value lower than 5, soil of karst fields, shallow or skeletal karst terrain, soil with saturated water, or frozen or covered with snow agricultural soil, in coastal and water protection areas. Because of certain restrictions, a large part of the agricultural land in Croatia is not suitable for sludge disposal.

The Ordinance limits the use of up to 1.66 tons of dry matter of sludge per hectare of soil. In cases where it is possible to use treated sludge in agriculture, the provisions of the Ordinance on Good Agricultural Practice in the Use of Fertilizers[22] should be further followed. Sludge use in agriculture differs considerably between individual EU countries and the World. Limited concentration of heavy metals used in agriculture (mg/kg dry matter sludge) shows that Austria, Belgium, the Czech Republic, Denmark, Finland, Germany, the Netherlands, Romania, Slovenia, Sweden and Croatia have stricter limit values than those prescribed, while Bulgaria, France, Greece, Hungary, Italy, Poland, Portugal, and Spain, in principle, hold the limit values set by Directive 86/278/EC. The possibility of using sludge in agriculture depends first and foremost on the origin of wastewater, the distance of agricultural land from water treatment facilities and as a very important factor, the readiness of farmers or landowners to accept sludge.

The ordinance on by-products and the abolition of the status of waste[23] prescribes specific criteria for the elimination of waste, including limit values for pollutants and harmful influence of substances or objects in the environment as well as specific criteria for determining the by-products. According to the Ordinance, specific criteria for the determination of by-products are: that there is a contract for the sale of substances or objects required for entry into the By-product Register, between the seller and the future user, and that there is no special rule which prohibits the use of this substance or objects for which registration is requested in the Register-product, and that it meets the specifications of future users of the substance or object for which registration is requested in the Register of by-products.

Due to all of the above, the sludge (or sludge compost) would ideally fit into the production of energy crops, which would be free from problems with the healthful reputation of the product. In the agricultural production of crops used for the production of food, when using the sludge obtained after the sewage purifier, the biggest problem recognized is the segment of acceptance of such products on the market. Namely, the market is distrustful to such a product from a health and environmental standpoint.

Furthermore, this method could utilize lower quality soils and poor agro-climatic conditions that cannot compete in conventional food production. From the perspective of energy planning, biomass represents the optimal form of renewable energy sources, as it is the source of almost all the useful forms of energy.

When defining suitable areas for application of sludge to agriculture, it is necessary to take into account the limitations on the use of agricultural land in agricultural production, i.e., it is necessary to regulate the criteria for possible use for areas or cultures which are not included in the food production system, and prohibition of use in ecological and integrated production according to special regulations.

The sludge generated by the purification of wastewaters can only be used in agriculture if it is previously composted, anaerobically degraded or stabilized and if the content of heavy metals and other harmful substances complies with the requirements of the Ordinance on Protection of Agricultural Soil Pollution[24] and Ordinance on sludge management from sewage treatment plants when sludge is used in agriculture[21].

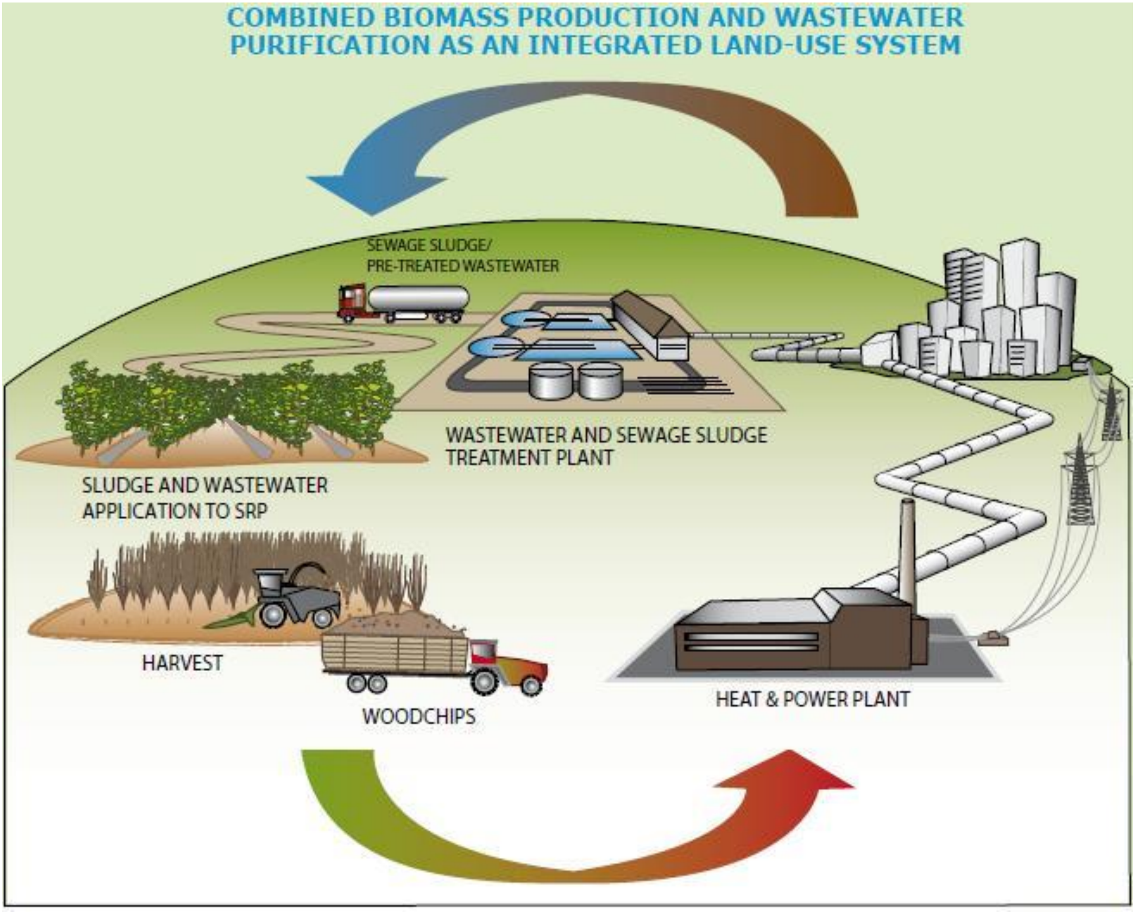

Figure 13. Utilization of sludge usage for short rotation crops production in EU (Source: www.sswm.info)

The sludge can contain various concentrations of heavy metals which, at high concentrations, may be toxic to humans, animals, and plants. The ordinance[21] permits maximum concentrations of 7 micro-elements in the sludge, in order to avoid their toxic effects when used in agriculture. Some of those elements are also present in the soil as nutrients (microelements) necessary for the growth and development of plants and are often introduced into the soil when fertilized with organic or mineral fertilizers.

The sludge in which was determined higher concentration than prescribed by the Ordinance, should not be applied on agricultural surfaces. On the other hand, the sludge that complies with this basic condition of the Ordinance is permitted for use in agriculture, but when calculating the amount of sludge for application, the lowest calculated amount should be used. Most sludge in Croatia doesn't contain heavy metals above values prescribed by Ordinance[21] and according to these standards, it in accordance with the conditions for application in agricultural purposes as a soil conditioner or fertilizer. The sludge may also contain various organic pollutants of synthetic origin from industrial wastewater, hygiene products, and pesticides. Most of the sludge contain a low level of these chemicals and don't pose a risk to human health or a threat to the environment.

The Directive[15] is one of the most important directives for environmental protection, especially soil when sludge from wastewater treatment plants is used in agriculture, which prescribes minimum quality standards for soil and sludge used in agriculture and defines limit values for heavy metals (Tables 6 and 7).

Table 6. Heavy metal concentrations limit for municipal sewage sludge

Heavy metal	**Levels of heavy metals concentration in dry matter of sludge in mg/kg not exceeding limits for use of municipal sewage sludge**		
	In agriculture or cultivation of land for agricultural purposes	For the cultivation of land for non-agricultural purposes	For land adaptation for special needs of waste management plans, land use or land development decisions and management conditions, for cultivation of plants not intended for consumption or production of animal feed
Cadmium	20	25	50
Copper	1000	1200	2000
Nickel	300	400	500
Lead	750	1000	1500
Zinc	2500	3500	5000
Mercury	16	20	25
Chrome	500	1000	2500

Table 7. Limit values for the concentration of heavy metals

Indicators	Directive 86/278/EC		Ordinance OG 38/08	
	In the soil sample (mg/kg)	In the sludge (mg/kg)	In the soil sample (mg/kg)	In the sludge (mg/kg)
Cadmium	1-3	20-40	0,5-1,5	5
Copper	50-140	1000-1750	40-100	600
Nickel	30-75	300-400	30-70	80
Lead	50-300	750-1200	50-100	500
Zinc	150-300	2500-4000	100-200	2000
Mercury	1-1,5	16-25	0,2-1	5
Chrome	/	/	50-100	500

Although the concentration limits of heavy metals for Croatia are more stringent than the Directive requires, it is important to note that the situation is similar in most EU member states, and the limit values are much stricter in the Netherlands and Sweden. Most countries have chosen to follow a sharper boundary for the range of concentrations. Stabilized sludge with appropriate treatment contain significant amounts of macro and micronutrients required for plant and animal growth. The sludge contains nitrogen, phosphorus, and potassium, and can also provide magnesium, zinc, nickel, boron, manganese, and cobalt. Due to its organic substance content, stabilized sludge introduced into the soil of a heavy mechanical composition, can improve processing conditions and improve the structure of sandy soils.

The high content of organic matter in the sludge allows the use of sludge as a soil conditioner that improves the physical, chemical and biological processes in the soil. Degradation of organic matter due to better regulation of water-air relations also leads to the microbiological degradation of the introduced organic matter which in the mineralization process releases biogenic substances like nitrogen, phosphorus, and potassium together with other essential microelements, which point to sludge as a fertilizer.

The nitrogen and phosphorus content is, in fact, a key factor for determining the amount of sludge used in agricultural crop production. Since the quantities of nutrients are lower than conventional mineral fertilizers, it is necessary to take into account that for the normal growth and development of cultivated crops, they have to be compensated by the application of mineral fertilizers.

Recently in the EU countries, the trend of extraction of valuable substances from waste has appeared, especially in using phosphorus. In 2014, the EU included phosphorus among 20 critical raw materials.

According to statistical data, it is estimated that the world's total phosphorus reserves will be utilized in the following 50-115 years, as phosphorus sources are irreversible and irreplaceable. Phosphorus is an essential element for plant growth, and indirectly for the entire living world on Earth.

Of the total amount of phosphorus used in the World, about 85% is used for agriculture. Thus, some EU countries have prepared Ordinance on disposal of waste sludge (by 2027), by which they prohibit disposal of the sludge in agriculture without the prior separation of phosphorus of larger capacity purifiers.

For smaller capacities, it is not forbidden, but it sets stricter criteria for permitted concentrations of certain parameters in the production of food cultures. Despite all the above, it can be stated that sludge disposal in agriculture remains a key direction in the overall sludge disposal strategy of Europe. It gradually becomes more difficult as an option for business economics and public perception. Introduction of the sludge in agriculture requires considerable effort and development, administration and regulation costs.

If sludge application isn't possible for agricultural or similar purposes, thermal treatment is recommended for larger devices (and/or groups of medium and small units), before sludge's final disposal. The best example of such sludge disposal is the Netherlands, which produces almost 350,000 tons of dry matter of sludge annually, managed solely by thermal means. It is understandable that within the thermal treatment, the energy of sludge will be utilized in anaerobic fermentation and biogas production.

Sludge combustion depends on the content of water and organic matter in the sludge. Lower the percentage of organic matter in the sludge is, the higher percentage of dry matter is required. Biologically stabilized sludge with organic matter content of about 50%, should be drained to the content of dry matter around 35-46.5%, depending on the type of incinerator. By applying sludge and communal solid waste combustion it is possible to dry the sludge to the level of self-inflammability, thus avoiding the need for adding more energy.

It should be noted that at the incineration of the sludge there is a risk of air pollution, and it is necessary to provide the purification of combustion gases. At a temperature of 800ºC unpleasant smells are removed, but still, smoke from the oven should be cleaned regarding dust content (flying ashes) and nitrogen oxides, heavy metals, total hydrocarbons, and toxic organics compounds. Currently, in Croatia, this form of sludge disposal is possible only in thermal power plants and cement furnaces, which often requires sludge pre-drying.

There are no municipal waste incinerators that would allow incineration of sludge together with municipal waste. Likewise, the cement industry is burdened by the requirements for incineration of the inorganic waste fraction (RDF), thus increasing the cost of such disposal. Potential sludge treatment processes can be carried out by combustion, together with municipal waste or co-incineration in cement industry, which is practiced in some of the EU member states.

The sludge, in this case, should pass the pre-drying process. Croatia has three factories for cement production. Co-incineration in thermoelectric power plants (together with coal and lignite) is also one of the practiced methods of sludge disposal. The sludge can be incinerated as a dried sludge (previously dried).

Cultivation of energy crops on agricultural soils unsuitable for food production has great potential for the future and the production of renewable energy sources. The rapeseed has already been imposed as a source of energy for the biodiesel production, but in the European Union, the emphasis is on the production of energy crops, especially for the production of second-generation biofuels (from lignocellulose biomass). Cultures for energy production (fast-growing energy crops) are those that are grown exclusively for the purpose of biomass production.

The aim of the cultivation of energy crops is production, as far as possible, larger amounts of biomass per unit of the surface with the aim of converting it into energy. Energy crops can be annual or perennial plants. Unlike one-year, multi-year energy crops do not have higher requirements during breeding, primarily in terms of agronomy and quality of agricultural soil.

The possibility of growing on soils of inferior quality is extremely important in order to avoid undesirable overlap in the production of energy and food.

There are currently a number of plant species suitable for energy utilization in Croatia, and the use of sludge from wastewater purifiers as fertilizers. However, taking into account the agro-climatic conditions prevailing in Croatia and the suitability of using sludge from wastewater purifiers as compost and land unsuitable for food production, such as miscanthus, which is actually the only one with a growing permit, based on the Opinions of the Ministry of Environmental Protection and Energy and the Law on Short Term Cultures[25].

According to the European Environmental Agency, the use of biomass as a renewable energy source could be significantly increased over the next few years, without significant adverse impacts on biodiversity, land and water resources. Biomass potential in Europe is sufficient to achieve ambitious goals of increasing the use of renewable energy sources in a sustainable manner, in the terms of solid (pellets and briquettes), liquid (biodiesel and ethanol) and gaseous state (biogas).

1.4.5 Utilization of digested residue as a fertilizer

Increase in energy demand and the issues about current non-renewable energy resources led researchers to investigate alternative energy sources during the last three decades. Renewable energy resources draw attention all over the world because they are sustainable, improve the environmental quality and provide new job opportunities in rural areas.

Every year in the world several million tons of various types of biowaste are being disposed through different ways. This global waste has a high potential as a renewable energy resource and can be turned into different types of energy. Biogas is generated in the process of anaerobic digestion of organic matter by activity of anaerobic bacteria, microorganisms that are present in matters and are responsible for the decomposition process[26].

In biogas production different kinds of biomass can be used, and the production and the quality of biogas are largely determined by the biomass contents. Biogas production is a key technology for the sustainable use of agricultural biomass as renewable energy source[27]. Because of its specificity and continuous inflow from different industries and agricultural production, organic waste represents potential danger for environment and human health[28]. This is why there is an increasing need for finding solutions regarding its processing and qualitative management.

Anaerobic digestion is an appropriate technique for converting organic biowaste with sludge into renewable energy because it is a purely bacterial process and anaerobic bacteria work best in water or in extremely damp environments. This makes anaerobic digestion particularly valuable when dealing with easily broken-down, wet or moist materials, namely organic waste. In addition, the goal of a sustainable cropping system can be achieved since the digested residue can be used as a fertilizer.

Moreover, in recent years, increasing awareness that anaerobic digesters can help control the disposal and odour of municipal solid biowaste has stimulated renewed interest in the technology. It is often the environmental reasons - rather than the digester´s electrical and thermal energy generation potential - that motivate farmers to use digester technology[29].

Anaerobic digestion is a biochemical process in which particular kinds of bacteria digest biomass in an oxygen-free environment. A number of families of bacteria, working together, in stages transform biological material into biogas[30]. The anaerobic bacteria are some of the oldest "inhabitants" of our planet. They developed at a time when the Earth's atmosphere contained no oxygen. With the exception of wood, which contains the indigestible compound lignin, they are capable of breaking down practically all biological material.

Hence, the process of anaerobic digestion occurs in a sequence of stages involving distinct types of bacteria. Hydrolytic and fermentative bacteria first break down the carbohydrates, proteins and fats present in biomass feedstock into fatty acids, alcohol, carbon dioxide, hydrogen, ammonia and sulphides. This stage is called "hydrolysis" (or "liquefaction"). Next, acetogenic (acid-forming) bacteria further digest the products of hydrolysis into acetic acid, hydrogen and carbon dioxide. Methanogenic (methane-forming) bacteria then convert these products into biogas[31,32].

Anaerobic digestion is a biochemical process where certain types of bacteria function as agents of biomass decomposition in anaerobic conditions. Combined activity of a large number of methanogenic bacteria leads to conversion of biological material in to biogas (methane and CO_2), which occurs in several phases[33]. However, due to complexity of microbe interactions, which take place in the anaerobic digestion, this process is difficult to control. The speed of anaerobic digestion depends on temperature at which the process develops; the conditions may be psychrophilic (up to 20°C), mesophilic (30-44°C) or thermophilic (45-55°C)[34].

The biogas plants in the EU most often apply the mesophilic process because of its satisfactory speed and low energy consumption. Also, anaerobic digestion becomes increasingly attractive as a method of treating highly organic biomass, since it enables the production of methane as a renewable energy source and the production of highly valuable digested residue, which can be used as a biofertiliser. The process of anaerobic digestion takes place in a sealed vessel (the so-called fermenter or digester) under controlled conditions. Process-control strategies currently available are those that have long been used for anaerobic digesters. Because of the complexity of microbial interactions involved, the process can be difficult to control[35,36].

To promote bacterial activity, the digester must maintain a temperature of at least 35°C. Using higher temperatures, up to 55°C, shortens processing time. However, there are more species of anaerobic bacteria that thrive in the temperature range of a standard design (mesophilic bacteria) than there are species that thrive at higher temperatures (thermophilic bacteria).

Digested residue obtained after the anaerobic digestion of any kind of organic substrate can be used as organic fertilizer[27], as well as for the purpose of irrigation of arable land. Digested residue has some advantages when used as a biofertiliser, and these are high content of nutrients, humus properties and high water content. Anaerobic process of degradation of organic compounds, in a closed system such as biogas plant, practically has no nutrient loss.

Degraded mineral compounds, especially nitrogen, remain in the digested residue and are “ready“ for fertilization. As opposed to fertilization with non-digested organic fertilizers, digested organic fertilizers have faster effect because of nutritive compounds which are already in mineral form and can be better utilized by plants. Since the digested residue is a by-product of anaerobic digestion (fermentation) and biogas production, which can be used as bio-fertilizer, chemical analysis of digested residue are shown in table 8[37].

Table 8. Mean values of chemical analyses from liquid digested residues of different raw materials[37]

Chemical analysis		Chicken manure	Pig manure	Cattle manure	Municipal solid biowaste	Biomass
pH directly		8.12	7.92	8.10	8.45	8.06
E.C. mS/cm		45.61	26.00	28.19	46.04	16.96
% D.M. (dry matter 105°C)		7.57	3.83	15.00	29.32	4.25
% H_2O		92.43	96.17	85.00	70.68	95.75
% annealing residue (550°C)		22.65	32.10	6.70	33.33	29.20
% anneal loss		77.35	67.90	93.30	66.67	70.80
% organic matter		74.96	65.90	66.28	64.60	68.78
% C organic		43.29	38.00	42.42	37.40	39.80
% N	in original sample	0.41	0.25	0.91	0.51	0,28
	overall on D.M.	5.38	6.52	3.10	5.45	6,58
	other forms (105°C)	3.79	6.45	2.89	3.98	5,10
	NH_3-N	1.56	0.07	0.21	0.69	1,48
% P_2O_5		1.68	1.70	0.79	1.65	1.80
% K_2O		3.64	3.56	0.97	3.21	2.55
% Ca		3.05	2.80	2.96	3.20	2.72
% Mg		1.01	1.02	1.09	1.15	0.86
% Na		0.51	0.62	0.57	0.77	0.52
mg/kg Mn		181.67	158.33	169.0	281.67	213.33
mg/kg Zn		72.33	65.33	125.0	55.66	68.33
mg/kg Cu		38.33	38.33	40.10	35.33	28.67
mg/kg Fe		647.67	599.67	1,016.0	592.67	425.00
mg/kg Pb		2.45	1.99	10.00	2.15	1.11
mg/kg Cd		0.29	0.28	0.37	0.36	0.12
mg/kg As		0.750	0.531	0.800	0.684	0.785
mg/kg Hg		<0.1	<0.1	<0.1	<0.1	<0.1
mg/kg Co		0.89	0.93	1.01	0.91	1.24
mg/kg Cr		2.74	2.96	2.66	2.85	2.57

Digested residue, obtained from anaerobic digestion of manure, can be used in the agricultural production, especially for fertilisation of grassland and crops. Its characteristics are a porous structure of a high air-containing capacity and dark colour (in its non-treated form) and, if diluted with water, there are no delayed chemical reactions or releases of gases.

Also, decomposed mineral matters (particularly nitrogen) remain fully “prepared” for fertilization. Unlike fertilisation with non-digested fertilisers, digested organic fertilisers produce quicker effects on soil, since, after digestion, the nutrients are already in a mineralised form which enables that plants use more efficiently. Also, its characteristic is a high level of nutrients, humus-like features and short maturation period. However, since heavy metals are not biodegradable and are exceptionally dangerous both for soil and plants, extreme precaution is necessary with regard to their presence in the digested samples. Therefore, it is necessary to carry out detailed analyses for heavy metals before applying digested samples as biofertilisers.

Figure 14. Digested residue after anaerobic treatment (Biogas plant in Austria)

Figure 15. Storage of digested residue after anaerobic fermentation (Biogas plant in Austria)

If the goal is to achieve optimal production of methanogenic bacteria and fast and quality decomposition of digested material as well as the methane and carbon dioxide production, the focus should be on neutral pH value of the digested material (pH 7-7.4). Further, attention should be paid to avoiding abrupt reduction in fermenter’s pH value, most often caused by evaporation of fatty acids and amassing of them in the digested material. In such cases, the process and methanogenic bacteria production is interrupted and biogas production is stopped up prematurely. In this case, a mild alkaline reaction of digested residues (pH 7.92-8.45) was found in all four samples examined, which might be partly caused by increased calcium (Ca) amount, so it can be concluded that pH value is within tolerance limits.

Determination of electrical conductivity (E.C.) of digested residue samples was intended to establish overall amount of salt in the solution. In electrical conductivity determination, various types of conductometers are used, most of which represent the modified "Wheatstone bridge". The values of electrical conductivity ranged from 16.96 mS/cm in biomass samples to 46.04 mS/cm in household biowaste samples. In other samples electrical conductivity was 45.61 mS/cm (chicken manure) 28.19 mS/cm (cattle manure) and 26,00 mS/cm (pig manure).

The reason for increased values in the digested household biowaste residues can be looked for in the assumption that the input substrate in the biogas production was made of remains of human food rich in minerals, which are added to food. For this reason, the level of major biogenic elements was monitored in the examined substrates, such as content of calcium, magnesium, and sodium. Thus, the found content of calcium in digested residues ranges from 2.72% for biomass to 3.2% for household biowaste.

Also, the magnesium content in digested residues was determined. The highest value was found in digested household biowaste residue and it amounts to 1.15%, while the lowest one was found in the sample obtained from biomass (0.86%). As expected, sodium content was the highest in the household biowaste sample and it amounts to 0.77%, and the lowest one in chicken manure, 0.51%. The contents of biogenic elements in examined digested residues were moderate, and these can be used in agricultural production as fertilizer.

When digested residue is used as biofertiliser in the agricultural production, it must satisfy the needs of plants for nutrients, and each sort of plant has specific need for nutritive matters, with specific ratios of nutrients: nitrogen, phosphorous and potassium ($N : P_2O_5 : K_2O$)[38]. For example, specific ratio of nutrients for wheat is 1.2:1:1.5; for potato 1:1:1.8; and for grass 2.4: 1:16,9.

In addition to nitrogen, digested residue as a fertiliser can meet the plants' needs for phosphorous, while potassium should be applied additionally. In the relevant literature it was found that N:P:K ratio in digested residues was 3:1:0.3. Thus, it is evident that with such ratios the digested residue can meet the plants' needs for nitrogen and phosphorus, while potassium should be added in the soil. In order to establish if the samples of examined digested residues are suitable for agricultural use, as fertilizers, the relevant ratios of basic biogenic elements, nitrogen, phosphorus and potassium, are determined, and they are as follows:

- in chicken manure N:P:K 3.20:1:2.17;
- in pig manure N:P:K 3.83:1:2.09;
- in cattle manure N:P:K 3.53:1:2.07;
- in biomass N:P:K 3.65:1:1.42;
- in household biowaste N:P:K 1.88:1:1.94.

The following fertilizer quality assessment referred to the C/N ratio. Bio-fertilizers generally have a narrow C/N ratio, from 10:1 do 15:1. In the examined samples, only the fermented samples from household organic waste match this ratio (12:1), while C/N ratio in chicken manure sample (8.05:1), pig manure sample (5.82:1), cattle manure (5.83:1) and biomass (6.04:1) is narrower.

The mentioned digested residues can be used in agricultural production, in particular in grassland cultivation and plant production. They are dark-coloured, still have offensive odour; when diluted in water there are neither chemical back reaction nor gas discharges. The digested residues are porous structures with high air capacity. After being applied on agricultural arable areas they quickly become subject to further biological decomposition by aerobic bacteria up to the stage of plant nutrient, which in addition to plant nutrition has very favourable influence on microbiological activity in soil.

Figure 16. Dry fraction of digested residue (Biogas plant Weltec, Germany)

Determination of heavy metals in the digested material is important because of methane bacteria performance in anaerobic fermentation. All methane bacteria require for their growth relatively high levels of iron, nickel, and cobalt. The literature on this subject contains data on monitoring amount of metals in digested materials of different input substrates.

Optimum levels of iron, nickel, and cobalt in digested materials are found in immensely wide divergence. Such divergence can be explained by presence of varieties of methane bacteria in substrates with different and specific needs for iron and cobalt. Due to this, the deficit of some of these metals can lead to limiting the biogas production process. In contrast, a higher level of metals may cause toxicity or prevent development of methane bacteria.

Harmful substance is any substance which exists in agricultural soil in amounts that temporarily or permanently compromises its essential function of being suitable habitat for cultivated and natural plants. Harmful substances include heavy metals and potentially toxic elements (Cd, Hg, Mo, As, Co, Ni, Cu, Pb, Cr, and Zn) and polycyclic aromatic hydrocarbons. Harmful substances are also those which are introduced in the agricultural soil without proper control or are inadequately applied in inadequate quantities, timing or type of soil.

The use of digested residues is allowed on plant production surfaces, meadows and plain pastures where soils contain some of heavy metals and persistent organic harmful substances below 50% of marginal values set out under the Regulation on ecological production in plant cultivation and plant products in the Republic of Croatia[39].

Thus, according to the mentioned Regulation, the use of biological waste is possible providing that zinc content does not exceed 210 mg/kg in dry matter, copper 70 mg/kg, lead 70 mg/kg and cadmium 0.7 mg/kg in dry matter. As shown in Table 1, these heavy metals analysed in all digested residues samples were found in contents which are below prescribed limits, and they meet the requirements set out in Croatia (and in the European Union as well) and can be used in plant production.

The amount of digested residues and their possible use in agricultural surfaces was compared and interpreted against to the mentioned Regulation which lists the harmful substances and allowed amounts of these substances in the soil. According to the Regulation, by-products of the production process, such as, in this case, digested residue – liquefied fertilizer, can be used on agricultural soil only providing that it is analysed and monitored by experts. In addition to fertilizer investigation, it is necessary to carry out the soil analysis in order to determine the quantity of liquefied fertilizer.

The potential health risk with digested residues from biogas plants is partly dictated by the substrate that is treated in the plant. It is well known that biowaste contain pathogenic bacteria. They originate from tissues of diseased animals and people and from healthy carriers who excrete bacteria in faeces, urine and exudates.

Therefore, biowaste may contain pathogenic bacteria of different species such as Salmonella, Listeria, Escherichia Coli and other pathogenic bacteria. It is for these reasons that the digested residues must be proven hygienically safe for both people and animals in order to be recycled. If not, a new way of transmission of pathogens between people and animal could be established. The growing interest in production of biogas in Europe makes it important to consider and regulate biosecurity aspects of recycling residues[40,41].

Since the digested residue that can be used as biofertiliser is a by-product of the production of biogas, it is very important to determine whether it is possible to use this fertilizer safely. For this reason, conducting of bacteriological tests is necessary to perform for the following bacteria: Escherichia, Bacillus, Enterococcus, Salmonella and Listeria[26].

The analysis of digested residue from table 8 where input raw material was chicken manure showed that at temperatures 4°C and 55°C after 72 hours there were no bacteria growth, while at 35°C a large number of various bacteria colonies were developed. Due to this, CFU determination was carried out. Investigation samples had CFU values of about 120 grown mesophilic colonies in 10^{-8} dilution. The isolated bacteria belonged to types: *Escherichia, Bacillus, and Enterococcus*.

Implementation of selective broth method did not result in isolating bacteria of types *Salmonella and Listeria*.

The investigation of digested residue whose input raw material is pig manure found that at temperature of 4°C there was no growth of bacteria colonies on nutrient pads during the 72-hour incubation. In incubation at 35°C a rise in number of *Bacillus* and *Micrococcus* bacteria on nutrient pads was recorded. The number of bacteria amounted to $22x10^4$ (CFU). In incubation at 55°C about 30 bacteria colonies of *Bacillus* type emerged.

The pre-enrichment and enrichment selective broth method did not prove the presence of *Salmonella and Listeria* type bacteria. The investigation of digested residue whose input raw material is cattle manure found that at temperature of 4°C there was no growth of bacteria colonies on nutrient pads during the 72-hour incubation. In incubation at 35°C a rise in number of *Proteus* and *Escherichia* bacteria on nutrient pads was recorded. *Proteus* bacteria are common in soil samples.

The number of bacteria amounted to $20x10^4$ (CFU). In incubation at 55°C about 30 bacteria colonies of *Bacillus* type emerged. The pre-enrichment and enrichment selective broth method did not prove the presence of *Salmonella and Listeria* type bacteria.

The investigation of digested residue whose input material was biomass showed that at temperature of 4°C there were no bacteria colonies growth on nutrient pads during the 72-hour incubation. At temperature of 35°C a large number of bacteria colonies *Bacillus*, *Nocardia,* and *Micrococcus* emerged.

In samples, number of bacteria (CFU) ranged from $15x10^6$ to $20x10^7$. In incubation at 55°C a large number of bacteria colonies of *Salmonella* and *Listeria* types emerged. The pre-enrichment and enrichment selective broth method did not prove the presence of *Salmonella and Listeria* type bacteria.

The investigation of digested residue whose input material was household biowaste showed that at temperature of 4°C there were no bacteria colonies growth on nutrient pads during the 72-hour incubation. At temperature of 35°C a large number of bacteria colonies *Bacillus*, *Nocardia,* and *Micrococcus* emerged. Number of bacteria was around $30x10^6$ CFU. Incubation at 55°C resulted in a large number of bacteria colonies of *Bacillus* type.

The pre-enrichment and enrichment selective broth method did not prove the presence of *Salmonella and Listeria* type bacteria. In table 9 were shown bacteria colonies in all investigated digested residues.

Table 9. Bacteria content in investigated digested residues

Digested residue	Bacteria colonies
Chicken manure	*Escherichia, Bacillus Enterococcus*
Pig manure	*Micrococcus*, *Bacillus*.
Cattle manure	*Proteus*. *Escherichia*, *Bacillus*
Biomass	*Bacillus*, *Nocardia*,*Micrococcus*
Municipal biowaste	*Bacillus*, *Nocardia*, *Escherichia*, *Micrococcus*

Furthermore, there is no presents of bacteria *Salmonella i Listeria* in all digested residues. From a bacteriological point of view fermented residues can be used as organic fertilizer in agriculture. However, the optimum pH level for development of pathogen bacteria *Salmonella* spp. is 6.2-7.2. Due to this, in order to prevent the development of pathogen bacteria and recontamination, digested material should be sterilized. This is why the digested residue samples (liquefied manure) have to be sterilized in the autoclave for household usage (e.g. fertilization of flowers). This procedure (sterilization) should be compulsory when liquefied fertilizer is applied in practice as to prevent human and animal infections.

2. IDENTIFICATION OF GOOD PRACTICE IN EU

In EU a sustainable waste management and energy farming is encouraged to promote sustainable development. Therefore, it is required not to have any deleterious effects on food safety and security for future generations and if possible energy crops should be rotated with food and other industrial crops without lowering production capacity. Nevertheless, there should be no disturbance to the soil and landscape characteristics, the ecology of the production area should not be disturbed unduly and the production process should be in line with urban environmental aims.

In order to reach these goals, some restrictive rules and regulations must be adhered to waste management sector and energy crops production management. Some of the good examples are presented in the following chapters.

2.1. Biowaste and sludge management

2.1.1 Henriksdal plant in Stockholm (Sweden)

This plant is one of three secondary wastewater treatment plants that serve the Greater Stockholm area (down from a former five plants). The treatment plant began in 1942 and has been expanded and upgraded almost continuously since then. The treatment plant currently serves a population of approximately 800,000 people. With the exception of the office and maintenance buildings shown in figure 17, the majority of the treatment plant is constructed completely inside a granite mountain.

Figure 17. Location of the Henriksdal plant[25]

Feedstock for the biogas production process is primary and excess sludge recovered during the wastewater treatment process. Furthermore, organic waste from the food industry and supermarkets as well as fat is used as feedstock. Organic municipal waste has only a share of less than 5% of the total feedstock fed to the biogas plant. Nevertheless, it has a high contribution to the total biogas production of the plant because of its higher specific gas production than sewage sludge. The wastewater treatment process at Henriksdal can be distinguished into three steps: mechanical, chemical and biological wastewater treatment. During these steps primary and excess sewage sludge are gathered. Before the gathered sludge is pumped into the digesters, it is dewatered through centrifuges to achieve dry matter content about 4-8% of dry matter.

The plant has 7 digesters with a total volume of ca. 39,000 m^3. Dewatered sewage sludge is pumped in at the bottom of the digesters and flows out over a weir at the top. Stirring the sludge inside the digester takes place by stirrers consisting of three blades, a larger one at the bottom and two smaller ones in the middle and at the top, located on a common long stirring axis. Three times a day for approximately 3 minutes each time reversal of the stirrers takes place. Some mixing in the digesters is also done through sludge recirculation. Hereby the recirculated sludge passes externally placed heat exchangers. Anaerobic digestion occurs at mesophilic conditions with an average retention time of about 18 days. The figure 18 provides an overview of the biogas production process.

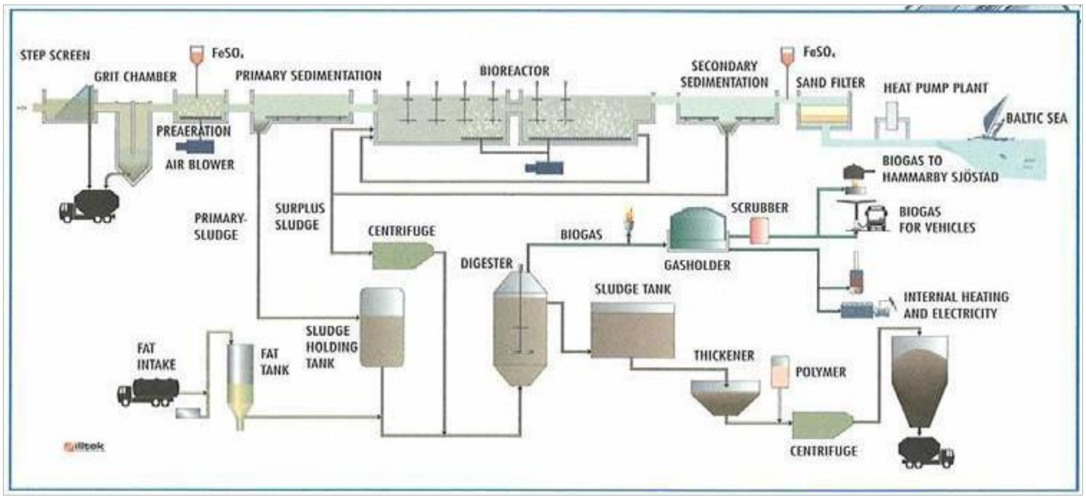

Figure 18. Waste water treatment and biomethane production process in the plant

The digester residues at Henriksdal are separated by centrifuges into solid and liquid parts. The liquid residues are transported back into the wastewater treatment process. The solid digester residue is used as soil improver to establish vegetation areas on waste rock dumps and sand stores at quarries.

Most of the produced biogas is upgraded to vehicle fuel in a water scrubber upgrading plant with a capacity of 1,400 Nm^3 raw biogas per hour. The produced biomethane with a methane content of about 97 Vol. % is transported via private gas pipeline to a bus depot and to gas filling stations in

Stockholm. Most of the public city buses in Stockholm run nowadays on biomethane. Furthermore company cars from “Stockholm Vatten” use biomethane as fuel.

Figure 19. Biomethane filling station at Henriksdal plant

2.1.2 Waste water treatment plant in Leoben (Austria)

The plant in Leoben is a waste water treatment plant with co-fermentation of organic urban waste. The facility has been built in the 1980s for Leoben and the surroundings. The additional biogas plant was built in the years 2008 to 2010 and commissioned in 2010. The biogas part of has been upgraded by the Energie Steiermark (owner of the gas grid in Styria).

Figure 20. Waste water treatment plant in Leoben[42]

The plant is using solid organic urban waste combined with the sludge (50:50), where around 5.000t/y of biowaste from brown bin is used. The main feedstock is urban biowaste from the city of Leoben, food waste, fat, oil and leftovers are used. The residue is dried and used in an incineration plant. The produced biogas is used for micro-gas-turbines and for the biomethane upgrading. The waste heat from the micro-turbines is used in the amine upgrading process. The amine-upgrading plant is positioned in two 20ft steel containers. The upgraded biomethane is fed into the natural gas grid.

Figure 21. Collected green waste

Figure 22. Storage of organic urban waste in Leoben

2.2 Usage of sludge as a fertilizer

Energy crops cultivation can potentially improve key ecosystem components, such as the soil, through synergies implemented by sustainable management criteria. Concerns about energy security and environmental threats (i.e. CO_2 effect on climate change) have led to strategies oriented towards sustainability, which established legally binding EU targets for 2020 in order to reach a 20% share of renewable energy on the final energy consumption. Within the renewable energy pool, energy obtained from biomass is expected to increase considerably, being partially fulfilled by dedicated energy crops grown in abandoned or marginal lands[43]. Energy crops cultivation aims to maximize biomass feedstock obtained per unit of area, minimize production inputs, and avoid land competition with edible crops. Complementary to these traits, several environmental benefits can be achieved through energy crops cultivation, such as the protection of soil, the increase in the terrestrial carbon sinks and reservoirs and the reduction of greenhouse gases emissions[44]. In order to achieve these environmental benefits key ecosystem components, as the soil, should be considered within energy crops management. Soil quality is regarded as an essential indicator of the sustainability of the agro-systems and is related with the quality and the quantity of soil organic matter[45].

In Croatia, soil organic matter stocks are low or very low, thus being prone to soil degradation and, consequently, vulnerable versus desertification processes. Moreover, it is expected that climate change will aggravate the conditions of Croatian environments, mainly due to an increase in the frequency of extreme events and due to the rise of temperature, which will likely induce a decrease of soil organic matter content. Therefore, the enhancement of soil organic matter levels is advisable, especially in Croatia has been recognized as an efficient option to tackle soil degradation. The implementation of this option within the context of energy crops cultivation turns out in the application of organic amendments to the soil, which partially fulfils crop nutritional requirements and improves soil quality.

Figure 23. Sludge utilization as an organic fertilizer

Regarding energy crops trials, it has been successfully applied as organic fertilizer, enhancing the quantity and the quality of the biomass produced[46], thus appearing as an interesting organic fertilizer to complement or even replace the inorganic fertilization usually applied to energy crops[47]. When sewage sludge is applied to the soil, fertility and plant growth are enhanced[48]. It should be considered that land application of sewage sludge is particularly effective in Croatian soils due to the improvement of their physical properties and soil organic matter levels for a comparatively longer period, which contributes to cope with soil salinization and erosion.

Although Miscanthus has many traits that make it ideal for biofuel production, environmental and management conditions can affect its productivity. As shown by many authors and studies, Miscanthus can produce much higher biomass yield after applying a fertilizer, e.g. municipal sewage sludge, which is the source of many valuable nutrients and has a value close to manure. That is why the interest in the use of sludge in the cultivation of energy crops such as Miscanthus has been studied by many authors and organizations[49]. The possibility of cultivation on poor quality soils is exceptionally important in order to avoid undesirable overlapping in energy and food productions. At present, in Croatia there are several plant species suitable for energy utilisation and use of sewage sludge as fertilizer. However, taking into account the agro climate conditions that prevail in Croatia and the possibility of using sewage sludge as fertilizer (compost) and use of land unsuitable for food production, the rhizome sterile grass Miscanthus and Sida hermaphrodita appears to be an appropriate choice[49,50].

Willow is mostly cultivated in the fields of southern Sweden, where about 1,250 farmers work with commercial plantations currently totalling about 13,500 hectares. The establishment period and intervals between harvests are 3 – 5 years and the yield can reach about 8 – 10 tonnes dry mater per hectare. Willow as energy crop is very demanding of water and nutrients, generally requiring 3 –5 mm of water per day during the growing season. The demand for nutrients varies according to age of the plantation and stage of crop development. For example, no N fertilisation is recommended in Sweden during the year of establishment, but 45 kg N per hectare should be applied during the second (i.e. the first harvest) year, and 100 – 150 kg N during the third and fourth years. Studies have suggested that an economic and environmental benefit may result from using waste water for irrigation, and sludge together with ash from biofuel combustion as fertiliser. Research has also demonstrated that willow can remediate soil contaminated by organic pollutants and heavy metals[51,52]. The multifunctional willow plantation in Enköping is one of the most successful cases of large-scale energy farming. Wastewater treatment, sludge recycling, leakage water filtration and heavy metal purification are combined with willow biomass production. The biomass of willow is then supplied in chips to the ENA Energy's CHP plant in Enköping, which has the capacity to produce 23 MW of electricity and 55 MW of heat. It generates 350 GWh (100 GWh electricity, 250 GWh heat) every year. The original concept comprises about 80 hectares of willow plantation, an irrigation system and 3 ponds connected to the municipal waste-water treatment plant. Each year, approximately 200,000 m^3

of nutrient-rich water, after a conventional purifying process, is distributed through the 350 km irrigation pipes to the 80 hectares of willow plantation[51,52,53].

The planning was initiated in 1993 – 1994 and the system was ready to use in 2001. Benefits of the willow-sludge Swedish concept can be summarised: use of a local energy resource - shorter distances and lower expenses for transporting fuel, the waste from society can be recycled as fertiliser – reduces uses of commercial fertilisers and environmental problems, reduction of nitrogen leakage into the Baltic Sea – also minimises environmental risks, saves the costs for building conventional nitrogen removal facilities, saves energy used in waste handling and improvement of soil environment through remediation by willow[54].

Figure 24. Establishment of new energy plantation of Sida hermaphodita

In Poland was trying to determine the effect of different doses of municipal sewage sludge (0, 10, 20, 40, 60 Mg DM/ha) on sweet sorghum yields and quality as well as changes in physico-chemical and biological properties of the soil. They found out that application of the highest doses of sewage sludge resulted in the highest yield of plants biomass. It was also observed that the content, uptake and index of bioaccumulation of macronutrients and heavy metals contained in the sludge increased along with the increasing dose of the applied biosolids, reaching the maximum at 60 Mg DM/ha[50].

Sorghum biomass was characterized by favourable net and gross calorific values, which were the highest in objects with the lowest doses of sewage sludge. Sorghum tissues bioaccumulated nitrogen and cadmium intensively, zinc, copper, and nickel-at a medium level, and potassium, phosphorous, magnesium, chromium and lead were slightly accumulated. Introduction of the higher doses of municipal sewage sludge significantly affected the physico-chemical properties and enzymatic activity of soil, decreasing its pH but increasing hydrolytic acidity, total nitrogen as well as the concentration of available macronutrients but at the same time the heavy metals content. Municipal sewage sludge contributed to an increase in the organic carbon concentration, which varied primarily due to the different doses of sewage sludge[55].

Sewage sludge introduction also resulted in a marked increase in enzymatic activity compared to the control objects, wherein the activity of dehydrogenases, acid and alkaline phosphatase, protease as well as urease increased progressively with increasing doses of sludge.

Figure 25. Energy crops planting

In Latvia there is case study about evaluation of increase of productivity of Salix energy crop and forest plantations by using sewage sludge fertilization, impact of sewage sludge on the environment, and to calculate economic income from plantations. They found that the most important problem during the first rotation cycle in willow plantations was weed control. After using sludge weeds grew up, because sludge contains large amounts of nutrients. After cutting of sprouts in the second growth season willow plantations produce more sprout from stand, and productivity increases from 0,2–0,6 t to 4,6–5,5 t of dry mass/ha. Effect of sewage sludge fertilization is greater in the second season both in control plantations and fertilized plantations. Average biomass production in fertilized plantations was 5.5t of dry mass/ha per year.

Shoot wood from fertilized plantations contained on the average by 4–8 % more heavy metals than control plantation wood. The concentration of heavy metals in the top soil layer increased, but it did not exceed the Regulations issued by the Cabinet of Ministers of Latvia about the soil quality, and the soil cultivation in the first three years was 760 LVL/ha. If the distance were not longer than 40 km and a willow-cutting combine operated without pauses, costs for cutting, chip crushing and delivery to consumers would achieve 4 LVL/m^3 [56].

Investigations on fertilization of short rotation crops with wastewater sludge are carried out in Lithuania. Namely, short rotation forest in Lithuania on a large scale is established on sludge utilization areas of Kaunas wastewater plant on cut away peat- lands.

In contrast to other countries, the future wastewater sludge of Kaunas wastewater plant, is foreseen to utilize in a concentrated way on cut away peatlands, seeking not to pollute large areas. Sludge with application doses about 250 t/ha dry matter is spreading on about 10 ha of area annually. On these areas short rotation forests is growing[57]. The results of their complex studies obtained in laboratory and in field analysis of absorbing capacity of various rocks has shown, that peat has from some ten to several hundred times higher absorbing capacity of heavy metals, as compared with sand . However, peat soils are very infertile, of very acid reaction, poor in nutritious substances. Under these conditions only some bushes and tree species naturally grow. Fertilization is necessary for improvement of peat soil. The cheapest fertilizer for them is wastewater sludge.

3. ZAGREB AGGLOMERATION

3.1. Location

Zagreb Urban Agglomeration has been found in 2016 and includes the City of Zagreb as the seat of the Agglomeration and parts of the Zagreb and Krapina-Zagorje counties (figure 26). More specifically, the Agglomeration encompasses a total of 30 local government units - 11 cities and 19 municipalities:

i) **City of Zagreb**,

ii) **Zagreb County**: City of Dugo Selo, City of Jastrebarsko, City of Samobor, City of Sveta Nedelja, City of Sveti Ivan Zelina, City of Velika Gorica, City of Zaprešić, Municipality of Bistra, Municipality of Brckovljani, Municipality of Brdovec, Municipality of Dubravica, Municipality of Pušća, Municipality of Rugvica, Municipality of Stupnik, Municipality of Pokupsko, Municipality of Klinča Sela, Municipality of Orle, Municipality of Pisarovina, Municipality of Kravarsko and Municipality of Marija Gorica, and

iii) **Krapina-Zagorje County**: City of Donja Stubica, City of Oroslavje, City of Zabok, Municipality of Gornja Stubica, Municipality of Jakovlje, Municipality of Luka, Municipality of Marija Bistrica, Municipality of Stubičke Toplice, and Municipality of Veliko Trgovišće.

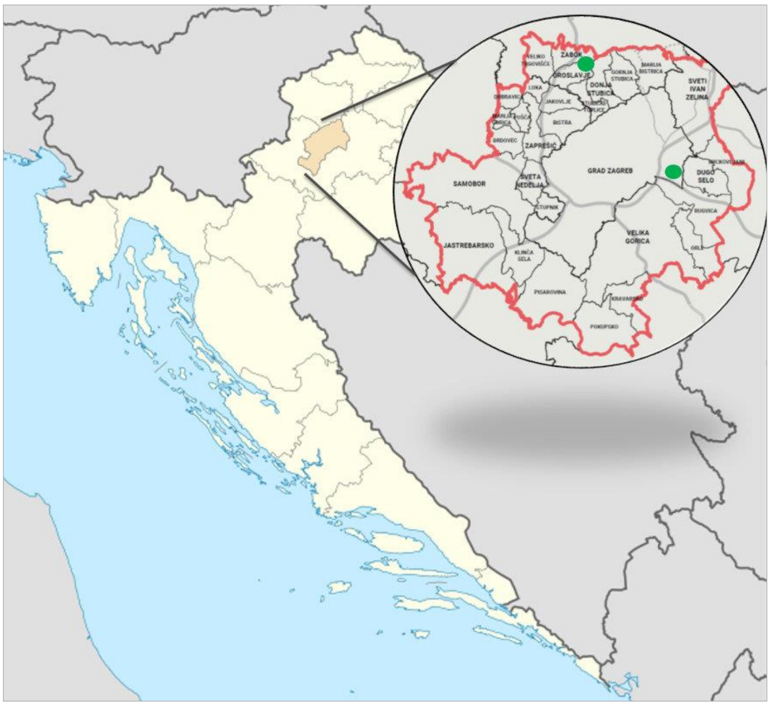

Figure 26. Location of the Zagreb agglomeration

Regarding the population, largest portion of total agglomeration inhabitants live in City of Zagreb (72.7%), but largest surface area i sin Zagreb County (67.7%). The main data of the agglomeration is presented in the table 10.

Table 10. Zagreb urban agglomeration – main data

Location	Area (km^2)	Population (2011)	Portion (%)	
			Area	Population
City of Zagreb	641,3	790.017	22,0	72,7
Zagreb County	1.969,7	256.689	67,7	23,6
Krapina-Zagorje County	300,3	39.822	10,3	3,7
Total	**2.911,3**	**1.086.528**	**100**	**100**

Cities and municipalities in the Zagreb Urban Agglomeration have the opportunity to carry out certain projects, for which there was no objective place in their budgets. On the other hand, through this Agglomeration, some strategic projects of the infrastructure that is extremely important for us will be implemented.

Zagreb Urban Agglomeration Development Strategy for the period up to 2020[58], as well as the related Action Plan and Communication Strategy, were enclosed by the end of 2017, thus commencing the implementation processes of the Strategy and creating the conditions for using more than €150 mil from the ITU mechanism. Three defined strategic goals of Zagreb Urban Agglomeration are:

(1) Improving quality of life, public and social infrastructure and human resources,

(2) Development of competitive and sustainable economy, and

(3) Improving environmental, nature and space management;

The largest area of Zagreb Urban Agglomeration occupies forest and agricultural land (about 89%) while the continuous urban area is represented with 0.1% and discontinuous urban area with 7.8%. The Land Cover relations (CLC) are due to the fact that Zagreb Urban Agglomeration, apart from its urban centers, includes the surrounding agricultural area with which it is closely linked either to labor migration or exchange of goods or functionally. According to the CLC database, the agricultural area of Zagreb Urban Agglomeration occupies about 51% of the total area of this area, and most of the agricultural land consists of arable land and gardens with crops, followed by meadows, pastures, vineyards, and orchards.

The number of agricultural households exceeds 40,000, while the average farm size per household is between 2 and 3 ha. In the area of Agglomeration, more than 15,000 family farms have been registered with a growth trend, since the production of healthy food and high-quality domestic products is a priority in today's agricultural production. The highest percentage of the land according to the CLC classification are deciduous forests (31.1%), complex and mixed crops (28.1%), primarily agricultural land with a significant share of natural vegetation (12.0%) and pastures (6.9%). Forest surface areas occupy about 38% of the total Zagreb Urban Agglomeration area. Most of the forests are privately owned and are characterized by a large fragmentation, while state-owned forest quality is considerably improved, and private forest management improvement is recognized as a priority in development. In the area of Agglomeration, predominant are the forests of economic value, while there are also protective forests and forests of special purposes.

The most widespread parts of the Agglomeration are the most elaborate western part and the Medvednica area, while the smaller forests are in the eastern part. The area along the Sava River is forest poorer, and because of its high humidity, some parts are planned to be afforested. In the first part of this analysis, there are available forestry data for all three counties that are part of Zagreb Urban Agglomeration, and in the second part, there are analyzed available data of local self-government units spatially included in the Zagreb Urban Agglomeration[58].

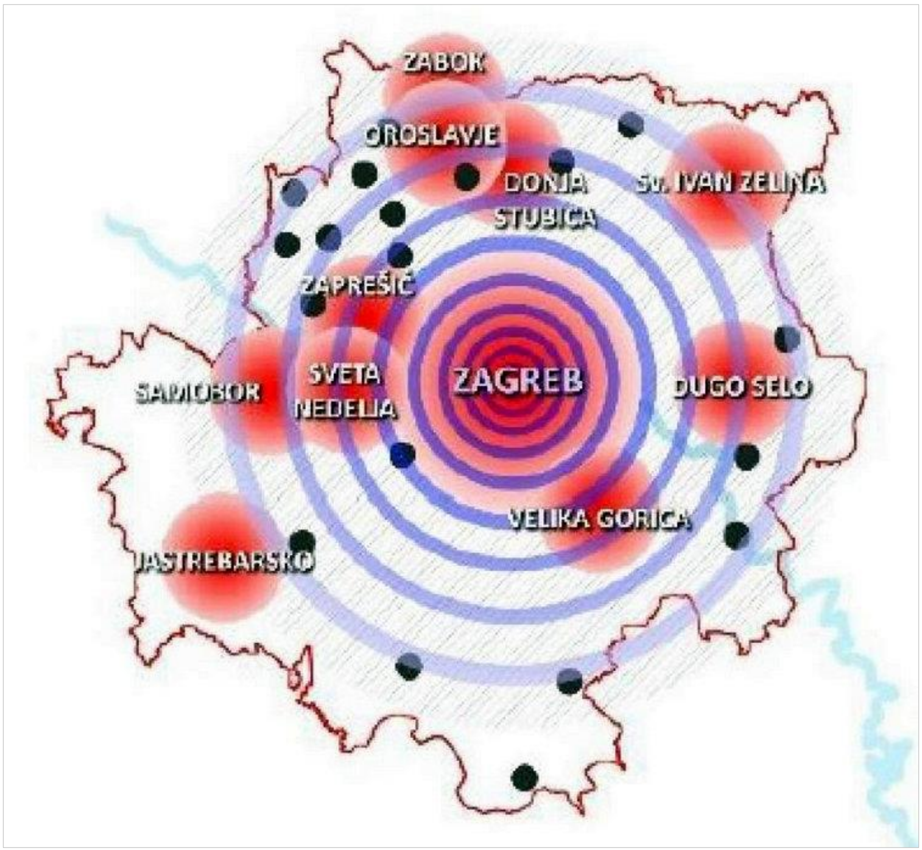

Figure 27. Main cities in Zagreb agglomeration

3.1.1 City of Zagreb

The total area of agricultural land in the City of Zagreb is 21.732,80 ha or 33.9% of the total area of the City. 70% of agricultural land is used for crops, for livestock and livestock production 18%, for vegetables 12.5%, and for growing fruit and viticulture 4%. The state owns a smaller part of the land (about 20%), while most of it is privately owned. The size of land and the fragmentation of land are extremely unfavorable, as almost 75% of the holdings in the City of Zagreb have less than 5 ha of land.

Figure 28. City of Zagreb

The fragmentation of the parcel further complicates the application of modern technology in the production process. The agricultural area of the City of Zagreb (outside the general urban plans of Zagreb and Sesvete), based on the benefits of the farm for agricultural production, is divided into four agricultural and economic regions: cattle breeding, vegetable growing, vineyards, and fruit growing. In the City of Zagreb, it is possible to irrigate 1,356.56 ha of agricultural land. The development problems of agriculture in the area of Zagreb, are a small average area per economy that doesn't allow rapid growth based on economies of scale, and fragmentation of the estates, accelerated urbanization that irreversibly changes the vision of the rural spaces and creates potential conflicts between old people and new inhabitants, production and market disorganization of producers, the unpreparedness of family economies to compete for EU funds, inadequate technology and equipment, lack of creative and innovative ideas, poor management and promotion, lack of interest among young people for agriculture and high age of average farmers, low level of professional qualifications and insufficient desire for lifelong learning and adopting new knowledge, variation of product quality, low specialization and lack of standardization of quality and low share of highly refined products, as well as a lack of branded products.

Zagreb area, in particular, should keep and evaluate its soil quality as a city natural and economic resource, and allocate it to agriculture as a permanent purpose, instead of increasing construction areas in the region of highest quality soils. Agricultural lands within the city of Zagreb and Sesvete are a special element of the traditional landscape and ecological potential. Farmland areas, along the woods in urban areas and beyond, make an ecologically invaluable, biologically diverse and landscape recognizable part of the City, which should be protected as unbuilt urban space and rationally utilized. Agricultural land is constantly being re-used for non-agricultural purposes. The biggest loss of agricultural land due to construction takes place on the most valuable soils in the Sava valley, and the loss of the agricultural soil is expressed in all categories. The most prominent is the reduction of the pasture area, but it is also a significant reduction in the size of fields and gardens, especially in urban areas.

In the area of the City of Zagreb, there are 19,515 ha of forests, of which 9,838 ha are state forests. The characteristics of private forests are that they are very fragmented, with an average size of the land of 0.43 ha and an average particle size of 0.15 ha. In the area of the City of Zagreb, there are a total of 15,399 forest owners with more than 43,500 particles. The use of forest resources from state, forests mainly falls on wood forest products, while non-wood forests products, the general forest functions, and tourism significantly lag due to the undefined market product which could be marketed[59].

Figure 29. Agriculture (strawberry production) in the City of Zagreb

3.1.2 Zagreb County

The County of Zagreb is located in the north-western part of the Republic of Croatia and surrounded on the east, south and west, the capital of the Republic of Croatia - Zagreb. Zagreb County borders on Krapina-Zagorje County, the city of Zagreb, Varaždin County, and Koprivnica-Križevci County in the north, Bjelovar-Bilogora County in the east, Sisak-Moslavina County in the southeast and Karlovac County in the southwest.

A part of the north-western border of the Zagreb County is also the state border of the Republic of Croatia with the Republic of Slovenia. The County of Zagreb, with an area of 310,000 ha, is one of the largest counties in Croatia. The County's share of the total area of the State, is over 5%.

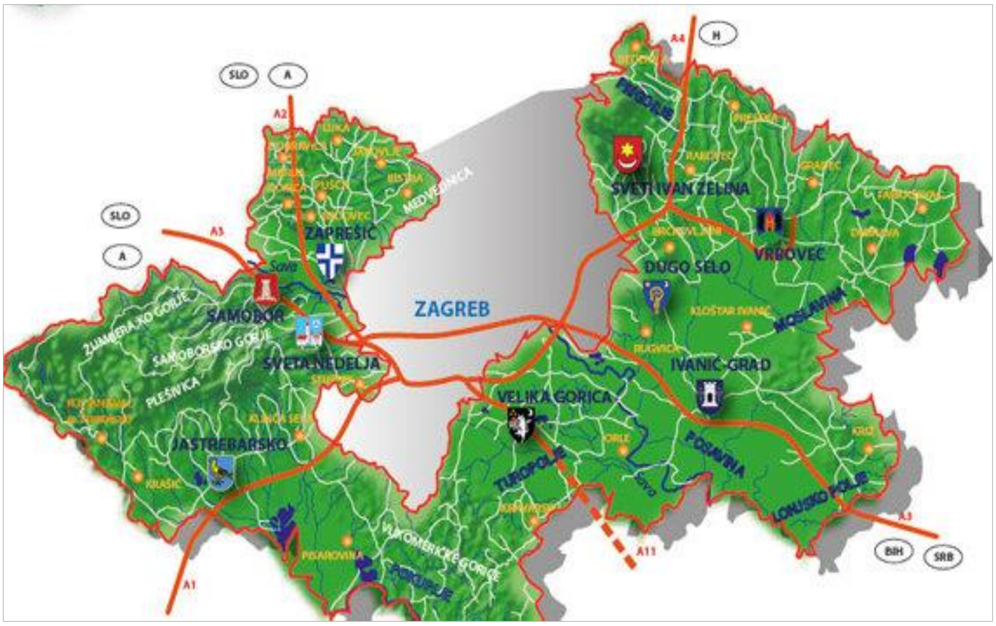

Figure 30. Zagreb County (source: www.zagrebacka-zupanija.hr)

The length of the Zagreb County border is 694.41 km. In the territory of the County, according to the Census of Population, Households, and Dwellings in the Republic of Croatia in 2011, there were 317,606 inhabitants (Report on the situation in the area of the Zagreb County, 2013-2016).

According to the Law, the area of the Zagreb County is administratively divided into 9 towns (Dugo Selo, Ivanić-Grad, Jastrebarsko, Samobor, Sveta Nedelja, Sveti Ivan Zelina, Velika Gorica, Vrbovec and Zaprešić) and 25 municipalities (Bedenica, Bistra, Brckovljani, Brdovec, Dubrava, Dubrava, Farkaševac, Gradec, Jakovlje, Klinča Sela, Kloštar Ivanić, Krašić, Kravarsko, Križ, Luka, Marija Gorica, Orle, Pisarovina, Pokupsko, Preseka, Pušća, Rakovec, Rugvica, Stupnik and Žumberak). The headquarter of the County is in Zagreb.

The agriculture is one of the most significant economic activities in Zagreb County. According to most indicators, the County of Zagreb in the agricultural production of the Republic of Croatia participates with about 10%, so it is the third among the counties after Osijek-Baranja and Bjelovar-Bilogora County.

It is among the leading counties in livestock production, fruit growing, fodder production, cow's milk production, eggs, wine, grapes, vegetable growing areas, and livestock. The County of Zagreb with over 170,000 ha of agricultural land has the necessary assumptions to become one of the most important counties in Croatian agriculture. The greatest contribution of the County of Zagreb value to agricultural production in Croatia is given by livestock production, fruit growing and the production of fodder crops. The dominant majority of agricultural land consists of arable land and gardens with about 60%, followed by meadows with about 27%, pastures with 7.5%, vineyards with 3% and orchards with 2% [60].

According to the data of the relevant Administrative Department, the following problems in the development of agriculture are: a large number of small, fragmented and non-competitive agricultural holdings; fragmentation and disorder of agricultural land; out-of-date technology and production; lack of stable and high quality production; no recognizable products with a higher added value; insufficient market infrastructure (refrigerators, wholesale markets); disorganization of agricultural producers; low educated level of farmers; unfinished property-legal issues of agricultural land; low level of entrepreneurial initiative on agriculture and the village; abandonment of villages and agriculture; inconsistent economic policy of agriculture and rural development[60].

According to the Development Strategy for the period 2014-2020. (Regional Development Agency of the Zagreb County, April 2015) 95% of the forest belongs to the economic vale forests, but there are also protective forests (land protection, watercourses, erosion areas, settlements) and forests with special-purposes (seed forests, nature parks, forests for relaxation and recreation, scientific research, defence, etc.). According to the ownership structure, 51.44% of the forest area is owned by the state, and 48.56% is privately owned. The case of forest on state-owned land is significantly better (double the stock of wood and the area of forests intended for logging) so an improvement of private-owned forests has been recognized as a priority in the development of the use of this natural resource. By implementing more scientific projects in the County area, the main developmental problems related to the management of private forests have been identified [61].

Among the above mentioned are the fragmentation and reduction of the forest holdings (average size of the forestry sector is 0.65 ha), high average age and low level of forestry education, extensive and improper management of private forests, low stock of timber and its poor structure, replacement of the most valuable species with less valuable, lack of proper reconstruction of stands and poor openness of private forest complexes (lack of forest pathways and roads). Improving management of private forests in the Zagreb County, and in cooperation with the advisory services staff, for the purpose of implementation, the County grants support for the biological renewal of forests and the purchase of small forest mechanization.

Figure 31. Zagreb County (city Zaprešić)

3.1.3 Krapina-Zagorje County

Krapina-Zagorje County is located in the north-western part of Croatian territory and belongs to the central Croatia. A separate geographical entity that is bounded on the north and the peaks Macelj Ivančice and Zagreb Medvednica mountain in the southeast. The western border, also the state border with the Republic of Slovenia, is a river Sutla, and the eastern borders of the watershed basin of Krapina and the Lonja. The area is one of the smaller counties (1,229 km^2) but has greater demographic importance, because the population density of 108,1 inhabitants per km^2 is over the Republican average of 75.8 inhabitants per km^2 and along with Međimurje and Varaždin County, is the most densely populated area of Croatian Republic.

According to official statistics and the census of 2011, 132 892 inhabitants lived in Krapina-Zagorje County, which is 3.1% of the total population of the Republic of Croatia. According to the Law on Counties, Cities, and Municipalities in the Republic of Croatia (OG 86/06), Krapina-Zagorje County comprises 25 municipalities and seven cities.

The towns are: Donja Stubica, Klanjec, Krapina, Oroslavje, Pregrada, Zabok and Zlatar, and Krapina is the headquarter of the Krapina-Zagorje County. The average number of inhabitants per unit of local government is 4 153, while in the whole Krapina-Zagorje County there are 422 settlements, with an average population of 315 inhabitants.

Figure 32. Location of the Krapina-Zagorje County (source: www.wikipedea.com)

This County has a major traffic significance, since the international highway route runs along with the entire County and is an integral part of the north-western entrance/exit of the Republic of Croatia towards Europe. Rural features dominate in the area of Krapina-Zagorje County.

Settlements that are declared cities, represent areas that have transitional characteristics between the urbanized area and the village, and appropriate activities are required to direct urbanization and development to the cities. The increase in the number of inhabitants is continuously present in all urbanized settlements of the County, while the decrease is present in rural settlements (www.kzz.hr).

According to the OECD regional level criterion, Krapina-Zagorje County is predominantly rural region with more than 50% of the population living in local rural areas. Out of the total number of County residents, 67.22% of the population lives in rural areas. Compared to the Republic of Croatia, this represents 6.75% of the population living in predominantly rural areas.

Comparing the other counties that make NUTS 2 region of North-western Croatia, the majority of the predominantly rural population lives in Zagreb County, followed by Varaždin, then Krapina-Zagorje and Koprivnica-Križevci County. The population of Međimurje County lives in a significant rural area, while the population of the City of Zagreb is predominantly urban (The Krapina-Zagorje County Rural Development Strategy by 2020).

The agriculture in the Krapina-Zagorje County is conditioned by the configuration of the terrain, soil quality, population displacement and the traditional way of living on smaller properties. In the County, the natural conditions are limited, the terrain is hilly, with a small part of the lowlands with an uneven regime of surface and groundwater. One of the basic characteristics of agricultural holdings is the land fragmentation. Only 16% of the total area of Krapina-Zagorje County is an agricultural area, and the largest share of agricultural arable land and meadows[62].

The County is characterized by fragmented and non-differentiated agricultural production as well as the underdeveloped market. Market-minded way of thinking and the intensified market performance they see as solutions for the shortage of commercial production. The primary task is focused on spatial transformation, the consolidation of agricultural land.

Agricultural holdings should be organized and linked for joint production and easier product placement on the market. It should focus on the development of specialized and long-term sustainable economies. Efforts should be made to prevent the degradation of small rural economies and depopulation of rural areas and encourage the increase of land ownership as well as to better exploitation of the existing (Development Strategy of the CIS by 2020) [62].

Agricultural areas of Krapina-Zagorje County cover 57.7%, of which cultivable crops covers 50.4 % of total County area. Of total agricultural land, 98.7% are privately owned, while the largest share of agricultural land are arable land and meadows [62]. County agricultural land area covers 70,277.95 ha, and basic characteristics of agricultural holdings are land size and its fragmentation. The average size of the land is 2.16 ha. There are 27.8 % lands with a size of up to 1 ha, 50.9% of 1-3 ha, only 5.2% of 5-10 ha and 0.3% above 10 ha. On average, each economy owns nine parcels of an average size of 0.25 ha. It is evident that agricultural holdings have begun with land consolidation, but there is also a trend of reducing vineyards and mixed perennial crops reduce. Furthermore, in recent years, great attention has been paid to the promotion of integrated and ecological production as well as the development of indigenous and ecological products.

The County through the implementation of the Rural Development Program of the Republic of Croatia 2014-2020 aims to help farmers from Zagorje, to raise quality level of agricultural food products and to ensure market competitiveness. In the future, Krapina-Zagorje plans to continue to affect the average reduction in the age structure of family farms (further OPG), as well as to increase the number of family farms through a variety of measures and support, which will attract and enable young farmers for the establishment and the development of their family economies [62].

The agricultural production of the Krapina-Zagorje County is largely used for the production of its own needs. Mostly of meat, milk, dairy products, eggs, fruits, vegetables, wine, cereals production, etc. The majority of agricultural income is realized by selling cows' and, to a lesser extent, goat's milk, calves, pigs, poultry, goats and lambs.

Livestock production is consisted mostly of cattle production, especially cow's milk production, and there is a noticeable increase in the number of pigs on family farms, from which it is possible to assume that there is a gradual substitution of cows with pigs. Besides, poultry breeding (chickens, hornbeam, ducks and geese) is traditionally present. Recently, there has been a growing interest in goat and sheep breeding[62]. Farming, primarily, in the function of animal feed production where wheat, corn, alfalfa and potatoes are present, while yields are lower than the national average due to the configuration of the field. There is a tradition of grape growing and wine production, favored by relief and climate. Fruit production is less well developed, and extensive orchards prevails. Agricultural production is carried out on agricultural holdings that can act like a village or family farm (OPG), crafts, a company or a cooperative if they are registered for carrying out agricultural activities.

The area of the Krapina-Zagorje County has been characterized by intensive process of abandoning agricultural activities and moving the population to non-agricultural activities without changing housing. Differentiated economic development resulted in the restructuring of the population from primary to other sectors of activity.

The process of abandoning agricultural activities has caused changes in the landscape, the structure of the population and in the way and quality of life. Agricultural activity in the area of Krapina-Zagorje County marks the collapse of the land and their dispersal, relief limitation for more intensive agriculture, an unorganized market, lack of melioration interventions and uneven regimes of surface and underground waters in lowland areas.

The County's agricultural production is largely in the function of self-supply of family farms and market supply of agricultural products such as meat, dairy and dairy products, fruit, vegetables, and wine. In the Krapina-Zagorje County area, approximately 35% of the area is still under the forests despite logging in the past and is estimated to 42,870 ha. The most afforested are the mountainous areas of Macelja, Stahinjčica and Ivančica, and the northern slopes of Medvednica [62].

Figure 33. Krapina-Zagorje County

3.2 Waste management

Biowaste is defined by the EU as biodegradable garden and park waste, food and kitchen waste from households, restaurants, caterers and retail premises, and comparable waste from food processing plants. It does not include forestry or agricultural residues, manure, sewage sludge, or other biodegradable waste such as natural textiles, paper or processed wood. It also excludes those by-products of food production that never become waste.

Currently the main environmental threat from biowaste (and other biodegradable waste) is the production of methane from such waste decomposing in landfills, which accounted for some 3% of total greenhouse gas emissions in the EU-15 in 1995. Considering the options for biowaste management and the related EU policies, most sustainable option is anaerobic digestion (table 11).

Table 11. Different treatment option for food waste

Waste treatment	Description
Landfilling	All organic waste goes to landfilling which recovers the landfill gas and uses it in a combined heat and power (CHP) unit.
Incineration	All organic waste is incinerated (together with the mixed waste). Ash is dumped in a landfill site. The energy is used to generate power.
Composting	All organic waste is collected separately at source and then composted in a large-scale composting facility. No energy recovery is made. The compost is used as fertilizer and substrate substitute. MBT derived organic waste is not considered here as recycled material as the use of the output is usually very limited due to high contaminations.
Anaerobic Digestion (AD)	All organic waste is collected separately at source and then digested. The biogas is upgraded to biomethane and used to substitute transport fuels. The digestate is used as fertiliser and substrate substitute. MBT derived organic waste is not considered here as recycled material as the use of the output is usually very limited due to high contaminations.

Most common waste producers of food waste in urban areas are: households, restaurants and canteens (kitchen waste), market places and retail stores (expired food waste), and also waste from food and beverage industry. Also, it is important how the biowaste is being collected. Main challenge is to have efficient collection with the lowest possible portion of impurities in the segregated biowaste. Some of the options are:

- **Door to door collection**: biowaste is collected at specified intervals near homes (brown bin). Citizens should dispose biowaste bin at specific time of collection. The citizens should put the container outside the house and it's usually collected once per week.

- **Special containers at public road for homes and door to door collection for commerce**. Citizens place food waste in special containers on public roads (near traditional containers with other waste, glass, cardboard, etc.). Commerce (markets, supermarkets, restaurants, etc.), however, place food waste in special containers that take out to the streets at certain times. It is recommended to use biodegradable bags as they facilitate subsequent treatment. For Both households and businesses system, the collection is performed daily.
- **Special containers at public road:** This case is basically as above but without distinguishing between households and businesses.

Figure 34. Waste collection in the City of Zagreb

3.3 Biogas production

Biogas production is one of the most efficient ways to treat biowaste. For that reason it is mentioned in about several legal documents that could be grouped in three main categories: energy, agriculture and environmental protection. Within energy policy, biogas is described as one of RES while in other policies, biogas is positioned as a tool for achieving some specific goal of agriculture policy (e.g. a rural development measure) and environmental policy (e.g. GHG emissions saving tool, agriculture pollution prevention measure).

In the Energy Act[63], biogas is recognized as one of the renewable energy sources. In the Energy Development Strategy of the Republic of Croatia[64], the use of energy from biogas is described as follows: "Biogas is a gaseous fuel produced by anaerobic digestion of organic matter. Raw materials for biogas production are waste from livestock production, animal breeding (slurry, manure and/or waste from agricultural production (silage, grass mixtures, etc.). Biogas is produced from waste from the agro-industrial and food industries, as well as a slaughterhouse and municipal waste, usually in a lesser extent[65].

By mid-2009, only three biogas plants were registered in the Republic of Croatia, with only one of them using feedstock originating from agriculture and with the status of eligible electricity producer (landfill biogas plant at Jakuševac, biogas plant from Zagreb Waste Water Treatment and the above-mentioned biomass biogas plant Ivankovo). The biogas power plant on agricultural biomass is owned by the agricultural cooperatives Osatina group, and with its regular operation and delivery of electricity to the electricity grid, it started on February 2009 and is also the first biogas plant of agricultural biomass in Croatia. The second biogas plant was operational in 2011 and is located at a farm site in Tomašanci (Osijek-Baranja County), while in 2013, a third biogas plant of this type Slašćak-Viškovci (Osijek-Baranja County) was installed (1MW).

After the first biogas plant was operational in 2009, their number has grown from year to year, so that number has already exceeded the number of 10 power plants in 2013, with the largest increase yet to follow. To date, the number of biogas power plants has increased to 61, 65,502 MW of installed capacity, as can be seen in Table 1. From 2009 to the end of 2018, 48 contracts for the purchase of electricity from biogas power plants were concluded in Croatia, of 53,920 MW, while 37 of them were connected to the Croatian energy system, with an installed capacity of 40,732 MW[66].

In Croatia, most biogas is produced in the East of the country, with 18 biogas plants in the Osijek-Baranja County, followed by Vukovar-Srijem and Bjelovar-Bilogora counties. It should also be pointed out that there are no smaller-scale biogas plants (from 100 to 500 kW) in the Slavonian-Baranja region that are not in the function of electricity production - but produce biogas for local consumption. The construction of these plants is significantly cheaper and easier to manage[67].

Possible directions for the development of the biogas market in Croatia are: micro biogas plants suitable for the size of Croatian livestock farms (for capacities of 10 - 50 kW, 3620 such farms identified), common biogas plants at the municipal / city level - concept the energy cooperatives, the door to the food processing industry (fossil sector companies to the biogas market and other CO2eq emitters and service providers) and the expansion of businesses and utilities to energy utilities and the concept of a circular economy.

Specifically, operating costs would be much lower if, on several farm-scale, more micro-biogas plants would separate biogas from energy production and transport produced gas to cogeneration or purifier treatment plants at the same location). From maximum utilization of biogas energy, all smaller biogas plants should use heat and electricity from biogas cogeneration, and larger ones should be turned to biomethane production either for gas grid or gas transportation purposes[65].

Table 12. Existing biogas plants in the Croatia

County	Number of biogas plants	Installed electric capacity (MW)
Zagreb	4	5,199
Krapina-Zagorje	0	0
Sisak-Moslavina	1	0,135
Varaždin	2	0,550
Koprivnica-Križevci	6	6,799
Bjelovar-Bilogora	10	9,351
Virovitica-Podravina	4	6,000
Požega-Slavonia	2	4,000
Osijek-Baranja	18	18,029
Vukovar-Srijem	11	12,299
Međimurje	2	1,140
City of Zagreb	1	2,000
Total	**61**	**65,502**

It is reasonable to assume that the biogas potential is much higher since the manure has a low energy value and low biogas yields. Biogas from the sludge of wastewater treatment plants and landfills has not been officially evaluated and yet there lies a significant potential for the biogas production.

To utilize that potential, it is necessary to assess the size of the biogas potential as well as to create a program with tailored measures supporting biogas production and utilization. Regardless of the official potential of biogas, the investors have tapped biomass available for biogas production, and these numbers show a significant increase in the last couple of years thus confirming the investors' increased interest in biogas. All of these biogas projects focus primarily on electricity generation. The result of only a small number of biogas plants compared to EU countries is a clear indication that administrative obstacles remain the main challenge to address in the following period in Croatia[65].

Realization of new projects of biogas plants in Croatia, would lead to job creation and disposal of problematic biodegradable waste, as well as improvement in terms of reduction of waste accumulation at landfills, creation of new value in the form of electricity and thermal energy and production of organic fertilizer which could be restored to the cycle of nature[66].

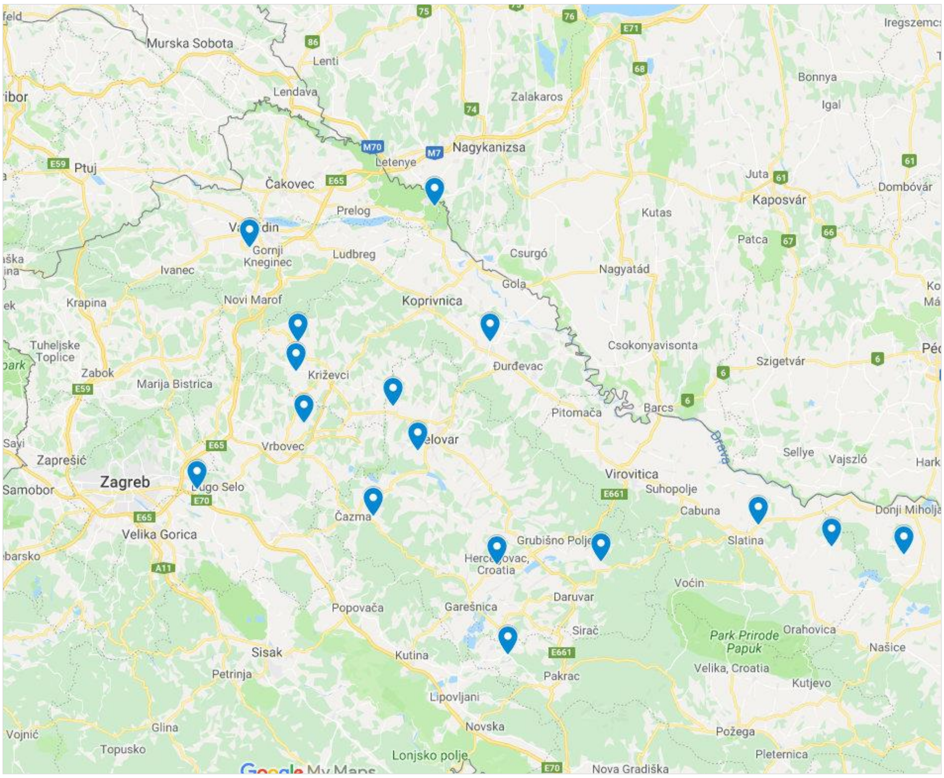

Figure 35. Location of biogas plants in northern Croatia

3.4 Sludge treatment

Regarding the sludge management, agriculture would be considered a natural way of sludge disposal, as it contains similar amounts of organic matter, nitrogen, and phosphorus with a little potassium and lime as well as manure. From this aspect, sludge is at first suitable for local farmers as an addition to fertilization and production of arable land crops.

The possibility of using it in agriculture in the first place depends on the willingness of farmers or landowners to accept sludge. However, there are also well-known negative sludge properties that limit its use (such as heavy metals and pathogens that reflect the wastewater content that is being treated on the device). Furthermore, there are potential problems with scents as well as sludge processing due to large volumes and large amounts of water in the sludge.

Today, sludge treatment technologies have been developed so they can reduce potentially unwanted problems that contribute to the maintenance of quality, and thus the use of sludge, but bear the problem of increased costs and the cost of using the sludge in agriculture. According to the Ordinance[19], the use of treated sludge located at an economically acceptable distance for its disposal in relation to the wastewater separator is prohibited to:

- Grassland and pastures used for livestock cattle breeding,
- The areas where the herbage is grown at least two months before harvest,
- Land on which grow fruits and vegetables except for fruit trees,
- The land intended for the cultivation of fruits and vegetables that can be in direct contact with the soil and which may be eaten raw in the period of at least 10 months before the date of harvesting or harvest,
- A land where there is a risk of sludge rinsing in surface water,
- Land with a pH value lower than 5,
- Land with saturated water, covered with snow and on frozen agricultural soil,

The production of sludge can be increased due to an increase in the amount of wastewater by extending the sewer system to other users connected to the wastewater treatment plant. Similarly, sludge production cannot be reduced but there are technologies that can reduce the amount of sludge already produced (drainage, dehydration of volatile substances - anaerobic/aerobic fermentation), which is to be permanently disposed of in an environmentally and economically adequate manner (application to soil-agricultural sector other ways, composting, incineration, etc.).

The priority policy is to use the quality sludge after the stabilization treatment which has the role of destroying the pathogen, preventing the spread of the scent, reducing the proportion of water and others (thermal hydrolysis, lime addition, thermal drying etc.) used in most economically beneficial way in the agricultural sector, and to avoid burning if it is possible.

The characterization of sludge is the first step in planning the sludge using by applying it on or in the soil. The sludge composition largely determines important decisions as to whether it is suitable for economically efficient soil application, which application technique to use in agriculture, forestry, field public areas and which technique is most appropriate.

Likewise, the composition depends largely on the amount of sludge that can be applied per unit of surface per year or cumulatively. Quality control measures depend on the sludge content. Important sludge properties should be considered when assessing benefits for use in agriculture include the amount of sludge, total dry matter content, pH, organic matter, nutrients, heavy metals, and organic pollutants. The sludge composition reflects the wastewater content that comes to the unit and process technology on the device. The greater the load of wastewater with industrial or precipitation waters is, the greater is the possibility that sludge will have more heavy metals, and thus the potential problem for its application to the ground will be generated.

In these cases, it is necessary to prevent wastewater pollution by a predefined program that requires measures to reduce the potential wastewater load. These can be pre-treatment of industrial waters before discharge into the sewage system or changes in the process on the device itself. The key factor determining the volume or mass of the sludge produced is, the intake of wastewater, the process technology of the wastewater treatment plant and the subsequent sludge treatment process.

Ultimately, each stabilization treatment in a certain way influences the application of stabilized sludge to the soil. It is important to note that it is permissible to apply sludge to the ground and the ground if it is possible to carry out the stabilization measures. Sludge stabilization is carried out for one or more of the following reasons:

- organoleptic properties (e.g., appearance or odor of the sludge),
- mass reduction,
- volume reduction,
- better dehydration (reducing water content),
- reduction of pathogenic microorganisms,
- Further use or sale of the final product.

Figure 36. Produced sludge after the waste water treatment in England (www haith-recycling.com)

For medium and large plants, it is recommended to use anaerobic fermentation of sewage stabilization. It is the only biological process that can utilize the energy potential of sludge. The biogas, which is a product of the anaerobic stabilization, in case of containing about 2/3 of methane and 1/3 of the carbon dioxide has a lower calorific value of 6.63 kWh/m^3 of gas.

Table 13. Impact of sludge treatment on sludge application

Sludge treatment and definition	Impact on sludge properties	Impact on sludge application on soil
Dampening: centrifugation, flotation or gravity	Reduces water and volume content while increases the proportion of dry matter	Reduces transport costs for all forms of sludge application (agriculture, forestry, sanitation, public areas)
Fermentation (aerobic and anaerobic): biological sludge stabilization by converting some organic matter into water, CO2 and methane	Reduces volatile and biodegradable organic matter and reduces sludge mass by converting it into gas and soluble substances. It can also reduce volume. It reduces pathogens and controls odors.	Reduces the amount of sludge produced
Alkaline stabilization: sludge stabilization by adding lime	Raises the pH reaction in the sludge. It temporarily reduces biological activity. Reduces the presence of pathogens and controls the odors of the sludge. Increases the dry matter content.	A high pH reaction to an alkali stabilized sludge can immobilize heavy metals for a certain time until a high pH value is maintained by the action of lime.
Conditioning: changing of the sludge properties to separate water easier. Application of inorganic substances (lime or iron chloride) or organic polymers.	Conditioning increases the dry matter mass without increasing the organic matter, and sludge dehydration improve.	Conditioned sludge require special care if applied to the ground.
Dehydration: Separation of water from solid particles by vacuuming, pressing, centrifuging	The concentration of dry matter increases due to drainage and reduces the volume of sludge. This method increases the dry matter content up to 40% in organic sludge and more than 45% in inorganic sludge. Nitrogen and some soluble substances are being lost together with water.	Reduces the required surface area and transport costs in all forms of application to the land.
Composting: An aerobic process involving bio-stabilization of sludge in composted piles.	Biological activity decreases. Most pathogens are destroyed. It breaks down the sludge to substances similar to humus. The dry matter content is increased due to mixing with other porous materials.	Great conditioner but requires storage. It can contain fewer nutrition than less processed sludge.
Heat drying: Loss of water by using heat and destroying pathogens.	Sludge disinfection. Partially reduces the potential for biodegradation and release of odors.	It hugely reduces the sludge volume

Liquid sludge is transported in tanks, and sludge with a higher content of dry matter is transported in trucks with a scraper box, etc. The farm must be provided with the washing possibility of transport equipment to avoid the scattering of residues on the roads. Equipment may be conventional manure spreaders if the sludge is dehydrated and have no dense mass. Application of liquid and dense mass is possible by injectors or devices for the application of manure and slurry. Sludge forms that can be used in agriculture are:

- Liquid product with low dry matter content (4% DS),
- Product with higher dry matter content after dehydration (20-35% DS),
- Lime-stabilized sludge, dehydrated with high dry matter content (60% DS),
- Thermally treated granulated sludge with a very high dry matter content (92% DS).

The sludge must be stored at the plant from the period from October to February because in that period it is foreseen that weather conditions do not permit application to the ground, as prescribed by the Ordinance[19]. Also, sludge can be stored at the end-user location if he wants it and if it has adequate storage space.

The reuse of sludge in the agriculture of Zagreb Urban Agglomeration is a steady process and, in any case, an optimal method for final sludge disposal, preservation and closure of the natural cycle of biogenic elements created at the site of its production. When using sludge in agricultural area of Zagreb Urban Agglomeration, its composition is important and needs to be carefully controlled to avoid soil and water pollution or soil degradation. Major problems are heavy metals, organic pollutants and pathogenic microorganisms, as well as the appearance of odour that occurs with further degradation of insufficiently stabilized sludge. The daily human activity of modern society has resulted in the disposal of many substances in wastewater sewerage. Untreated sludge can contain:

- bacteria, viruses, parasites, that could potentially cause diseases,
- heavy metals from the source, i.e., materials from which the water and drainage system was built, rainwater and roads, industrial processes and cosmetic products,
- various organic micro pollutants that originate mainly from industrial processes, detergents and irresponsible waste disposal in sewage.

Potential pollutants can be eliminated or reduced if:

- a strict application of environmental legislation is carried out,
- prevention and limitation of the use, i.e., input of pollutants into sewage systems is carried, or by selecting the appropriate sludge treatment technology on the device.

Therefore, in the case of Zagreb Urban Agglomeration, it's assumed that the use of sludge previously subjected to treatment (stabilization) is permitted for agricultural purposes, in order to achieve the adequate standards prescribed by the Ordinance OG 38/08. The main reason for raising sludge pH is temporarily rising of temperature to reduce the pathogen and the odour of the sludge. The low pH of sludge (pH <6,5) allows heavy metals release while high pH of sludge (pH >11) destroys bacteria in contact with ground neutral or alkaline reaction limits the solubility and mobility of heavy metals. Applying soil sludge affects soil pH changes that can affect the accessibility of heavy metals in growing plants as well as the storage of heavy metals in the soil.

It is very frequent that a stabilized sludge has high pH values, which is commonly achieved if additional lime sludge treatment (stabilization) is carried out. Additional benefit of applying it to the agricultural soil is raising its pH (which is a serious problem in Zagreb Urban Agglomeration) as well as increased microbiological activity of soils, i.e., remineralisation of organic matter. Content of the sludge includes suspended and dissolved solids. This indicator can affect the potential way of land use in several ways:

- the size of the transport and storage system. Higher dry matter content decreases the volume of sludge that is stored or transported because it contains less water;
- type of transport - the choice of transport mode to the place of application will be determined depending on the content of the dry matter;
- equipment and application vary depending on the proportion of dry matter in the sludge (scattering, injection, spraying).

Figure 37. Sludge produced at the Zagreb WWTP

Composting is another possibility of using sludge in the Zagreb Urban Agglomeration because it can be considered waste, but if the by-product is of the waste code 19 08 05, it can be used in the process of recuperation by composting. Thus, compost III is obtained, according to the Ordinance on by-products and the withdrawing the status of waste. Namely, it is necessary to declare the sludge as an anaerobic fermentation product (digestion). According to the Appendix of this Ordinance, sludge from municipal water treatment (waste code 19 08 05) can be used for the production of class III compost, intended for use on land that is not used for food production, on forest or park area, for landscaping or cultivation and the final cultivation of the landfill. The use of Category III compost can be an opportunity for the development of a sludge program to produce energy crops. Composting requires a bulk volume (straw, wood waste) and it could simply fit into the energy crops production without products that could cause health problems.

Specifically, in the agricultural production of cultures used for food production, when compost produced from sludge after sewage treatment is used, the biggest problem is defined in the market acceptance segment. The market is reluctant to such a product with a health and ecologically standpoint. One of the interesting solutions is the use of sludge, for non-food purposes on the forest areas of Zagreb Urban Agglomeration.

The biggest problem occurs with the control of the local population who has the habit of going to the woods since, after sludge usage, people shouldn't enter the forest to 12 months after. It is also important to take care of certain conditions and limitations here. Accumulation of toxic substances in forest soil can cause their penetration into groundwater and drinking water storage. It can also be affected by changes in the balance of special forest habitats, resulting in the biodiversity problem.

Summarily, according to the legal framework of the European Union and Croatia, the following options for sludge disposal are possible within the Zagreb Urban Agglomeration:

- the disposal of the treated sludge at landfills, either in special areas or solid waste dumps,
- composting with the organic fraction of solid municipal waste or waste from livestock production,
- use in agriculture and forestry,
- energy options,
- processing in regional waste management centers,
- temporary warehousing and processing,
- other solutions (construction).

As can be seen from in the figure 12, Zagreb Urban Agglomeration in its composition along to the city of Zagreb, and has part of Zagreb County and a part of the Krapina-Zagorje County in whose area the sludge from both wastewater purifiers should be disposed of. However, within the estimated potential areas for sludge disposal from the wastewater purifier, some of them should be excluded, such as water protection areas, or flooded areas.

Ultimately, it is necessary for each specific area identified as potential to determine both the nutrient and heavy metals status by Art. 7th of Ordinance. Therefore, the following parameters should be considered when designing a program for assessing the suitability of an area for sludge application:

- the type, quantity, and quality of sludge produced on the site,
- the available area on the site,
- culture in the locality and fertilization,
- the availability of other organic fertilizers, the available surface for the application of organic waste,
- soil type, soil quality, transport suitability, nutritional status,
- local climatic conditions,
- local topography,
- presence of nitrates in groundwater,
- the vulnerability of underground and surface waters,
- hydraulic soil capacity,
- heavy metals concentration in the soil,
- accessibility to road traffic.

Due to the agricultural production within the Zagreb Urban Agglomeration, and with the current technological development of urban wastewater processing, it is not possible to achieve a significant part of the contaminants transfer from the water to the slurry. Therefore, in the future, wastewater treatment plants will exist as producers of not strictly controlled sludge which cannot be safely and permanently disposed of. Available data on sludge quantities in the surface calculation, a mean amount of approximately 50,000 t/year of sludge from the Central Wastewater Treatment Plant in Zagreb was taken, containing about 30% of dry matter. Estimated quantity and estimated average dry matter were taken as an orientation value based on the available indicators of monthly stabilized sludge analysis.

The total annual dry matter content of sludge is around 15,000 t/y. By applying art. 8. of the Ordinance, the maximum annual quantity of sludge that can be applied to agriculture is 1.66 t/ha. Therefore, we obtain that approximately 9,036.2 ha of surface area per year is needed. As for the other wastewater treatment plant of Zagreb Urban Agglomeration, which is located in the Zabok area, the average quantity is 1490 m^3/y of sludge, containing about 75% of the dry matter. Estimated quantity and estimated average dry matter were taken as an orientation value based on data available from the indicators of the same stabilized sludge technology as is done in the City of Zagreb.

According to the above, for the wastewater treatment plant in Zabok, the total annual dry matter content of sludge is approximately 600 t/year and the maximum annual quantity of dry matter that can be applied to agriculture is 1.66 t/ha, meaning that around 361.4 ha of land annually is required. Total for Zagreb Urban Agglomeration is necessary to ensure 9,114.7 hectares of agricultural land, on which the sludge from the wastewater treatment plant in Zagreb and Zabok would be applied.

Table 14 sublimated data descriptions for both wastewater purifiers in the Zagreb Urban Agglomeration area.

Table 14. Estimated quantities of sludge in Zagreb Urban Agglomeration

Zagreb Urban Agglomeration	Estimated quantities of sludge (t)	Required area of agricultural land for sludge disposal (ha)
Central wastewater treatment plant Zagreb	50,000	9,036.2
Wastewater treatment plant Zabok	1,117.5	361.4
Total	**51,117.5**	**9,397.6**

Total annual quantity of dry matter sludge is approximately 51,000 t for the entire Zagreb Urban Agglomeration. By applying art. 8. of the Ordinance, the maximum annual quantity of dry matter sludge that can be applied to the agriculture is 1.66 t / ha. Therefore, in the calculation process by dividing the total amount of dry matter sludge with maximum quantity in the application, we obtain that approximately 9,400 ha of surface area per year is needed.

As more agricultural areas are needed for food production, the cultivation of energy crops on marginal soils has great potential for the future. Insects have already been imposed as a source of energy to produce biodiesel, but the EU is currently focusing on the production of energy crops. Cultures for energy production (fast-growing energy crops) are those that are grown exclusively for the purpose of biomass production. The aim of their cultivation is to produce as large as possible amounts of biomass per unit of the surface with the aim of converting it into energy. Energy crops can be annual or perennial. Unlike one-year, perennial energy crops do not have higher requirements during breeding, primarily in terms of agronomy and quality of agricultural soil.

The possibility of growing on soils of inferior quality is extremely important to avoid undesirable overlap in the production of energy and food. Currently, in Croatia, there are several plant species suitable for energy utilization and use of sludge from wastewater purifiers as fertilizers. However, considering the agro-climatic conditions prevailing in Croatia and the suitability of using sludge from wastewater purifiers as compost and land use disadvantageous for food production, miscanthus is imposed. However, in the Zagreb Urban Agglomeration, such production is difficult to perform due to the structure and the process of agricultural production. Such production has potential in neighboring counties, primarily in Sisak-Moslavina, where approximately 63,000 ha of abandoned agricultural areas are ready to produce energy crops on neglected or marginal soils.

Namely, the land covers the physical space: soil, climate, hydrological and geological properties, vegetation in the extent that affects the possibility of use, then the results of past and present activities of man with or without socio-economic conditions, i.e., land is in a broader sense the term of how to use the soil. Also, we can look at land as well as on a limited resource that is the link between human activity and the environment.

The data provided by Ministry of Agriculture, agricultural land includes agricultural areas: arable lands, gardens, meadows, pastures, orchards, olive groves, vineyards, ponds, rivers and swamps, as well as other lands that can be economically justified to agricultural production. Also, bare forest land and land covered with initial or degrading stages of forest development that is suitable for agricultural production is considered as agricultural land. Agricultural land includes cultivable land and agro-forest systems where vegetation is below limit values of some indicators used for defining forests (within *Forest Land*), and following the relevant national definitions.

Lands under crops includes all areas with annual and perennial crops as well as land that is temporarily not processed - areas that are not cultivated for one or more years after which they are re-cultivated. One-year crops include cereals, oilseeds, vegetables, root vegetables, green fodder.

Today, agricultural areas cover 2.6 million hectares, of which only 1.3 million hectares are cultivated. At the same time, Croatia has 2.6 million hectares of forests and forest land with annual increment of 10.526.000 m3, while cutting area of wood is 6.564.000 m3. Grassland covers about 1.2 million hectares. Table 15 shows the amount of agricultural and forest land and grasslands in Zagreb Urban Agglomeration (for calculation, the entire Zagreb and Krapina-Zagorje County have been used because there is no data for reduced JLS outside Zagreb Urban Agglomeration) and neighbouring counties.

The County of Zagreb was in general confirmed as a potentially very strong area with approximately 169.000 ha of agricultural land available for agricultural producers. If we look at the representation of agricultural areas in neighbouring counties, agricultural areas with greatest potentials, along with Agglomeration, are located in Sisak-Moslavina County, which has a very high potency of agricultural land with amount of 194.648 ha. Convincingly, least agricultural areas are located in the City of Zagreb and they cover only 24.472 ha.

Table 15. Amount of agricultural and forest land, and grassland in urban agglomeration Zagreb

Zagreb Agglomeration	Total agricultural land (ha)	Forest land (ha)	Grassland (ha)
City of Zagreb	24,472	20,803	8,001
Zagreb County	169,268	120,818	52,212
Krapina-Zagorje County	70,266	50,361	30,832
Total	**264,006**	**191,982**	**91,045**

The ARKOD is a national system for the identification of land parcels or records of agricultural land in the Republic of Croatia. It is a national program that establishes a database designed to record the actual use of agricultural land. ARKOD's goal is to get a clear picture of how much land in Croatia is used for agricultural production, regardless of the cultures that are grown on and to provide farmers with easier and simpler ways to apply for support as well as their transparent use. Thus, ARKOD is a database that registers the real use of agricultural land, which in practice means that the farmer registers land he really uses for agricultural production and therefore differs from the CLC system that also shows those lands, along with ones that are not in support system or agricultural system production.

The ARKOD is an upgrade of Register of Agricultural Holdings, which is the basic record used by Paying Agency in agriculture, fisheries and rural development for financial support. The problem in ARKOD in Croatia is that it does not include fully utilized agricultural land but only what is in direct support system (about 60% of agricultural land). The following table shows the quantities of land in Zagreb Urban Agglomeration registered in ARKOD concerning Corine Land Cover 2012 database (table 16).

Table 16. Comparison of land by ARKOD and Corine Land Cover in Zagreb Urban Agglomeration

Zagreb Agglomeration	Total land area in ARKOD (ha)	Land under crops not in ARKOD (ha)	Land under crops - CLC 2012 (ha)
City of Zagreb	6,393	10,077	16,470
Zagreb County	69,802	47,253	117,056
Krapina-Zagorje County	19,255	20,178	39,433
Total	**65,450**	**77,508**	**172,959**

Lands under crops that are not in ARKOD shows land surface detected through CLC 2012 (one-year crops and perennial crops i.e., areas without meadows and pastures). This is actually data on land areas under use, that are not recorded anywhere and are used for agricultural production purposes. As previously stated, land under crops includes all areas with annual or perennial crops, as well as temporarily unprocessed lands.

According to ARKOD for Zagreb Urban Agglomeration, shows treated agricultural land areas by type of use at the end of 2014. In the grain production structure, the dominant part is maize with 62.4%, wheat with 27.1% and barley with 7.2%.

Potential surface for the purpose of calculating the available areas based on the part of the above mentioned limitations prescribed by Ordinance OG 38/08 narrows the choice of agricultural crops by category of use.

Table 17. Area of agricultural land in ARKOD by type of use for Zagreb Urban Agglomeration (ha)

Zagreb Agglomeration	Arable land	Meadow	Pasture	Vineyard	Fruit types	Nut tree varieties	Mixed permanent crops	Other land area	Total
City of Zagreb	4,391	1,529	48	107	189	52	15	56	6,387
Zagreb County	53,598	12,129	1,067	987	1,429	325	54	211	69,800
Krapina-Zagorje County	10,582	6,418	344	779	900	104	69	63	19,259
Total	**68,571**	**20,076**	**1,459**	**1,873**	**2,518**	**481**	**138**	**330**	**95,446**

Following table shows abandoned agricultural areas in Zagreb Urban Agglomeration, which have been extended with the entire counties of Zagreb and Krapina-Zagorje. These are the areas that are in the CLC category of grasslands and are actually marked as agricultural areas with a significant share of natural vegetation (neglected areas or areas with poor processing), i.e., they could be relatively fast converted to intensive agricultural production.

Table 18. Agricultural land in Zagreb Urban Agglomeration and neighbouring counties

Zagreb Agglomeration	Land under crops - CLC 2012 (ha)	Neglected/Abandoned areas (ha)	Possible land under crops (ha)
City of Zagreb	16,470	5,467	21,937
Zagreb County	117,056	32,791	149,847
Krapina-Zagorje County	39,433	14,640	54,073
Total	**172,959**	**52,898**	**225,857**

It is evident from the table that in counties that are wholly or partly part of Zagreb Urban Agglomeration there is less than 53,000 ha of neglected areas. Unfortunately, they are mostly fragmented, whose enlarging for agricultural production requires a significant expense. However, primarily in the counties that are part of Agglomeration is agricultural food production. Without energy cultures, or without introducing miscanthus as energy plant and main raw material for the production of biomass and biofuels of the second generation on more serious areas, it is very difficult to perform the disposal of sludge from the wastewater purifier on the agricultural areas of the County as part of Zagreb Urban Agglomeration. Following the above, without the assistance of neighbouring counties, especially Sisak-Moslavina County, where agricultural production is intensive and where it is possible to organize agricultural production for non-food chains, the disposal of sludge from Agglomeration will not be fully realized. Table 19 shows the potential of surrounding counties in terms of total agricultural and forest land as well as grasslands while the agricultural land types are shown in table 20 and table 21 shows abandoned agricultural areas of neighbouring counties of Zagreb Urban Agglomeration.

Table 19. Amount of land in counties outside of Zagreb Urban Agglomeration

Counties	Total land area (ha)	Forest land area (ha)	Grassland (ha)
Bjelovar-Bilogora County	145,583	106.862	38.771
Karlovac County	120,900	232.783	73.355
Koprivnica-Križevci County	104.005	63.834	23.414
Međimurje County	51.191	13.823	9.264
Sisak-Moslavina County	194.648	236.709	98.075
Varaždin County	70.815	46.916	23.389
Virovitica-podravina County	116.936	79.306	14.857
Total	**804.078**	**780.233**	**281.125**

Table 20. Area of processed agricultural land in ARKOD by type of use in neighbouring counties of Zagreb Urban Agglomeration (ha)

Counties	Arable land	Meadow	Pasture	Vineyard	Fruit types	Nut tree varieties	Mixed permanent crops	Other land area	Total
Bjelovar-Bilogora County	71,782	14,704	2,578	316	802	966	123	66	91,337
Karlovac County	13,668	5,171	1,511	115	629	263	53	1,315	22,725
Koprivnica-Križevci County	59,078	8,856	282	625	806	329	16	65	70,057
Međimurje County	25,982	1,742	127	538	826	184	11	111	29,521
Sisak-Moslavina County	41,973	8,830	4,781	255	1,437	488	55	227	58,046
Varaždin County	23,833	3,954	159	575	526	200	10	153	29,410
Virovitica-Podravina County	76,239	2,014	1,131	477	1,051	714	9	153	81,788
Total	**312,555**	**45,271**	**10,569**	**2,901**	**6,077**	**3,144**	**277**	**2,090**	**382,884**

The table shows how the total of neglected land in neighbouring counties is 173,965 ha. Most of these areas are in Sisak-Moslavina County with slightly less than 64,000 h. Possible land under crops are areas where intensive agricultural production could be carried out, without reducing the area under the meadows and pastures, but their use is not possible without a thorough review of the field, soil analysis, climatic conditions, and property relations. The use of sludge is also possible in the forestry area, while the area of Zagreb Urban Agglomeration under the forests involves about 38% of the total area. Most of the forest is privately owned, and are characterized by high fragmentation, while the quality of forests owned by the state is much better.

Table 21. Current state of agricultural land in neighbouring counties of Zagreb Urban Agglomeration

County	Land under crops - CLC 2012 (ha)	Neglected/Abandoned areas (ha)	Possible land under crops (ha)
Bjelovar-Bilogora County	106,811	20,935	127,747
Karlovac County	47,545	53,273	100,818
Koprivnica-Križevci County	80,591	12,839	93,430
Međimurje County	41,926	6,076	48,002
Sisak-Moslavina County	96,572	63,062	159,635
Varaždin County	47,426	8,809	56,235
Virovitica-Podravina County	102,079	8,971	111,051
Total	**522,950**	**173,965**	**696,918**

In the area of Agglomeration, predominant forests are for commercial purposes, and others are protected forests or forests for a special purpose. The most widespread parts of the Agglomeration are the most elaborate western part and the Medvednica area, while the smaller forests are in the eastern part. The area along the Sava River is forest poorer, and because of its high humidity, some parts are planned to be afforested. Considering that much unknown information, it is difficult to express indicative costs. For comparison, experiences from EU countries can be taken. Thus, the use of sludge in agriculture is assessed as the most economical way if all preconditions for its application are accomplished. According to the EU reports, the cost price in euros per ton of sludge is shown in table 22.

Table 22. Indicative costs for sludge options.

Treatment	Cost (€/t)
Agriculture application	150-400
Composting	250-600
Drying	300-800
Incineration	450-800
Landfilling	200-600

4. CASE STUDY - ZABOK

4.1 Location and its relevance

The WWTP Zabok is in its construction phase and will be built in 2020 and owned by the public company Zagorski vodovod ltd. This company has been found by 26 local self-government units, is engaged in public water supply and public drainage, operates in the urban agglomeration of Zagreb and supplies water to 90,000 residents in more than 31,000 terminals.

Public water supply system of Zagorski vodovod ltd. includes 6 springs, 60 reservoirs, and 80 hydrophobic and pumping plants. The total distribution network of public water supply is over 2,000 km. Primary activities of Zagorski vodovod ltd. are public water supply and public sewage.

In the year 2006 Zagorski vodovod ltd. has registered the activity of public sewage and waste water treatment and started preparations for taking over existing sewage systems in the area of Krapina-Zagorje County.

Figure 38. Zagorski vodovod Ltd (source: www.zagorski-vodovod.hr)

4.2 Current status

Zagorski vodovod Ltd. Is planning to build WWTP Zabok with the capacity of 36.940 PE, and will be consisted of these stages:

- *Prior purification* – separation of particles
- *Second stage* - consists of temporarily holding the sewage in a quiescent basin where heavy solids can settle to the bottom while oil, grease and lighter solids float to the surface.
- *Third stage* - removes dissolved and suspended biological matter, as well as dehydration of the sludge.

The schematic overview of the WWTP Zabok is presented in the figure 39. The main data of the Zabok plant is presented in the table 23.

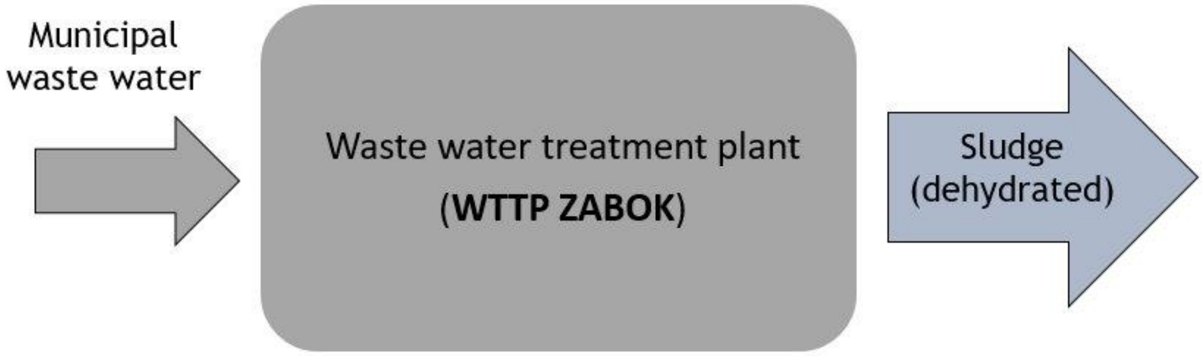

Figure 39. Overview of the WWTP Zabok

Table 23. Zagreb agglomeration – main data for WWTP Zabok

Zagreb Agglomeration	Location	Population	WWTP size (PE)	Sludge amount (m^3/y)	Dry matter	Total amount (t/y)
WWTP Zabok	City of Zabok	9,000	36,940	1,490	75%	1,117.5

Besides its energy potential, one of the options for sludge treatment is application in the agriculture, usually as a soil improver for the usage on non-food land. In this sense, it is important to have in mind the total costs of sludge disposal, it is not negligible and can reach up to 50% of the total business and in some cases may be significantly higher with the addition of other socio-economic-ecological parameters. The data on the land availability within the Zagreb agglomeration is presented in the table 24.

Table 24. Agriculture data of Zagreb agglomeration

Zagreb Agglomeration	Used land -different crops, ha	Unused land (ha)	Total land potential (ha)
Grad Zagreb	16,470	5,467	21,937
Zagreb County	117,056	32,791	149,847
Krapina-Zagorje County	39,433	14,640	54,073
Total	172,959	52,898	225,857

The location of the WWTP Zabok will be administratively within the City of Oroslavlje (Stubička Slatina). The position of the WWTP Zabok is presented in the figure 40.

The key aspect in finding a suitable location was to assess the city urban zoning and land use. In the case of the proposed location, city's urban plans have classified this area and communal, which allows further steps in the development of waste water treatment plant. Also, it is of utmost importance to have public acceptance. Location of the WWTP Zabok fulfils both of the terms. The location of the WWTP Zabok is easily accessible from the main city's road, motorway and in this sense future transportation routes will not be considered as an issue.

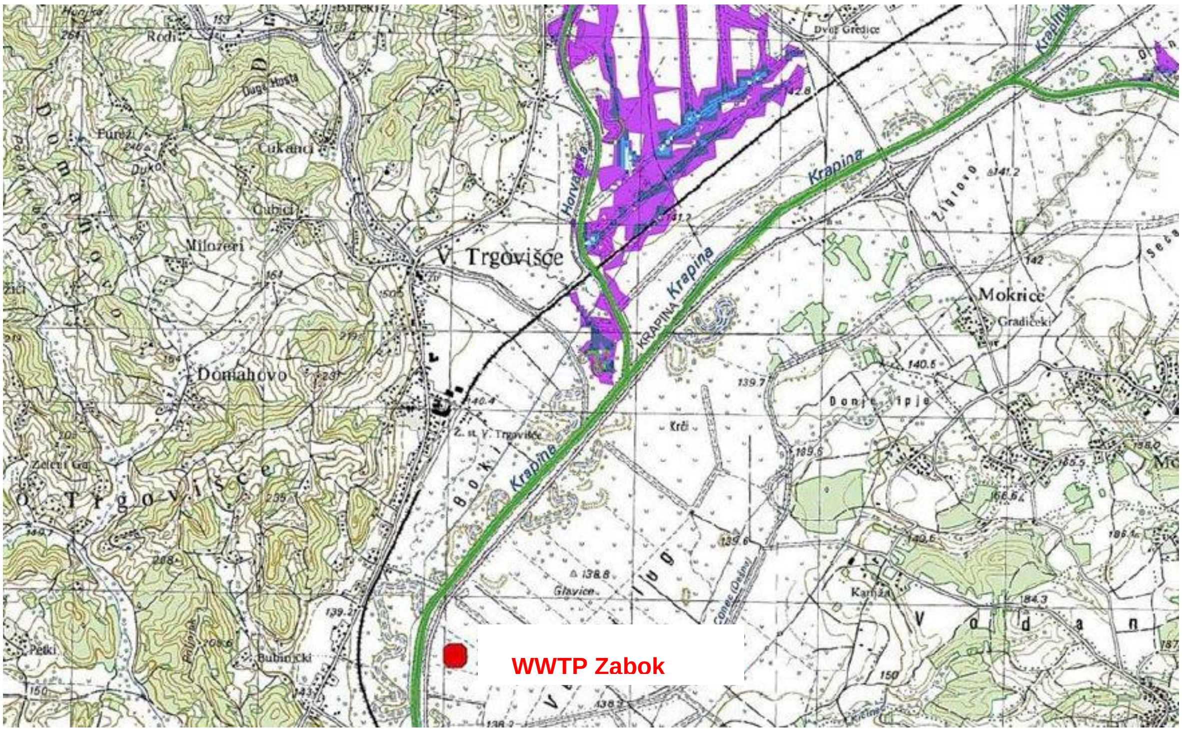

Figure 40. Location of the WWTP Zabok

4.3 Waste water treatment plant Zabok - plant description

The construction of wastewater treatment plant with the capacity of 36.940 ES with second and third degree of purification is planned. According to the Ordinance on the limit values of wastewater emissions (OG 87/10, 80/13, 43/14, 27/15), municipal wastewaters in the delicate area of the Sava basin, are purified by the third purification degree, and the effluent must meet at least the following parameters. Waste water limit values for Zabok plant are presented in the table 25.

Table 25. Waste water limit values

Indicator	Limit values	Minimum load reduction percentage
Suspended matter	35 mg/l	90
Biochemical oxygen consumption BOC5	25 mg O_2/l	70
Chemical Oxygen Consumption COC	125 mg O_2/l	75
Total nitrogen	15 mg N/l	70
Total phosphorus	2 mg P/l	80

The construction activities of WWTP Zabok are:

i) Pre-purification treatment - separation of coarse and fine particles, grease and sand separation and acceptance from septic tanks,

ii) Second stage of purification- purification COD and BOD_5, sludge sedimentation,

iii) Third stage of purification - nitrification, denitrification and dephosphorization,

iv) Sludge treatment thickening of sludge and sludge dehydration;

i) Pre-purification treatment

Pre-treatment is an important part of the wastewater treatment process because it ensures that the main parts of the process perform the proper function later. It involves the removal of large floating particles and suspended matter, sand, oil, and grease. The process and equipment were selected considering: Impact of flow change, reduction of hydraulic retention time to prevent septicity, process reliability, frost protection where necessary on exposed systems.

Wastewater from the sewage system is pumped into the station via a supply channel with a mechanical coarse grate. Wastewater is pumped into the unit through a combined unit where is cleaned of coarse and fine particles, sand and grease. The mechanically cleaned wastewater after the first phase of pre-treatment drains into II. degree of purification by gravity.

Coarse mechanical grate

A coarse mechanical grate cleans wastewater from paper, fabric, plastic and other pieces or particles. The grate has an opening of 20 mm, which allows the collection of larger particles. The particles are separated into a municipal waste container.

The coarse grate is dumping waste into the compactor and has a service bypass, which is manually opened and closed by the latch system. The kinetic for the reception of draining water encloses a coarse grate, compactor and municipal container.

Inlet pumping station

There are 3 submersible pumps located at the inlet pumping station. Two pumps can be operated simultaneously, and third serves as the active backup pump. The drain is designed for the wastewater treatment plant operation safety reasons.

The pumps are controlled by frequency inverters and a flow meter. By pumps, the wastewater is pumped into the pre-treatment phase. The operation of the pumping stations is controlled by ultrasonic level sensors. The pumping station is equipped with a manual pump crane.

Internal pumping station

There are 3 submersible pumps located in the internal pumping station. Two pumps can be operated simultaneously, and third serves as the active backup pump. The drain is designed for the safety reasons of wastewater treatment plant operation.

The pumps are controlled by frequency inverters and a flow meter. By pumps, the wastewater is pumped into the pre-treatment phase. The operation of the pumping stations is controlled by ultrasonic level sensors. The pumping station is equipped with a manual pump crane.

Combined device

The combined device consists of three functional components for the removal of coarse and fine particles, sand and lighter substances than water. The wastewater is pumped from the tank into the "Spiramatic" sieve of the compact unit. The choice of sieves enables the protection of the equipment of the treatment plant and prevents the flow from being blocked and therefore stopping the system. A coarse mechanical grate purifies wastewater from paper, cloth, plastic, and other pieces or particles.

The grate has an opening of 2 mm, which allows the collection of particles larger than the opening. The particles are separated into a municipal waste container. The combination device has its automated sieve control system.

The combination device has an automated control system. The wastewater goes to the aerated sand, fats and grease system (FGS), where they are aerated to eject on the surface particles lighter than water (floating particles and grease).

The sand is precipitated and transported by a spiral conveyor into a collecting shaft from where it is disposed of in a municipal waste container by a spiral conveyor. Particles with a minimum diameter of 0.3 mm are separated in the sand. The sand is a single channel with a bypass built-in that allows wastewater to be diverted as needed (maintenance work).

The grease is discharged into the sump funnel, from where it is pumped into the grease pan via screw pump. The device cannot replace FGS located at the outflow from facilities such as hotels, restaurants or kitchens… All facilities in the sewer system (hotels, restaurants, peasant tourism, factories, schools, etc.) that supply wastewater to the WWTP must have certified and maintained FGS installed.

Sand washing

The sand separated from the wastewater by the combined plant is pumped for washing. The precipitated and washed sand is transported to a municipal volume container with the help of a spiral conveyor.

Grease collector

It is a storage facility that holds grease until it is taken away by the user. The grease is pumped into that storage area by a spiral pump from the combined unit and, as such, is transported by the utility vehicle to the intended location.

Reception of septic tank contents

Reception of tank truck effluent, which empties and cleans septic tanks, is done by a receiving pipe equipped with an electric motor valve, an inductance meter, a pH meter, and a flow meter. If the inappropriate quality of contents of septic tanks are received, the electric motor stops automatically and prevents the flow of contents.

The flow meter registers the amount of septic tank content on the inlet to the wastewater treatment plant. Reception of septic tank contents is done only by a projected acceptance using an identification card that opens the electric motor latch. Using this card, the computer records the quantity and quality of septic tank contents delivered.

ii) Biological purification phase

Based on the analysis of variant solutions, the PVA-MBBR biological wastewater treatment process was selected. Biological treatment is intended to remove organic pollutants from wastewater, as well as nutrients (nitrogen and phosphorus) - the so-called second and third stage of treatment.

The biological reactor

Wastewater is fed into the flow pool for BOD_5 biodegradation, nitrification, and denitrification. The biological reactor ends with a pool for perception and coagulation, in which chemical dephosphorization by settling (PAC) is performed. From here, the water flows to the next lamellar precipitate, where the biomass is deposited using the coagulant itself, thus completing the II and III purification steps. The pre-deposited sludge is pumped into the sludge thickener. Dehydration is done by machine dehydration and the dehydrated sludge is discarded into the lagoons. The biological reactor contains a hyperboloid air mixer, with continuously operating frequency-controlled electric motor.

The operation of the blower is controlled by the frequency controller and the oxygen probe signal in the biological pool. In the event of a malfunction, the blower operation automatically switches to the default mode, which is optimized during the plant test run.

The basic model includes the selected operating frequency of the blower. The oxygen level can be adjusted, and the basic level is 2 mg O2 / l. Oxygen transport capacity in wastewater ensures the biodegradation and oxidation efficiency of nitrogen compounds.

Air blowing is performed with three blowers. Two blowers meet the capacity and required reserve. The third blower was in reserve. In the event of a one blower failure, enough air is always available. Air is introduced via a hyperboloid aeration mixer. The precipitation and coagulation pools are mixed with an immersion mixer. The wastewater gravitationally drains from the precipitating and coagulation pools into the subsequent settling tank.

Subsequent sedimentation tank

The treated wastewater is gravitationally discharged into a lamellar subsequent sedimentation tank, where the biomass is deposited and separated from the treated water. Proper precipitation provides the coagulant synergistically in terms of phosphorus precipitation and thickening for proper sludge deposition. The precipitated sludge is scraped by a bridge that goes along the bottom, collects the sludge in the middle and pumps the excess sludge into the sludge settler/thickener.

The pumps operate on a timed basis. The treated wastewater is discharged into the receiver, through a Thompson overflow channel, which extends along the entire perimeter of the basin. Sedimentation tank has a built-in barrier in the overflow channel for the retention of the floating sludge. In the subsequent sedimentation tank, wastewater treatment stages II and III are completed.

Table 26. Relevant loads of the wastewater treatment plant for 36,940 PE

Description	Label	Value	Unit	Value	Unit	Value	Unit
capacity (population)	P	32,577.00	ES				
Flows							
population inflow	Qm	38.60	l/s	138.96	m3/h	3,335.04	m^3/d
industry inflow	Qi	12.12	l/s	43.6	m3/h	1,047.0	m^3/d
annual average wastewater flow	QWW,aM	50.72	l/s	182.58	m3/h	4,382.04	m^3/d
infiltration	m	0.50					
infiltration waters	Qinf,am	2.35	l/s	91.3	m3/h	2,190.6	m^3/d
average annual dry flow	QDW,aM	76.07	l/s	273.9	m3/h	6,572.6	m^3/d
peak flow	QDW,hmax	104.77	l/s	377.2	m3/h		
mixed system							
requested inflow to UPOV	QComb	234	l/s	843.4	m3/h	10,933	m^3/d
Daily loads		**Popul.**	**Ind.**			**Total**	
biological oxygen consumption	BPK5	1,954.62	261.78			2,216.40	kg/d
chemical oxygen consumption	KPK	3.909.24	523.56			4,432.80	kg/d
suspended substances	SS	2,280.39	305.41			2,585.80	kg/d
total kjeldahl nitrogen	TKN	358.35	47.99			406.34	kg/d
ammonium nitrogen	NH4+	258.01	34.55			292.56	kg/d
total phosphorus	TP	58.64	10.91			69.55	kg/d
Average daily							
biological oxygen consumption	BPK5	337.22	mgO2/l				
chemical oxygen consumption	KPK	674.43	mgO2/l				
suspended substances	SS	393.42	mgSS/l				
total kjeldahl nitrogen	TKN	61.82	mgN/l				
ammonium nitrogen	NH4+	44.51	mgN/l				
total phosphorus	TP	10.58	mgP/l				
ES calculation							
Population	32,577						
Industry	4,363						
Others	0						
TOTAL	**36,940**						

As is common for municipal wastewater treatment plants, there are three separate wastewater treatment steps: pre-treatment, biological treatment and processing of excess sludge Each of these steps will be dealt with separately, and a comparison of the different UPOV variants will suggest the most suitable solution.

Pre-treatment

Pre-treatment is an important part of the wastewater treatment process because it ensures that the main parts of the process perform the proper function later. It involves the removal of large floating particles and suspended matter, sand, oil, and grease. The process and equipment were selected considering:

- impact of flow change,
- reduction of hydraulic retention time to prevent septicity,
- process reliability,
- frost protection where necessary on exposed systems;

Wastewater from the sewage system is pumped into the station via a supply channel with a mechanical coarse grate. Wastewater is pumped into the unit through a combined unit where is cleaned of coarse and fine particles, sand and grease. The mechanically cleaned wastewater after the first phase of pre-treatment drains into II. degree of purification by gravity.

Biological purification phase

Biological treatment is intended to remove organic pollutants from the wastewater as well as nutrients (nitrogen and phosphorus), the so-called second and third stages of purification. The two most commonly used types of technology are: with fixed biomass or with suspended biomass. The surface on which fixed biomass is fixed may be: stationary or mobile (floating biomass carriers). Following is used for suspended biomass:

- a flow system, where the various stages of biological treatment and the deposition of excess sludge are carried out in separate pools, and constant flow is made through the pools; or

- a batch system where all processes including subsequent sludge deposition, take place in a single pool and flow through the pools is carried out in a batch

Sludge treatment

The resulting sludge needs to be treated to the appropriate degree of dry matter content, which would allow it to be further treated. Due to the sludge aging of 25 days or more, the sludge is considered to be at least partially aerobically stabilized.

Considering the composition of wastewater treated on the plant, which is mostly faecal-sanitary water, the sludge that will be obtained after dehydration will be disposed of following the applicable legislation in the Republic of Croatia. MBBR sludge aging is not possible due to fixed biomass, but theoretically, it can be estimated to be 80, 100 and more days aged. This sludge is also better aerobically stabilized with more mineral content in the sludge composition. That is why the production of sludge is significantly smaller.

The sludge is deposited and thickened in the sludge thickening pool. The thickener is equipped with a mixer to homogenize and improve sludge deposition before the mechanical dehydration process. The purpose of mechanical dehydration is to dehydrate sludge up to 18% of the dry matter before additional drying/storage in lagoons. By mechanical dehydration, the sludge volume is reduced to 6x. The dehydrated sludge is transported by a conveyor belt into a municipal container or concrete depot, which can be emptied manually or with a small excavator into the solar beam/lagoon system.

The system uses solar energy to further sludge drying. After mechanical dehydration, the sludge is discharged into covered beams, which are ventilated by fans, due to humidity control. The sludge is dried by sun, ventilation and sludge mixing. The final sludge is dry up to 70-90% and thus the volume of sludge for disposal is reduced up to 4 times. Average annual dry matter of sludge is estimated at 70%, while the optimal operation of the sunbeams is limited by the sunny days and the outside temperature. The following sludge treatment and disposal options are possible under the EU and RH law:

- Disposal of treated sludge at landfills,
- Composting with the organic fraction of solid municipal waste or animal waste,
- Use in agriculture and forestry
- Energy recovery
- [Optional] Treatment at (regional) waste management centers
- Temporary storage and processing (reed fields)
- Other solutions by the law (e.g., use as construction materials, etc.)

The further use or disposal of dehydrated sludge is possible in the three following ways: utilization of nutrient value of sludge, utilization of energy value of sludge, and landfill. Sludge with satisfactory properties could be applied directly or after additional aerobic stabilization (composting) on agricultural land.

However, the conditions for land application are very strict, and the possibility of such sludge application can only be determined after the production of dehydrated sludge (samples) and the carrying out of appropriate analytical tests.

Another option is to use the energy value of the sludge, which means combustion (after pre-drying the sludge to at least 65% dry matter). However, municipal waste incineration plants are a major investment and often problematic for the general public and should be sought at the County, regional or even state level. WWTP Zabok is a relatively small device so it would not be economically justifiable to propose any special sludge treatment. This should be dealt with the larger UPOVs nearby.

For now, landfill disposal seems to be the only realistic (but temporary) possibility. However, the reality is that dehydrated sludge, without other options, will continue to be disposed of in special landfills, and if a solution is found at the regional or national level, there is a possibility of transporting dehydrated sludge for incineration. Following the existing Ordinance on the method and conditions of waste disposal, categories and conditions of work for landfills (OG 114/2015), dehydrated sludge will be handed over to an authorized person with the appropriate accompanying sheet completed.

The layout of the WWTP Zabok is presented in the figure 41.

Figure 41. Layout of the WWTP Zabok

4.4. Waste management

Waste generated during the device performance, except for grease, is stored in municipal containers. The grease is stored in the grease collector. Drained water of municipal containers is directed to the inlet pumping station.

Table 27. Waste generated during the device performance

Waste type	Quantity (m^3/a)
Waste from the coarse grate	59.98
Fine grate waste	95.96
Sand	239.9
Grease	219.88
Excess sludge	751

The County of Krapina-Zagorje, together with the Koprivnica-Križevci, the County of Međimurje, Varaždin County and the Koprivnica Ivanec Municipality, founded the PIŠKORNICA d.o.o. - a regional waste management center of north-western Croatia.

The company was established on 12 March 2009 in Koprivnica and registered in the Court Registry of the Commercial Court in Bjelovar to actualize the project of the Regional Waste Management Center of North-western Croatia, all under the Waste Management Plan for the Republic of Croatia for the period 2007-2015.

The company was established to realize the project of the Regional Waste Management Center of north-western Croatia, all following the Waste Management Plan for the Republic of Croatia for the period 2007-2015.

The project of the Regional Waste Management Center (RWMC) of northwestern Croatian, for now, is the only regional center in Croatia and the region of northwestern Croatian envisioned six transfer stations. One of those stations is also planned at Zabok. Recycling yards will be located at the relocation stations where the recyclable waste will be collected. From the transfer stations, waste will be transported by special trucks to the RWMC in Koprivnicki Ivanec.

The Waste Management Plan for the City of Zabok was affirmed based on the Waste Act in November 2008 and published in the "Official Herald of the County of Krapina-Zagorje" No. 21/08. The plan was adopted for 8 years, following the Plan.

City of Zabok has carried out the activities provided for the provisions of the Report on the Implementation of the Waste Management Plan for the City of Zabok for 2014, adopted at the 17th assembly of the City Council and published in the Official Herald of the County of Krapina-Zagorje number 7/15. The report was submitted to Krapina-Zagorje County on 15th of April in 2015.

Service of collection and disposal of municipal waste in the City of Zabok was carried out by the utility company Komunalno-Zabok Ltd. from Zabok (a company co-owned by the City of Zabok). In 2016, the number of users of the collection and disposal of waste was 3260.

Several containers for separate collection of waste by types of waste are:- green islands - 25 paper containers, 25 containers for plastic, 25 containers for glass, 19 textile containers, 25 containers for metal - containers are placed at users' home - 75 paper containers, 75 selective waste containers, 3.100 a selective waste bins, by a month 1,500 paper bags and 800 garden composters are divided. In the territory of the County, waste is disposed of at six official landfills ("Gorjak" Jesenje, "Gubaševo" Zabok, "Lesićak" Bedekovčina, "Medvedov Jar" Klanjec, "Tugonica" Marija Bistrica and the Hum na Sutli landfill). Apart from the waste collected in the City / Municipality areas, where the collector of waste Eko-flor plus d.o.o. is, waste is transported outside the Krapina-Zagorje County area.

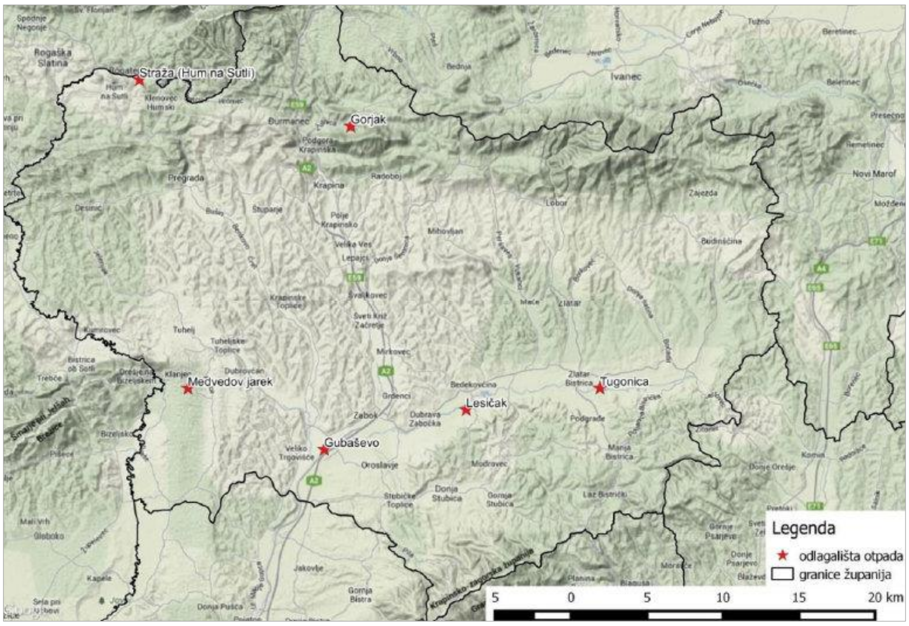

Figure 42. Cartographic depiction of waste landfills in Krapina-Zagorje County

5 PROPOSED REEF 2W SOLUTION

5.1 Waste water treatment facility

The main intention for the pilot site in Zagreb Agglomeration is to establish a pilot case and test the possibility to utilize the separately collected biowaste, as well as the sustainable usage of produced sludge. This will be the main challenge for the WTTP Zabok operator in the future period.

The WTTP in its full capacity will be producing 1.117,5 tonnes of dehydrated sludge. The proposed REEF2W solution is presented in the figure 43. Main aspects of this proposal are:

i) Possibility to use biowaste fraction of municipal waste,
ii) Anaerobic treatment – co-digestion of sludge and biowaste,
iii) Utilization of biogas – CHP and biomethane,
iv) Application of digestate as a soil improver;

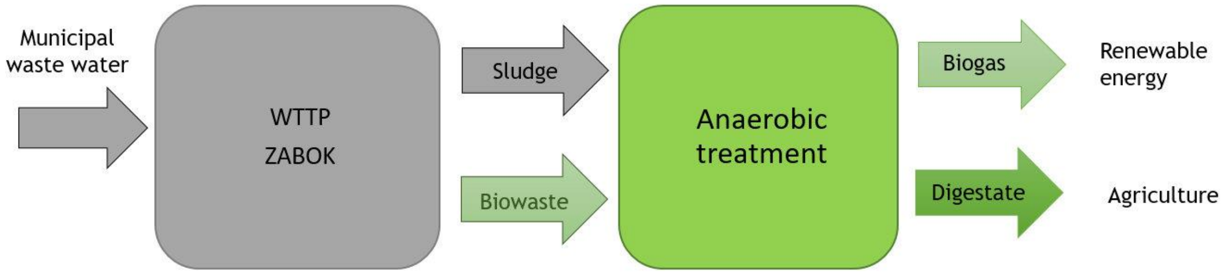

Figure 43. Proposed REEF2W solution for WWTP Zabok

Besides the treatment of waste water treatment plant, one of the most important issues is the sustainable waste management in the Zagreb agglomeration. Waste management is highly sensitive issue for many years, mostly due to the constant landfilling and very slow implementation of separate collection. That is why the planning any kind of waste management facilities in Zagreb agglomeration has to be very carefully with special sensitivity to the possible locations of such plants.

The combined treatment of waste and waste water is one of the main benefits of the proposed REEF2W solution. The main idea behind this proposal is to successfully utilize separately collected biowaste with current waste water treatment. This extension will also result in a production of renewable energy.

5.1.1 Utilization of biowaste fraction

Considering the experience so far as well as the targets for biodegradable municipal waste landfilling, the introduction of and improvements in separate collection of biodegradable municipal waste in the Zagreb agglomeration must be set as a priority. Otherwise, the goals and targets at the national level will certainly remain beyond reach even after 2020, the year set as a final deadline. This is especially crucial for the management of largest portion of biodegradable waste biowaste.

In the following table a overview of the biowaste in Zagreb agglomeration is presented. The 30% of biowaste portion in mixed municipal waste has been used as well as a collection efficiency of 40% for the determination of the expected amount.

Table 28. Biowaste potential in Zagreb agglomeration (in tonnes)

Zagreb Agglomeration	Total amount of produced mixed municipal waste, t	Total potential of biowaste, t	Expected amount of collected biowaste, t
City of Zagreb	217,380	65,214	26,085
Zagreb County	57,621	17,286	6,914
Krapina-Zagorje County	19,388	5,816	2,326
Total	294,389	88,316	35,325

5.1.2 Renewable energy production

The energy potential of the pilot location Zagreb agglomeration is presented in the following tables. Table 29 is showing the energy potential of the biowaste from the all three counties that are part of the Zagreb agglomeration. The overview of the sludge energy potential from the WWTP Zabok is presented in the table 30.

Table 29. Overview of the energy potential in the pilot location

Zagreb Agglomeration	Expected amount of collected biowaste, t/y	Energy content (m^3 biogas/t)	Biogas potential (m^3/y)
City of Zagreb	26,085	100	2,608,500
Zagreb County	6,914		691,400
Krapina-Zagorje County	2,326		232,600

Table 30. Overview of energy potential of the sludge at WWTP Zabok

Total amount (t/y)	Energy content (m^3biogas/t)	Anaerobic digestion				
		Biogas potential (m^3/y)	Biomethane (m^3/y)	CHP (kW)	Electricity (MWh/y)	Heat (MWh/y)
1,117.5	60	67,050	40,230	20.1	152.9	169.0

5.1.3 Sludge management

The Waste Management Plan stated that it is necessary to improve the management system for special categories of waste, and one of the tasks also relates to the establishment of a sludge management system from wastewater treatment plants. It is important to note that projects for the construction of wastewater treatment plants that do not address the final disposal of sludge as a by-product of wastewater treatment are not considered fully completed, because they do not include technological solutions related to the costs and technology of sludge disposal.

Besides the energy potential of the sludge presented in the table 29, there is an option of its application as a fertilizer.Total amount of estimated sludge and required land for its application is presented in the table 31.

Table 31. Estimated amount and required land for the pilot project

Total amount (t/y)	Required land for sludge utilization (ha)
1,117.5	673.2

5.2 Proposed scenarios

5.2.1. Technical aspects

The WWTP Zabok has not anticipated any biowaste or energy recovery on site. As mentioned before, main purpose of the REEF2W proposal is to propose solution for the upgrade of the WWTP Zabok and introduce sustainable biowaste treatment within the existing facilities. In order to develop proposed scenarios and consider all required technical aspects, authors have investigated current situation regarding the biowaste and sludge treatment in northern part of Croatia.

Separate biowaste collection is at its beginning and it will take certain time to completely organise the system. The similar issue is also with the sludge. Even though the treatments plants are being built, there is yet not a solution for its utilization.

Biogas plants in the area (figure 35) are capable to treat these kinds of waste fractions but its utilization is not completely applicable. Some of them already invested in process equipment needed for pretreatment of the biowaste (shredders, impurity removers, etc.) but local waste management companies are at very slow pace introducing separate collection of biowaste.

Also, it can be expected that new biogas plants will be built, mainly due to the exclusion of feed-in tariffs and unclear situation regarding the incomes from produced renewable energy.

Due to the aim of the study (figure 2), potential biofuel production has been also analysed. The production of compressed biomethane is completely novel approach in Croatia, and no facilities are existing at the moment. One of the main reasons is lack of the infrastructure (filling stations) combined with the low consumption (small number of CNG vehicles).Having in mind the technical limitations of the proposed upgrade, within this analysis three proposed solutions (scenarios) have been analysed:

- **Scenario 1: Local sludge utilization**
- **Scenario 2: Anaerobic digestion on site**
- **Scenario 3: Utilization of biowaste and sludge at remote biogas plant**

The main characteristics of each scenario are following.

Scenario 1 – Local utilization of sludge

In this scenario business as usual is foreseen, where the plant is s processing waste water and produce 1,117.5 tonnes of sludge each year. In this scenario no energy utilization will be provided. The produced sludge will be treated as a waste and will be facilitated as a soil improver at the available local land. The organisation of the plant is according to figure 41, where the main setup for the proposed solution is presented in the figure 44.

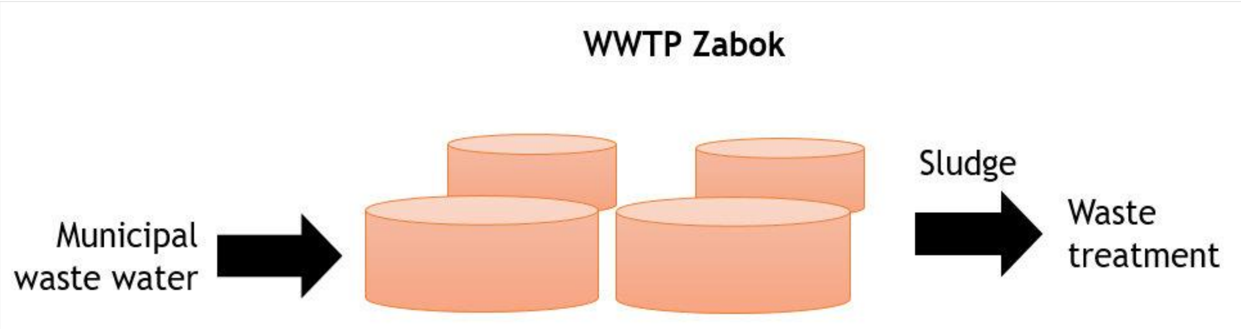

Figure 44. Proposed REEF2W solution – local utilization of sludge

The WWTP Zabok in this scenario will not have to invest in any adaptations or upgrades at the chosen site. The main properties of the proposed scenario are presented in the table 32.

Table 32. Main aspects of the local sludge application

Location	Estimated quantities of sludge (m^3/y)	Dry matter of sludge (t)	Required area of agricultural land for sludge disposal (ha)	Total land available (ha)
Wastewater treatment plant Zabok	1,490.0	1,117.5	673.2	54,073

Within this analysis authors have contacted several agriculture companies in Croatia in order to investigate concrete possibility to utilize the produced sludge on land. Companies that are producing energy crops, such as Miscanthus, are willing to use the sludge as a soil improver or fertilizer, as long as its complied with the Ordinance[21]. The letter of intent from one of the contacted companies are part of this study (annex I).

Scenario 2 – Onsite anaerobic digestion

This scenario is proposing the upgrade of the current facility in Zabok. The upgrade is consisted of the onsite anaerobic treatment of the sludge at the WWTP Zabok as well as the installation of gas engine for the utilization of produced biogas. The proposed solution is presented in the figure 45. The WWTP Zabok will produce energy and utilise it via cogeneration. Also, produced sludge will be used locally.

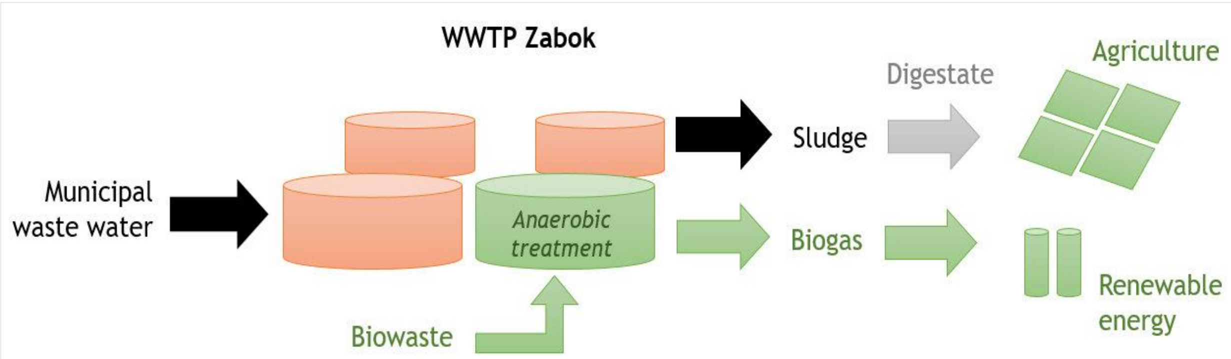

Figure 45. Proposed REEF2W solution – anaerobic digestion on site

Besides the anaerobic treatment of the waste water, the WWTP Zabok will in this scenario also have possibility to utilize separately collected biowaste. The main reason for this concept is the fact that there is a lack of the biogas plants in Krapina-Zagorje County (table 12). The closest biogas plant capable to receive and treat biowaste from the County is located 100 km from the WWTP Zabok. It is foreseen to use the biowaste produced from the area of Krapina-Zagorje County. Separately collected biowaste will be treated together with the waste water in order to produce renewable energy.

Produced electricity will be used locally and excess will be sent to the national grid. Produced heat energy from the cogeneration will be used within the WWTP Zabok, usually for the heating of the fermentation tank. The potential production of compressed biomethane (CNG) is also calculated, even though the estimated production is not sufficient for the construction of the upgrade unit. In the table 33 main aspects of the proposed scenario are presented.

Table 33. Scenario 2 - Main technical aspects of the onsite anaerobic digestion

Location	Total amount (t/y)	Origin	Anaerobic digestion		Energy utilization				Sludge management	
			Biogas potential (m^3/y)	Biomethane (m^3/y)	CHP (kW_{el})	Biomethane production (t/y)	Electricity (MWh/y)	Heat (MWh/y)	Produced sludge (t/y)	Required land (ha)
Krapina Zagorje County	2,326.0	Biowaste	232,600	139,560	61.1	83.7	488.5	625.2	1,163	700.6
WWTP Zabok	1,117.5	Sludge	67,050	40,230	17.6	24.1	140.8	180.2	1,117.5	673.2
Total	**3,443.5**		**299,650**	**179,790**	**78.7**	**107.9**	**629.3**	**805.5**	**2,280.5**	**1,373.8**

Scenario 3 – Utilization of biowaste and sludge at remote biogas plant

In this scenario it is foreseen that the WWTP Zabok will be operating as in scenario 1 but the produced sludge will not be used locally for agriculture, but rather transferred to the remote biogas plant where it will be used for renewable energy production.

Also, separately collected biowaste from all three counties that are part of the Zagreb agglomeration will be transferred to the biogas plant in order to be utilize for renewable energy production (cogeneration or biofuel production).

The main reason for this approach is the need to define complete energy potential of the biowaste fraction in the Zagreb agglomeration. This is one of the main goals of the REEF2W project. The proposed solution is presented in the figure 46.

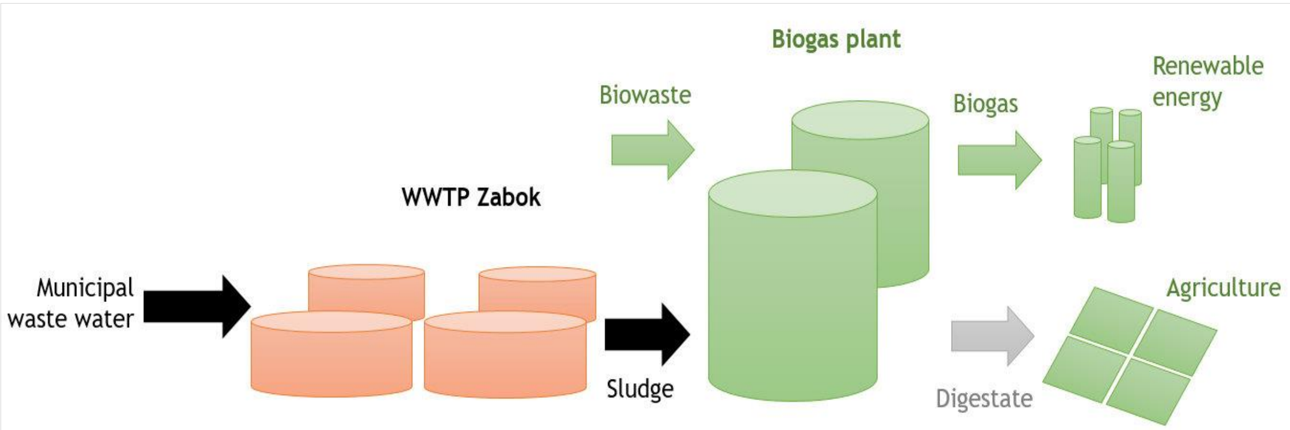

Figure 46. Proposed REEF2W solution – utilization of biowaste and sludge

As mentioned above, in this scenario the sludge produced at the WWTP Zabok will be combined together with the separately collected biowaste in the counties that are part of the Zagreb agglomeration. Total amount of substrate will be transferred to the remote biogas plant outside of the agglomeration (figure 35.).

During this study authors have investigated the possibility to treat this substrate at the biogas plants located near the WWTP Zabok. Once again, the lack of suitable plants in the area of the Agglomeration is the reason for remote treatment and transfer or biowaste and sludge.

Produced renewable energy at the remote biogas plant will be used for electricity/heat or biofuel production.

The main technical aspects of the proposed scenario 3 is presented in the table 34.

Technical overview of all three scenarios is presented in the table 35.

Table 34. Scenario 3 - Main aspects of the remote biowaste and sludge utilization

Location	Total amount (t/y)	Origin	Anaerobic digestion		Energy utilization				Sludge management	
			Biogas potential (m^3/y)	Biomethane (m^3/y)	CHP (kW_{el})	Biomethane production (t/y)	Electricity (MWh/y)	Heat (MWh/y)	Produced sludge (t/y)	Required land (ha)
City of Zagreb	26,085	Biowaste	2,608,500	1,565,100	684.7	939.1	5,477.9	7,011.6	13,042.5	7,856.9
Zagreb County	6,914	Biowaste	691,400	414,840	181.5	248.9	1,451.9	1,858.5	3,457	2,082.5
Krapina-Zagorje County	2,326	Biowaste	232,600	139,560	61.1	83.7	488.5	625.2	1,163	700.6
WWTP Zabok	1,117.5	Sludge	67,050	40,230	17.6	24.1	140.8	180.2	1,117.5	673.2
Total	**36,442.5**		**3,599,550**	**2,159,730**	**944.9**	**1,295.8**	**7,559.1**	**9,675.6**	**18,780**	**11,313.3**

Table 35. Summary of all three scenarios

Scenario	Total amount (t/y)	Origin	Anaerobic digestion		Energy utilization				Sludge management	
			Biogas potential (m^3/y)	Biomethane (m^3/y)	CHP (kW)	Biomethane production (t/y)	Electricity (MWh/y)	Heat (MWh/y)	Produced sludge (t/y)	Required land (ha)
1 - Local utilization of sludge	1,117.5	Sludge	0	0	0	0	0	0	1,117.5	673.2
2 - Onsite anaerobic digestion	3,443.5	Biowaste/ Sludge	299,650	179,790	78.7	107.9	629.3	805.5	2,280.5	1,373.8
3 - Utilization of biowaste and sludge at remote biogas plant	36,442.5	Biowaste/ Sludge	3,599,550	2,159,730	944.9	1,295.8	7,559.1	9,675.6	18,780	11,313.3

5.2.2. Financial overview

The WWTP Zabok is in its construction phase and for this reason there is a lack of concrete operational costs that can be calculated within the economic assessment, so basic level analysis was done and presented as a financial overview. Although there are possibilities for various subventions in Croatia, regarding waste management and energy production, the calculation is done under assumption of no external grants and subventions.

In each of the proposed scenario certain investment are expected, and their brief overview is presented in the table 36.

Table 36. Overview of the potential investments of the current WWTP Zabok

Type of investment	Scenario 1	Scenario 2	Scenario 3
Upgrade of the current waste water treatment process (anaerobic digestion)	NO	YES	NO
Installation of cogeneration module or CNG filling station	NO	YES	NO

Each of the proposed scenarios has certain benefits which can be revenue in the future. Also, certain expenditures are expected. Their overview is presented in the table 37.

Sludge treatment is always an expenditure, even in scenario 2 where onsite biogas production is foreseen. The financial calculation is based on a gate fee for biowaste management through anaerobic digestion. In scenario 2 it will be source of income but in scenario 3 it will be expenditure. Also, different ways of utilization are presented (cogeneration and biofuel), and their current price is presented in the table below.

Table 37. Main source of revenue/expenditure of the proposed scenarios

Type of revenue/expenditure	Price
Waste management – gate fee	
Sludge treatment	63 €/t
Biowaste treatment	38 €/t
Renewable energy production	
Electricity production	70 €/MWh
Heat production	25 €/MWh
Biofuel	1.2 €/kg

Table 38. Overview of overall revenue/expenditure cash flow

Scenario	REVENUE (€/y)					EXPENDITURE (€/y)
	Energy utilization				Biowaste gate fee	Waste treatment
	Electricity	Heat	Total CHP	Biofuel		
1 - Local utilization of sludge	0	0	0	0	0	70,402.5
2 - Onsite anaerobic digestion	44,048.6	20,136.5	64,185	129,448.8	88,388	114,596.5
3 - Utilization of biowaste and sludge at remote biogas plant	529,133.9	241,889.8	771,023.6	1,555,005.6	1,342,350	1,183,140

Table 39. Overview of the WWTP Zabok cash flow

Scenario	REVENUE (€/y)					EXPENDITURE (€/y)
	Energy utilization				Biowaste gate fee	Waste treatment
	Electricity	Heat	Total CHP	Biofuel		
1 - Local utilization of sludge	0,0	0,0	0,0	0,0	0,0	70.402,5
2 - Onsite anaerobic digestion	44.048,6	20.136,5	64.185,0	129.448,8	88.388,0	114.596,5
3 - Utilization of biowaste and sludge at remote biogas plant	0,0	0,0	0,0	0,0	0,0	70.402,5

6 ISA FOR PILOT REGION

6.1 General and specific indicator evaluation

Table 40. General indicators used for the pre-assessment

Sustainability criteria	General indicator	Measurement	Categories	Status Quo	REEF 2W
Availability of excess energy (Software tool N.1)	Electric excess energy provision	Difference between electric energy production and consumption in kWh	> 0 ≤ 0	≤ 0	> 0
	Thermal excess energy provision	Difference between thermal energy production and consumption in kWh	> 0 ≤ 0	≤ 0	> 0
	Excess digester gas provision	Difference between digester gas production and consumption in m^3	> 0 ≤ 0	≤ 0	> 0
Availability of energy consumers (Software tool N.2)	Excess electricity demand	Electricity demand in the vicinity of the WWTP and in kWh	> 0 = 0	> 0	> 0
	Excess heat demand	Heat demand in the vicinity of the WWTP and in kWh	> 0 = 0	= 0	= 0
	Excess digester gas demand	Digester gas demand in the vicinity of the WWTP and in kWh	> 0 = 0	= 0	= 0

Table 41. Specific indicators used for ISA and their weights

Sustainability criteria	Indicator	Measurement	Categories	Graduation	Status Quo	REEF 2W	Weight
Environmental context	CO_2 emissions reduction for consumed electric energy (internal and external)	%	> 0 = 0	A C	C	A	0,1
	CO_2 emissions reduction for consumed gas (internal and	%	> 0 = 0	A C	C	A	0,1

	external)						
	CO_2 emissions reduction for consumed thermal energy (internal and external)	%	> 0 = 0	A C	C	A	0,1
	Share of renewable electricity (internal and external)	%	> 100 100-40 <40	A B C	C	B	0,2
	Share of renewable thermal energy (internal and external)	%	> 100 100-40 <40	A B C	C	B	0,2
	Share of renewable gas (internal and external)	%	> 100 100-40 <40	A B C	C	C	0,2
	Sludge production change	Delta t DM / year	<0 0 >0	A B C	B	C	0,1
Social context	Affordable energy	%	Lower Same (+-10 %) Higher	A B C	B	B	0,1
	Number of applied technologies for electric energy provision (*Resilience*)	Quantity	3 1-2 0	A B C	C	B	0,25
	Number of applied technologies for thermal energy provision (*Resilience*)	Quantity	3 1-2 0	A B C	C	B	0,25

	Additional employment	Change of employment, job creation or loss	>0 0 <0	A B C	B	A	0,30
	Local environmental welfare	Indication of local welfare change	Positive Neutral Negative	A B C	B	B	0,1
Economic context	Return of Investment (ROI)	Years	<3 3-10 >10	A B C	C	C	0,4
	Additional income	€	>0 0 <0	A B C	B	B	0,3
	Energy costs saving	€	>0 0 <0	A B C	B	A	0,3
Technical context (energetic & spatial)	Degree of electric self-sufficiency	Ratio between electric energy production and consumption in %	>75 25-75 <25	A B C	C	B	0,2
	Degree of thermal self-sufficiency	Ratio between thermal energy production and consumption in %	>100 20-100 <20	A B C	C	B	0,2
	Degree of externally usable excess heat	Ratio between heat production and consumption in %	> 0 0	A C	C	C	0,1
	Degree of usable excess gas	Ratio between gas production and consumption in %	> 0 0	A C	C	C	0,1
	Electric energy consumption at WWTP	$kWh/PE_{120}.a$	< 20 20 - 50 > 50	A B C	B	B	0,1

	Thermal energy consumption at WWTP	$kWh/PE_{120}.a$	<30 > 30	A C	A	A	0,1
	Electric energy generation at WWTP (with anaerobic stabilisation)	$kWh/PE_{120}.a$	>20 10-20 <10	A B C	C	B	0,1
	Thermal energy generation at WWTP (with anaerobic stabilisation)	$kWh/PE_{120}.a$	>40 20-40 <20	A B C	C	C	0,1

All indicators were or calculated using REEF 2W tool or using the data provided by WWTP operator, except of the social indicators which were determined or estimated based on proposed technological changes.

6.2 Multi-criteria decision analysis (MCDA)

In order to have detailed information about specific parts of ISA (social, environmental, economic and technical) are calculated separately to be used by decision makers for their own analysis and decision. The following formula was used for the evaluation of each criterion.

$$CI_{s,en,ec,tech} = \sum_{i=1}^{n} w_i \, u_i$$

where CI is the composite index of the ISA for social, environmental, economic and technical segment, w is value of indicator and u is weight of indicator. The result of each ISA criterion is shown in the following table.

Table 42. The result of multi-criteria decision analysis

Criterion	Composite Index (Status Quo)	Composite Index REEF 2W Technology
Environmental	4.8	3.0
Social	4.0	2.4
Economic	3.8	3.2
Technical	4.4	3.4

7 CONCLUSIONS

The principles of sustainable development are becoming more and more important in modern societies and as such more acceptable to the public. The analysis performed within this study indicates that waste water treatment is sustainable and can be combined with the utilization of separately collected biowaste. This approach could have not only positive environmental, but also financial impact on the investigated location.

The application of sludge in agriculture is already part of practice in many EU regions, and its implementation could be a solution for waste water treatment plants. New regulations of the sludge application and its monitoring of the environmental condition are assuring its safe application in agricultural production. This will be especially interested for larger capacity plants (with already constructed anaerobic digestion) from their economic and technological point of view due to the lack of thermal processing in the area. Also, this is much easier to perform because NIMBY (not in my backyard) effect in the local community is avoided.

According to data, the WWTP Zabok will produce 1,117.5 t/y of sludge possible to use on 673.2 ha of agricultural land. Since the investigate area has sufficient land availability, it can be assumed that possibility of local sludge application is realistic.

This study has also investigate the possibility to use sludge for renewable energy production, and in that sense proposed different scenarios. Besides the first proposed scenario, others are giving the overview of the plant upgrade when the separately biowaste fraction is involved in the process. This will for sure improve cash flow of the plant (scenario 2) but certain investment are expected which cannot be foreseen in detail in this stage of plant construction.

This practise of energy recovery of biowaste is still not widely implemented in Croatia and its implementation is at its beginnings. Also, produced electricity is without feed-in tariff so adoption of existing plants is challenging. This is especially the case when the biofuels are being produced and its limited consumption.

Considering the comprehensive environmental, social, economic and technical analysis, the REEF 2W technology is beneficial for the selected WWTP and has better composite index in all categories, which means, that implementation of proposed REEF 2W solution could bring additional benefits in these fields.

Finally, it can be concluded that the use of sludge on agricultural soils is nowadays efficient way to sustainably treat wasted generated in wastewater treatment plants. Also plant operators will have to take into consideration the fact that sludge has energy potential which can be sustainably combined with the biowaste produced at local or broader area.

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List of tables

List of figures

Annex I

Bank: Raiffeisenbank Austria d.d.
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Account # 1107689914

To whom it may concern,

Bio Eco Energy Company d.o.o. (BEECO) is a company based in Zagreb, Croatia. BEECO is developing biomass supply chains based on energy crop Miscanthus giganteus. The main aim is to establish secured and uniformed feedstock supply for bio-based industries.

The company's project is separated in two phases:

Phase 1 - Establish certified Miscanthus giganteus nursery plantation on 25 hectares of agricultural land. This step secured the source of high-quality planting materials (rhizomes) which is crucial for further project implementation and biomass plantation establishment.

Phase 2 - Industrial biomass production on 250 hectares of agricultural land. This phase includes planting of rhizomes and growing of Miscanthus giganteus biomass for pellet production (6000 tons capacity/year per business unit) with possibility to scaled up the project up to 1000 hectares of land. This considers 4 business units with total production of 24 000 tons of pellet per year.

Based on "Regulations of waste management from water treatment waste when sludge is used in agriculture" (*Pravilnik o gospodarenju muljem iz uređaja za pročišćavanje otpadnih voda kada se mulj koristi u poljoprivredi)* (NN 38/2008-1307), Bio Eco Energy Company d.o.o. is ready to use sludge from waste water treatment as a fertilizer in growing process of energy crop Miscanthus giganteus.

Sincerely,

Sergii Chabannyi, director

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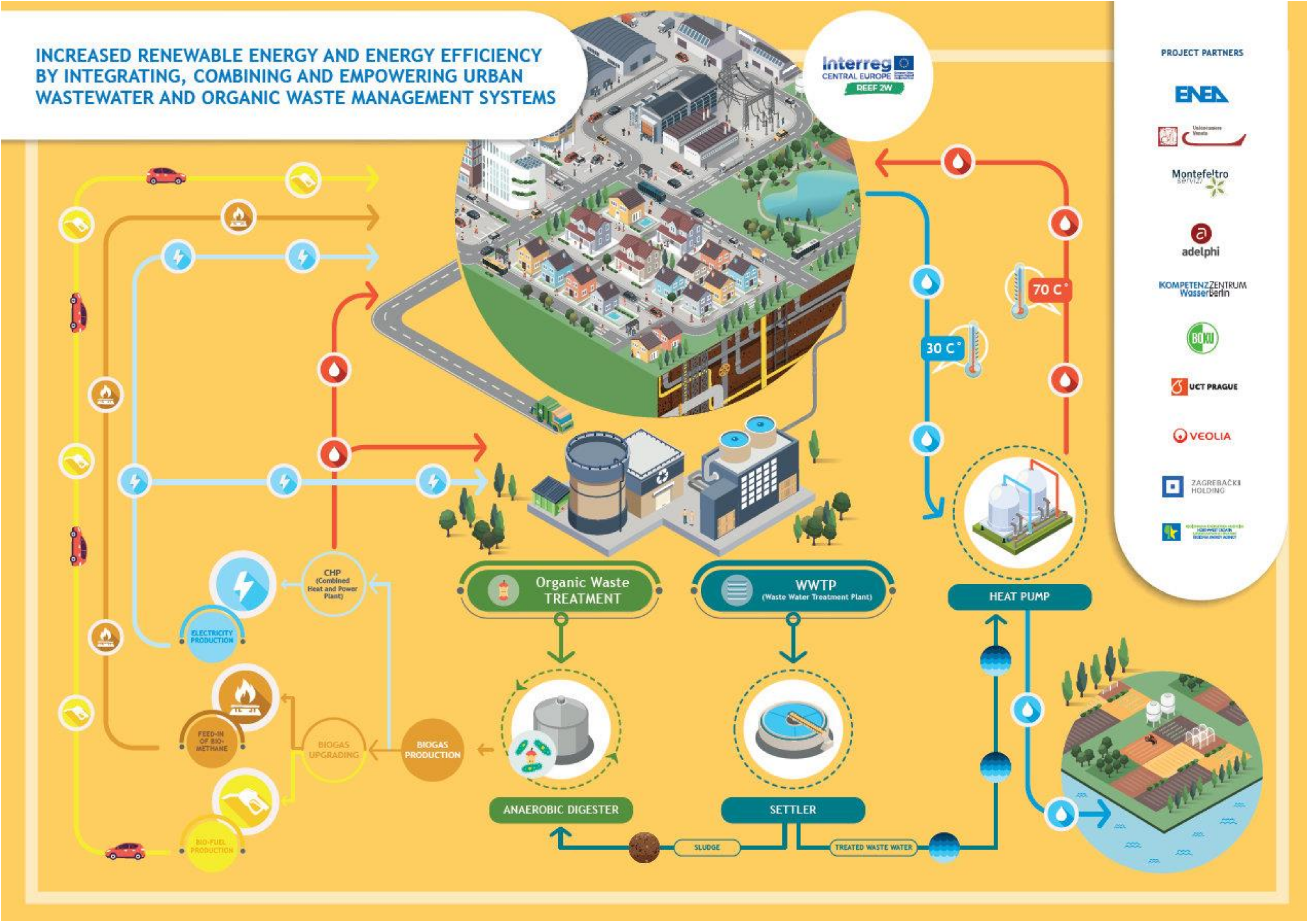

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