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STUDY SHOWING THE STATE-OF-THE-ART AND POSSIBLE REEF 2W IMPROVEMENTS IN RELEVANT INFRASTRUCTURES

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Description of the deliverable

In this deliverable will be described the most relevant technologies and practices that could help the reduction of the energetic impact of the organic waste and wastewater treatment platforms in Central Europe.

The selection of the technologies was based on the availability of the technologies ready to market, and on the possible future trends in the sector for those technologies that are strongly promising, already implemented in a relevant number of treatment plants, but not yet largely applied in the sector.

These criteria were decided on the observation that in the Central Europe area are present countries with a very different degree of implementation of the water and waste directives and different approaches at the treatment.

For this reason it was important to identify those technologies that could fit with the knowledge in each country and the real possibility to reduce the energy consumption of the treatment plants.

1. Introduction

Wastewaters and organic wastes to be treated have extremely heterogeneous characteristics, which make it necessary to use many different processes and technologies for their treatment. Some of these technologies have already been in use for many decades, very often paying more attention at the treatment process than at its energetic efficiency, although some of these technologies could already provide the recovery of the energy content present in the water and are widely used in full scale.

This document are not intended to describe the technologies available today for the production of energy from wastewater and organic wastes, but present a panorama of opportunities that a public administrator or plant manager can use to assess the feasibility of energy production during the treatment process.

It is quite difficult to identify available data for waste and wastewater treatment specifically dedicated at the Central Europe area and for this reason it is quite difficult to provide detailed information of the actual situation. For this reason a more general evaluation of the potential of the effects of the implementation energetic technologies at treatment plant level is quite difficult.

On the other side it is not possible to implement technologies that can recovery energy from wastes in all the treatment plans because the size of the plant is a key factor. In treatment plants that serve less of 50.000 inhabitants is quite difficult to implement any technology, because available machinery present on the market are oversized for this kind of plants and the investments or their maintenance costs will be too high for the economic convenience. In this types of plants anyway it is possible to implement other technologies not strictly related with the treatment of the water that can provide an advantage at the treatment plant. Specifically technologies like photovoltaic panels or wind turbines that can take advantage from the available space normally present in the treatment plants.

2. Energy impact of organic waste and wastewater treatments

Purification treatments have, as their main objective, the removal from wastewater of those substances that released into the environment, water bodies or soil, could cause damage to the environment itself or to human health.

The waste treatment plants in use today have been designed and built without giving priority to the containment of energy consumption, since, after years of industrial development that saw the environment only as a resource to be exploited, the legislations of the countries with stronger economies and those of the European Union itself have become more focalized on the prevention of environmental pollution for the protection of human health.

As regards the treatment of wastewater, conventional treatment systems have undergone profound transformations in recent decades, to make them functional to the increasingly stringent quality standards of water discharged into the receiving water body. The need to remove nutrients (mainly nitrogen and phosphorus) has been added to the goal of removing organic matter. The improvement in the quality of the discharges has generally entailed a considerable increase in the complexity of the treatment systems which include different processes which are usually carried out in different tanks. This approach has undoubtedly led to an improvement in the quality of discharges in recent decades, but this improvement has also led to an increase in the energy required to achieve the highest quality standards (Spagni et al., 2016).

For solid wastes and in particular organic solid wastes the approach is quite similar form the landfilling of unsorted wastes that was the main management approach for solid wastes till the end of the last century, and in some case it is still used. The separate collection of different fractions of wastes and their disposal in more appropriate ways leaving the landfilling as last possibility and only for those wastes that are enough stable to provide sufficient guaranties of stability and environmental safety, is now the usual approach at the treatment of this material.

Also in this case anyway the first and main objective prosecute is the protection of the environment without take too much attention at the energetic costs. An example for the treatment of organic wastes is the composting technology that actually is the most used in their treatment, but that require a lot of energy to inflate the air necessary at the stabilization of the organic fraction.

Wastewater contains about five to ten times the energy required for their treatment (WERF, 2014). The energy is contained in the waste in chemical, thermal and, to a lesser extent, kinetic form. Of these forms of energy, the only one that is currently exploited on a large scale, albeit to a lesser extent than potential, is the chemical fraction. In fact, several plants are already in use at national and international level for the treatment of wastewater with the production of methane (contained in the biogas produced by the anaerobic digestion processes of wastewater or sludge).

The recovery of this energy from wastewater could make purification plants independent of energy needs. By combining energy production with innovative wastewater treatment processes (to maintain wastewater quality objectives) and optimizing energy consumption, purification plants could turn into renewable energy production systems in the near future.

It should be remembered, however, that all the possible strategies for the production of energy from the purification of waste water must necessarily pay attention to maintaining the purification capacity of the treatment process, so as to comply with the laws.

Of the three components, thermal energy constitutes about 80%, while about 20% is represented by chemical energy (Fig. 1) (WERF, 2014). Kinetic (hydraulic) energy generally represents less than 1% of the energy that can be obtained from wastewater, although the weight of this fraction can change considerably depending on the characteristics of the territory (for example, mountain communities).

Thermal energy can be extracted through the use of heat pumps. However, there are various obstacles that limit the recovery of heat from wastewater, such as the lack of infrastructure, especially for the distribution of any recovered heat. In addition, the infrastructures capable of using the thermal energy produced in this way must be located in the vicinity of the installations that produce it, in order to contain heat losses (WERF, 2014). The use of wastewater thermal energy therefore, apart from specific favourable situations, would require targeted investments in future urbanizations.

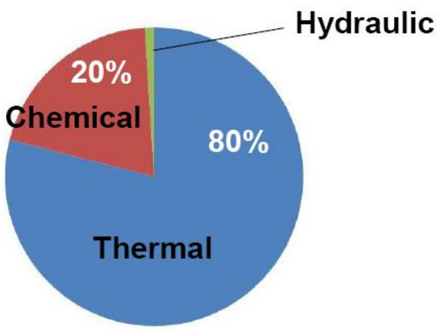

Fig. 1: Estimation of the energy content in wastewater (WERF 2014)

In any case it is possible to see several examples in Europe for the use of this energy especially in the North European countries. This could seems quite strange because the use of thermal energy if is more advantageous in those countries with longer cold periods in more temperate countries thermal energy content in the treated wastewater could be used even during the warm period to cool down residential and non-residential buildings providing a strong advantage in the depreciation period of the necessary infrastructures.

Some of these are reported in the table 1 below

Location	Inlet flow	Heat pumps	Use of heat cool	Temperature inlet	Drop
Hammarbyverket in Stockholm	4000 – 18 000 m^3/h	seven total capacity of 225 MW	95.000 residential buildings	7 and 22 °C	1-5°C
Lapua waterworks		120 kW	buildings treatment utility		3°C
Sandvika	180 m^3/h	60 MW	Residential buildings		4

Table 1: example of heat recovery facilities in Europe.

The above reported values are particularly relevant considering that from an evaluation of US EPA (US EPA, 2006) the management of the water cycle in the United States is responsible for about 3% of the country's entire electricity needs. A recent article provide an overview for Europe considering wastewater treatment plants not smaller than 2000 person equivalent (PE). For this size of plants the energy consumption represent the 0.8% of the total energy consumption in the EU-28. It is interesting to notice that small plants (less than 50 000 PE) represent almost 90% of the total number of plants, but process only 31% of the PE and require 42% of electricity use. Plants from mid to very large size (more than 50 000 PE), being only 10% of the plants, process about 70% of the PE with 58% of the total electricity use.

With a more energetic efficient management of the larger size plants it could be saved about 13.500 GWh yr^{-1} (Daniele Ganora et al 2019).

On the other side there is another force pushing to increase the energetic impacts of the treatments and it is the trend to a more stringent quality requirement for the treated wastewater that push the increase of the energy consumption of the treatment plants.

All the above consideration done are mostly focussed on the energy production and recovery from treatment plants. It is important consider that the first step necessary to improve the energetic performances of any appliance is to improve its efficiency.

For this reason before any further action to produce energy it is necessary evaluate and if possible increase the energy efficiency of the treatment plant. To do this it is necessary to develop a benchmark approach that analysing the energetic performance of the treatment plant or better, if possible, the different treatment processes stages of the treatment and comparing them with the national benchmark where available or with other benchmarks available in the scientific bibliography it is possible ameliorate the energetic process performances and only after this step it will be reasonable to think about the possibility to produce energy.

A last aspect that must be considered in the possibility to recovery energy from wastes is the legislation. Only during the last year European legislation stress more the aspect of the energy efficiency and the recovery of energy from wastes as renewable energy.

This oblige the member states to take in consideration this aspects in their national legislations. This new approach at the production and management of energy modify the situation of the energy market in Europe broking some monopoly and opening to new players. On the other side the distribution grids are still under the control of few companies that several times make resistances at new connection alleging security reasons or quality of the energetic vector introduced.

The EU legislation in the sector of renewable energies since 2009 put some minimum target for the production of renewable energies in EU and each country has to reach. The targets were established for the different kind of energy, electricity, automotive fuels, and GHG reduction. The directive was modified in 2016 providing new criteria and new targets to be reached before the 2030.

3. Description of the selected technologies

Selected technologies has to satisfy the request to be really energetically effective and, in the meantime, to have a Technology Readiness Level (TRL) equal to 8 or higher to give the real opportunity to be implemented in relevant infrastructures in a reasonable period of time. For these reasons most of the available technologies, even with a quite high development level, but not yet commercialized have not been considered in the panel of the opportunities for their application in the pilots considered in the project.

3.1. Ananerobic Digestion

Anaerobic digestion is probably the most widely technology used in the wastewater treatment that can help in the generation of energy at treatment plant. It consist in a biological process that use organic matter present in the wastewater and transform it in biogas, a gas with a variable content of methane ranging from 50 to 80%. This gas can be easily burned in a Combined Heat and Power (CHP) unit that can transform the gas in electricity and heat. Electricity find an immediate use in the treatment plants instead heat is very often released in the environment because in a treatment plant heat requirements are quite low and in general limited in the winter periods.

For many years this technology was coupled at the classical activated sludge process even in small size plants just because there is an advantage in the reduction of the sludge produced. The gas produced was normally burned in a flare. For bigger plants, where it could be convenient use it, the problem was the unavailability of CHP units specifically studied for the biogas use. The opening at the production of biogas even in agriculture increase a lot the request of more reliable CHP units even with this kind of fuel stimulating the mechanical industry to adapt the existing machinery and opening the possibility to use them also to the other sectors.

A last, but not minor point is the change in the legislation present in some country. Very often the production of electricity was limited to one or few monopoly and it was forbidden for any other private company produce electricity. Only with its change and giving the possibility, under a strict regulation, to all the companies to produce electricity the recovery of energy from wastewater has begun to develop in a larger scale.

3.2. Combustion processes

Probably the combustion process is the second most used in the sector of waste and wastewater treatment. Even for this process, as well as for anaerobic digestion, at the beginning of its use the main scope was to reduce the amount of wastes and stabilize them. Wastes could be burned directly in big central incinerators instead for wastewaters the excess sludge produced was firstly dehydrated and then burned. In both processes it was possible to introduce further energy to favourite the combustion. With the increase of the cost of fossil fuels and the necessity to increase the efficiency of the process the incineration process was modified and now this plant are modified, not only in the name, in waste-to-energy plant.

Even for this plants the consideration done in the previous paragraph on the possibility to produce electricity is valid.

3.3. Biogas upgrading

Biogas upgrading is the process that through different technologies can separate methane, often in this case called biomethane, from the other components of biogas.

This kind of technology became economically convenient when national governments open at the possibility to inject biomethane in the gas grid. This approach was due to the large increase of the biogas production and, in the meantime, to achieve the European targets in for the production of electricity from renewable sources. There was a surplus of biogas production that was no more convenient to transform in electricity and without convenient utilization way could be only burned.

Nevertheless there is still some difficulty in the standardization of the introduction connected mainly at the quality of the injected biogas and the problems related with the odorization of the gas.

For the biogas treatment produced in the fermentation anaerobic process especially at waste water treatment plants (WWTPs) and also at biogas stations or gas storage sites, there are following technologies used in the world:

- Physical absorption - through a selective dissolving of parts of biogas in scrubbing liquids.
- Chemical absorption - this method can remove H_2S from the biogas via organic solvents or anhydrous salts.
- Adsorption - this method also remove H_2S from the biogas via highly porous solid material - sorbents or activated carbon. It is complex and expensive because of the need to regenerate the sorbent.
- Pressure Swing Adsorption (PSA) - used in combination with adsorption serves to remove H_2O, H_2S and NH_3 from the biogas. The technology therefore includes compressors, chambers, and adsorption units. Before scrubbing via this method, it is necessary to remove water from the biogas.
- Separate condensation by compression - this method removes CO_2 from the biogas. The technology is based on the compression and decompression.
- Freezing systems - cryogenic technology - this method removes in particular H_2O from the biogas. Technology includes industrial cooling equipment.
- Biodegradation - this method removes H_2S from the biogas. After dissolution in water, there are deployed microorganisms of the species Thiobacillus and Sulfolobus in presence of the oxygen, with S and H_2O as outputs.
- Molecular sieves (filters) - this method removes H_2O, CO_2 and H_2S from the biogas via the molecular sieves (filters). The method is simple but a periodic regeneration of the sieves is necessary.
- Membrane separation - this method is used to final removal of CO_2, H_2S and N_2 from the biogas.

The above overview shows a wide range of possibilities for separating biogas components. Not all methods are however applicable for the upgrading of the raw biogas to the natural gas level due to the wider range of the gases to be removed.

The produced biomethane can be used for:

a) Injection in the pipeline system

b) Production of bio- Compressed Natural Gas (CNG)

c) Production of bio Liquid Natural Gas (LNG)

The injection of biomethane in the distribution network or transport systems are often considered individually and within the respective operator of the distribution system.

The use of CNG or LNG is more related with the automotive sector and the quality requirement could be a little less stringent. In any case the possibility to use CNG or LNG is strongly dependent from the development of the national legislations and the possibility to differentiate the fuel coming from fossils sources or from renewable sources.

3.4. Power to gas

Biogas upgrading can generate a flow of carbon dioxide, more or less equal to the biomethane produced. This carbon dioxide should be released in the environment as the possible alternative use is quite difficult.

One very new possibility is the possibility to use this excess of carbon dioxide as gas for soft drinks. This could be a very interesting opportunity from the economic point of view for the treatment plants, but the resistances from the sanitary authorities and the public acceptance is generating some difficulty for this approach.

Power to gas is a possibility that combine a biological approach with an electrochemical one. It was known that hydrogenotrophic bacteria can transform carbon dioxide in methane in presence of hydrogen. The difficulty of this technology is to provide large amounts of hydrogen for the process. The most environmentally acceptable solution is to generate it through the water electrolysis. But this process requires a large amount of energy that if it is renewable it is acceptable, otherwise the environmental costs are too high.

The potential advantage of this process is that a side flow from the electrolysis is a flow of oxygen that could be used directly in the treatment plant for the oxidation of the organic matter, but in this case as it is a pure gas not obtained from wastes could be used also for other more economically convenient sectors (pharmaceutical, medical).

3.5. Thermal Hydrolysis

Thermal hydrolysis is a two-stage process combining high-pressure boiling of waste or sludge followed by a rapid decompression. This combined action sterilizes the sludge and makes it more biodegradable, which improves anaerobic digestion performance. Sterilization destroys pathogens in the sludge resulting in it exceeding the stringent requirements for land application in agriculture (Barber et al. 2012).

In addition, the treatment adjusts the rheology to such an extent that loading rates to sludge anaerobic digesters can be doubled, and also dewaterability of the sludge is significantly improved (Neyens et al. 2003; Skinner et al.2015) The first full-scale application of this process for sewage sludge was installed in Hamar, Norway in 1996. Since then, there have been over 30 additional installations globally (Barber et al. 2012).

The energetic requirement of this process is quite high in terms of heat, but the usual availability of CHP units where it is possible recovery a lot of heat, and from the recycle of the heat from the treated material reduce a lot the requirements and the final energetic balance is very convenient.

The only disadvantage of this process is an increase of the non-biodegradable substances that is some case can generate some problem especially in those countries where the legislation has implemented also this kind of parameters for the release in the environment.

3.6. Gassification

Gasification is a thermal process that converts biomass based carbonaceous materials into a gas. As the combustion is normally obtained using air as oxidizing the largest fraction of this gas contain nitrogen (N_2), and in smaller quantities carbon monoxide (CO), hydrogen (H_2), and carbon dioxide (CO_2). This is achieved by reacting the feedstock material at high temperatures (typically >700 °C), without combustion, via controlling the amount of oxygen and/or steam present in the reaction. The resulting gas mixture is called syngas (from synthesis gas) or producer gas and is itself a fuel due to the flammability of the H_2 and CO of which the gas is largely composed. Power can be derived from the subsequent combustion of the resultant gas, and is considered to be a source of renewable energy if the gasified compounds were obtained from biomass (IEA Bioenergy, 2020).

An advantage of gasification is that syngas can be more efficient than direct combustion of the original feedstock material and the solid residue material is quite limited and in the case of organic wastes or sludge the char could be also used as a carbon source in the field application. Syngas might also be used directly as the hydrogen source in fuel cells but in the case of treatment plants it is much more convenient use it in the CHP unit.

3.7. Heat recovery from treated wastewater

Heat recovery from treated wastewater is a process that is under strong development in the wastewater treatment plants because it strong energetic advantage. As mention in a previous paragraph 80% of the energy content is represented by the thermal energy present. It is possible to recover this energy using a heat pump. The heat recovered represent more or less three times the energy necessary to drive the pump. The advantage in this sense is clear. The difficulty for the application of this technology is the distribution of the heat. The first and easiest way is to use it to conditioning offices and other spaces of the WWTP where people lives. Then it is possible to use this heat to warm up the water for sanitary uses, third is the possibility to enhance the sludge drying.

Although this could provide an advantage the amount of heat is quite limited and the period of use during the year in mainly limited at the winter period.

The bigger advantage of these technology is the possibility to distribute the energy at the neighbourhood hoses or industrial areas. In this case the contribution of this heat to warm up the sanitary water or for the conditioning of the hosed could be much more relevant taking the bigger advantage from the recovery.

The limitation factor of this technology is the distribution system quite complex and expensive without considering other legal aspects (Hawley and Fenner, 2012).

3.8. Other renewable energies sources

In the potential possibilities for the recovery of energy in a treatment plant it has been considered also other technologies not connected to the treatment of the wastes or wastewater but that could be implemented in the treatment plants as a further renewable source.

In some case the kinetic energy (hydraulic) could be a good opportunity for an easy production of electricity with almost no impact on the environment. For sure the application is limited at some specific case where the amount of water is quite large and there is a fall sufficient to provide the energy.

The other energy considered is the photovoltaic energy that could be installed above the roofs of the buildings of the treatment plants but also above the process tank using large surfaces and with a limited impact.

4. State-of-the-art in CEU countries

From the description of the technologies considered in the project it is quite clear that the different solution must be tailored on the local situation. The complexity to provide a state of the art for the CEU is furthermore complicated by the limited availability of information for this specific area and the presence in it of countries with very different economic levels.

Another aspect that should be considered in general but that it is not part of the project is that the implementation of new energetic technologies could represent also a further step to implement those technologies that, in the wave of the circular economy approach, try to recover also material, as sulphur, phosphorus, bioplastic precursors, fertilizers.

It is clear that in this view it is necessary a more general approach that is very well described in figure 2

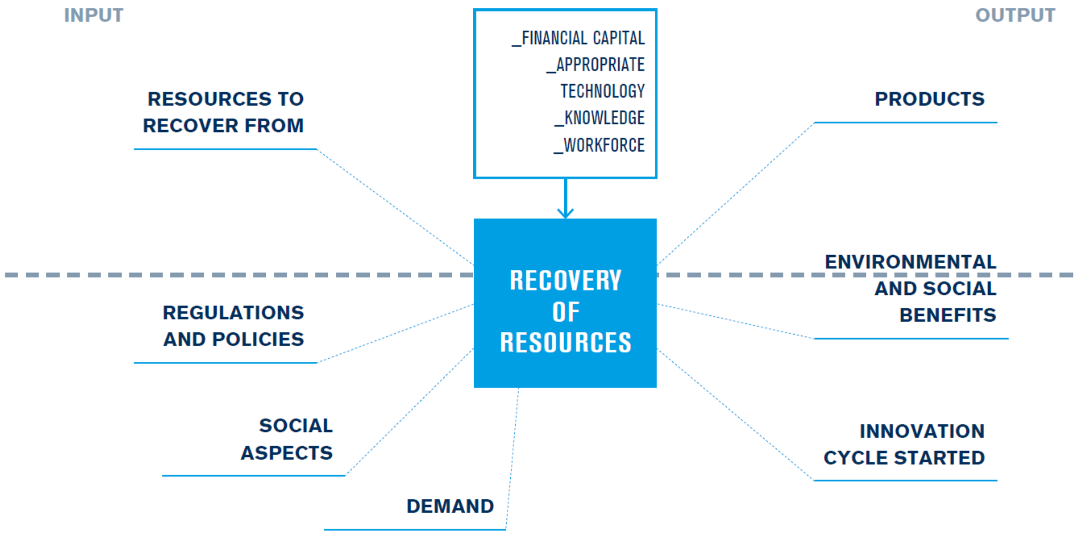

Figure 2: Schematic view driver's interactions for Resource Recovery in a treatment plant. (Holmgren, et al. 2015).

In this sense treatment plants in the future will change strongly their focus moving from the simple removal of pollutants to the production of energy and recovery of material.

If some example is already implemented in Europe and in the world it is necessary to go a long way to rename the treatment plants as real biorefineries.

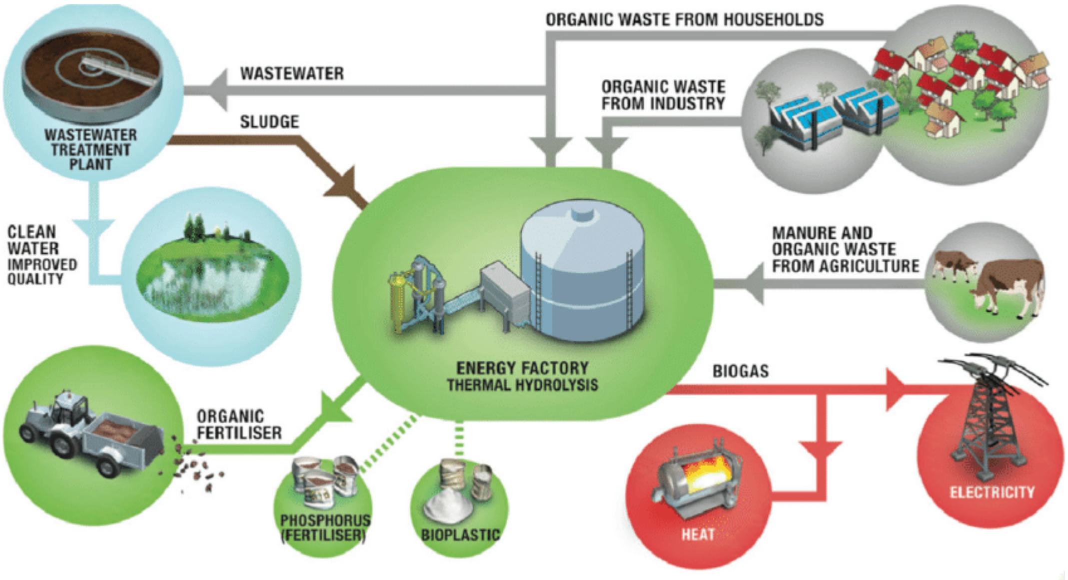

Figure 3: The biorefinery concept in Billund, Denmark. The conventional wastewater treatment plant has been remodelled to carry out the processes indicated, and many other wastewater treatment plants are following with various modifications. (https://www.billundbiorefinery.com/our-refinery/)

If the treatment capacity of wastewater in the CEU area reached rapidly a good level also in the countries more recently became EU members (EEA, 2020) few information are provided on the capacity of the plants to recover the energy to cover totally or partially their energetics needs.

In Austria most of the municipal wastewater treatment plants bigger than 30.000 PE are equipped with mesophilic anaerobic sludge digestion towers and the gas obtained used to generate electricity and warm up the digestor (Novak et al., 2015). In the meantime the evaluated potential of thermal energy recoverable from the treated wastewater via heat pumps amounts up to 450 GWh/y (Bucar et al., 2007).

In Croatia wastewater and industrial wastewaters are treated in over 200 WWTPs with a total capacity of 4.1 million PE. More than half of the wastewater and sewage sludge is produced in the four major agglomerations, with 91 agglomerations with a wastewater loads larger than 10,000 PE while another 190 agglomerations have wastewater loads in the range between 2000 and 10,000 PE (Durdevicet al., 2019). This situation strongly limit the possibility to implement the anaerobic digestion process in those small realities. On the other side the 5 main plants present in Croatia are producing more than 5 millions of cubic meters of biogas that is used to produce electricity and dewatered the sludge.

In the meantime to reduce or prevent the landfill disposal of stabilized sludge there is a plan for their incineration and recovery of energy.

In Germany where almost all the wastewaters are treated with a tertiary treatment the energetic costs for their treatment per PE is quite high if compared to those situation where this treatment is not applied so largely. The Guide value for large treatment plants in Germany is 26 kWh/PE-year (MURL, 1999).

For this reason almost all the larger plants use anaerobic digestion for the stabilization of sludge. Even in this case as in Croatia incineration, mono-incineration or co-incineration, is the most used final technology to reduce the impacts of sludge in the environment, reduce their volumes and recovery some inorganic fertilizer (Wiechmann et al. 2013).

In Italy although the treatment of wastewater in large agglomerates include tertiary treatments not all the wastewater are treated at this level in smaller cities. During the last 10 years, thanks to the legislation that stimulate the recovery of renewable energy from wastes, several of the existing treatment plants have implemented the cogeneration unit after the anaerobic digestion process. Instead it is still quite unusual the mono-incineration of residue sludge because the resistance of the population at this kind of technology.

Also in Czech Republic the most common technology to recover the energy from wastewater is the anaerobic digestion process, which is applied in the larger treatment plants in the country. In the treatment plant of Prague it is under evaluation the possibility to install a biogas upgrading unit for the injection of the biomethane in the grid.

No further technologies for the recovery of energy from excess sludge it seems that are applied.

5. Conclusions

From the analysis of the state of the art of the countries involved in the project there is the confirmation that anaerobic digestion is the main technology used for the recovery of energy during the treatment of wastes. As second option there is the incineration process as mono-incineration or co-incineration with other kind of wastes. Although this technology is not always well accepted in by the population it represent a good solution for the stability of the final product, its sanitation, the reduction of the volumes and the possibility to recovery some inorganic fertilizer and other valuables products as suggested by the trend of the EU legislation in terms of sustainability and circular economy.

Regarding the recovery of heat it seems that only in Austria there is a clear view for the recovery of heat from treated wastewater and its distribution in the neighbourhood houses. In the other countries heat recovery is limited at the recovery of heat from CHP units for the conditioning of treatment site offices.

All the other technologies considered in the project are almost neglected. It is difficult to say why. One of the reason is the slow reaction time that the sector of waste and wastewater has at the innovation, sometime due also at the necessity that of the innovation require also some changes in the legislation. The other reason could be the cultural obstacle of the Multiutilities. In most of these companies professional competences are on the treatment of wastes. Recovery of energy requires new competences that must be allocated in the company, and also this process could take time.

Anyway it is possible to say that the available technologies could represent a good opportunity for the reduction of the energetic impact of the treatment plants in central Europe but for sure they need some time to allow to all the stakeholders, public authorities, multiutilities, and citizens that only with the integration of the technologies and with e more careful use of the natural resources we will be able to maintain the quality of life reached at the moment without any prejudice for the future generations.

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