MSc Program
Renewable Energy in Central and Eastern Europe

Optimizing gas production and net income of waste water treatment plants with co-digestion of industrial and commercial wastes

A Master's Thesis submitted for the degree of
"Master of Science"

supervised by
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Affidavit

I, **Manuel Valer HERLO,** hereby declare

1. that I am the sole author of the present Master Thesis, "*Optimizing gas production and net income of waste water treatment plants with co-digestion of industrial and commercial wastes*",
   57 pages, bound, and that I have not used any source or tool other than those referenced or any other illicit aid or tool, and
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Vienna, 30 November 2012 ______________________________

Date Signature

Abstract

A daily topic now it is energy. Energy demand, energy production or energy savings. All come together finally to our comfort demand and greenhouse gases reductions. We need energy, this is true. Depends on where we live, the country and the town, we have or we do not have at our disposal, energy, electrical energy or thermal energy, we have infrastructure or we do not have, roads, water supply, sewage systems and wastewater treatment plants. A lot of wastewater treatment plants were built in the past, but even if the technology to transform the energy from the wastewater in useful energy, like biogas, was a technology known for a long time, it was only in a few cases implemented.

Romania is a developing country, with only a part of the population connected to a sewage system, only a part of this population has the sewage system connected to a wastewater treatment plant that works according to the regulations. Romania has a lot of ongoing projects regarding wastewater treatment plants and extension of sewage systems, but only a few with biogas installation. In Romania, the first desire is the urban comfort and to have access to resources and only after, this, the issues will be energy savings or environmental problems. The energy recovery from wastewater treatment plant are projects that are very little implemented, and maybe only forced by the European standards will give a push to this technologies. Things have to change.

The core objective of this work is to calculate the economic and environmental benefits and disadvantages of energy recovering systems from the wastewater treatment plants, from the wastewater sludge. The main questions are if such a project is economically feasible for small municipalities, of 15.000 inhabitants, and to show how the production of biogas can be improved by designing a CHP plant with a mixed feedstock of sewage sludge and municipal and industrial wastes. Maybe the biogas production from sewage sludge and wastes has not so much economically role for a small comunity, but it has regarding the environment, regarding the sludge treatment, or the chemical products used for Its treatment, regarding the degradation of the wastes and so on.

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1 Introduction

From the ancient times people were preoccupied with water supply and water disposal for the settlements. In Nineveh and Babylon were built channels, to dispose liquid wastes. In Egypt, 4000 years ago, were built open channels to dispose the waste water. The Greeks and the Romans have built large scale sewage systems and the first sewer was built in Rome, in year 541. Construction of sewage systems began in the Middle Ages, but once the beginning of industrialization and development of the countries, the need for sewage systems became increasingly larger. Once with the industrial development, not only the need for sewage systems became larger, but also the water supply, the food, the transportation, or the urban comfort, in a few words, the primary energy supply has seen a huge increase. The countries have found rapidly a solution, in fossil fuels. Fossil fuels, whose exact amount was unknown to those moments. The developing of the Countries grew more and more, increasing together the need of energy. Fossil fuels slowly began to see their end, and other forms of energy necessary to satisfy our needs became our main concern. Solar energy, wind energy, biomass, biogas, or geothermal energy are now the main players in energy supply systems. Solar energy has one of the highest energy potential, being 15.000 times highest by the energy consumption of the whole planet, calculated in one year. Wind energy capacities growing year by year, being one of the most widely used form of renewable energy. Geothermal has the highest theoretical potential from all forms of renewable energy, but due to higher costs, has not developed as much as others.

Biomass and biogas are some forms of renewable energy are still in development. Theoretically, any raw material, organic matter contains energy. The problem is how to extract this energy from the raw material. There are many types by which biomass can be converted into useful energy. What will be explained further in this project is the modality to convert energy from wastewater and from wastes in biogas and further into useful energy.

The project begins with a short introduction in what wastes are. What is the waste-water, how it is treated, and what are the main products of it. The next step is to describe the municipal and industrial wastes, how are collected, how are deposited and what are the next steps for treating, recycling or energy recovery. The method of energy recovery, through the anaerobic digestion is explained into more detailed, because it is the way that can produce energy in form of biogas from sewage sludge. It is shown that there is a further possibility to mix the feedstock of the anaerobic digestion, with sewage sludge and different wastes. Depending on the ration that is chosen and the wastes that are mixed, a higher amount of biogas can be produced. Also for such a project, the economical part is very important, taking into account the investment costs, which are also higher. The operational costs for such a system, (because here it is about a complete system, regarding the collection, transport and anaerobic digestion of sewage sludge and wastes) are also higher, but it is shown in the case study, that such a project is not only economically feasible, but also environmental feasible.

The case study presented in this project is taking into account a new project regarding the waste-water and the waste management in the city of Chisineu Cris, from Romania. It is a small municipality, but highly industrialized, with a surrounding population of about 15.000 inhabitants.

2 Wastes

2.1 Waste-water

2.1.1 Introduction

Beginning with the cities and continuing with the rural area, because of the increasing in the urban comfort, which has provided modern kitchens, showers, toilets, fast foods, pools, road cleaning, industrial processes etc., the waste-water flow increased year by year. The industrial development and the big percentage of the population that has now access to sewage systems has increased the waste-water discharge. Both urban and rural areas accumulates and needs to evacuate sewage water and storm water.

Regarding the different types of the waste-water, it can be:

- domestic wastewater from households or industrial facilities
- wastewater from local industry
- wastewater from farms
- wastewater from washing the streets
- clean storm water collected from the populated areas
- harmful storm water collected from local industry, which needs pre-treatment before it is discharged in the sewage system
- surface water coming from watercourses, lakes, ponds or swamps, when they are discharged in the sewage system
- ground water from constructions or from infiltrations

Sewerage systems can be simplest or very complex. Depending on the capacity, the origin, the chemical composition, and the legislation regarding the waste-water discharge, the treatment is designed and made through a so-called "Waste-water treatment plant".

2.1.2 Sewage systems

There are different types of sewage schemes, depending on the area which has to be collected, by the quality of the waste-water, the different paths, the connection possibility to the sewerage system, or depending on the emissary etc.

Different from the sewerage scheme, we have the sewerage system. The sewerage system comprises of all the constructions and the installations which collects, transports, treats and discharges in emissary the waste-waters. The sewerage system contains three groups of objects:

- Channel network and connections for different objects
- Pretreatment and treatment plants
- Constructions and installations for discharging the treated waste-water into the emissary and constructions and installations for removal of the remaining sludge

One important point that has to be taken into account when designing a sewerage system is the sewerage flow. The sewerage flow is composed from the sum of:

- The total flow of the domestic wastewater
- The total flow of the storm water
- The total flow of the surface water
- The total flow of the ground water

The next steps in designing the sewerage systems are the hydraulic calculations of the sewerage networks which includes the sizing of the channels, related constructions - manholes, manholes for breaking the slope, manholes for washing and cleaning the channels, spouts, including the pumping stations, and the static calculation and channel resistance, which establishes the resistance requirements for the construction elements.

Whatever the sewerage scheme and system has been chosen, the waste-water has to be treated before it is discharged into the emissary. The waste-water treatment has as primary objective, the removal of substances in suspension, toxic substances, microorganisms and so on, in order to protect the environment. The discharge of the waste-water that has not been treated can put in danger the public health, so the waste-water has to be discharged downstream of the point of use. Also, the European regulations establish qualitative properties of the waste-water that can be discharged into the emissary.

2.1.3 Waste-water treatment

The treatment of the waste-water is made in so-called waste-water treatment plants. A waste-water treatment plant represents all the constructions, installations and equipment, where the waste-water is subject to a treatment process, which changes the chemical properties of the waste-water, properties set by the applicable regulations in the country. After this, the waste-water is successfully discharged into the emissary. The waste-water treatment plants can be divided into two categories:

- Municipal waste-water treatment plants
- Industrial waste water treatment plants

The Municipal waste-water treatment plant receives for the treatment domestic waste-water, industrial waste-water, storm waste-water and surface water. The Industrial waste-water treatment plat receives for the treatment only industrial waste-waters. Often, the industrial waste-water treatment is made in the municipal waste-water treatment plants.

Figure 1 – Municipal waste-water treatment plant

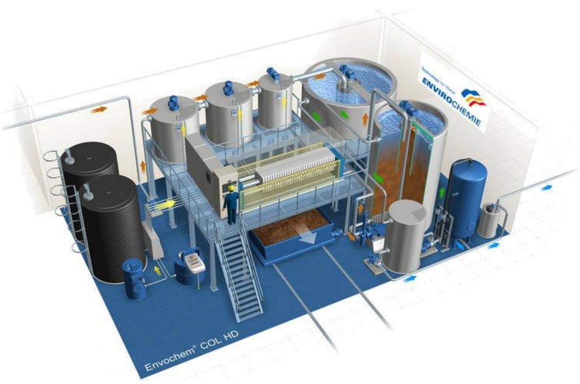

Figure 2 – Industrial waste-water treatment plant

The composition of the waste-water largely determines the size and the type of the WWTP. However, in choosing the treatment process and scheme can occur also the emissaries that will be used after the treatment. The composition of the waste-water is determined through chemical analysis, which determines the type and the quantity of the materials that it cointains. The chemical analysis also helps tracking the decomposition of the waste-water, through the determination of BOD5, O_2, and pH. Based on the biological and chemical characteristics, the wastewater needs to be treated before it is disposed into the emissary. The maximum admission levels for the chemical-biological characteristics differs from country to country. For example, in EU, the requirements are:

Parameters	**Maximum concentration**
Phosphorous	2 mg/l P (10.000 – 100.000 PE) 1mg/l P (> 100.000 PE)
Total nitrogen	15 mg/l N (10.000 –100.000 PE) 10mg/l N (> 100.000 PE)
BOD_5	25 mg/l O_2
COD	125 mg/l O_2
Total suspended solids	35 mg/l

Table 1- Maximum admissible concentrations

To meet the requirements, different waste-water steps and technologies can be applied. In the waste-water treatment, there are three steps:

- Mechanical processes: refers to the decantation of the waste-water, where the solids or suspended materials are removed.
- Biochemical processes: refers to the interaction of the biological and chemical processes. In this step, the decomposition of organic materials takes place.
- Chemical processes: refers to the application of chemical substances to the waste-water, for removal of different chemical substances

Whatever the technology is used for the treatment of the waste-water, usually it has to follow certain steps. In the next figure it can be seen the basic scheme of a waste-water treatment plant:

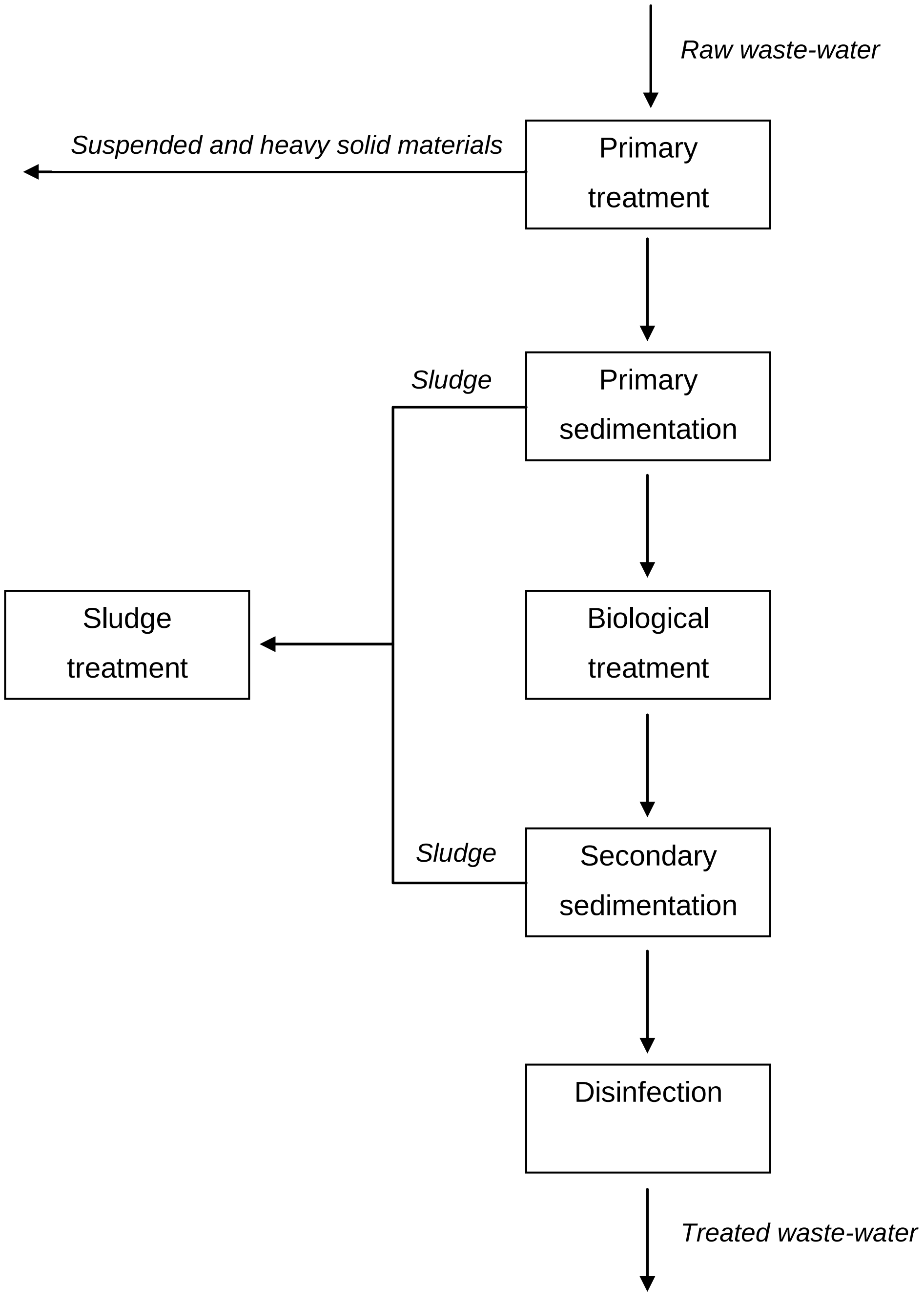

Figure 3 - Waste-water treatment plant flow diagram

Raw waste-water enters the waste-water treatment plant, after the primary treatment, suspended materials and heavy solid materials that cannot be treated in the waste-water treatment plant are removed (sticks, rags, sand, and other debris). This materials are collected in a garbage container and transferred to the landfill. Next, it follows the steps, the treated water is discharged into the emissary and the primary and the excess activated sludge is collected and treated. Usually the sludge is dehydrated and disposed to the landfill or transferred to an anaerobic digestion, for biogas production. This will be discussed with more details in another chapter.

2.1.4 Waste-water sludge

The exactly mass flow of the waste-water treatment plant is difficult to determine for a general scheme, because it depends mostly of the composition of the raw waste-water and the treatment technology used in the waste-water treatment plant. However, as a general rule of thumb, the sludge quantity produced in a typical waste-water treatment plant is approximately 0.24 kg/m^3 of wastewater treated.**[1]**

Figure 4 - Sewage sludge

2.2 Municipal and industrial wastes

2.2.1 Introduction

The waste can be understood as any substance or object which the holder discards or intends or is required to discard. The total wastes mean all the waste generated in urban and rural areas. Wastes from households, institutions, industry, street waste collected in public spaces, streets, parks, and construction and demolition waste. We can talk about the total wastes into more categories, such as:

- Municipal wastes, is waste collected by or on behalf of a local aurhority. It comes from households, commercial activities and other sources whose activities, are similar to those of households and businesses. The municipal wastes are mostly composed of:

- Organics 25%
- Textiles 2%
- Aluminum 1%
- Ferrous 2%
- Plastic 11%
- Glass 6%
- Paper & Cardboard 35%
- Others 18%**[2]**

As we can see, one of the most predominant wastes are organic wastes, which can be used for energy purposes. Others, such as plastic, glass, paper and aluminum must be collected separately and recycled.

- Industrial wastes, which comes from manufacturing industry. The industrial wastes can come from the production of basic metals, food, beverages and tobacco, wood and paper products.
- Other wastes can be included in a category, such as:
  - Dangerous wastes
  - Wastes from construction and demolitions
  - Wastes from mining
  - Electrical wastes
  - Agricultural wastes

In urban or rural areas are generated huge amounts of wastes daily, which do raise issues only for the storage or aesthetic, but are also a source of pollution, threatening the health of the populations. All the waste pollutes the environment, and possibly to contaminate the groundwater.

The wastes are solid residues collected from the populations, usually made of paper, plastic, fabric, ceramic, glass, packaging, batteries, tires, oil and, food residue. Waste disposal is recognized as impact-generating environmental and public health risk. We can mention changes in landscape and visual discomfort, odor, air pollution, surface water pollution, or changes in soil fertility. Most of these wastes are not biodegradable because the variety of organic and inorganic substances contained, the aerobic and anaerobic degradation by microorganisms is difficult to be done. The way in which waste may disappear naturally in nature by complete degradation:

- Metal containers: degrades in approx. 150-300 years.

- Aluminum containers: disappear in approx. 300-400 years.

- Plastic: does not degrade, eventually breaks into small pieces that are ingested by animals.

- Glass objects doesn’t degrade, they suffer only a process of granulation.

For these reasons, there must be a waste management and regulation of it.

Figure 5 – Landfill in Australia

In the next table, the total municipal wastes generated in European Union countries can be seen, from year 2005 to 2010. To note is that the total volume of waste in EU27 is approximately constant, or even tends to decrease:

GEO/TIME	2005	2006	2007	2008	2009	2010
European Union (27 countries)	253,888	257,960	259,497	259,162	255,203	252,095
European Union (15 countries)	216,469	219,919	221,916	220,961	218,231	215,794
Euro area (16 countries)	176,219	179,232	181,513	181,824	180,578	178,777
Euro area (15 countries)	174,660	177,608	179,844	180,052	178,833	176,969
Belgium	5,024	5,093	5,256	5,242	5,276	5,074
Bulgaria	3,680	3,548	3,314	3,615	3,561	3,091
Czech Republic	2,954	3,039	3,025	3,176	3,310	3,334
Denmark	3,990	4,021	4,313	4,560	4,206	3,732
Germany	46,555	46,426	47,887	48,367	48,466	47,691
Estonia	587	536	602	524	464	417
Ireland	3,041	3,385	3,398	3,224	2,953	2,846
Greece	4,853	4,927	5,002	5,077	5,154	5,175
Spain	25,683	26,209	26,154	25,317	25,108	24,664
France	33,366	33,990	34,630	34,714	34,504	34,535
Italy	31,664	32,508	32,542	32,467	32,110	32,090
Cyprus	553	571	587	608	620	611
Latvia	716	942	861	752	753	680
Lithuania	1,287	1,326	1,354	1,369	1,206	1,253
Luxembourg	313	323	333	341	338	344
Hungary	4,646	4,711	4,594	4,553	4,312	4,129
Malta	251	253	266	276	268	246
Netherlands	10,178	10,164	10,311	10,258	10,123	9,887
Austria	5,084	5,396	4,951	4,997	4,941	4,960
Poland	12,169	12,234	12,264	12,194	12,053	12,038
Portugal	4,745	4,898	4,967	5,472	5,496	5,464
Romania	8,173	8,392	8,161	8,439	7,768	7,830
Slovenia	845	866	886	923	913	864
Slovakia	1,558	1,623	1,669	1,772	1,745	1,809
Finland	2,506	2,600	2,675	2,768	2,562	2,519
Sweden	4,347	4,500	4,717	4,732	4,486	4,364
United Kingdom	35,121	35,479	34,780	33,424	32,507	32,450
Iceland	153	171	174	175	177	182
Norway	1,968	2,140	2,312	2,324	2,269	2,295
Switzerland	4,940	5,330	5,460	5,650	5,460	5,560
Croatia	1,449	1,654	1,719	1,788	1,743	1,630
Macedonia	:	:	:	714	726	721
Turkey	31,352	30,082	30,366	28,454	30,196	29,733
Bosnia and Herzegovina	:	:	:	1,367	1,493	1,550

*Figure 6 - Municipal waste statistic (thousand of tonnes)***[3]**

The total ammount of wastes that is treated can be seen in the next table. In year 2005 - 96.5% of the waste was collected and treatead and in year 2010 – 96.7%:

GEO/TIME	2005	2006	2007	2008	2009	2010
European Union (27 countries)	245,250	251,519	254,721	247,339	246,641	244,026
European Union (15 countries)	213,518	219,430	222,231	214,162	213,915	211,597
Euro area (16 countries)	173,484	178,873	182,102	175,262	176,592	174,893
Euro area (15 countries)	172,045	177,363	180,524	173,630	174,924	173,142
Germany	45,568	44,139	46,048	46,416	48,466	47,691
United Kingdom	34,880	35,370	34,626	33,215	32,223	32,220
France	33,366	33,990	34,629	34,714	34,504	34,535
Italy	35,297	36,714	37,101	29,860	30,369	30,335
Turkey	26,286	24,964	25,818	24,074	26,015	25,098
Spain	22,554	26,209	26,154	25,317	25,108	24,664
Poland	9,352	9,877	10,083	10,036	10,054	10,044
Netherlands	8,451	8,453	8,643	8,511	8,394	8,291
Romania	6,558	6,335	6,159	6,561	6,246	6,296
Austria	4,982	5,396	4,951	4,997	4,941	4,960
Switzerland	4,940	5,330	5,460	5,650	5,460	5,570
Belgium	4,813	4,740	4,948	5,060	4,944	4,732
Greece	4,867	4,927	5,002	5,077	5,154	5,175
Portugal	4,745	4,898	4,967	5,472	5,496	5,466
Hungary	4,606	4,671	4,365	4,426	4,283	4,129
Sweden	4,447	4,549	4,679	4,688	4,440	4,312
Denmark	3,987	4,021	4,301	4,547	4,206	3,732
Bulgaria	3,144	2,751	2,980	3,359	3,421	3,041
Czech Republic	2,495	2,659	2,817	2,757	2,894	3,186
Finland	2,547	2,600	2,675	2,832	2,562	2,519
Ireland	2,779	3,100	3,175	3,115	2,769	2,622
Norway	1,785	1,929	2,284	2,300	2,240	2,258
Slovakia	1,439	1,511	1,579	1,632	1,668	1,751
Lithuania	1,198	1,237	1,297	1,292	1,146	1,142
Slovenia	1,037	1,049	1,045	1,036	992	964
Latvia	596	709	782	756	753	680
Cyprus	553	571	587	608	620	611
Estonia	502	467	531	440	383	349
Luxembourg	234	323	333	341	338	344
Malta	251	253	266	274	266	234
Iceland	:	:	:	164	166	169
Croatia	:	:	:	1,791	:	:
Macedonia	:	:	:	531	:	:
Bosnia and Herzegovina	:	:	:	:	:	:

Figure 7 - Municipal waste - total waste treatment (thousand of tonnes) **[3]**

2.2.2 Waste management

Waste management is perhaps one of the most critical segments of the environment. The management in the wrong way led to undertaking by the population of very unhealthy practices of transport and storage, whose effects will be felt for many generations to come. It is a field that requires close monitoring and investments in intensifying the collection, sorting, recycling and storage, combined with measures to reduce the amount of household and industrial waste.

Waste management subordinates to different waste laws. The waste legislations in EU is composed of the main following directives:

- Battery Directive: Directive 2006/66/EC of the European Parliament and of the Council of 6 September 2006 on batteries and accumulators and waste batteries and accumulators
- Landfill Directive: Council Directive 1999/31/EC of 26 April 1999 on the landfill of waste
- Waste framework directive: Directive 2008/98/EC of the European Parliament and of the Council of 6 September 2006
- Waste incineration directive: Directive 2000/76/EC of the European Parliament and of the Council of 4 December 2000 on the incineration of waste**[4]**

The directives establish legal frameworks for the disposal and treatment of the wastes. It aims at protecting the environment and human health through the prevention of the harmful effects of waste generation and waste management.

The responsibility for waste management activities lies to the generators. However, the local authorities have their role also. The waste management activity is based on some principles, enunciated in the legislations:

- primary resource protection principle: refers to the need to minimize and effective use of primary resources, focusing on the use of secondary raw materials;
- prevention principle: refers to the hierarchy for the waste priority in the prevention and waste management, as: prevention, preparing for reuse, recycling, other recovery and finally disposal in environmental safety conditions.
- substitution principle: refers to the replace of hazardous materials with non-hazardous materials, leading to the minimization of hazardous waste;

- principle of subsidiarity: refers to the establishment of providing the skills, that the decisions in waste management should be taken at the lowest administrative level from the source of generation; ;
- proximity principle: that waste should be treated and disposed of, as close as possible to the source of generation;
- principle of preliminary measures: the main aspects that must be considered for every activity: the current state of technology development, environmental protection requirements, selection and application of those measures that are economically feasible.

The main objectives of waste management that take into account the principles set out above, are:

- prevention and reduction of waste production and reduction of their degree of hazard.
- reuse, waste recovery through recycling, recovery or any other process to obtain secondary raw materials or the use of waste as an energy source.

The waste management and the steps to a clean environmental disposal are shown in the next figure:

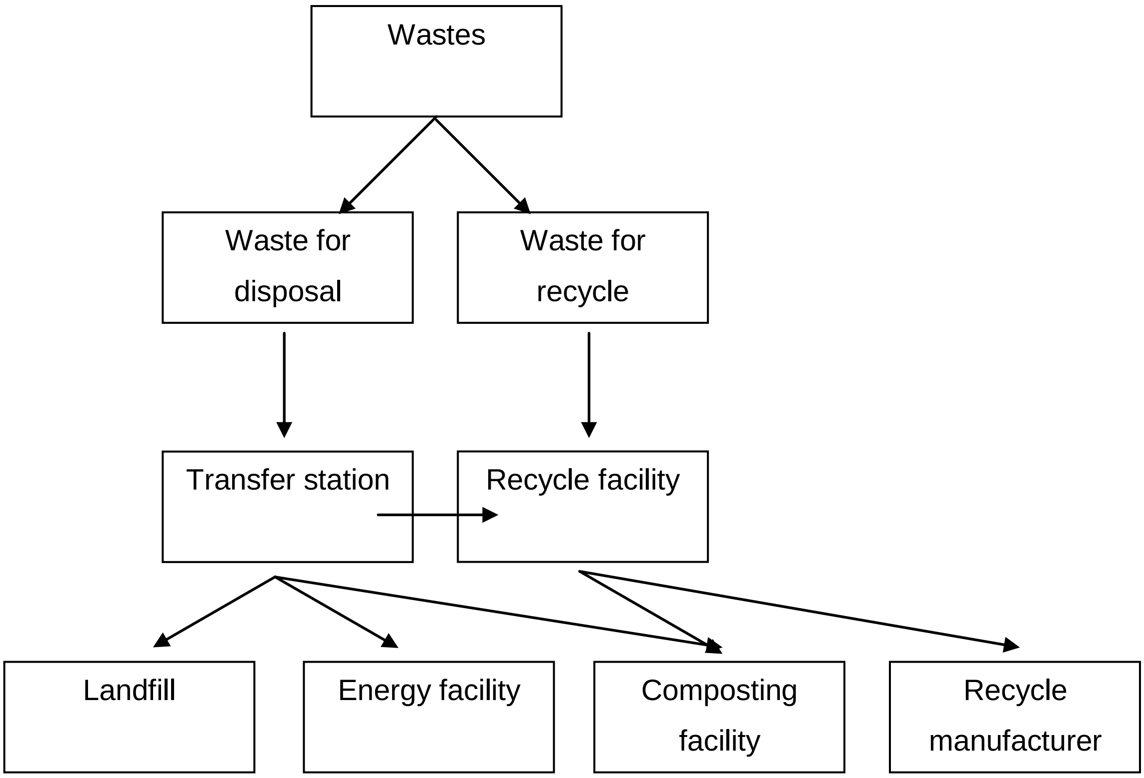

Figure 8 - Waste management diagram

2.2.3 Recycling

Recycling is the recovery and processing of already used materials, to make possible their reuse. Taking into account the limited availability of natural resources, recycling has environmental benefits, reducing the environmental pollution, and economic, saving energy. The waste that mostly can be recovered, are: ferrous metals, non-ferrous and precious metals, chemical wastes and plastics, paper products and glass. For example, by recycling the glass shards, it can get: 20% reduction in energy consumption, 10% fuel reduction and 50% reduction in raw material costs.

The recycling of waste materials involves several steps:

- Selective collection (Figure 9)
- Transportation (Figure 10)
- Storage (Figure 11)
- Intermediate processing: sorting, shredding, compacting (Figure 12)
- Final processing

The benefits of recycling are conserving natural resources, but the collection, transport and the final processing requires additional energy consumption. There are also problems in the recycling process, such as identifying recyclable materials, identify opportunities for recycling and identification of markets for recycled materials. Usually, each type of material that can be recycled has its own manufacturing process. Therefore, the recycling process should start at the collecting point, where the recycled materials are selectively collected. The EU, for example, is implementing selective waste collection projects, through which, paper, plastic, glass and metal are collected separately, each type having its own container (Figure 7). The remaining waste is collected and transported by specialized companies, to the transfer station. The transfer station is also running a selection process for the waste and recycling the remaining waste, including ferrous and non-ferrous metals. After this step, the recycling material is compacted, for an easier transportation to the recycle facility. At the recycle facility, the material it is shredded and finally it reaches its last destination, the recycle manufactures.

Figure 9 - Recycling containers

Figure 10 - Waste transportation vehicle

Figure 11 – Recyclable waste at transfer station

Figure 12 – Recycable waste transfer station

The next table shows the total ammout of material recycled in EU, from 2005 to 2010. Compared with Figure 6 - Municipal waste statistic (thousand of tonnes) (page 11) we can see that in year 2005 - 21% of the waste was recycled and in year 2010 - 24% of the total waste generated was recycled:

GEO/TIME	2005	2006	2007	2008	2009	2010
European Union (27 countries)	51,754	54,108	57,741	61,293	61,342	60,809
European Union (15 countries)	50,054	52,419	55,704	58,829	58,302	57,053
Euro area (16 countries)	41,605	43,069	45,615	48,287	47,984	47,139
Euro area (15 countries)	41,596	43,060	45,587	48,244	47,937	47,074
Germany	20,734	21,195	22,555	22,752	22,204	21,251
France	5,365	5,661	5,964	5,972	6,004	6,143
Spain	3,685	3,646	3,496	3,898	3,811	3,724
United Kingdom	6,362	7,107	7,680	7,775	7,890	8,050
Italy	3,683	3,813	4,063	6,047	6,327	6,340
Netherlands	2,543	2,637	2,760	2,783	2,701	2,729
Switzerland	1,730	1,785	1,850	1,890	1,870	1,880
Belgium	1,537	1,593	1,697	1,760	1,844	1,883
Sweden	1,570	1,680	1,738	1,658	1,587	1,560
Austria	1,100	1,258	1,320	1,470	1,490	1,495
Denmark	974	977	1,137	1,559	1,310	857
Finland	652	677	695	715	615	495
Norway	519	575	642	670	620	609
Ireland	898	1,064	1,081	988	846	910
Greece	543	551	905	797	936	895
Portugal	406	475	528	567	648	630
Romania	145	41	34	72	78	79
Poland	367	487	580	895	1,421	1,783
Slovenia	377	323	357	321	330	375
Hungary	403	432	490	607	576	737
Cyprus	64	72	75	78	80	95
Slovakia	9	10	28	43	47	65
Iceland	:	:	:	23	23	23
Czech Republic	166	201	276	280	353	452
Estonia	121	70	122	78	52	50
Latvia	26	29	38	43	56	60
Luxembourg	1	84	86	89	89	91
Malta	8	10	6	9	11	17
Bulgaria	0	0	0	0	0	0
Lithuania	14	14	29	40	37	43
Turkey	0	0	0	0	0	0
Croatia	:	:	39	35	28	53
Macedonia	:	:	:	0	:	:
Bosnia and Herzegovina	:	:	:	:	:	:

*Figure 13 - Municipal waste - material recycling (thousand of tonnes)***[3]**

2.2.4 Waste to energy

Waste to energy is the process of converting the waste into energy. Energy can be produced in form of electricity, heat or in form of energy carrier: methane, methanol, ethanol or synthetic fuels**[5]**. The processes are varied, such as:

- Incineration
  - Incineration is the most common process from converting waste to energy. The process refers to the combustion of organic materials from the wastes. However, the technology of incineration must met strict regulations regarding the emissions, such as nitrogen oxides, sulphur dioxide, heavy metals and dioxins. This is an old technology, but the modern incinerators reduce the volume of the original waste by 95-96%**[5]**.

Figure 14 - Spittelau incinerator - DH plant

- Gasification
  - Gasification is the process of converting waste into carbon monoxide, hydrogen and carbon dioxide. Gasification is a different technology to Incineration. The process takes place at higher temperature (over 700 ^{o}C), without combustion, in the controlled presence of Oxigen or steam. From the process is produced a synthetic gas, which can be converted into electricity or heat, through a gas engine, or converted through the Fisher-Tropsch process into synthetic fuel**[6]**. This

process has some advantages compared to Incineration, such as a higher efficiency, tolerance to the moisture content (upt to 65%) and less emissions**[7]**.

Figure 15 - Gasification Plant in Gussing

- Pyrolysis
  - Pyrolysis is the process of converting waste into energy, through a thermic decomposition of the organic material. The process takes place without the presence of oxygen and at a low temperature. The disadvantage of waste pyrolysis is that the fuel has to be as homogenous as possible. The advantage is the more environmental friendly technology, compared to the incineration. Through the process, energy in form of electricity or heat can be “generated”, or products, such as oils, recyclable materials or char can be produced.

Figure 16 - Pyrolysis plant

- Thermal depolymerization
  - Thermal depolymerization is the process of producing crude oil from organic materials. Under pressure and heat, long chain polymers of hydrogen, oxygen, and carbon decompose into short-chain petroleum hydrocarbons. One of the advantage of this technology is that it does not require a drying of the material before it enters the process**[8].**

Feedstock	**Oils**	**Gases**	**Solids (mostly carbon based)**	**Water (Steam)**
Medical waste	65%	10%	5%	20%
Paper (cellulose)	8%	48%	24%	20%
Plastic bottles	70%	16%	6%	8%
Sewage sludge	26%	9%	8%	57%
Tires	44%	10%	42%	4%
Turkey offal	39%	6%	5%	50%

*Table 2 - Feedstocks and outputs of TDP***[8]**

- Mechanical biological treatment
  - Mechanical biological treatment is the process that mechanically separates some parts of the waste and biologically treating the other**[9]**, by producing energy anaerobic digestion or composting. MTB technology processes mixed household wastes as well as commercial or industrial wastes. The process is composed of two steps:
    - Mechanical sorting, where the recyclable or materials that are not processable in anaerobic digestion are removed and sent either to recycle facility or to the landfill.
    - Biological processing, where energy is converted from the mixed waste through anaerobic digestion and composting.

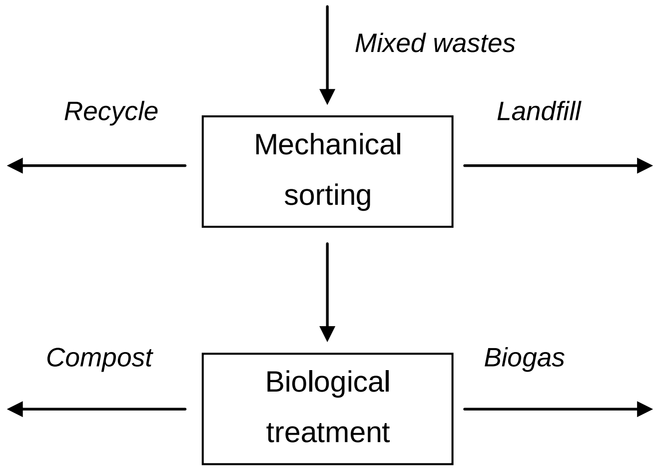

Figure 17 - MBT flow diagram

The biological treatment, in this case, the anaerobic digestion will be explained into more details in the next chapter.

In the next figures, the total ammount of waste used for energy recover is presented. Figure 18 shows the total ammout of waste, in thousand of tonnes, used for energy recover, without AD and Figure 19 shows the total ammout of waste, in thousand of tonnes, used for energy recover, through AD and composting.

GEO/TIME	2005	2006	2007	2008	2009	2010
European Union (27 countries)	33,114	36,514	38,578	41,006	41,998	42,007
European Union (15 countries)	32,421	35,728	37,686	40,070	41,087	40,925
Euro area (16 countries)	25,161	28,188	30,183	32,320	33,282	33,212
Euro area (15 countries)	25,159	28,188	30,067	32,163	33,163	33,041
France	11,372	10,731	10,657	11,619	11,408	11,200
Netherlands	3,300	3,253	3,267	3,269	3,240	3,229
United Kingdom	2,935	3,295	3,239	3,441	3,740	3,744
Switzerland	2,430	2,650	2,680	2,830	2,660	2,760
Italy	3,776	3,904	3,923	4,106	4,587	4,590
Denmark	2,146	2,138	2,203	2,186	2,025	2,025
Sweden	2,182	2,108	2,178	2,293	2,173	2,124
Spain	1,915	2,025	2,202	2,170	2,241	2,236
Belgium	1,675	1,707	1,734	1,820	1,748	1,743
Portugal	1,057	978	948	993	1,083	1,058
Norway	656	675	866	873	941	1,154
Austria	1,341	1,430	1,452	1,356	1,455	1,465
Czech Republic	380	391	389	367	370	495
Hungary	303	389	382	393	406	406
Finland	176	168	236	347	349	441
Germany	430	3,871	5,525	6,265	6,808	6,840
Luxembourg	117	120	123	124	121	122
Slovakia	2	0	116	157	119	171
Latvia	7	5	3	3	1	0
Iceland	11	11	15	17	18	19
Slovenia	1	1	0	13	14	9
Bulgaria	0	0	0	0	0	0
Estonia	0	1	2	1	1	0
Ireland	0	0	0	82	111	108
Greece	0	0	0	0	0	0
Cyprus	0	0	0	0	0	0
Lithuania	0	0	0	0	0	1
Malta	0	0	0	0	0	0
Poland	0	0	0	0	0	0
Romania	0	0	0	0	0	0
Turkey	0	0	0	0	0	0
Croatia	:	1	:	5	:	:
Macedonia	:	:	:	0	:	:
Bosnia and Herzegovina	:	:	:	:	:	:

*Figure 18 - Municipal waste energy recovery (thousand of tonnes)**[3]***

GEO/TIME	2005	2006	2007	2008	2009	2010
European Union (27 countries)	38,176	40,441	41,869	36,161	35,968	35,936
European Union (15 countries)	37,727	39,873	41,277	35,491	34,976	34,710
Euro area (16 countries)	33,626	35,099	36,031	29,962	29,160	29,006
Euro area (15 countries)	33,605	35,047	35,955	29,882	29,071	28,916
Germany	7,633	7,631	7,709	8,082	8,388	8,234
Italy	10,564	11,432	12,171	3,607	3,948	4,010
France	4,532	4,728	5,091	5,581	5,748	5,917
Spain	4,370	4,523	4,498	6,158	4,516	4,433
Netherlands	2,424	2,317	2,401	2,333	2,388	2,300
Austria	2,250	2,502	2,016	2,012	1,963	1,965
United Kingdom	3,007	3,626	4,016	4,402	4,566	4,550
Belgium	1,165	1,183	1,237	1,202	1,179	1,041
Switzerland	770	885	930	930	930	930
Denmark	660	703	757	627	741	720
Turkey	339	255	334	276	315	194
Sweden	485	535	561	597	618	587
Norway	255	289	344	343	356	358
Poland	318	358	363	386	672	790
Finland	190	197	258	234	305	332
Portugal	313	302	321	382	424	395
Hungary	41	58	64	85	90	148
Luxembourg	56	58	64	68	67	70
Slovakia	21	52	76	80	89	91
Ireland	48	55	79	107	88	107
Greece	29	81	98	100	37	50
Malta	31	38	12	0	0	15
Slovenia	0	0	0	17	20	22
Czech Republic	16	23	30	50	56	76
Estonia	11	23	17	28	43	33
Iceland	:	:	:	4	4	4
Bulgaria	0	0	0	0	0	0
Cyprus	0	0	0	0	0	26
Latvia	1	5	5	5	2	4
Lithuania	10	11	22	15	16	19
Romania	0	0	2	3	4	4
Croatia	:	:	15	15	12	13
Macedonia	:	:	:	0	:	:
Bosnia and Herzegovina	:	:	:	:	:	:

*Figure 19 - Municipal wastes - composting and digestion (thousand of tonnes)***[3]**

2.3 Anaerobic digestion

2.3.1 Introduction

Anaerobic digestion is a more complex process, here being presented only the basic principles. A very important factor, perhaps the most important is related to the available feedstock. Depending on this, it can be designed a biogas plant. Available substrates can be sewage sludge, agricultural wastes, municipal solid wastes or industrial wastes. If we talk about sewage sludge, we can say that at a fist see, there are only advantages, given the high costs of treating the excess sludge from waste-water treatment plants, problems appear when we realize that many treatment plants are made for small communities, thus, they are producing a very small amount of sewage sludge, which is not constant, if we talk about the amount. If we talk about agriculture waste, actually just thinking about the word waste, we realize that materials the usually remain after the harvesting, or animal manure can be a source of energy. Another issue is the use of materials from agriculture, for energy production, but this could be a thing for discussions, because food is used for energy purposes, not for feeding the population. Talking about agricultural waste, we can also mention the energy crops, which can be a very good solution for energy production, even if we talk about AD, combustion, gasification etc., but unfortunately these projects will give also discussions, given that the land is used for energy and not for food. If we talk about municipal or industrial wastes, we can imagine so good ideas, only when thinking at wastes converted into energy, but such projects require a long-term designing and higher investment costs.

Eventually, a biogas project, and not only, involves also the local communities where such projects are implemented, and not only the investors and the people who are involved in the project. But population needs energy, food, and a clean environment, so the things should be balanced somewhere.

The basic principle is simple, as shown in the following figure:

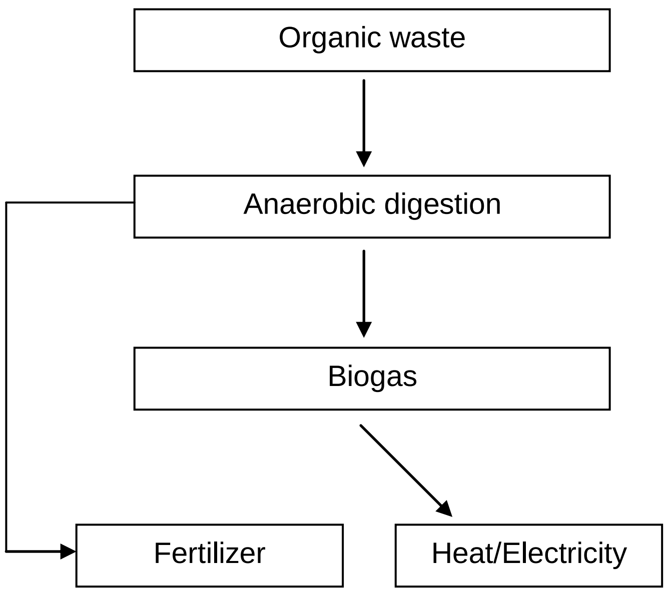

Figure 20 - AD basic principle

Anaerobic digestion is a more complex biological process, through which, the organic matter is converted into biogas, consisting mainly of methane and carbon dioxide. The process takes place in the absence of Oxygen. The percentage of methane in the biogas varies, from 50% to 80%, depending on the type of organic matter digested. Approximately 90% of the energy from the degraded biomass is retained in the form of methane, so very little excess sludge is produced**[10]**. The biogas is formed in the presence and the activity of different bacteria. The groups of bacteria that participate at the process are:

- Hydrolytic bacteria
- Acidogenic bacteria
- Acetogenic bacteria
- Methanogenic bacteria

The four stage process is illustrated in the next Figure:

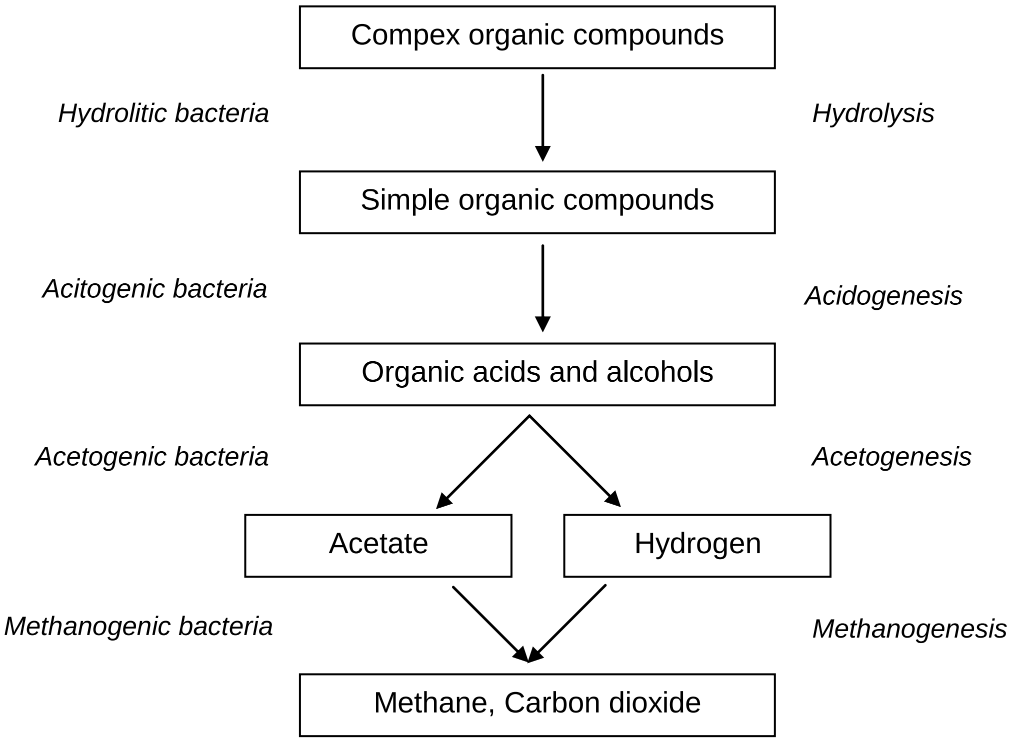

Figure 21 - Anaerobic Degradation of Organic Substances ***[11]***

- Hydrolysis is the process where complex molecules are broken down to constituent monomers
- Acidogenesis is the process where acids are formed
- Acedogenesis is the process where acetate and hydrogen is formed

- Methanogenesis is the process where methane is produced from acetate or hydrogen.

The process of methane formation takes place under optimal conditions. There are a lot of conditions to be met, all are very important for the process and only a few can be modified in their minimum or maximum limits. For example:

- Temperature: temperature can vary, in practice we have three different categories:
  - Psychrophilic temperatyure: from 10 ^oC to 25 ^oC
  - Mesophilic temperature: from 25 ^oC to 42 ^oC
  - Termophilic temperature: from 49 ^oC to 60 ^oC**[12]**

  The most common processes uses Mesophilic or Termophilic temperature range. The temperature range used can also affect the gas yield, depending also on the feedstock used and the retention time.
- Retention time: The hydraulic retention time describes the average time that the substrate remains in the digester. The retention time depends mostly from the feedstock, on the degradation rate of the material. Lower degradation rate means higher retention time.
- Organic loading rate: the organic loading rate means the total amount of organic material that is feed-ed into the digester.

Digestion can be made in so called wet systems or dry systems. Wet systems operate between 6% and 12% total solids and dry systems above 30% total solids. In both, we have continuous or discontinuous feeding. The advantages of wet and dry systems are explained in the next table:

System type		**Advantages**	**Disadvantages**
Wet system	Single stage	* Well know process * Low cost * Standardized * Degradation is limited	* Short-circuiting * Sink and floating layers * Abrasion with sand * High consumption of water or expensive recycling * Equipment to handle slurries is cheaper * Higher energy consumption for heating larger volume
	Multi stage	* Can be adapted to the optimal condition (temp. pH) * Fast operating * High content of CH4 * Faster process * Easier separation of undesirable materials after partial degradation * Cheaper than CSTR or solid waste digester	* The buffer capacity is high and does not allow adjustment of pH * The hydrolysis stage produces a poor gas * The separation of the degradation chain might lead to instabilities * Expensive polishing of the liquid phase before recycling * High energy consumption for the post-treatment of the hydrolysed solid material
Dry system		* Does not require huge amounts of water to dilute the feedstock * The substrates do not require to be pumped through pipes * The substrates can be easily sorted for unwanted materials	* High price * Limited in size

Table 3 - Comparisson of wet and dry systems [14]

The most wide spread type of system is continuous-flow. A continuous flow system can be explained as tanks, where an amount of raw feedstock is feed-ed into the digester, taking out an already digested material, equal in quantity with one that was introduced. The part that is taken out was subjected of anaerobic treatment, for the retention time that was established.

The biogas produced during anaerobic digestion is mainly composed of methane (CH_4) and carbon dioxide (CO_2) with small amounts of hydrogen sulfide (H_2S) and ammonia (NH_3). You can find small ammouts of hydrogen (H_2), nitrogen (N_2), carbon monoxide (CO), saturated or halogenated carbohydrates and oxygen (O_2). The composition of the biogas is different from that of natural gas, and depends on the type of substrate used in the anaerobic digestion process and the of the technology.

2.3.2 AD of sewage sludge

The digestion of sewage sludge follow the principles explained above, but uses as substrates, the excess sludge from the waste-water treatment plants. As presented in Chapter 2.1, in a waste-water treatment process, we have as products, the treated water and excess sewage sludge, which as usually is dehydrated or used for biogas production. Anaerobic digestion of sludge from wastewater treatment takes place in a wet system, with very low solids content.

The principle and the process of sewage sludge digestion is shown in the next figure:

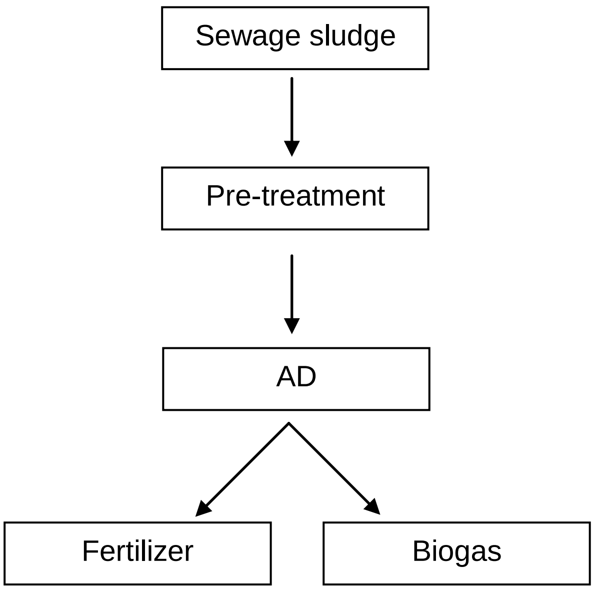

Figure 22 - Sewage sludge digestion flow diagram

A precise energy flow is difficult to determine, but for example in a pilot-scale digester for sludge reduction and biogas production, was achived 40% reduction of the sludge and a biogas production of 0.5 Nm^3 of biogas/kg of sludge.**[16]** From this, we can realize the following diagram:

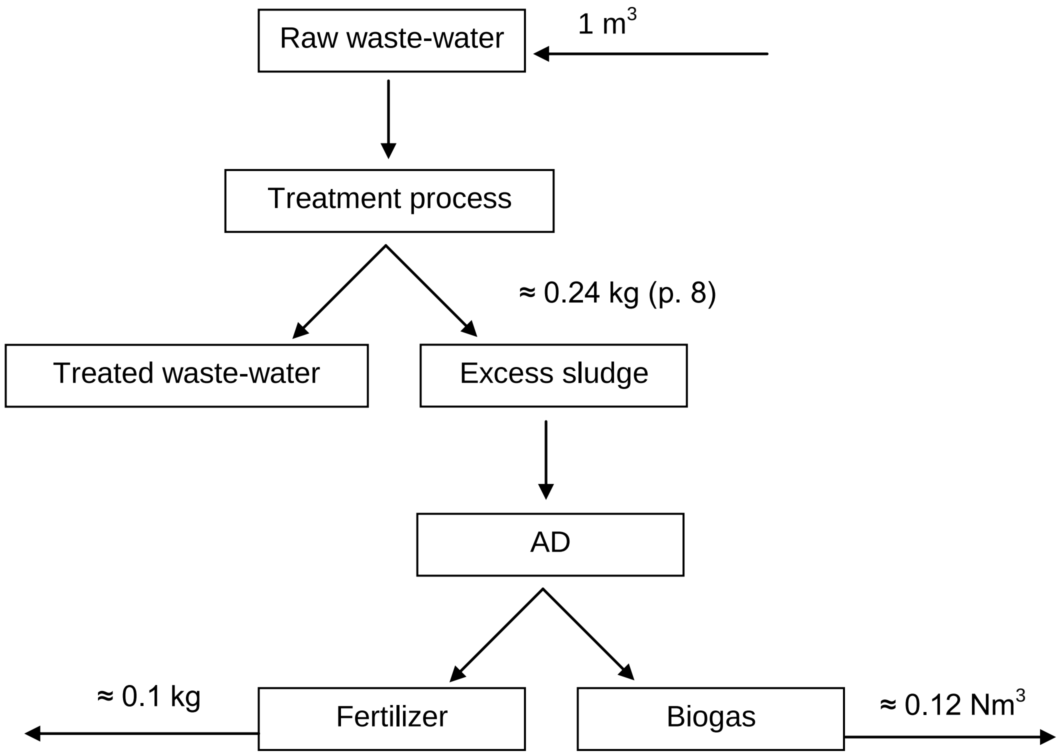

Figure 23 - Mass flow of sewage sludge digestion

The cotal content of methane in the biogas comming from the anaerobic digestion of sewage sludge canvarry between 45% and 55%.**[17]**

2.3.3 AD of municipal and industrial wastes

The principle of anaerobic digestion of organic waste is the same as presented above, just the substrate is different. Anaerobic digestion of municipal and industrial wastes can be achieved in a wet system or in a dry system, depending on the substrates. Here, mechanical pre-treatment is required, for removal of plastics, metal, textile and sand.

The principle and the process of municipal and industrial waste digestion is shown in the next figure:

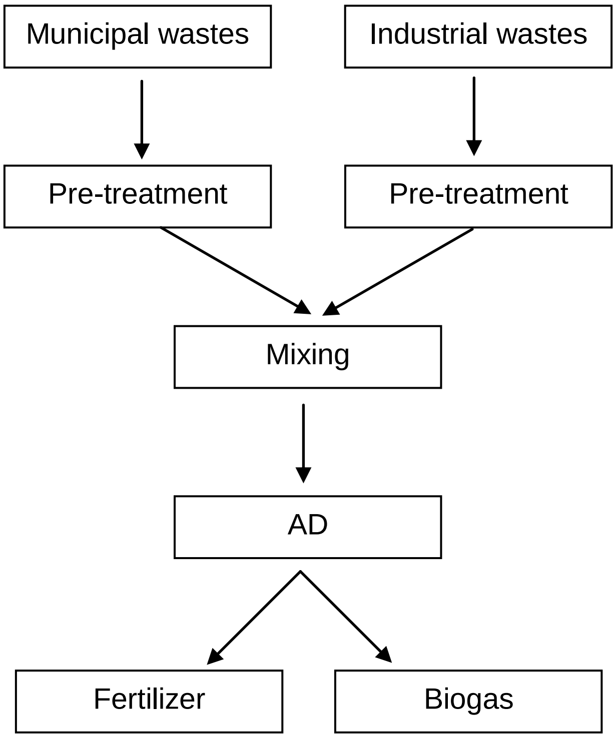

Figure 24 - Municipal and industrial wastes digestion flow diagram

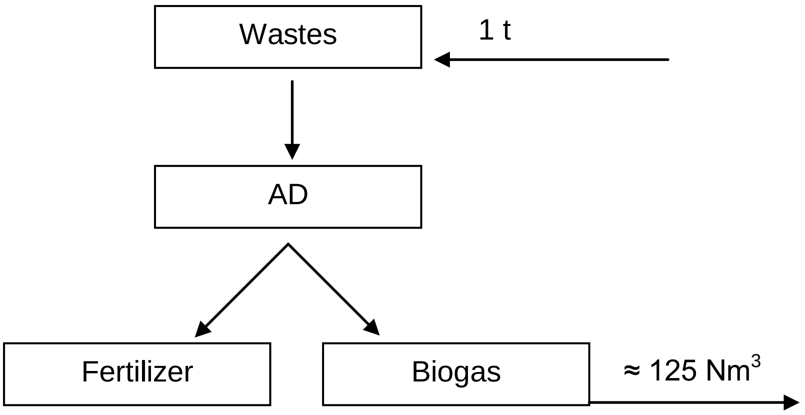

Figure 25 - Mass flow of municipal wastes digestion [19]

The cotal content of methane in the biogas comming from the anaerobic digestion of sewage sludge canvarry between 55% and 70%.**[19]**

2.3.4 Co-digestion of sewage sludge and organic wastes

Co-digestion means the mixing of two ore more types of substrates, for AD purposes. Without returning to the anaerobic digestion process, we can specify that there are three types of digesters used for the co-digestion:

- Single stage reactor with small solids content
    - The advantages of this system are the easy operation and accessible equipment. It can be used for sewage sludge and/or animal wastes. The disadvantage of these systems is the high cost of investment for the construction of large reactors and the required pre-treatment of the biogas.
- Single stage reactor with high solids content
    - The advantages of such systems, with high solids content are primarily the result of large quantities of biogas when used undiluted waste. In dry systems, the materials that is digested has a solids content between 20% and 40%. But because of the large amounts of solid matter, there are problems for the transportation. The digester is feed-ed using conveyor bands, screw elevators and special pumps.
- Multiple stage reactor
    - The advantage of this process is that there are separate reactors for different stages, which creates flexibility in optimizing each reactor. In general, using two reactors, the first reactor for hydrolysis/ liquefaction - Acetogenesis and second rector is used for methanogenesis. In the first reactor, the reaction is limited by the rate of hydrolysis of the cellulose and the reaction in the second reactor is limited by the microbial growth.[15]

The principle and the process of co-digestion is shown in the next figure:

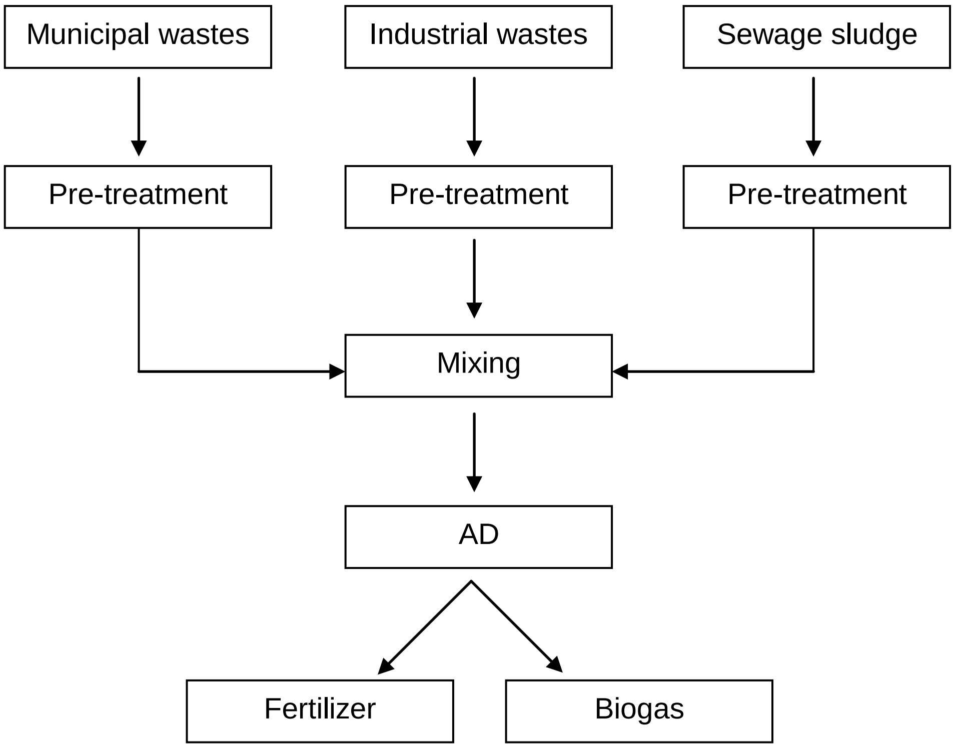

Figure 26 - Co-digestion flow diagram

The digesters are feed-ed and usually the materials and the material is degraded to 30-40% solid mass. Mechanical pre-treatment is required, for removal of plastics, metal, textile and sand.

Co-digestion is a very complex process, taking into account the calculation for mixing the quantities of substrates. Also other parameters should be taken into account such as operating temperature, retention time, or homogenization, which can influence the biogas yield. It has been shown that high performance in biogas production is achieved when the ratio is 80% is municipal-industrial waste and 20% sewage sludge.**[18]**

Taking as a reference plant, the Baden Baden WWTP, where the co-digestion of sewage sludge and organic waste, increased the biogas yield with aprox. 100 kWh/ton of organic waste[20], equivalent to 360 MW. Calculating with an average energy content of the biogas of 15-20 MJ/Nm^3, gives us an increase with almost 20-25 Nm^3 of biogas per ton of organic waste. From this, we can realize the following diagram:

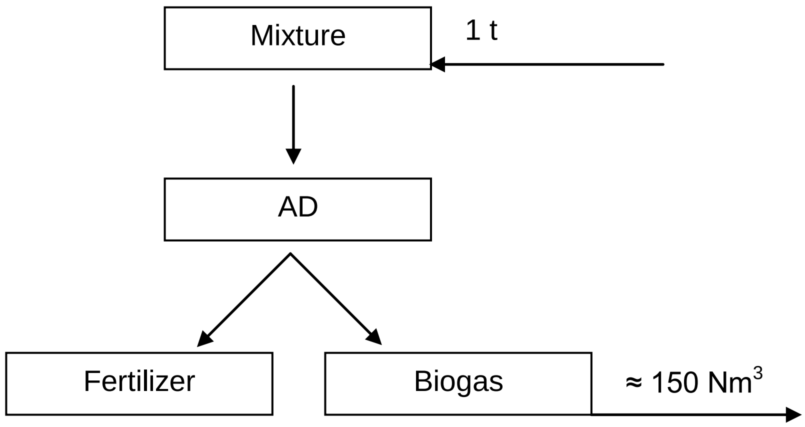

Figure 27 - Mass flow of co-digestion

3 Case study – Chisineu Cris

3.1 Waste-water and waste disposal in Romania

Romania is an Eastern European country, with a total area of 238.391 km2, a total population of 21.5 million. From the administrative point of view, Romania is an European Union country, from 2007. It is divided into 42 Counties, 320 cities and 15817 villages. From the hydrographic point of view, it is crossed by the river Danube (1075 km), and the most important rivers are Mures (761 km), Prut (742 km), Olt (615 km), Siret (559 km) and it has a total of 128.932 ha of surface water. The average yearly temperature is 12^0C. The population is divided, 54% living in the urban area and 46% in the rural area. From those in the rural area, 86.3% of the cities has under 50.000 inhabitants, representing 18.4% of the total population of the country. The villages with 1000-5000 inhabitants, represents 81.2% of the total rural area.

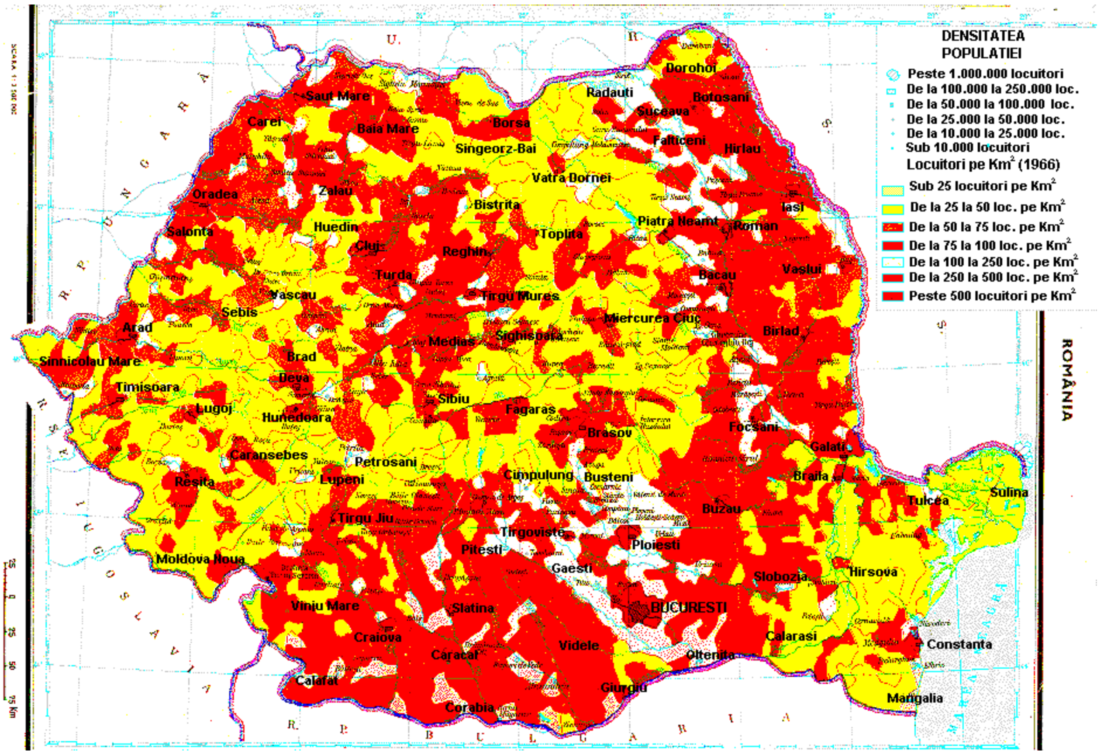

Figure 28 - Population density in Romania

The primary energy demand is decreasing, 1,601.8 kg of oil equivalent per capita, 76% is fossil fuel energy consumption, CO_2 emissions counts 4.4 metric tones per capita. Regarding the water resources, 76% of the rural area has access to a water resource and 99% of the urban area has access to a water resource. Regarding the waste-water, only 56.9% of the population has access to a sewage system and only 45.7% of the population is connected to waste-water treatment plants.

As case study, we will discuss the city of Chisineu Cris in Arad County. Arad County is located in the Western part of Romania, with a total population of 461791 inhabitants, 10 cities and 338 villages. From this, all the cities and a number of 18 villages has access to sewage systems and waste-water treatment plants. The total length of the sewage systems is 660 km. Regarding the water supply, there is a better position, all the cities and a number of 58 villages has access to a water-distribution system. The total length of the water distribution in the County is 2152 km. The volume of water supplied to the consumers, was in year 2011 16.780.000 m^3. The gas supply is available for 8 cities and 12 villages, 1064 km of pipes and 80.362.000 m^3 of gas supplied in year 2011.

Figure 29 - Arad County

The city Chisineu Cris, is a small city in Arad County, with a total population of 7.000 inhabitants. It is surrounded by 4 villages: Nadab, Sintea Mare, Adea, Tipari, with a total population of 7.000 inhabitants. Chisineu Cris and its area count 14.000 inhabitants. The city of Chisineu Cris is highly industrialized, all the population from the villages surrounding the city, working in factories like:

- Continental – Thermopol: manufacturing silicone rubber hoses (2000 employees)
- Sapa: Aluminum products (500 employees)
- EKR – Elektrokontakt: Auto wiring (1500 employees)
- Guala Pack: manufacturing flexible packaging (2000 employees)
- Maschio Gaspardon: manufacturing agricultural equipment (1500 employees)

The rest of the population works in smaller businesses or agriculture. The current situation of the waste-water is with 90% of the city connected to the sewage system, the village Nadab (1500 inhabitants) 90% connected to the sewage system and one waste-water treatment plant, very old, that does not operate at the required parameters, Because of this, the administration of the city accessed European Union funds for construction of new waste-water treatment plant and to connect all the villages around it. The new waste-water treatment plant will be designed for 15.000 PE, taking into account also the possible population growth.

3.2 Waste-water treatment plant and waste disposal in Chisineu Cris Area

The city of Chisineu Cris has in this moment an old waste-water treatment plant. As told before, the waste-water treatment plant will be designed for 15.000 PE. The technology that was chosen is an SBR WWTP. This system is similar to the classic treatment of the waste-water, system that was described before. The difference is in the secondary treatment step, where the primary sedimentation, biological treatment (aeration) and secondary sedimentation takes place in only one tank. This is the advantage of the SBR technology.

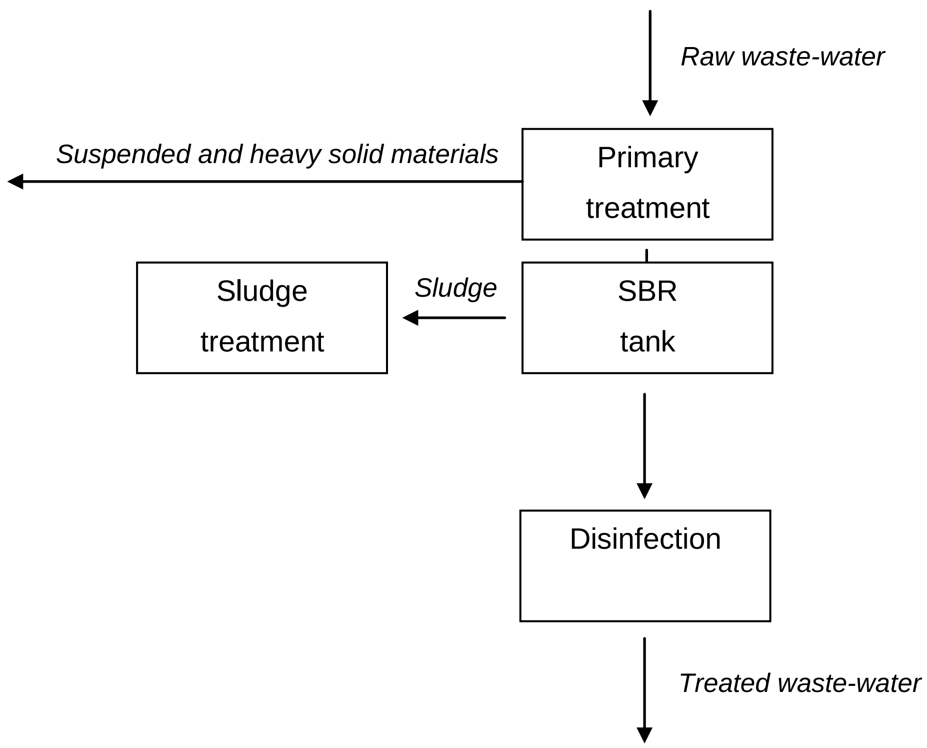

Figure 30 - SBR Flow diagram

First, the SBR tank is filled with the waste-water, the new waste-water is mixed together with the containing activated sludge. Aeration begins after the filling, next there is a settling time, after a determined period of time, the sludge decants and the treated waste-water is discharged into the emissary, and if there is a need, it is disinfected with different technologies (chloride, UV filters etc.). A part of the sludge that is formed in the SBR tank is taken to the sludge treatment process and a part of it needs to remain in the tank, as an activated sludge, to mix together with the new filling waste-water and begin the cycle again. The advantage of such a system is the lower investment costs, and lower operating costs. The SBR technology is more suitable for small waste-water treatment plants, and a very high economical solution is the SBR WWTP built out of containers. Concrete tanks are also a good solution.

Regarding the sludge treatment, a solution is to dehydrate the sludge and after this transfer it to the landfill, or to recover the energy from it. The first solution it consumes a lot of energy, but it has a lower investment cost, and the second solution it consumes energy but it produces also, but it has a higher investment cos. The dehydration of the sludge can be made through very high energy consuming centrifugal dehydration systems and/or with chemical addition to it. The economical calculations will be discussed later in this project.

Regarding the landfill and the waste-disposal system in the city of Chisineu Cris, it cannot be said to much. The landfill no longer meets the EU legislations and the waste collection is leased to a private company, because of the excessive costs for the municipality to cover. The municipality however owns the landfill and will try to receive money for the modernization of it. At this point there is no selective waste collection, but the municipality takes this into account for the future project. The new landfill and waste-disposal project will be as it was described in Figure 6. The complete waste management system will not cover only the city of Chisineu Cris, but will cover also the neighboring villages, counting 30.000 inhabitants.

Next, taking into account that in the city of Chisineu Cris has the need to start new projects for waste-water and waste management, we will make a comparison between two scenarios: a classical WWTP with a classical waste management, without energy recovery systems, and a modern WWTP with a modern and innovative waste management, with energy recovery systems:

- Scenario 1: first scenario is based on:
    - construction of a new wastewater treatment plant, based on the SBR technology, using the classic sludge dewatering.
    - Keeping the lease contract with a private company for the waste collection and transportation
    - Improving the system based on the EU regulation, regarding the selective waste collection
    - Construction of a new landfill, with transfer station and recycle facility owned and administrated by the municipality.

- Scenario 2: second scenario is based on:
    - construction of a new wastewater treatment plant, based on the SBR technology, using the digestion of the excess sludge with biogas production.
    - Keeping the lease contract with a private company for the waste collection and transportation
    - Improving the system based on the EU regulation, regarding the selective waste collection
    - Construction of a new landfill, with transfer station and recycle facility, owned and administrated by the municipality.
    - Construction of AD plant for co-digestion of sewadge sludge and municipal and industrial wastes.

Taking into account the parameters for designing a new waste-water treatment plant, and the parameters for total organic waste collected in the area, and based on the results from Figure 27, we can calculate the total amount of biogas that can be produced, and thus to size the plant:

Parameter	**Quantity**
Waste-water daily amounts	
Capacity	15.000 PE
Maximum daily flow/PE	0.31 m^3/day
Maximum daily flow of waste-water	4650 m^3/day
Specific loads of the waste-water	
Specific BOD_5 load	60 g/PE*d
Specific CCO load	150 g/PE *d
Specific MS load	70 g/PE *d
Specific NH_4-N load	60 g/PE *d
Specific total Nitrogen load	7 g/PE *d
Specific P_{tot} load	2 g/PE *d
Specific daily loads	
Daily BOD_5	840 kg/day
Daily CCO	1100 kg/day
Daily MS	980 kg/day
Daily NH_4-N	98 kg/day
Daily total Nitrogen	154 kg/day
Daily MS	1680 kg/day
Daily P_{tot}	24 kg/day
Waste-water concentrations entering the waste-water treatment plant	
BOD_5 concentration	250 mg/l
CCO concentration	625 mg/l
MS concentration	291.67 mg/l
NH_4-N concentration	29.17 mg/l
total Nitrogen concentration	46.04 mg/l
MS concentration	8.33 mg/l
P_{tot} concentration	

Table 4 - Waste-water treatment plant, design parameters

Note: The parameters are taken from the fesability study regarding the new waste-water treatment plant construction in city Chisineu Cris, fesability study developed by the company Aqua Vest from Arad, Romania in year 2011.

The total generated wastes in Romania was shown in Figure 6. From this, according to the Romanian National Institute of Statistics, 48% are organic wastes. According to the same institute, the average waste generated by a person in

Romania was 400 kg/yr, resulting in aprox. 190 kg of organic wastes per person per year. From this, we can calculate for the area in Chisineu Cris, that can be generated for a population of 15.000, a total of 7.8 t of organic wastes/day.

For the mass of the waste-water, we can estimate 4650 m3/day of waste-water entering the plant, resulting, based on Figure 23, in 1.1 t sewage sludge/day.

Substrate	**Quantity/day**
Sewage sludge	1.1 t
Organic wastes	7.8 t
Total	8.9 t

Table 5 - Substrate quantity / day

- ⇨ Ratio 15:75 (sewage sludge – organic wastes)
- ⇨ Based on Figure 27
    - o 1 t of mixed substrates = 150 Nm3 of biogas
    - o 8.9 t of mixed substrates = 1335 Nm3 of biogas
- ⇨ For a retention time of 20 days, taking into account 8.9 t of substrates per day, results in 178 m^3 of substrates in the digestor, resulting a optimal size of the digestor of 200 m^3.
- ⇨ Feedstock is mechanically pre-treatead and feed-ed daily into the digester, taking out the exactly same ammout of already digested material.
- ⇨ To calculate the size of the biogas plant, we have to take into account:
    - o Maximum biogas production / day = 1335 Nm3
    - o Average electrical efficiency: 30 %
    - o Average CHP availability: 85%
    - o Average hours of availability / day = 20
    - o Average energy content of biogas: 20 MJ /Nm3 of biogas

    - o => 1335 Nm3/day * 20 MJ/Nm3 of biogas = 26700 MJ = 7.4 MWh/day (100% efficiency)
    - o => Taking into account the CHP availability of 85%, we can size the biogas plant at an average of 400 KW installed capcaity

3.3 Economical calculations

Economical calculations are made based on the following references:

- Co-digestion plant Baden-Baden Germany
- Rudolf Braun, Peter Weiland, Arthur Wellinger: Biogas from Energy Crop Digestion, IEA Bioenergy
- Rudolf Braun, Peter Weiland, Arthur Wellinger: Potential of Co-digestion

3.3.1 Scenario 1

Waste-water treatment plant calculation inputs		
PE	15,000	
Total daily flow (maximum)	4,650	m3/day
Total yearly flow (maximum)	1,697,250	m3/yr
Waste-water treatment price	0.5	Eur/m3
Discount rate	4%	
Capital recovery factor	0.0899411	

Table 6 - Scenario 1 - input calculations

Note:

- *PE, Total daily flow: Table 4*
- *Total yearly flow: 365 * Total daily flow*
- *Waste-water treatment price: Average price for treating the waste-water in Arad County, 2012*

Waste-water treatment plant investment costs		
Total investment cost	2,250,000.00	Euro
Investment cost / PE	150.00	Euro
Total investmet costs /m3	483.87	Euro/m3

Table 7 - Scenario 1 - investment costs

Note:

- *Total investment cost: Estimated cost from similar project: Design and construction of new waste-water treatment plant in Siria, Arad County, Romania, 2011*
- *Investment cost/PE: Total investment cost/PE (Table 6)*
- *Total investment costs/m3: Total investmet cost/Total daily flow (Table 6)*

Waste-water treatment plant operating costs			
Labour	32%	0.032	Euro /m3
Electricity	16%	0.016	Euro /m3
Chemicals	4%	0.004	Euro /m3
Maintenance	18%	0.018	Euro /m3
Other costs	14%	0.014	Euro /m3
Sludge treatment	16%	0.016	Euro /m3
Total operating costs		0.100	Euro /m3
Total yearly operating costs		169,725.00	Euro/yr

Table 8 - Scenario 1 - operating costs

Note: Estimated costs from: Wastewater treatment plant operating costs in Korea: public vs. private - Vol 13, Issue 11, November 2012, http://www.globalwaterintel.com/archive/13/11/analysis/chart-month-wastewater-treatment-plant-operating-costs-korea-public-vs-private.html, viewed 23.11.2012

Waste-water treatment plant income calculation		
Daily Waste-water treatment	2,325.00	Euro
Yearly waste-water treatment	848,625.00	Euro

Table 9 - Scenario 1 - income

*Note: Daily waste-water treatment: Total daily flow (Table 6) * Wastewater treatment price (Table 6)*

Year	DiscountedCF	NominalCF	Investment	O&MCosts	Income	Cash flow
0	€ (2,250,000.00)	€ (2,250,000.00)	€ 2,250,000.00			€ (2,250,000.00)
1	€ 652,788.46	€ 678,900.00	€ -	€ 169,725.00	€ 848,625.00	€ (1,597,211.54)
2	€ 627,681.21	€ 678,900.00	€ -	€ 169,725.00	€ 848,625.00	€ (969,530.33)
3	€ 603,539.63	€ 678,900.00	€ -	€ 169,725.00	€ 848,625.00	€ (365,990.70)
4	€ 580,326.57	€ 678,900.00	€ -	€ 169,725.00	€ 848,625.00	€ 214,335.87
5	€ 558,006.31	€ 678,900.00	€ -	€ 169,725.00	€ 848,625.00	€ 772,342.18
6	€ 536,544.53	€ 678,900.00	€ -	€ 169,725.00	€ 848,625.00	€ 1,308,886.71
7	€ 515,908.20	€ 678,900.00	€ -	€ 169,725.00	€ 848,625.00	€ 1,824,794.92
8	€ 496,065.58	€ 678,900.00	€ -	€ 169,725.00	€ 848,625.00	€ 2,320,860.50
9	€ 476,986.13	€ 678,900.00	€ -	€ 169,725.00	€ 848,625.00	€ 2,797,846.63
10	€ 458,640.51	€ 678,900.00	€ -	€ 169,725.00	€ 848,625.00	€ 3,256,487.14
11	€ 441,000.49	€ 678,900.00	€ -	€ 169,725.00	€ 848,625.00	€ 3,697,487.64
12	€ 424,038.94	€ 678,900.00	€ -	€ 169,725.00	€ 848,625.00	€ 4,121,526.58
13	€ 407,729.75	€ 678,900.00	€ -	€ 169,725.00	€ 848,625.00	€ 4,529,256.32
14	€ 392,047.83	€ 678,900.00	€ -	€ 169,725.00	€ 848,625.00	€ 4,921,304.16
15	€ 376,969.07	€ 678,900.00	€ -	€ 169,725.00	€ 848,625.00	€ 5,298,273.23
NPV	€ 5,298,273.23					
ANN	€ 476,532.52					
IRR	25%					

Table 10 - Scenario 1 - NPV calculation

Note:

- *Nominal CF = Income – O&M costs*
- *Discounted CF = Nominal CF/(1+Discount rate)^Year*
- *NPV = Sum of Discounted CF*
- *ANN = NPV * Capital recovery factor*

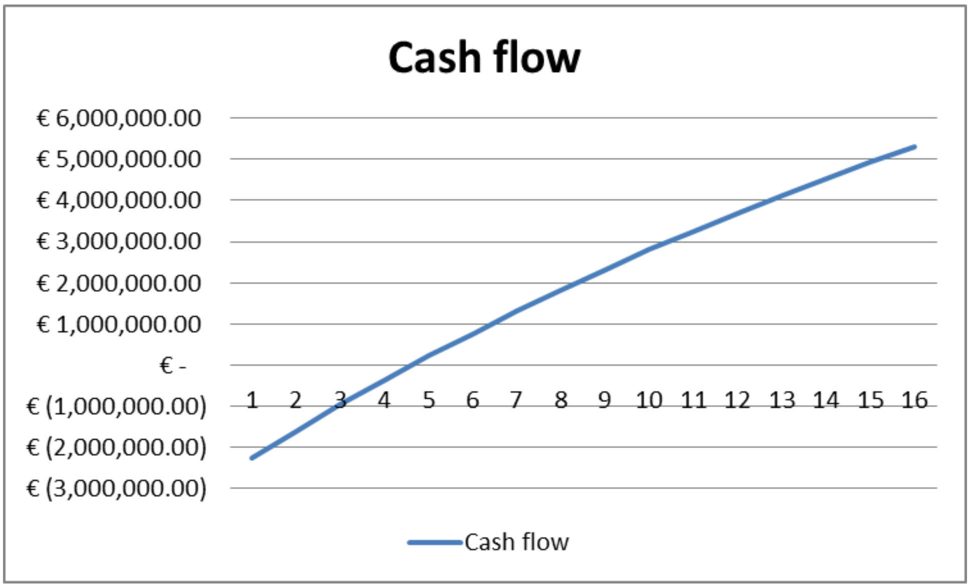

Figure 31 - Scenarion 1 - cash flow

3.3.2 Scenario 2

Waste-water treatment plant calculation inputs		
PE	15,000	
Total daily flow (maximum)	4,650	m3/day
Total yearly flow (maximum)	1,697,250	m3/yr
Waste-water treatment price	0.5	Eur/m3
Discount rate	4%	
Capital recovery factor	0.0899411	

Table 11 - Scenario 2 - input calculations for waste-water treatment plant

Note:

- *PE, Total daily flow: Table 4*
- *Total yearly flow: 365 * Total daily flow*
- *Waste-water treatment price: Average price for treating the waste-water in Arad County, 2012*

CHP co-digestion plant calculation inputs		
Installed capacity	0.40	MW
Mixed feedstock	8.9	t/day
Mixed feedstock / year	3,248.5	t/yr
CHP yearly operational hours	7300	hours
Electrical efficiency	35%	
Thermal efficiency	20%	
Total GC	4	GC/MWh
Electricity price	40	Euro/MWh
GC price	50	Euro/GC
Thermal price	60	Euro/MWh-t

Table 12 - Scenario 2 - input calculations for CHP plant

Note:

- *Mixed feedstock: Table 5*
- *Mixed feedstock/year: Mixed feedstock * 365*
- *CHP yearly operational hours, Electrical efficiency, Thermal efficiency: Rudolf Braun, Peter Weiland, Dr. Arthur Wellinger: Biogas from Energy Crop Digestion, IEA Bioenergy*
- *Total GC: Romanian Renewable Energy law 220/2006*
- *Electricity price: Average price from OPCOM 2012*
- *GC price: Average price from OPCOM 2012*
- *Thermal price: Average price from Arad heating plant*

Waste-water treatment plant investment costs		
Total investment cost	2,250,000.00	Euro
Investment cost / PE	150.00	Euro
Total investmet costs /m3	483.87	Euro/m3

Table 13 - Scenario 2 - investment costs for waste-water treatment plant

Note:

- *Total investment cost: Estimated cost from similar project: Design and construction of new waste-water treatment plant in Siria, Arad County, Romania, 2011*
- *Investment cost/PE: Total investment cost/PE (Table 6)*
- *Total investment costs/m3: Total investmet cost/Total daily flow (Table 6)*

CHP co-digestion plant investment costs		
Investment cost / MW installed	3,000.00	Euro
Total investment cost	1,200,000.00	Euro

Table 14 - Scenario 2 - investment costs for CHP co-digestion plant

Note:

- *Investment costs/MW installed taken from: Rudolf Braun, Peter Weiland, Dr. Arthur Wellinger: Biogas from Energy Crop Digestion, IEA Bioenergy*
- *Total investment costs: Total investment cost/MW installed * Installed capacity (Table 12)*

Waste-water treatment plant operating costs			
Labour	32%	0.032	Euro /m3
Electricity	16%	0.016	Euro /m3
Chemicals	4%	0.004	Euro /m3
Maintenance	18%	0.018	Euro /m3
Other costs	14%	0.014	Euro /m3
Total operating costs		0.084	Euro /m3
Total yearly operating costs		142,569.00	Euro/yr

Table 15 - Scenario 2 - operating costs for waste-water treatment plant

Note: Estimated costs from: Wastewater treatment plant operating costs in Korea: public vs. private - Vol 13, Issue 11, November 2012, http://www.globalwaterintel.com/archive/13/11/analysis/chart-month-wastewater-treatment-plant-operating-costs-korea-public-vs-private.html, viewed 23.11.2012

CHP co-digestion plant operating costs				
Labour	3%	of investment costs	36,000.00	Euro
Maintenance	2.50%	of investment costs	30,000.00	Euro
Various	3%	of investment costs	36,000.00	Euro
Total operating costs		per year	102,000.00	Euro/yr
Total operating costs /input	31.40	Euro /t		

Table 16 - Scenario 2 - operating costs for CHP co-digestion plant

Note: Operating costs taken from: Rudolf Braun, Peter Weiland, Dr. Arthur Wellinger: Biogas from Energy Crop Digestion, IEA Bioenergy

Waste-water treatment plant income calculation		
Daily Waste-water treatment	2,325.00	Euro
Yearly waste-water treatment	848,625.00	Euro

Table 17 - Scenario 2 - income calculation for waste-water treatment plant

Note:

- *Daily waste-water treatment: Total daily flow (Table 6) * Wastewater treatment price (Table 6)*
- *Yearly waste-water treatment: Daily waste-water treatment * 365*

CHP co-digestion plant output		
Total electricity generation	1,022	MWh
Total GC	4,088	GC
Total heat produced	584.0	MWh

Table 18 - Scenario 2 - output calculation for CHP co-digestion plant

Note:

- *Total electricity generation: Installed capacity (Table 12) * CHP Yearly operational hours (Table 12) * Electrical efficiency (Table 12)*
- *Total GC: Total electricity generation * Total GC (Table 12)*
- *Total heat produced: Installed capacity (Table 12) * CHP Yearly operational hours (Table 12) * Thermal efficiency (Table 12)*

CHP co-digestion income calculation		
Electricity sale	40,880.00	Euro
GC sale	204,400.00	Euro
Heat sale	35,040.00	Euro
Total yearly income	280,320.00	Euro

Table 19 - Scenario 2 - income calculation for CHP co-digestion plant

Note:

- *Electricity sale: Total electricity generation (Table 18) * Electricity price (Table 12)*
- *Electricity sale: Total GC (Table 18) * GC price (Table 12)*
- *Heat sale: Total heat produced (Table 18) * Thermal price (Table 12)*

Year	DiscountedCF	NominalCF	Investment	O&MCosts	Income	Cash flow
0	€ (3,450,000.00)	€ (3,450,000.00)	€ 3,450,000.00			€ (3,450,000.00)
1	€ 850,361.54	€ 884,376.00	€ -	€ 244,569.00	€ 1,128,945.00	€ (2,599,638.46)
2	€ 817,655.33	€ 884,376.00	€ -	€ 244,569.00	€ 1,128,945.00	€ (1,781,983.14)
3	€ 786,207.04	€ 884,376.00	€ -	€ 244,569.00	€ 1,128,945.00	€ (995,776.09)
4	€ 755,968.31	€ 884,376.00	€ -	€ 244,569.00	€ 1,128,945.00	€ (239,807.78)
5	€ 726,892.61	€ 884,376.00	€ -	€ 244,569.00	€ 1,128,945.00	€ 487,084.83
6	€ 698,935.20	€ 884,376.00	€ -	€ 244,569.00	€ 1,128,945.00	€ 1,186,020.02
7	€ 672,053.08	€ 884,376.00	€ -	€ 244,569.00	€ 1,128,945.00	€ 1,858,073.10
8	€ 646,204.88	€ 884,376.00	€ -	€ 244,569.00	€ 1,128,945.00	€ 2,504,277.98
9	€ 621,350.85	€ 884,376.00	€ -	€ 244,569.00	€ 1,128,945.00	€ 3,125,628.83
10	€ 597,452.74	€ 884,376.00	€ -	€ 244,569.00	€ 1,128,945.00	€ 3,723,081.57
11	€ 574,473.79	€ 884,376.00	€ -	€ 244,569.00	€ 1,128,945.00	€ 4,297,555.35
12	€ 552,378.64	€ 884,376.00	€ -	€ 244,569.00	€ 1,128,945.00	€ 4,849,933.99
13	€ 531,133.31	€ 884,376.00	€ -	€ 244,569.00	€ 1,128,945.00	€ 5,381,067.30
14	€ 510,705.10	€ 884,376.00	€ -	€ 244,569.00	€ 1,128,945.00	€ 5,891,772.40
15	€ 491,062.60	€ 884,376.00	€ -	€ 244,569.00	€ 1,128,945.00	€ 6,382,835.00
NPV	€ 6,382,835.00					
ANN	€ 574,079.20					
IRR	20%					

Table 20 - Scenario 2 - NPV calculation

Note:

- *Nominal CF = Income – O&M costs*
- *Discounted CF = Nominal CF/(1+Discount rate)^Year*
- *NPV = Sum of Discounted CF*
- *ANN = NPV * Capital recovery factor*

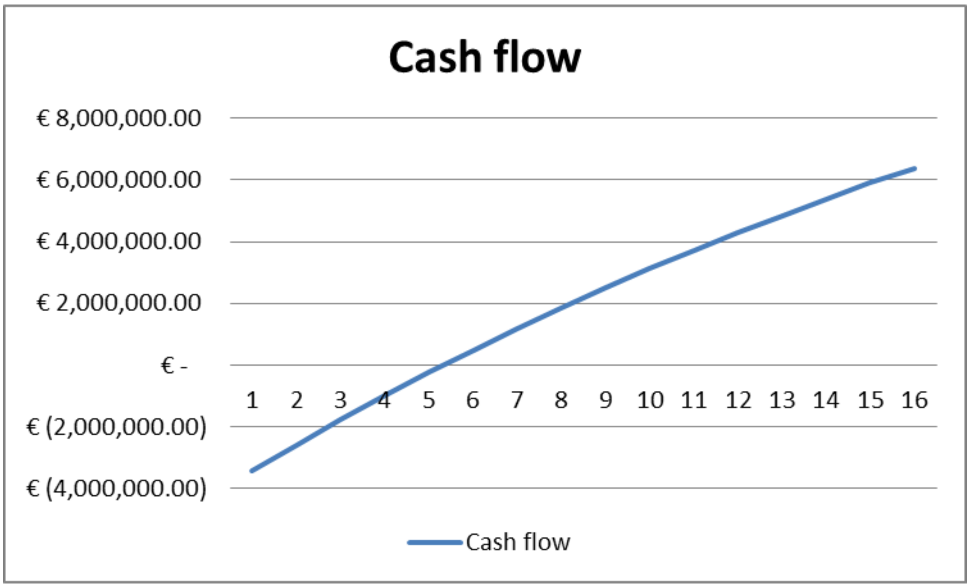

Figure 32 - Scenarion 2 - cash flow

4 Conclusions

As conclusions, we can say that any project for new energy production units, using alternative sources, should be promoted and implemented. In Romania such projects are almost nonexistent. Although due to new investments in wastewater infrastructure, investments financed by the European Union, are being built or modernized in every part of the country new wastewater treatment plants, very few are those who use a method of converting energy from the resulting sewage sludge. Although many projects that are funded by the European Union for investment in waste management system, very few are those who use a method of conversion of energy from the waste. Perhaps is everyone's problem, from consultants, designers, companies that build, and final users, which are not yet aware and do not care about energy. For example, in this project was taken into account what is "normal" in other countries, more developed countries, the sale of the compost that results from bio-degradation of the material, composts that can be used by farmers in agriculture. Why it could not be taken into account in this project? For example, in year 2012, Arad Municipality has provided for free the degraded sewage sludge for the farmers, but did not had too much victory. It was simply refused. Why? We do not know, perhaps because of the fear and no knowledge of these practices, although, the properties of this material are well known. The farmers continue to use classic fertilizers, made out of chemicals, even though they cost. But the cost is supported by the population, and unfortunately, the population is not supporting only the costs, but also the negative effects on organisms.

This project presents a solution for the area of Cris Chisineu in Romania, an alternative to the classical waste-water treatment plant that uses old technology. The economic feasibility of such a project was showed. Although, the investment costs are higher by about 50%, operating costs are higher by about 30%, however, there is significantly increase in revenues, by about 45%, leading to a payback in just three years and profits in a period of at least 12 years. At this time, the city is waiting for funds, for a new wastewater treatment plant, which, after projection hopefully, will have implemented such a system. The implementation of a new wastewater treatment project is an obligation of municipality, for compliance with European norms, for waste-water discharge, but a project regarding the producing energy from waste is up to them if it will be implemented or not. From such a project, not only the municipality would benefit, but also the population and the local businesses, which could have an income from the collection and sale of organic waste. Such a project is a long term project, it requires a lot of involvement, but first, it needs desire, it needs the idea. Such a project will have not only an economic impact on the municipality and population but also an environmental impact in the long term.

It is possible, for the municipality to lease the services. If at this time, is waiting for funding from the European Union to build a new wastewater treatment plant, the municipality may lease public waste collection service, and if does not have any landfill project for the city, there is the possibility of a public-private partnership to build a transfer station, waste storage, recycling facilities and biogas production facility. As you can see, such a project, presented in in this paper, is actually a combination of several projects, which all have in common the municipality. The municipality, should initiate and coordinate the implementation of such projects, that will have only benefits from them.

5 Abbrevietions and symbols

CH4– methane symbol

CO_2 – carbon dioxide symbol

d - day

h – hour

h/d – hours per day

H2O – water symbol

kW – Kilo Watt

kWh – Kilo Watt hour

m - meter

m^3 – cubic meter

mg - milligram

MS - Materials in suspension

NH - Ammonium

Ptot – Total phosphor

WWTP – Waste water treatment plant

yr – year

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