MAURÍCIO SARAIVA PACHECO E SILVA

THE ANAEROBIC DIGESTION OF THE ORGANIC PORTION OF HOUSEHOLD WASTE: STUDY CASE DRESDEN

Projeto de Formatura apresentado à Escola Politécnica da Universidade de São Paulo, no âmbito do Curso de Engenharia Ambiental

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ABSTRACT

This work focuses on biogas production by using source-separated organic waste from households as feedstock. The energy use of the produced gas should contribute to the transformation of Dresden into a more sustainable city.

Dresden still has an energy matrix that is highly dependent on fossil fuels and musst seek cleaner energy production in order to meet the national targets for renewable energy production defined in recent years.

The current work covers, among other things, a bit of the actual treatment, that has been given in Dresden for its domestic waste, the legal background concerning waste management and energy production in Germany, the state-of-the-art of anaerobic digestion in Europe and in Germany, a description of the biological process that occur during the anaerobic digestion of the residue and still, financial aspects of the technology.

DEDICATION

Dedico este trabalho à minha irmã Laís, meu maior exemplo de luta e de superação! Te amo muito!

ACKNOWLEDGEMENTS

Agradeço a meu pai e à minha mãe, por toda sua dedicação e por todo seu sacrifício. Vocês são pessoas incríveis!

Ich bedanke mich bei denen, Freunden aus Deutschland, die mich während meines Aufenthalts an diesem wundervollen Land irgendwie unterstützt haben! Die letzten Monate waren für mich nicht einfach und ohne deren Unterstützung wäre diese Arbeit nicht möglich.

Besonders will ich mich bei der "Gesellschaft von Freunden und Förderern der TU Dresden e. V." bedanken für die finanzielle Unterstüzung und für das Vertrauen in meine Arbeit.

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1 INTRODUCTION

1.1 Purpose

The purpose of the present work is to evaluate the potential energy production, through the installation and operation of a biogas plant in the city of Dresden; the plant is to be fed by the organic portion of the residential waste from the city.

Many scientific papers have been produced and published in the last 20 years presenting more details about the technique and some of its potential. This scientific production has been further intensified by the publication of European and German laws encouraging the production of renewable energy, which must hide an increasing share of the German energy matrix within the next few years.

In addition, there are also many academic works and information available about the city of Dresden and the treatment being given to municipal solid waste in the city, within is possible to deliver a comprehensive view of the status quo of the treatment of organic waste in the city.

In spite of all this, there is still no work that evaluates the possible energy production, in terms of heat and electricity quantity, if the organic portion of the residential solid waste in the city starts been treated in a biogas plant, thus following in a European and German trend and appearing as an alternative for local energy production, which should be less and less dependent on non-renewable sources and nuclear power plants, which has to come to an end till 2022 in Germany.

The proposed course of action developed in this study intend not only to complement the current solid waste management system, but also to support and to recommend the development of a comprehensive, integrated solid waste management plan in the future and the long term.

1.2 Background

As a result of growth of world populations and its abundant supply, global energy demand presented a raplidly growth in recent years (Surendra et al., 2014). Worldwide, energy consumption reached 524 QBTU in 2010, and is estimated to peak at 800 QBTU by 2040, corresponding to an average growth of 1.5% per year (EIA, 2013).

Non-renewable fossil resources such as coal, oil, and natural gas provide approximately 85% of the world’s total energy demands. These resources are not only limited in supply but also present conflicting effects on the environment, in view of the substantial emission of greenhouse gases (GHGs) into the atmosphere (EIA, 2013).

In agreement with the “Climate Action Plan 2050”, signed by Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety in 2016, the Federal Government plans to reduce the emisson of GHG’s by 40 percent in Germany by 2020 and still by 80 to 95 percent by 2050 (compared to 1990 levels of emission). For the accomplishment of this goal, a sustainable energy economy is crucial. That includes energy savings, regenerative energy generation and still efficiency of energy use.

In view of this ambitious objective, it is fundamental to examine the contribution that waste management, and here more specific the biowaste management, has to offer, as regards emission restriction. Improvements on solid waste policies have proven to be very efficient in this regard and in 2011, an official document from the German government already pointed to a significant emission reduction reached by the sector. 56 million tones of CO_2-equivalent were avoided, if compared to the emission registered in 1990, as reported by the German Federal Environment Agency (2011).

Bioenergy production, especially biogas produced through the anaerobic digestion (AD) of renewable feedstocks, is seen to be one of the most promising alternatives to fossil-derived energy thanks to its great capability (Kaparaju et al., 2009; Cheng et al., 2011). Because of its advantages over conventional fossil-derived resources, AD has been adopted and integrated into the worldwide energy matrix over the last century, with thousands of plants currently in operation.

2 OBJECTIVES

In order to provide the municipal decision makers in Dresden support in the optimization of biowaste manipulation, this work presents the potential of its use and technical processes currently applicable for the handling of this portion of MSW.

Convinced that the organic waste can be better processed, resulting in energy recovery in a cost effective and environmental friendly manner (without endangering human health and harming the environment), the current work supports the construction and operation of a biogas plant in Dresden, in order to enable good practice of waste management, creating a circular economy.

The use of the organic portion of the municipal waste has the potential to provide the key to energy recovery and sustainability from biodegradable waste. The scheme decribed in this work meets the new EU and German regulations, covering the “Waste Framework Directive”, the “Closed Substance Cycle Waste Management Act”, the “Renawable Energy Resources Act” and still the “Biomass Ordinance”.

An estimate of the amount of energy that would be poduced is carried out and should be used as basis for further discussion. A financial analysis of the enterprise is also made.

3 METHODS

The work is based primarily on secondary data.

First of all, so that the reader can understand what is currently done with the household waste from Dresden, including its organic plot, a sort of garbage mapping, including the paths that it traverses till the treatment site was made. Greater attention was given to the organic portion, for obvious reasons. Official numbers from the city of Dresden, found in the county reports were used to quantify each of the different portions of waste. In addition, previous analysis made by renowned German authors were used to define the physical and chemical characteristics of the material, on an attempt to identify the real energy and elements recovery potential from it.

After that, in an attempt to introduce the technology, which the use is here proposed, and its status quo in Europe and more specifically in Germany, books and papers were used, establishing within not only the existing conditions of the technology but also technical aspects that must be understood prior to its introduction into any waste management system.

Still, in order to justify such a choice, points in favour of a sustainable energy generation and the legal background, that supports such a practice will be presented and examined. For that, some books about the production of renewable energies were used and laws, acts and ordinances were considered.

As intended result of the current work, the potential of energy generation by treating the organic waste portion with an anaerobic digester is to be estimated. Still, as for any other large investment to be made, a financial analysis of the venture is indispensable. For all that, some values previous observed and documented for other anaerobic plants in Europe are going to be used as a basis of comparison.

4 OVERVIEW OF THE WASTE MANAGEMENT IN DRESDEN

4.1 Demographic and geographical data of Dresden

Dresden is situated in the southeastern part of the Free State of Saxony, formerly part of GDR (German Democratic Republic). Saxony bound on four german regions (Bavaria, Thuringia, Brandenburg and Saxony-Anhalt), it still borders on Poland and Czech Republic. The city lies on the Elbe valley.

Figure 1 illustrates the map of Germany, featuring some of its major cities. The city of Dresden is located in the central eastern part of Germany, near the border with Czech Republic.

Figure 1: Map of Germany.

Source: Google Maps (2017).

The city is located in thee center-east region of Germany, very close to the city of Prague, Czech capital.

The city extends over 30.000 ha as stated on the official website from Landeshauptstadt Dresden (2017).

According to informations from the "Statistical Office" form Dresden (Melderegister der LH Dresden; Kommunale Statistikstelle; Statistisches Landesamt), Dresden had a population of about 550.000 in 2015.

The city is divided into nine different areas, called Ortsamtsbereich. The areas with the largest numbers of habitants are Blasewitz and Cotta, in this order. These and the other areas are shown in Figure 2.

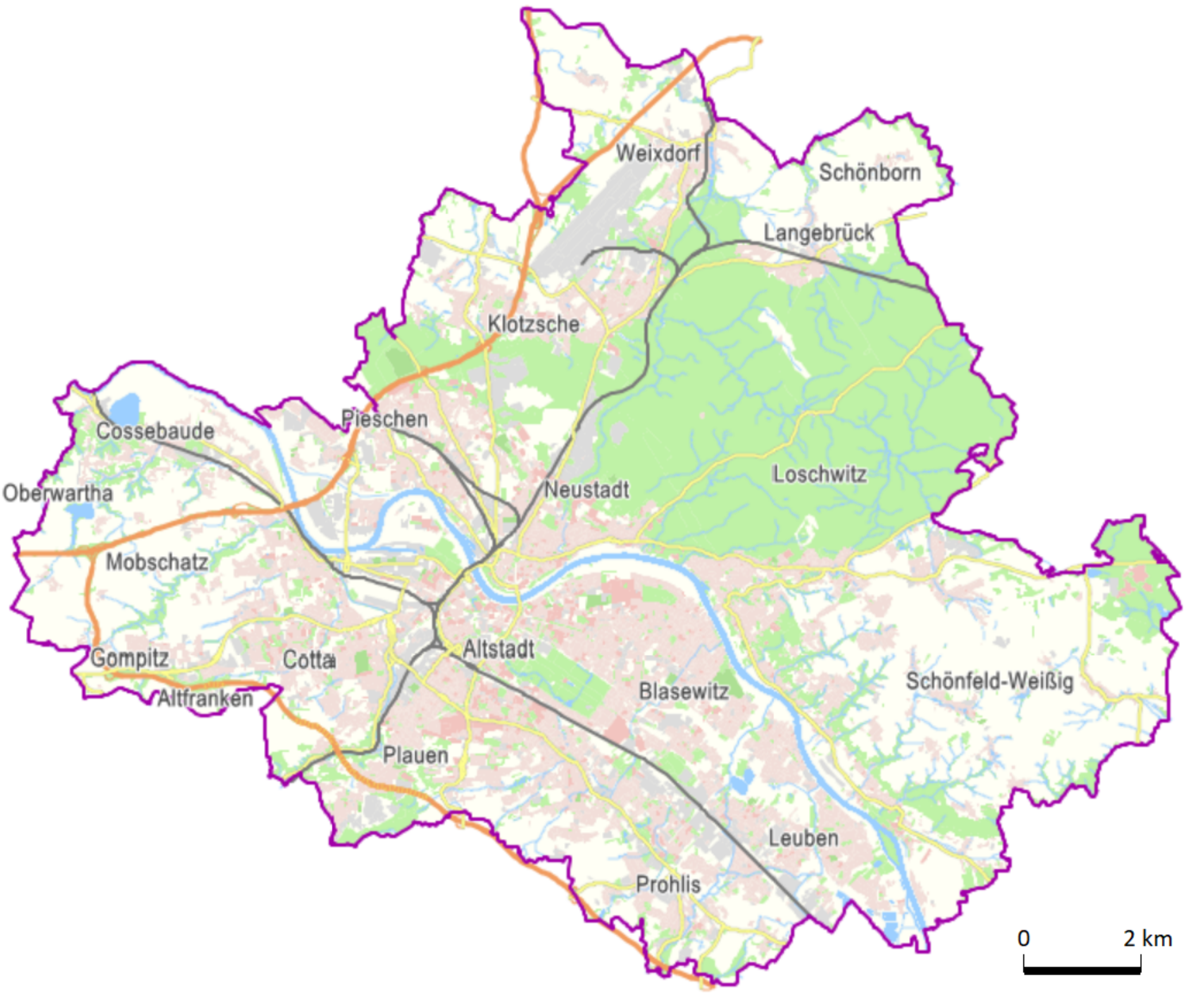


Figure 2: Map of Dresden and its districts.

Source: Staatsbetrieb Geobasisinformation und Vermessung Sachsen (2017).

4.2 Waste management summary

In Dresden, the domestic waste comes mainly from private households and is regularly collected by public waste utilities in standardised containers, and transported away for further treatment.

Domestic waste collection, transport and treatment are exclusively responsibility of the local authority. The right to provide such services is given to a company after a public auction. In Dresden the firm responsible for running such services is the Stadtreinigung Dresden GmbH (SRD).

All households are obliged to take part in this system and to pay waste collection fees to the local or municipal authority. All households are defined by law as the generators of waste and therefore do not have the power of choice, wheter or not they will benefit from the public collection service. That means, they are mandatorily part of this system and have to pay a fee for the collection and treatment of their garbage.

Source separation of the organic fraction of municipal solid waste (OFMSW) is mandatory, which contributes to the growth of biological treatement industries.

As stated in the Waste Balance of Dresden 2016 (Abfallbilanz der Landhauptstadt Dresden 2016) a bit more than 90% of municipal waste in Dresden is domestic waste, and the remaining 10% is composed mostly by commercial garbage and street sweeping dreck.

In 2017, the official Waste Balance from Dresden pointed that 179.503 metric tonnes of waste were generated in 2016. That represents 4.000 metric tonnes more than in the previous year.

The mass increased by 537 metric tones for plastic and 665 metric tones for bio- and green waste. Residual waste had a significant increase of 1.281 metric tones.

327 Kilograms per inhabitant was the per capita quantity of allwaste registered.

Lastly, Dresden is a member of the "Climate Alliance", the world's langest city network dedicated to climate action. In line with the agreement, each of the cities that become part of the alliance approved a local resolution in which they accepted the following voluntary commitments:

- To reduce of CO_2 emissions by 10 percent every 5 years, equivalent to the halving of per capita emissions by 2030 (from a 1990 baseline);

- To strive for a per capita emissions level of 2.5 tonnes CO_2 equivalent through energy conservation, energy efficiency and the use of renewable energy;

- To work towards climate justice in partnership with indigenous peoples by supporting their initiatives, raising awareness, and abstaining from the use of unsustainably managed tropical timber.

4.3 The waste from households and its many ways

With the aim of illustrating the various paths of domestic waste, from its producer (households) to the appropriate handling sites, these being a function of their characteristics, and later to the place of final use or disposal of these, the following items illustrate these paths, encompassing distinct collection systems.

4.3.1 Door-to-door colletion

Once separated, the different portions of household waste are collected by SDR's trucks and each of the different binns are then transported till the appropriate plant.

By Figure 3, it is possible to see the many possible destinations that are taken by the portion of waste, which is collected in front of the houses (door-to-door collection).

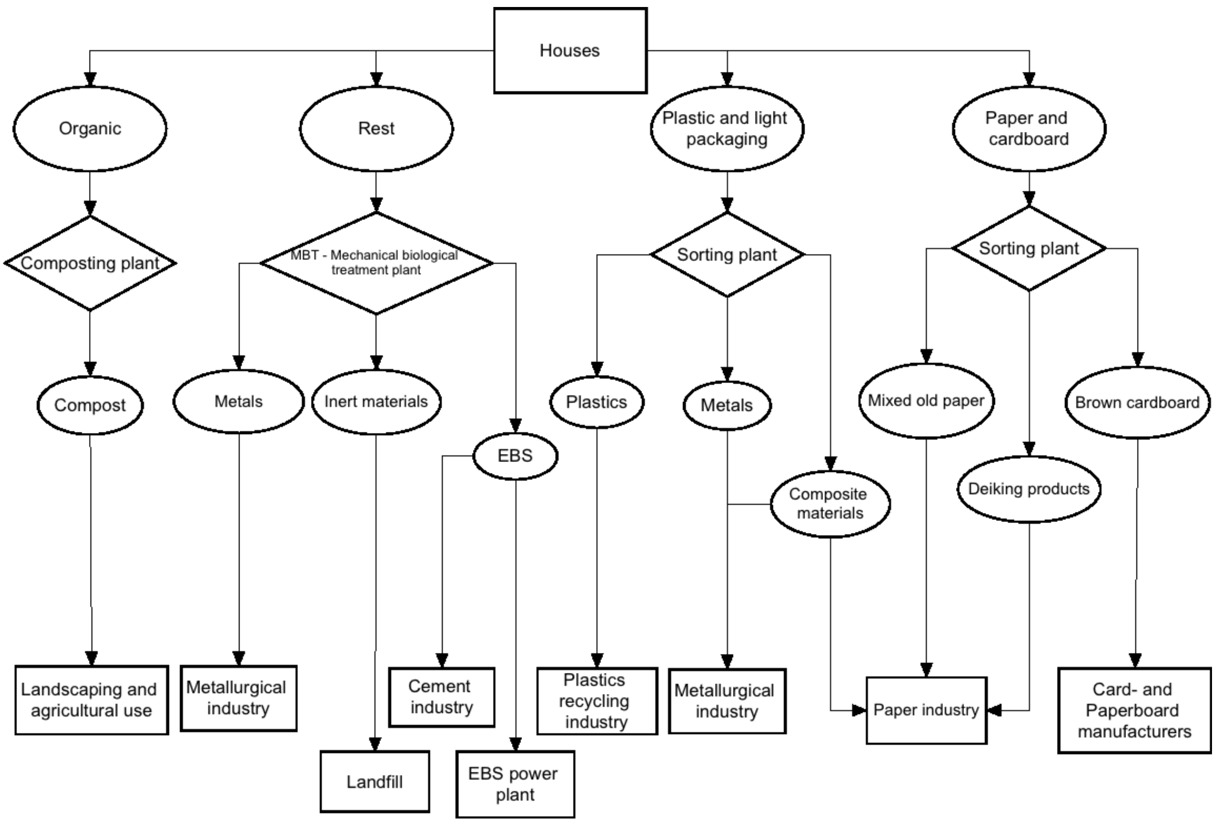


Figure 3: Waste ways – from households till specific facilities.

Adapted from: Stadt Reinigung Dresden (2017).

Furthermore, Figure 4 shows a primary segregation, which uses physical processes to separate some parts of recyclable waste. This step is the first stopping point for the waste in this recycling center in Dresden.

Figure 4: Recycling center in Kaditz (Dresden).

Source: Figure of own authorship (2017).

The “Residual waste” is taken to a MBT Plant, where it is first separated. This sorting process usually involves the employment of industrial magnets, eddy current separators, trommels and even manually work at hand picking stations. The valuable material is then taken to recycling plants and the metallic portions, both ferrous and non-ferrous metals, are taken to “black” and “colored” metallurgical industry plants respectively, while the rest subsequently undergoes mechanical combined with a biological treatment, resulting in the production of a high calorific value material, so called Refused Derived Fuel (RDF). The RDF is normally used as a co-fuel in the industry; it can be used in cement kilns or in thermal combustion power plants. Still, there is an inert portion derived from this mechanical biological treatment, which can be used as soil amendment, which can improve poor soils, rebuild soils which habe been damaged or still it can be used simply in order to give mechanical stability to the soil, where it is needed, for example in slopes for the contruction of landfills.

Recyclable materials are first taken to a separation building and from there to the specific recycling plant.

Plastics, metals and composite materials are commonly the output of sorting process from the material found into yellow bins. Mainly light packagings are thrown into those bins. Packagings identified with the “Green dot” are to be thrown into these specific bins.

Besides that, wastepaper is first divided in three different portions. Newspaper and magazines must first be sent to a deinking plant, since the ink used in their printings is toxic and therefore requires greater care when processed. Afterwards, the three different fractions have two possible destinations, the paper industry or the card- and boardpaper manufactures.

The organic portion is taken to a composting plant, called “Humuswirtschaft Kaditz”, with the intention of producing compost from that, which can be used in agriculture in areas near Dresden or else in the recovery of contaminated areas or still, in nutrient replenishment.

4.3.2 In the residential areas

Besides the door-to-door collection services, residential areas are equipped with larger containers, capable of storing a much bigger quantity of waste. These containers are used in order to ensure the correct collection and subsequent transport of glasses and papers till the correspondingly recycling plants.

The distribution of these containers in residential areas is design in such way that all residents have easy access to such ones, so that everyone is capable of disposing it correctly.

Here papers, cardboards, and newspapers and magazines are collected separately, diffent from what is seen in the door-to-door collection, where the different “paper parcels” are first sorted at an industrial plant. That ensures a better separation of these parcels and thus better recycling rates of these materials.

Special care is given to newspaper and magazines due to the large amount of ink they present. These undergo a process called “deinking”, an industrial process of removing printing ink from paperfibers in preparation for producing new paper.

Besides that, glasses are also collected from these containers. Each household is obliged to take the used glasses to these containers, where they still must be separated according to their color. Each color requires a specific temperature range during its recycling and therefore the different glasses must be precessed separately.

Figure 5 shows us the many paths; the different portions of waste, collected from these containers take till their final destiny.

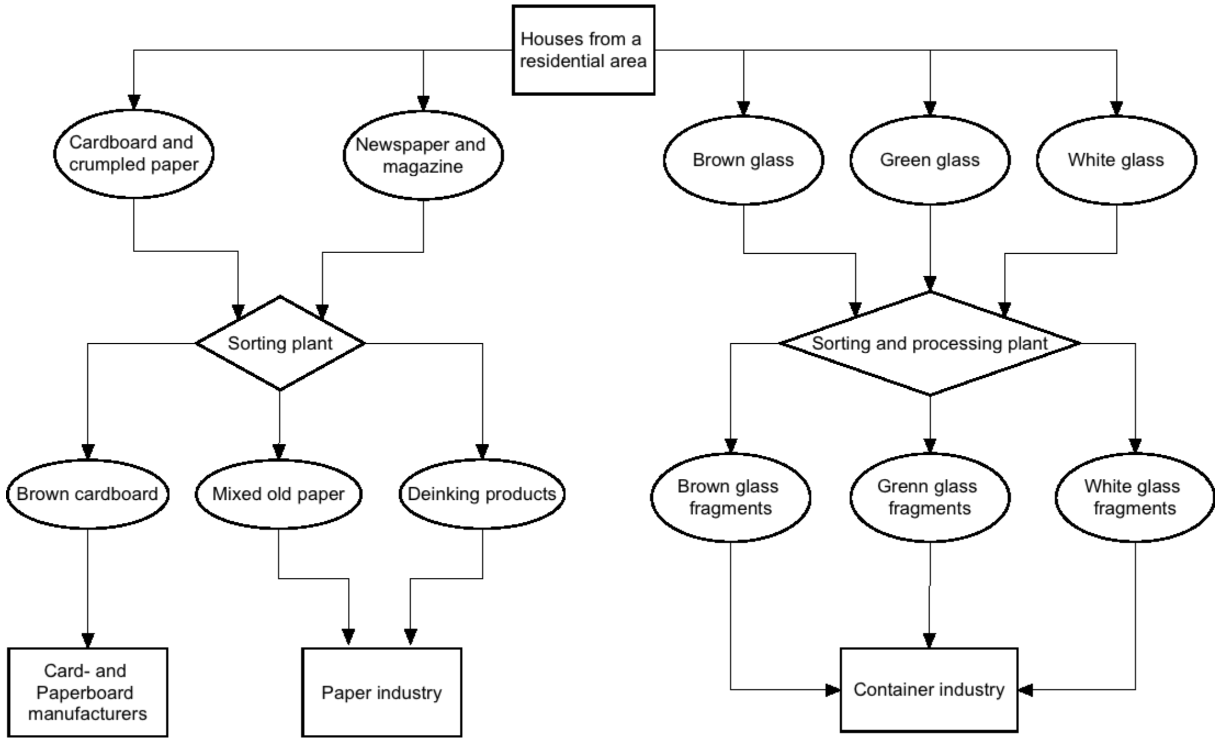


Figure 5: Waste ways – from residential areas till specific facilities.

Adapted from: Stadt Reinigung Dresden (2017).

Still, Figure 6 illustrates how these containers look like in reality. From left to right, first a container with two openings, of which the first one for “brown glass” and the second for “green glass”; the second container exclusively for “white glass”; the third one for “newspaper” and “magazine”; and finally, rightmost, a container for cardboard and crumpled paper.

Figure 6: Containers in residential area in Dresden.

Source: Figure of own authorship (2017).

4.3.3 Bulky waste and domestic appliances

Besides the services above mentioned, the residents still have other alternatives for the correct destination of the many different portions of their waste.

The residents have the possibility to schedule the collection of larger materials, which cannot be disposed in the containers, previously mentioned.

They must simply call "SRD' call center" and set up a date and time for the collection of the material to be disposed of. This service is free of extra charges.

Bulky waste is taken to a sorting plant. A big and powerfull magnet is responsible for the separation of the existing metal portion and after that, some mechanical processes are followed for the separation of the remaining part. The plastic portion is subsequently sent to a recycling plant. Wood is used as burning material, contributing to energy recovery. The remaining material from this process is typically composed of textiles, small pieces of wood and plastic and non-recyclable plastics, presenting therefore a very high calorific value. This portion is separated by different processing steps from other foreign materials, such as stones and shredding into a uniform grain size, producing a homogenous material, the RDF, been used as a co-combustor mainly in the cement production and power plants.

Domestic appliances are delivered to an industrial plant, where all these appliances are disassembled. By refrigerators dissambling process, special care is given to the gas refrigeration system of these appliances, in order to avoid the escape of this gas into the atmosphere. The metallic portions, both ferrous and non-ferrous metals, are taken to “black” and “colored” metallurgical industry plants, respectively. All plastics that can be recycled are then shipped to recycling industry plants.

The ways covered by these waste types are shown in Figure 7.

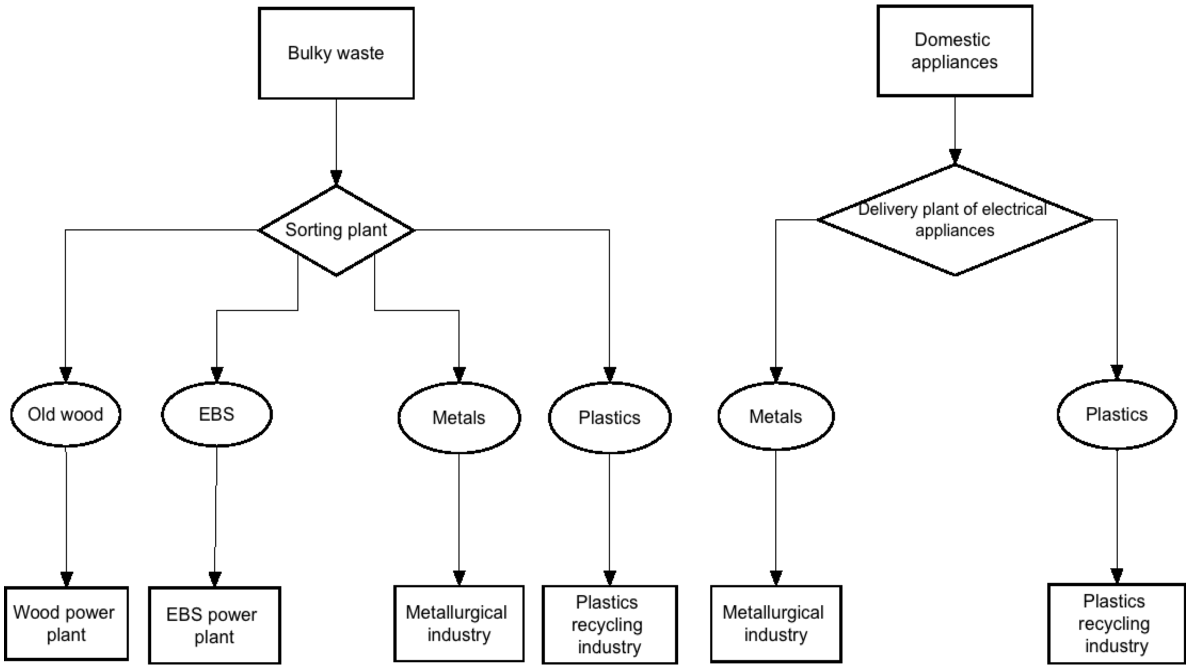


Figure 7: Waste ways – bulky waste and domestic appliances.

Source: Stadt Reinigung Dresden (2017).

4.4 Qualitative and quantitative analysis of MSW

In Dresden almost 180.000 metric tons of domestic waste were produced on 2016, according to official sources. From that almost 25.000 metric tons were just organic waste, which represents approximately 15% of the total waste by weight.

Table 1 shows the values in tons of waste produced in Dresden during the year 2016, and Figure 8, contains the percentages of each different portions.

Waste from Households	(t)
Total	179.503
Residual*	74.462
Valuable material	47.994
from that, Glass	11.395
from that, Paper and paperboard	19.876
from that, Light packaging	16.384
from that, Plastic	289
Organic waste	24.904
Wood and leaves / Garden clippings	16.644
Bulky waste	6.842
Old wood (from Forniture)	7.201
Scrap metal	1.071
Pollutant / Harmfull substance	435

** "Residual" refers to the portion of waste so called.*

Table 1: Quantity of the household waste generate in 2016.

Source: Abfallbilanz der Landeshauptstadt Dresden (2017).

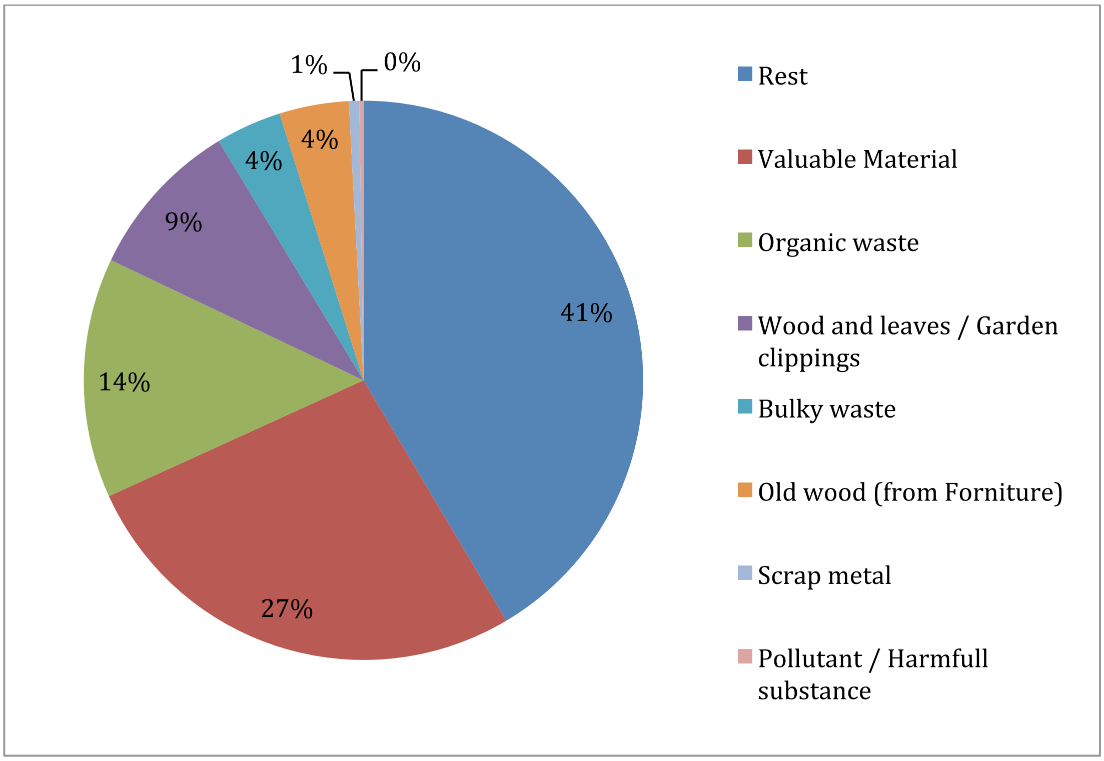


Figure 8: Composition of the household waste in 2016.

Source: Abfallbilanz der Landeshauptstadt Dresden (2017).

4.4.1 "Rest" of household waste

The "Rest waste" is described on the website from SRD as a mixed of municipal waste which, after separate collection of waste for recovery and still pollutants, remain as waste to be disposed of. It is the sum of the waste which were not assigned to separately collected material fractions due to contamination or mixing. The residual waste includes for instance, ash and cigarette butts, hygiene products, crockery, ceramics etc.

This portion of the household waste deserves special attention. This portion continues to present a very high percentage of organic on its composition. In 2016 almost 33% of the quantity by weight was organic waste.

Table 2 presents the composition of the "Rest waste" in percentages for the years of 2003, 2005, 2007 and 2009. It is possible to see that the parcel of organic matter didn't get any smaller over these years; instead it actually got bigger till 2009.

Substance	2003	2005	2007	2009
Fe - Metallic	1,9	1,7	1,4	1,8
Other metals and alloys	0,6	0,6	0,7	0,8
Paper	13,1	12,6	13	10,4
Glas	6,6	5,8	6,4	5,6
Plastics	5,2	5,1	6,1	5,3
Foam packaging	0,2	0,1	0,1	0,2
Organic	32,7	34,6	36,9	38,4
Wood	1,3	0,9	0,8	1,8
Textiles	2,6	2,6	3,2	2,9
Inorganic mineral salt	4,9	2,8	1,9	1,8
Composite	7,7	8,7	5,6	7,6
Diaper and hygiene products	5,6	8,1	8,1	5,6
Pollutant	1,4	1,5	1,5	1,2
Fine fraction from ashes	11,5	10,1	8,9	11,8
Other	4,9	4,9	5,2	5

Table 2: Composition of the "Rest waste" from household in Dresden.

Source: BIWA (2010).

Besides that, the composition of the "Rest waste" for the year 2016 is also presented, in Figure 9. The percentage of organic content got smaller but is still considered very high. The lower numbers in relation to previous years may be result of warnings made by the local government, in order to reduce the presence of organic matter in the "Rest bin".

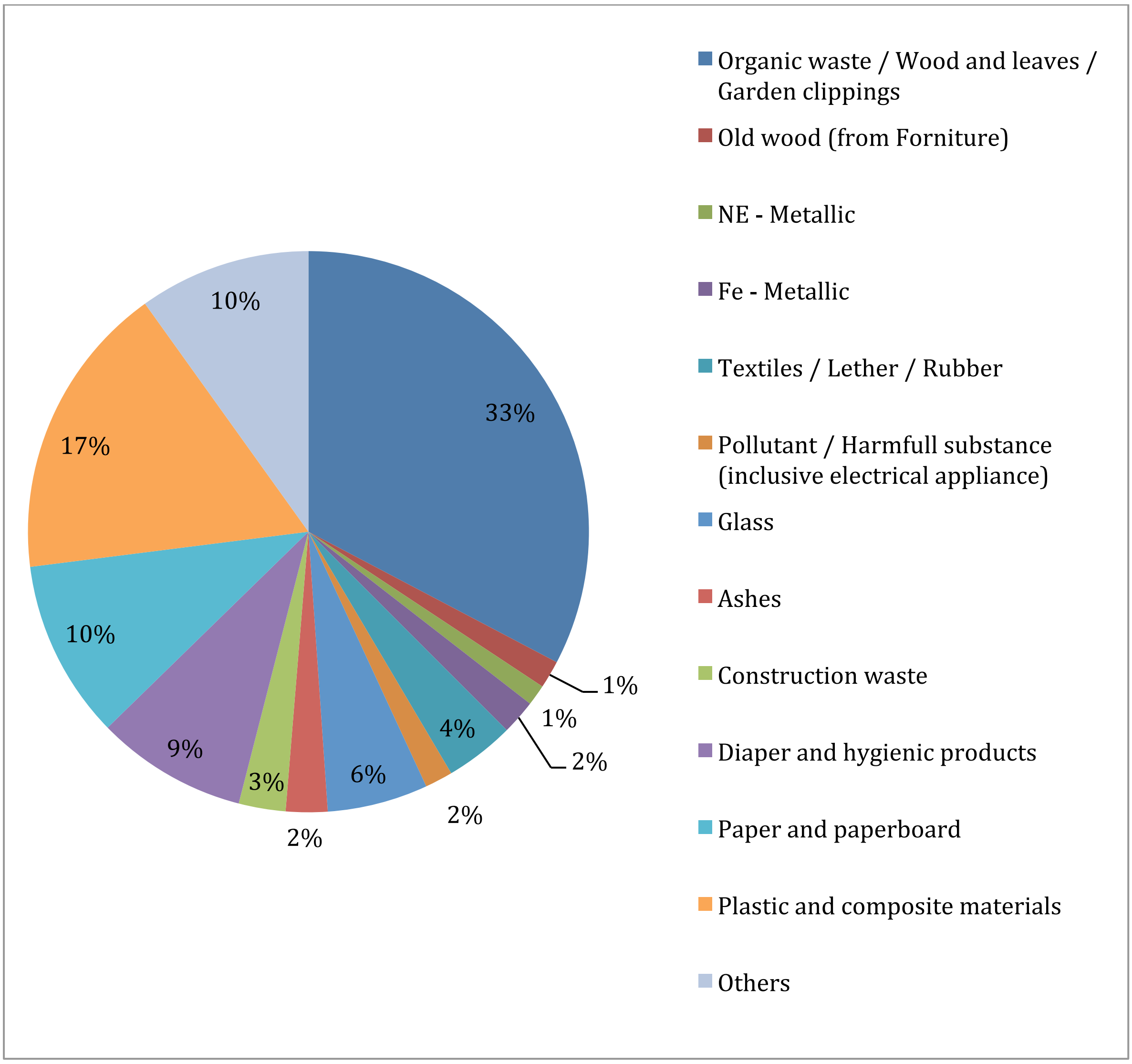


Figure 9: Composition of the "Restmüll" ("Rest waste") from household in 2016.

Source: Abfallbilanz der Landeshaupstadt Dresden (2017).

Analyzes of the composition of household waste in Germany pointed that about four to five million tons of "green" and "organic waste" are found every year in the Rest waste bins. Of this quantity, it is considered feasible to deduct nearly two million tonnes per year by means of suitable measures, according to the *Bundesministerium für Umwelt, Naturschtz und Reaktorsicherheit* (2012).

4.4.2 The organic portion of MSW characteristics and its composition

For a good design of waste-processing facilities and their components, accurate data on quantity, composition and also the chemical and physical properties of waste materials are indispensable. A good waste analysis represents an important tool for the prosperity of policy measures.

As in any other city in Germany, the composition of the organic waste in Dresden varies in course of the year. In the summer, a big quantity of bones can be found inside the biowaste bins, probably a consequence of the many barbecues. In the winter, it can be found a big number of citrus peels in the bins. In winter, the concentration of contaminants in the bins is also higher, result of the smaller concentration of green waste, if compared to vegetation times. During vegetation time, the big quantity of green waste dilutes the concentration of contaminants.

Figure 10 displays a typical bin, where the organic portion of household waste is disposed of, until these are emptied and sent to further handling.

Figure 10: "Bio-Abfall" (Organic waste) bin in Dresden.

Source: Figure of own authorship (2017).

According to Stadtmüller (2004), the organic portion is composed of 90% organic matter, which includes garden waste (bushes, flowers, cones, roots, potted plants etc), rest from fruits, vegetable and food (meat, sausage, bones, fishes and cheese), 2 to 4% paper and still 3 to 8% impurities and that means, plastic and textiles (1-2%), fine fraction (smaller than 10mm) (1–2%), glass (0,5–2%) and also ferrous and non-ferrous metallic portions.

Still according to Stadtmüller, the water content of organic waste from households is around 55% of mass value, a relativ high value for its burning and therefore its use as co-fuel in incineration plants is not recomended.

Table 3 shows some of the main chemical characteristics from the organic portion of MSW, according to two german authors.

Source	*Loss of ignition*	*C/N - relation*	*N (% TS)*	*P_2O_5 (% TS)*	*K_2O (% TS)*	*CaO (% TS)*	*MgO (% TS)*
Bidlingmaier und Müsken (2001)	30 - 70	10 - 25	0,6 - 2,7	0,4 - 1,4	0,5 - 1,6	0,5 - 1,6	0,5 - 2,0
Fricke (2002)	---	10 - 25	0,6 - 2,7	---	0,5 - 1,6	0,5 - 5,5	0,5 - 2,0

Table 3: Chemical characteristics – Organic portion of MSW.

Source: Bidlingmaier and Müsken (2001) and Ficke (2002).

Furthermore, still about physical-chemical characteristics for organic waste, hereby the values found by Braun (1992) will also be included. The values pointed out by the author are indicated in Table 4.

Waste	**DM content**	**Organic substances % of DM**	**C/N ratio**
Waste from households	40-60	40	18

Table 4: Physical-chemical characteristics of organic waste.

Source: Braun R. (1992).

4.4.3 Recyclable materials

In 2016, 537 metric tons more of recyclable material than in previous year were registered in the city.

Based on the “polluter-pays principle”, extended producer responsibility claims at the internalisation of external environmental costs, by the producer So, these has to take the responsibility for their products along their entire life cycle, including its proper handling after use. That means, producers are obliged to take back his product for recycling or disposal.

Hence collection and recycling costs of packaging materials are intrinsic in the price of product, which comes into these packagings. As soon as a consumer buys a good in the supermarkt and disposes the packaging into the proper binn, he should demand a proper processing of this packaging, and that includes proper collection and recycling.

Although light packaging appears to be perhaps the largest amount of recyclable waste produced in a residence, this parcel has very low density and lies only in the third place among the materials destined for recycling in Dresden in 2016.

Figure 11, shows the composition of valuable material, collected in Dresden.

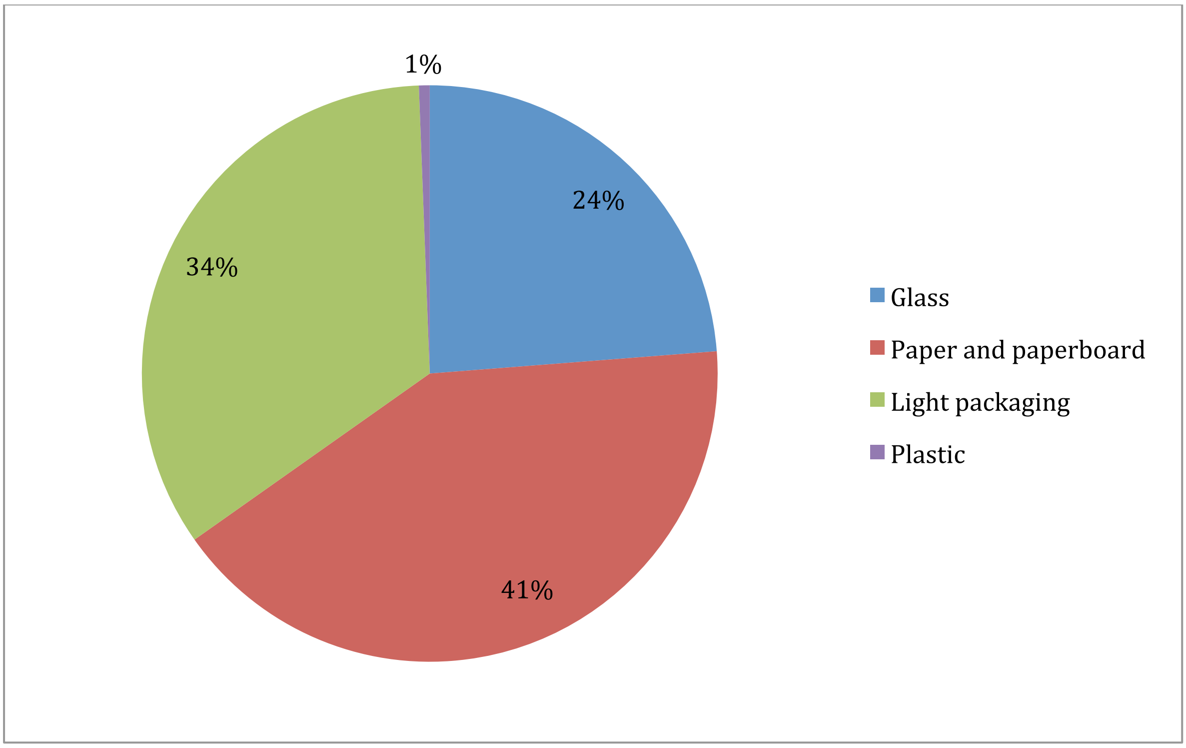


Figure 11: Composition of valuable material.

Source: Abfallbilanz der Landeshauptstadt Dresden (2016).

4.5 Existing biogas plants in Dresden

The intention of this part of the work is to make it clear, that there are already a few biogas plants in Dresden, evidencing that the technical knowledge and technology required for the installation and operation of one of these industrial plants already exists.

According to Amt für Geodaten und Kataster (2017) from Dresden, there are currently seven biogas plants operating in Dresden. From these seven plants the biggest one is located in Klotzsche and has 967 kW of thermal power and 834 kW of electricity power. Despite its instaled capacity, the plant doesn't take organics from the MSW of Dresden.

Figure 12 points the location of each one of them on the map of Dresden.

Figure 12: Biogas plants in Dresden.

Source: Landeshauptstadt Dresden – Amt für Geodaten und Kataster (2017).

Still, there are two plants located in Schönfeld, one with 537 kW and the other one with 1500 kW of capacity installed. The one in Cotta has 526 kW installed and the other three only 142 kW.

Figure 13 displays the biggest biogas plant in Dresden, located in Klotzsche.

Figure 13: Biogas plant in Klotzsche, Dresden.

Source: DREWAG (2017).

5 BIOLOGICAL TREATMENT IN EUROPE – ANAEROBIC DIGESTION

5.1 Introduction

As reported by Bilitewski (1994), initially, biogas facilities were used for the treatment of manure and also in sewage treatment plants, for sludge stabilization and for cleaning highly contaminated wastewater. The organic portion of household waste, when treated by a biological method, was treated with the presence of oxygen, i.e., it was composted.

During the last thirty years though, new waste management policies have sought to reduce environmental and social impacts caused by the disposal of waste in landfills, thus creating a serie of restrictions on this last technology. It was just then, that new technlogies gained space and anaerobic digestion matured as technology for the treatment of municipal solid waste. The prices for landfilling of waste became very high and combined with the many financial incentives for the production of clean energy, the technologie got the attention of investors and an active market for AD was created (Fachverband Biogas e.V., 2017).

In the early 1980s, highly efficient digesters were already much more developed and sewage treatment had progressed, biogas plants were becoming more used for the handling of solid and sludgy organic wastes. Still in the 1980s, extensive scientific studies indicated the feasibility of fermantation plants for the treatment of solid waste.

This process has many environmental benefits. Among the most important are the requirement of less space, reduction in odor potential and the production of biogas, which can be used to produce heat and power. Therefore, very quick this new technology anaerobic digestion won a lot of credit.

Nowadays, the anaerobic digestion is an established technology for the treatment of several types of waste and wastewater. AD has matured in the field of the treatment of the organic fraction, derived from MSW, more so than any other alternative treatment technology developed in the last 20 years (De Baere, L., Mattheeuws, B., 2012).

It is estimated that installed AD capacity for the treatment of MSW in Europe is already bigger than 6 million tons per year. And it can only be expected that anaerobic digestion will continue to increase on a steady basis (Fachverband Biogas e.V., 2017).

5.2 State of the art in Europe

In Europe alone, 244 installations dealing with the organic fraction of MSW as a significant portion of the feedstock have been constructed or are permitted and to be constructed (up to 2014). The cumulative capacity of all of these anaerobic digestion plants amounts to 7,750,000 metric tons per year of organics going into the digestion phase. If one assumes 300 kg of biodegradable waste generated per person and per year, this capacity represents about 5 % of the biodegradable waste generated across Europe (excluding former USSR-States) by 550 million inhabitants. In addition, this capacity represents 25 % of all biological treatment in Europe, which is estimated at around 20 % of all municipal solid waste disposal, according to Thomé-Kozmiensky (2012).

Germany has the highest installed capacity between European countries, with power to send around 2 million tons to its plants. After Germany comes Spain with 1.6 million tons. Such numbers can be seen in the Figure 14.

A big variation in size can be observed between installations in different European countries. Due to local geography, population density among other factors, the size of anaerobic digestors varies greatly from country to country. The largest ones can be found in France, while the smallest in Sweden. In these countries, the digestors have an avarage size of 56,130 and 10,000 metric tons per year, respectively.

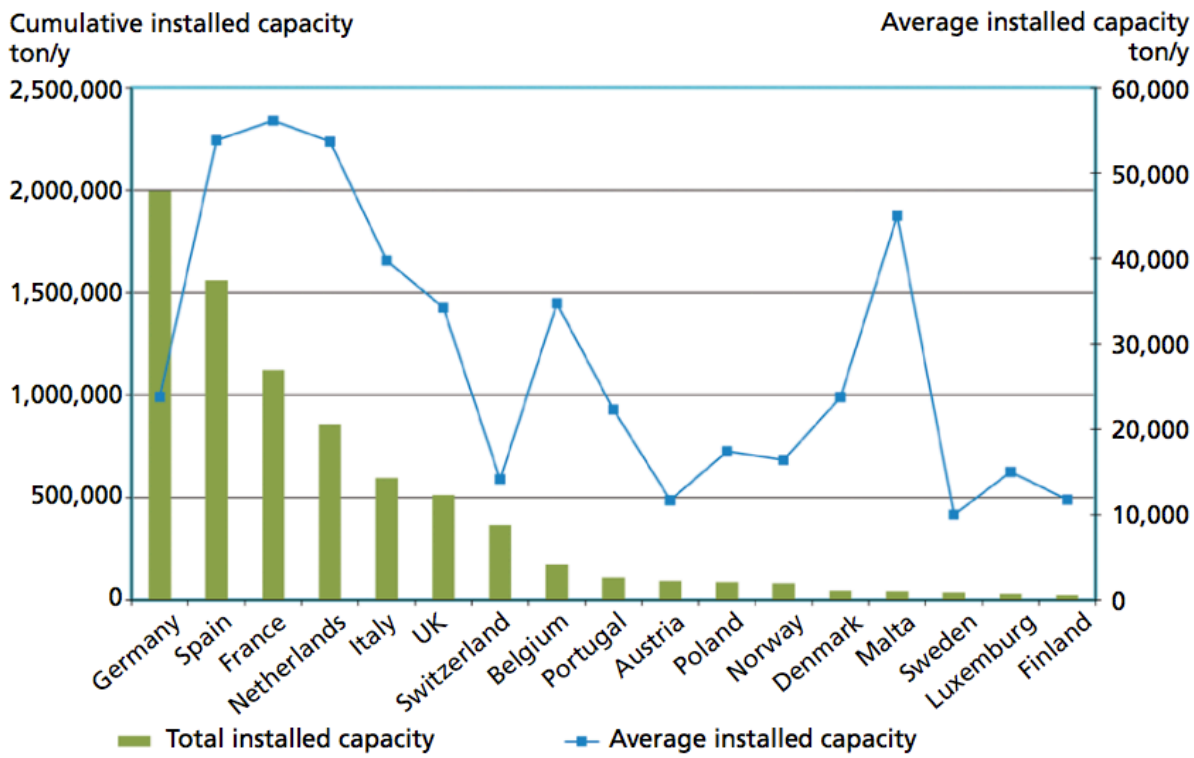


Figure 14: Total and average installed capacity per country.

Source: De Baere, L., Mattheeuws, B. (2012).

Besides that, The Netherlands and Switzerland present the highest installed capacity per capita (except for Malta and Luxemburg, but these countries can be considered as an exception due to their tiny size) with 52,400 and 49,000 metric tons per million people per year, respectively, as shown in Figure 15.

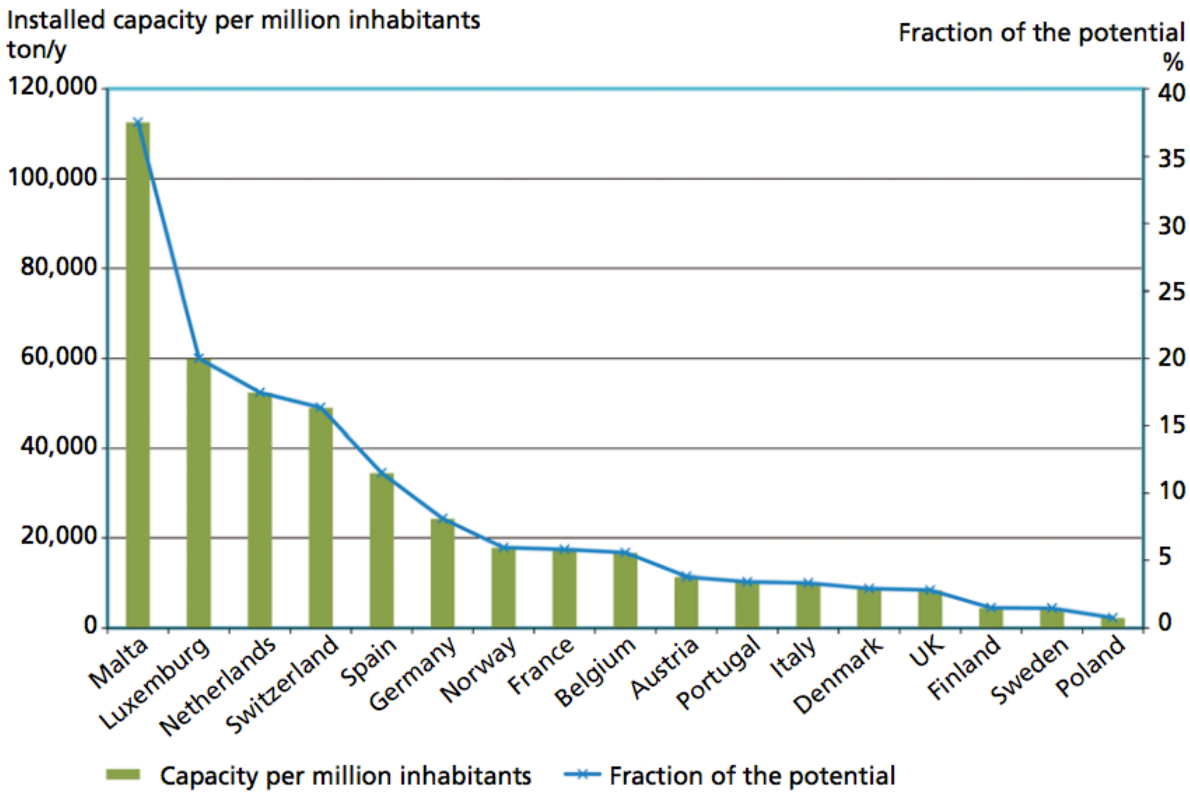


Figure 15: Installed capacity per million inhabitants and per country.

Source: De Baere, L., Mattheeuws, B. (2012).

In Europe the avarage size of an anaerobic digester is 31,700 metric tons per in year, but a big discrepancy is observed between different countries. In the Netherlands for instance, the avarage capacity is 54,000 metric tons per year, while in Switzerland this number is 14,000 metric tons, nearly 4 times smaller. This difference is mainly due to the dense population in Netherlands, while in Switzerland geographical complications in transporting waste from one area to another, requests the construction of many small plants, spread all over the country. Besides that, public policies also have a strong impact on the choice of type and capacity of plants to be instaled.

Economically speaking, AD plants should have at least the capacity to handle 30,000 metric tons of organic waste.

The Figure 16 shows the expansion in installed capacity per inhabitant in the countries, with the biggest rates in Europe. From the same figure is possible to say that Germany was an early adopter of the treatment technique, in the other hand, France and Spain started much later to implement the anaerobic digestion as a treatment of the MSW. Through Figure 16 it also can be said, that the technology in quest is well known and widespread in Germany, which is another point in favor of the implementation of the technology.

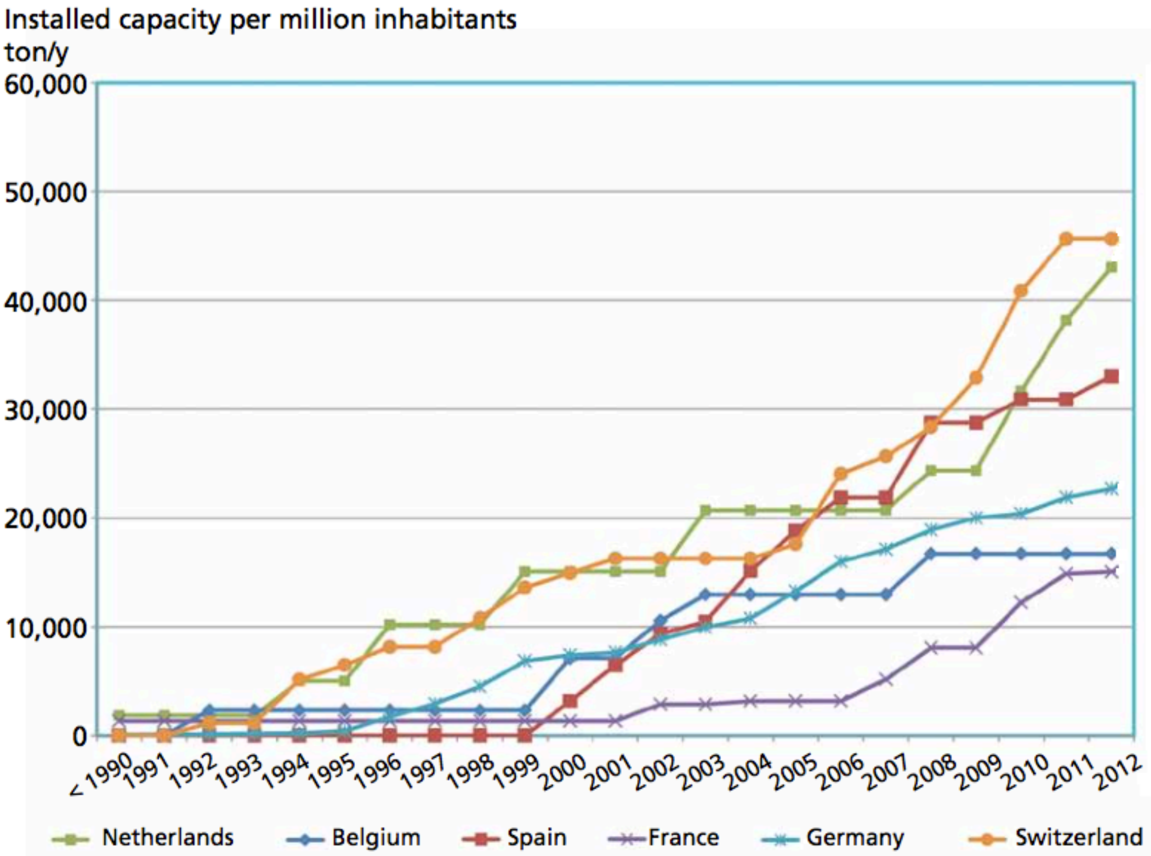


Figure 16: Development of the capacity per million inhabitants per country.

Source: De Baere, L., Mattheeuws, B. (2012).

5.3 Biogas plants in Germany

This section seeks to give a greater focus to the state of the art of the technology particularly in Germany.

Figure 17, brought below, indicate the number of biogas plants installed in Germany and still, the corralated installed capacity in MW (megawatt) of electricity from the year 2001 till 2010.

As perceived from the Figure 17, the number of biogas plants increased extensively over the past few years and yet, the electrical capacity also growth. The number of plants has practically doubled in a period of less than five years, from 1360 plants in 2001 to 2680 plants in 2005. Furthermore, the electrical installed capacity has increased almost tenfold within 5 years, taking into account the period from 2001 to 2006.

Another valuable aspect from the Figure 17 is the demarcation of two milestones in the national policy for renewable energies. Through the figure it is evident an acceleration on the increase of the number of plants right after those two events and so it is reasonable to point out a probable correlation between those national policy instruments and the necessary support for the construction of new plants in Germany.

National policy instruments will be better discussed further on the current work, including the Act, indicated in the Figure 17.

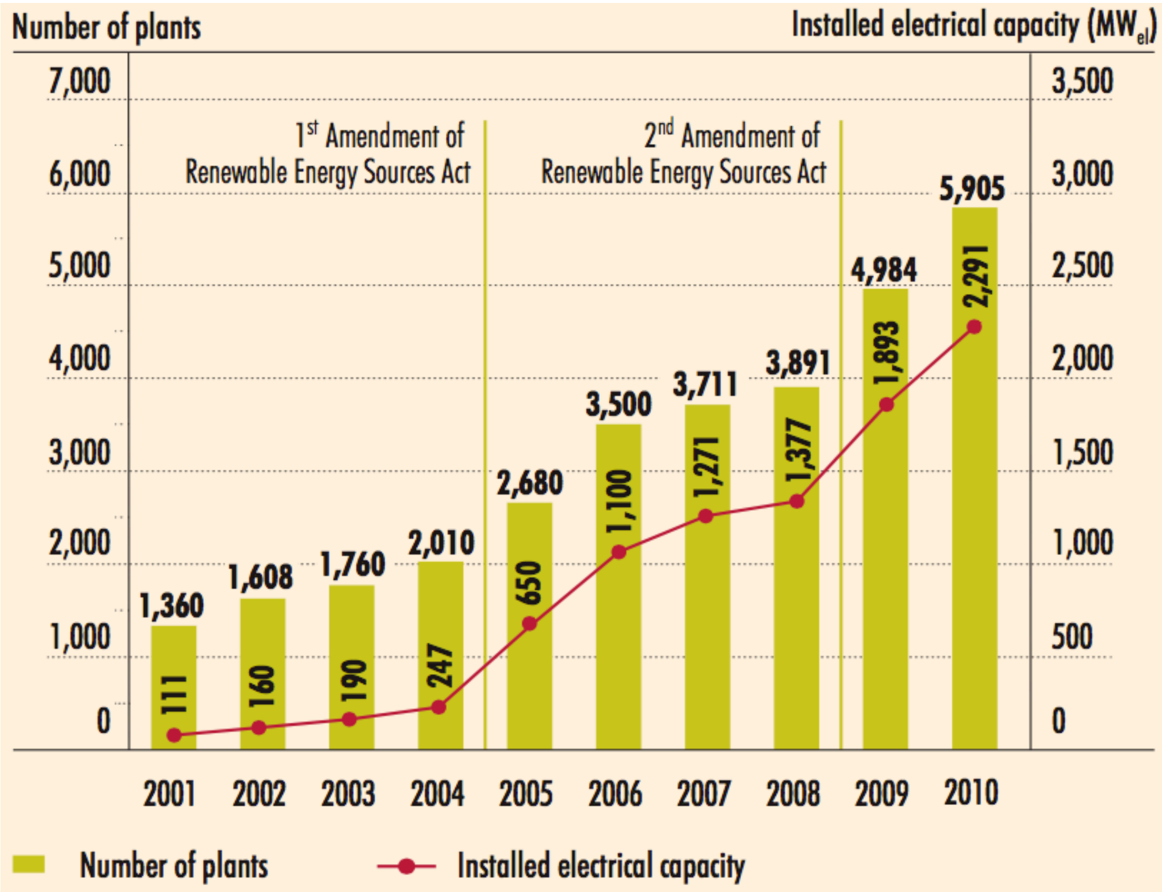


Figure 17: Development of biogas installations and its electrical capacity in Germany.

Source: Fachverband Biogas (2011).

Still, according to the German Biogas Association (2016), nearly 9000 biogas plants digesting energy crops, manure and biowaste were located in Germany by 2014. Furthermore, around 400 biogas plants were using exclusively biowaste as feedstock in Germany by 2015.

6 THE POTENTIALS OF RENEWABLE ENERGY

According to Goldemberg (2006), the development and use of renewable energy can contribute substantially to some very important points of global interest, such as the diversification of energy supply, energy security in general or still, poverty reduction.

Here, in this work, it will be discussed some aspects pointed out by Goldenberg, which, apply to Dresden reality. This deeper discussion is made below:

1. Mitigate climate change

The current world energy system is closely dependent on fossil fuel sources. In 2002, according to the Carbon Dioxide Information Analysis Center, worldwide, oil, coal and gas totaled 78 percent of the world's primary energy production. Still, according to the Center, fossil fuel combustion is the major source of carbon dioxide (CO_2) emissions in the world. The emissions are growing at the rate of 0.5 per cent per year (CDIAC, 2005).

The emissions of anthropogenic GHG, mainly due to the production and the use of energy, transform the atmosphere in ways that disturb the climate. The Third Assesment Report of the Intergovernmental Panel on Climate Changes (IPCC) pointed out a new and stronger evidence that most of the warming registered over the last 50 years is to be attributed to anthropoid activities. Still according to IPCC, if the energy demand of the 21st century is reached without a extensive reduction in the level of carbon emissions of the global energy system, notable climate change should be observed. The current CO_2 emission trends, if not controlled, will lead to atmospheric concentrations more than twice as large, before 2050, if compared to pre-industrial levels. Changes in climate patterns have already been observed that correspond to scientific projections based on the increasing of concentrations of GHG.

The mitigation of climate change is a major challenge to sustainable development, and some of the central plans of actions to avert this change are:

- Increased reliance on renewable energy sources;

- More efficient use of energy;

- Quick development and deployment of new and advanced energy technologies.

A greater share of renewable energies, which are carbon-free (or neutral), in the energy matrix, should contribute significantly to the reduction of carbon dioxide emissions and so, make climate changes less severe.

In order to ratify the concept presented in this part of the paper, below, Figure 18 is presented, containing data taken from the Working Group on Renewable Energy –

Statistics (AGEE-Stat.), on how much emission was already avoided through the use of renewables.

It is evidente, through Figure 18, that as renewables gain bigger market shares, the avoidance of emissions also increases, confirming the point discussed.

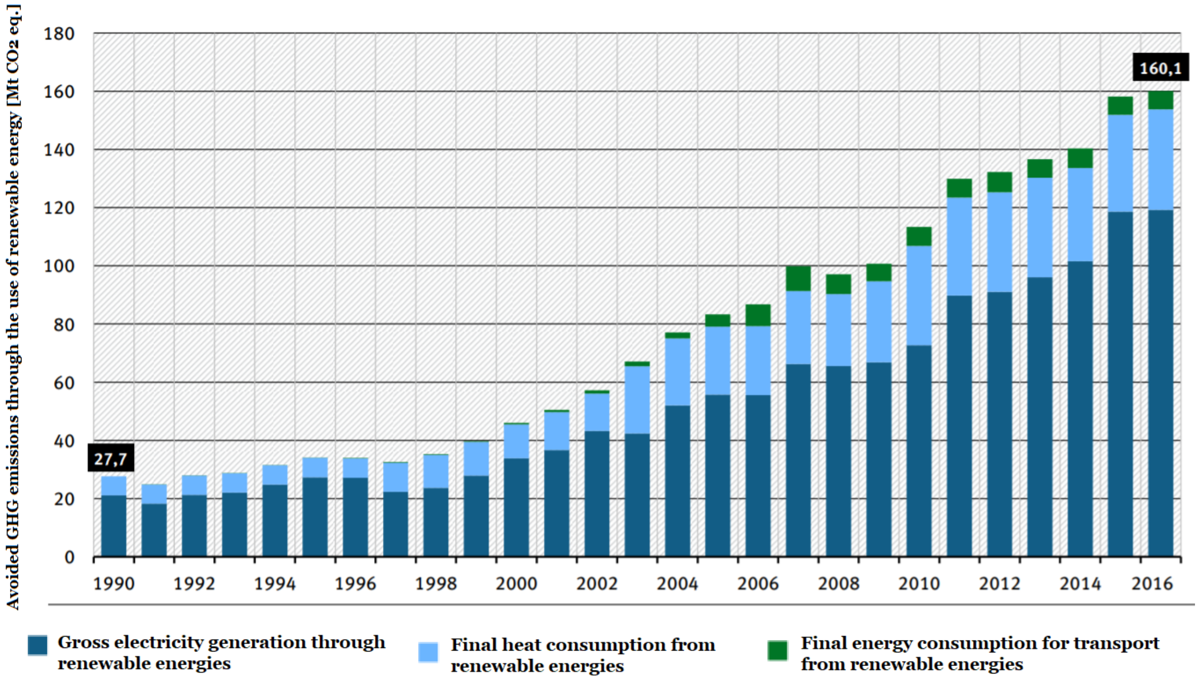


Figure 18: Avoided GHG emissions through the use of renewable sources of energy.

Source: AGEE-Stat (2017).

Still from Figure 18, the biggest share of emissions avoided is due to the generation of electricity from renewables.

2. <u>Diversification of energy supply, energy security and prevention of conflits over natural resources</u>

Much of the political and economic stabiity is under constant risk due to the volatily of the world market price for conventional energy sources, mainly in the case of oil, with sometimes great effects on energy-importing developing countries. In this sense, the development of renawable energies is the key to the diversification of the energy supply, less energy dependence and consequent increase in the energy security of countries that depend on the importation of imputs with the objective of energy production or energy itself. It also should increase the economical benefits, related to the changes in energy trade patterns. Furthermore, in the medium and long-term aspects the development of renewable energies tends to decelerate the consume of fossil fuels, thus extending the availability of most fossil fuels, and thus meeting energical and also non-energetical needs, involving their future use.

The present energy system found in industrialized countries, including Germany (Frauenhofer Institut, 2017), is heavily dependent on fossil fuels, which are geographically concentrated in a few regions of the world. This dependence on fossil fuels, leaves these countries vulnerable to disruption in supply. The risk of conflict, sabotage, disruption of production and trade of fossil fuels exists and cannot be dismissed.

Particularly in the case of oil, almost two-thirds of the world's resources are in the Middle East, mostly in the Gulf region. And any indication or warning of probable trouble involving the commerce of this, induce to abrupt short-term price increases, causing economical problems in many countries and disturbing the growth of global economy. This phenomenon is also known as price spikes.

In this context, renewable energies, appear as a solution for the reduction of this dependence, shielding their economies from external factors, thus giving them greater stability.

3. Health-related impacts

The combustion of fossil fuels is responsible for the emission of several pollutants into the atmosphere, for example, sulphur and nitrogen oxides, carbon monoxide and suspended particulate matter, thus causing negative impacts at local and regional level.

A large group of energy-related emissions, including suspended fine particles and precursors of ozone and acid deposition lead to local and regional air pollution and ecosystem degradation. Withal the human health is also affected by such emissions.

At the local level, the urban air pollution is pointed as the cause for some hundreds of thousands of deaths annually around the planet. At the regional level, precursors of acid deposition from fuel combustion can be precipitated thousands of kilometres from their point of origin. The subsequent formation of acid causes significant harm to natural systems, crops and human-made structures (cars and even buildings), and can still, over time, modify the composition and function of entire ecosystems.

The renewable energies in turn contribute much less to such emissions compared to fossil energy sources. In this way, their use should contribute positively to the maintennance of ecosystems and the relative reduction of atmospheric pollution.

6.1 Energiewende – Promotion of renewable energy in Germany

Aware of the relevance for economic development and welfare, the German goverment created the Energiewende, a national program that aims to reach the "age of renewable energy" as quick as possible and at the same time, keep the price of electricity affordable.

But the implementation of renewable energy technology, as the introduction of any new, innovative technology in an existing market depends on its economic performance, and that rely upon favourable framework condition and the involvement of the finance and business sectors.

6.2 The role of public power in the German energy transition and some legal measures

As previously mentioned, to make the implementation of renewable energy sources a success, favorable framework condition was a required condition. An in this sense, the German government had to create such conditions through various public policy instruments. Here, will be discussed a bit more deeply the fundamental role of the German government to make this transition possible.

In July 2005, the German Federal Government passed the National Climate Protection Program. By signing this document, the German government undertakes to reduce the emission of GHG within its territory by 21% in relation to the levels, registered in 1990, within the period from 2008 to 2012, demonstrating its commitment to tackling climate change. In addition, the government has set goals that are more ambitious than the one from the EU, assuming a leadership role inside the block and committed to reducing its emissions by up to 40% by the year 2020 in case that EU establishes its target as 30% for the same period. Furthermore, the German government still aims a reduction of 80% till 2050.

In Germany about 40% of the total emissions of carbon dioxide are related to the energy sector and for this reason it plays a fundamental role in climate protection and that may be the biggest reason, why the German government set targets for the production of renewable energy. The idea is very simple, goals were drawn in favor of a cleaner production of energy, and thus enabling the success of the goals set in relation to GHG emissions.

With the iniciative the government seeks to double the share of renewables in the national energy matrix in relation to its contribution, compared to the portion in 2000. This means an increase to 4.2% for primary energy consumption and with regard to electricity; it means an increase to 12.5%.

In order to make these numbers possible, the government adopted measures such as the Renewable Energy Sources Act (EEG), which is going to be further discussed in this work, among other measures, such as regulations and ordinances.

In 2007, a publication from the Federal Ministry for the Environment, Nature Conservation, and Nuclear Safety pointed out that, 12% of the electricity and 5.8% of the consumed primary energy were derived from renewable sources for the previous year. The fact that the numbers, that had been established, have already been practically achieved, by the end of 2006, evidences the success of the measures taken and the need for continuity of the national policy and the establishment of more ambitious goals.

In the next items, the measures considered more important for the context of the present work will be presented and discussed with greater detail.

6.2.1 Renewable Energy Sources Act (Erneuerbare Energien Gesetz – EEG)

On account of the declining quantity of fossil fuels and the various environmental problems that involve its use, it is crucial today to focus on sustainable economic use of existing limited resources and on identifying new technologies and renewable resources, such as biomass, for future supply.

The Renewable Energy Sources Act is a vital component of energy policy. It aimed to enable the energy supply in Germany to develop in a sustainable manner, mitigating climate change and protecting the environment. It is intended to deliver an increase on the level of renewable energy sources in Germany, following European tendence.

This Act entered into force in 2000 and it was essential for making the energy transition a success. At that year around six per cent of total energy in Germany was coming from renewable sources. The Act had established some rules in order to enable young technologies, such as wind and solar energy, to enter the market. Support was provided by purchase guarantee and fixed tariffs, making such technologies, interesting investments for investors. That means that the act obligates electrical suppliers to accept the delivery of electricity from renewable sources, such as biomass and still, to pay certain minimum fees for it.

In 2014 there was an important revision of such Act. By this revision, it has been imposed that, new large-scale instalattions have the responsability for marketing the electricity they genarate, integrating those into the electricity market. Besides that, this Act freezed the uprising prices. The price of electricity is, if not the most, one of most important factor guiding competitiveness between energy-intensive industries, which compete in internacional level. These companies are covered by the special equalisation sheme, which in certain circunstances provides for a reduced EEG surcharge.

On 8th July 2016, the new German Renewable Energy Sources Act 2017 was adopted. This new legal framework came into force on 1st January 2017. The revision establishes that, from 2017 onwards, the government wills no longer set the funding rates for renewable eletricity, as it used to be before. Instead, future rates of renewables funding are to be determinated by means of dedicated auction schemes.

Nowadays, renewable energy represents around 33% of total energy in Germany. It is intended to increase this share up to 40-45% by 2025 and to 55-60% by 2035 according to the Federal Ministry for Economic Affairs and Energy (2017).

Figure 19 shows the different sources of energy in Germany and its shares.

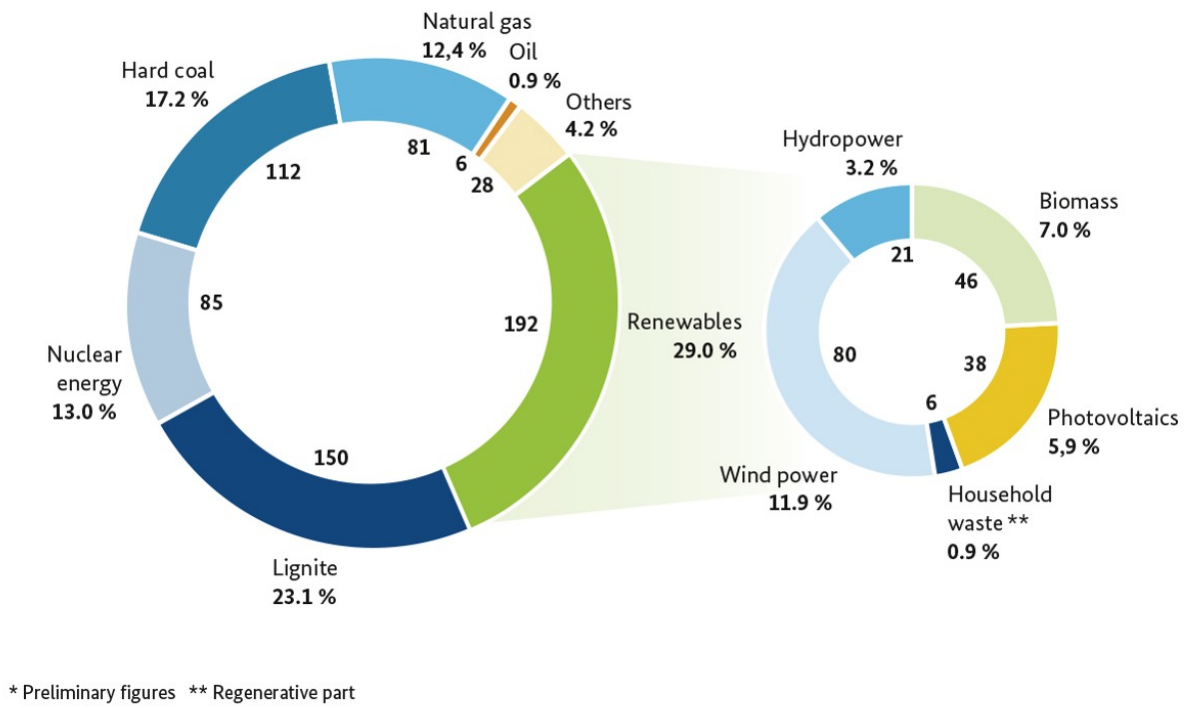


Figure 19: Gross electricity generation in Germany in 2016.

Source: Working Group on Energy Balances (2017).

Since the present paper addresses the cleaner production of energy through the fermentation of the organic portion of waste, here it will be given a major focus for the direct influence that this law has on the production of renewable energy as a whole and for the particular case of energy being produced through the fermentation of organic waste.

As already pointed before, for renewable energies to make a significant contribution for the matter pointed on Section 6.2 from the present work, viable, clear and long-term government commitment is essential. In this sense, the law now under discussion, directly collaborates not only to install capacity, but also to provide the conditions for the creation of a sustained and profitable industry, which, in turn, shall result in higher renewable energy capacity and generation rates, and by doing it, drives costs down. So that all is possible the law seeks to create markets and ensure a fair rate of return for investors. Below, the means used, so that the law can accomplish it all will be discussed.

6.2.1.1 Regulations governing market access: Feed-in law: pricing system

According to Jante L. Sawin (2006), to date, in several cases of implementation of the pricing systems, this type of system was determinant for the growth of predictability and consistency in market, thus stimulating banks and other financial institutions to provide the capital needed for investment.

In Germany, the feed-in law establishes that, electricity distributors are obligated to enable renewable energy plants (including the biogas plants indeed) to connect to the electric grid and also that, the energy coming from renewable sources has its purchase guaranteed, at fixed, minimum prices.

The prices for electricity produced through the fermentation of organic waste is tabulated and given in paragraph §43 from the EEG, outlining a transparent system. Those are set higher than the regular market price and vary depending on the plant's installed power and the material used as feedstock.

The costs related to above-average payments to renewable energy are covered by an additional per kilowatt-hour (kWh) charge on consumers, depending to their level of use.

The ideia behind this model is as follows; the tariffs for electricity coming from biomass fermentation must be high enough to cover costs and even more than that, to encourage the development of the technology. It's the pricing law driving down costs by driving economies of scale and innovation. Technological improvements increase profits, giving support for innovation. Still, about the tariff, this has to be guaranteed for a period of time long enough to assure investors of a sufficient rate of return.

Tariffs defined by law are established with the cooperation with research institutes (as Fraunhofer Institut oder Witzenhausen-Institut) and the renewable industry, with insight into production costs.

6.2.1.2 Financial stimulus for renewables: Low-interest loans and loan guarantees

Around the world one of the biggest obstacles to cleaner production of energy are the high initial costs associated with the deployment of these systems and it becomes nearly impractical to create a system without financial support from banks or any other financing intitution. Therefore, financing assistance in the form of low-interest, long-term loans and loan guarantees should play a key role by reducing the cost of capital, effectively cutting down the avarage cost of energy per unit and thus, the risk of invesment.

In Germany, the goverment devotes effort in this matter by guaranteeing long-term, low-interest loans offered by major banks and refinanced by the federal government (Jante L. Sawin, 2006).

6.2.2 Biomass Ordinance

For the scope of application of the Renewable Energy Sources Act (Erneuerbare-Energien-Gesetz), this Ordinance regulates which substances are classed as biomass, the substances for which an additional substance-based tariff may be claimed, which energy-related reference values are to be used to calculate this tariff and how the substance-based tariff is to be calculated, which technical procedures for electricity generation from biomass fall within the scope of application of the Act and which environmental requirements must be met in generating electricity from biomass.

The values determined in this document will serve as basis for further calculation of the theoretical value of the energy produced through the anaerobic digestion of the organic portion of household waste, for the production of biogas.

Through Figure 20 and Figure 21, it is possible to affirm that the use of biomass as raw material for the production of heat and electricity in Germany has been growing more and more in recent years.

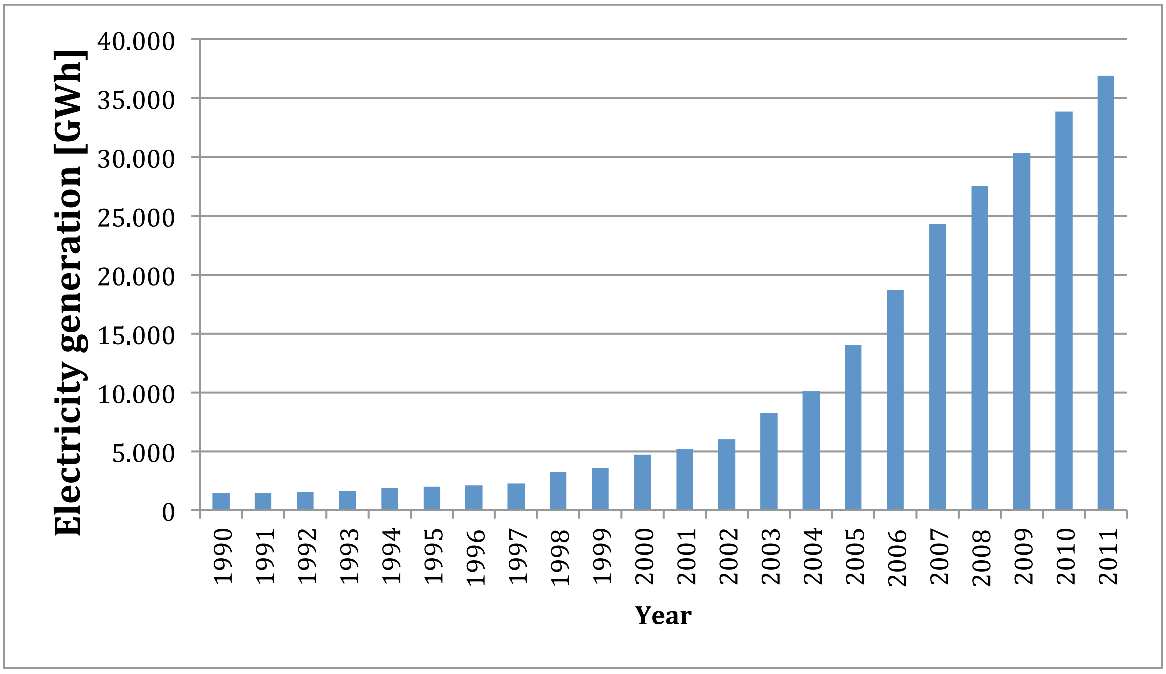


Figure 20: Development of electricity supply from biomass plants in Germany from 1990 to 2011.

Source: BMUB (2012).

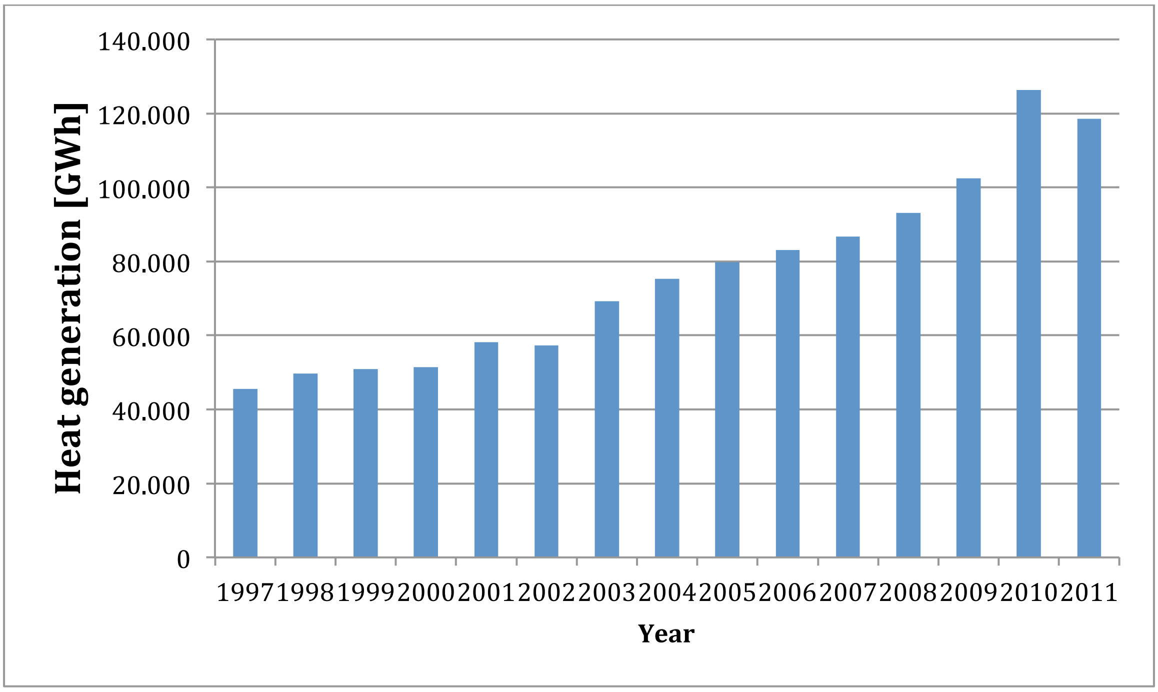


Figure 21: Development of biomass use for heat production in Germany in the years 1997 to 2011.

Source: BMUB (2012).

As it can be noticed, through Figure 20 and 21, Germany demonstrates great experience to recover and use biomass energy.

With regard to the increase in energy generation through the use of biomass, there is strong evidence that, this fact is closely linked to the existence and validity of legislation that supports this practice. By analyzing both figures presented above, Figure 20 and Figure 21, it is possible to say that, the almost exponential increase in the production of electricity and heat starts in the year 2000, precisely the year that, EEG entered into force, ratifying the idea that legal support culminated in an increase in primary energy production from biomass.

The adaptation of waste management practices, to include biogas generation and collection, can be considered an alternative option to improve the environment condition caused by organic solid waste and at the same time taking an advantage as an environmentally friendly resource of energy.

6.2.3 Closure of nuclear power stations

The anti-nuclear movement gained strenght after the Fukushima nuclear accident in Japan in 2011. Within days, large anti-nuclear protests occurred in Germany.

On June 30, 2011, as a response to anti-nulcear protests, the government ordered the immediate end of the activities of eight of Germany’s 17 reactors. Besides that, the Federal Government established that the rest of the nuclear power plants have to shut down by 2022, hence avoiding the risks associated with this technology.

Over 80 percent of parliamentarians in the Bundestag passed the nuclear phase-out plan.

The Figure 22 exhibits a symbol of protests, for the closure of nuclear power plants in Germany. The image brings the following words: “Atomic power? No thanks”.

Figure 22: "The Smiling Sun".

Retrieved from: http://www.smilingsun.org/

This means that Germany has a huge challenge ahead of it, seeing itself obligate to compensate the energy, that currectly comes from atomic power plants, for energy from other sources. Currently the atomic energy represents 13% of all the energy produced in the country, according to the Figure 19, previously presented.

This reinforces Germany's need for the development of technologies for alternative and renewable energy sources.

6.2.4 Taxation on conventional energy

Further, in favor of the promotion of renewable energies, goverments have to eliminate any kind of policies that favour conventional fules and its technologies, failing to recognize the social, environmental and economic benefits from renewables.

In this sense, the German government enacted three laws, in 1998, 1999 and 2002, also known as "Eco-Tax" (short for "ecological taxation"). An Eco-Tax is a tax imposed on activities, which are recognized as harmful to the environment. It seeks to promote environmentally friendly activities via economic incentives, in this way.

From the lwas above mentioned, the first introduced a tax on electricity and fossil fuels, at variable rates; renewable sources of electricity were not taxed. The second only adjusted the taxes in favor of efficient conventional power plants. Already the third increased the tax on fossil fuels, making them less competitive and less interesting from the point of view of investors.

The energy tax has become the third largest source of income fro Germany’s Finance Ministry, behind income tax and sales tax only (BMUB, 2017).

7 LEGAL BACKGROUND CONCERNING WASTE MANAGEMENT AND ENVIRONMENTAL PROTECTION

Dealing with large-scale biodegradable waste often results in many logistical problems and environmental impacts to be considered. These can become great barrier when the integration of solid waste management is concerned. Extra care is needed to plan such waste disposal or treatment services and facilities, especially with respect to the ecological impact, involving problems such as air and water pollution, due to gas and leachate production. A Solid Waste Management programm is therefore integral for proper sanitation of any city.

This chapter provides an overview of the waste management policy measures and instruments, in the European and in the German level, which, more or less strongly, can have an impact on the handling and use of biowaste from households.

7.1 The development of waste policy in Germany

The “modern era” of waste management did not begin in Germany until the mid-1960s. At that time, the federal government established the legal basis for proper waste disposal, which designated local communities as responsible for the disposal of waste, accompanied by the threat of legal penalties (Bilitewski, 1994).

Primarily, waste managers in Germany had to think about, how to deal with the problem of waste volume. Till the end of the 1960s, waste was simply disposed of in a large group of small dumps. As late as 1972, the quantity of waste generated per year was crudely estimated to be between 9 and 18 million tonnes (Ersner, H. 1972). At that time, there were about 50,000 garbage dumps in the Federal Republic of Germany; most of them unregulated dumping grounds. As soon as the risks related to these uncontrolled refuse dumps were acknowledged, particularly the exposure of groundwater, the closing of those was given a high priority.

There was a demand for the construction of sanitary waste disposal facilities. At first, public and political interest was focussed on build safer disposal sites and also to turn the incinerators cleaner (BMUB, 2017). Also, managers should prevent any danger to the health welfare of the human and animal population.

All that was finally became law in 1972, when the “Waste Disposal Act” was signed, representing a big step towards dealing with waste problems. Regulations were adopted for dealing with different types of waste; those established stricter emissions limits for the incineration plants and also imposed more rigorous requirements for the construction and operation of waste disposal sites. In order to meet the new specifications imposed, municipalities and private disposal companies had to invest billions in the waste business.

Yet, a waste disposal crisis was imminent and it was soon recognized that, safe disposal on its own wasn't enough to solve the "waste problem" faced in the country. A harsh reduction of waste volumes was necessary. In addition, responsible resource management by recycling and energy recovery was also fundamental. In 1986 a new Act was elaborated, trying to fix waste amount dilemma. The "Waste Avoidance and Management Act" set waste avoidance and recycling of waste, in order, as priorities over waste disposal, marking a policy reorientation, as shown in Figure 23.

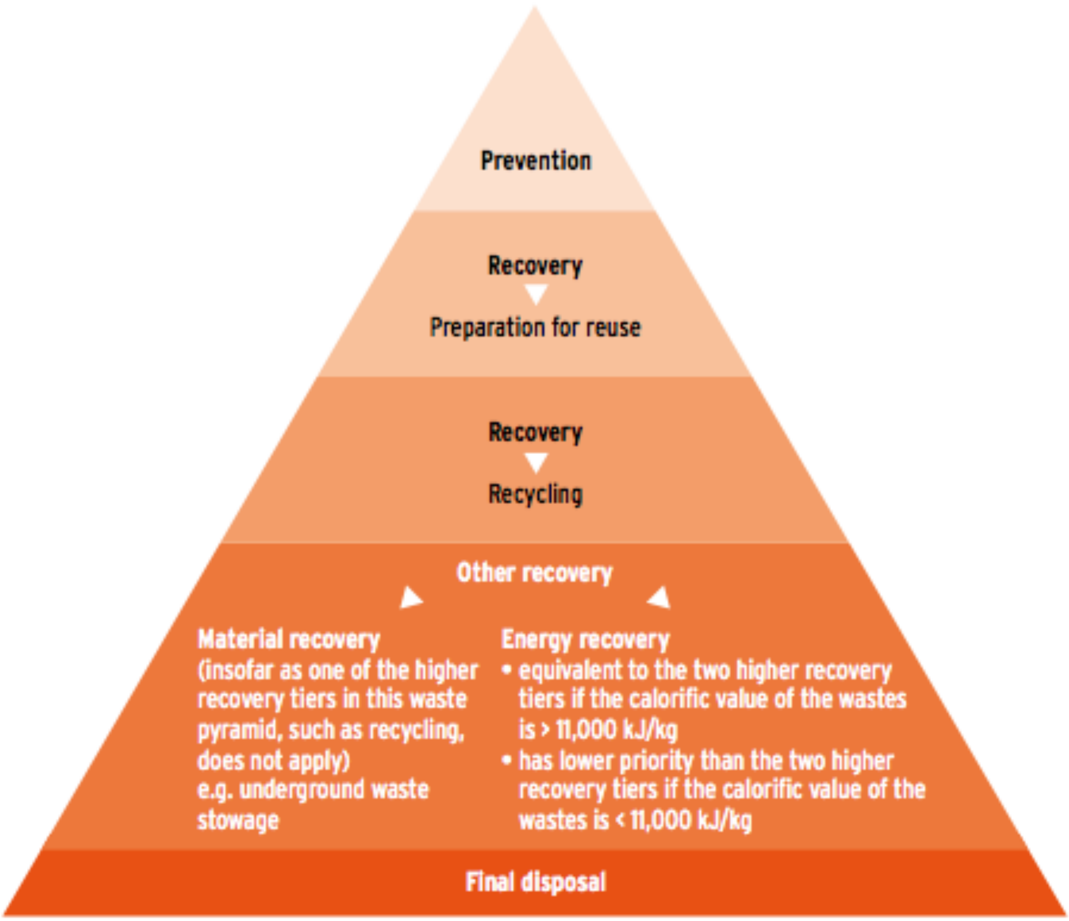


Figure 23: Waste hierarchy.

Source: Federal Ministry for the Environment, Nature Conservation and Nuclear Safety - BMUB (2011).

The most recent waste management policies seek to establish and develop a more sustainable economy, focussing environmental protection and prevention through conservation, reusing and recycling of resource, in order to minimize pollution from the source and reduce overall waste per unit output.

Among the last decades it's possible to notice a change on the way that the public sector and the society recognize and deal with their solid waste. Waste became an important source of money, energy and even raw material for the manufacturing of new products, if proper treated.

7.2 Principles and measure of environmental policy

Any instrument of environmental policy should aim to limit ecological damages related to production, consumption and disposal of goods, or to remedy the problems after they occur, in order of priority.

Waste management is a component of environmental legislation, which defines the concept of waste, as well as the transport, treatment and the disposal of waste.

7.2.1 European Union law

Due to its level of development, Europe plays a leadership role in the intergovernmental process of defining the universal sustainable development goals called for at the summit meeting on sustainable development in Rio in June 2012.

Europe has no choice but to make an effective transition to a greener economy, to develop more sustainable technologies, and to respond to the challenge of sustainable development in the economic, social and environmental sectors. Germany's domestic approach and progress on sustainability definitely will be indispensable for achieving this wider sustainability goal for the whole of Europe [texto sustentabilidade].

About the law system in the EU, its waste law forms the legally binding basis for waste legislation of the EU member states. The EU influences the legislation of each Member State, including Germany, through numerous directives and regulations.

7.2.1.1 Waste Framework Directive (WFD)

On 19th November 2008, the Waste Framework Directive (WFD) was adopted. This Directive defined waste prevention as the first priority of waste management.

A new definition of "waste" is given, and waste should be understood as "movable property, which has been or is intended to be discarded", distinguishing this from its by-products.

The Directive still requires recycling materials to be collected separately. And still, for the first time, percentages for recycling paper, glass, plastics and metal are specified, 50% by 2020.

At last but not least, the Article number 22 of the Directive says that, the Member States of the European Union should take the necessary measures to promote the segregate collection of biowaste, with a view to composting or to fermentation.

7.2.2 German Federal Legislation

Germany is a Federal Republic consisting of sixteen Federal States (Bundesländer). The national Ministry for environmental matter ("Bundesministerium für Umwelt, Naturschutz, Bau und Reaktorsicherheit" or just BMUB) sets national priorities, defines requirements for waste facilities participate in the law "making-process" and so on.

National laws must always be more restrictive than those at European level, ensuring that they are not disregarded.

Besides that, each federal state can also adopt its own waste management act, containing supplementary regulations to the national law, e.g. concerning regional waste management concepts and rules on requirements for disposal.

There is no national waste management planning in Germany. Instead, each Federal State develops a waste management plan for its area (EEA, 2009).

7.2.2.1 Closed Substance Cycle Waste Management Act (Kreislaufwirtschafts- und Abfallgesetz, KrW- / AbfG)

The key Federal waste law in Germany may be the "Closed Substance Cycle Waste Management Act", which first came into force on 1996. On 1 June 2012, the Act was enhanced and transformed into the "Circular Economy Act". This transposed the EU Waste Framework Directive into German law.

The law says that, waste must, primarily, be avoided and secondarily, be subjected to substance recycling or used to obtain energy.

In addition, this Act still establishes requirements for "Closed Substances Cycle Waste Management" or for a "Circular Economy", in the most current terms.

The Act establishes even more demanding rates of recycling, than targets set at the European Union level (on the WFD). By 2020, 65% of all domestic waste is to be recycled.

The aim of the Act is to promote low-residue, closed-loop waste management, by using the waste, when it is possible, in order to conserve natural resources and to protect people and the environment, by not eliminating wastes pollution potential.

On § 11 paragraph 1, the Act obligates the introduction of segragation collection system of biowaste at latest on 01.01.2015. The date can be subjected to postponement, by use of other regulations.

Still, § 12 claims the conditions for the quality assurance in matter of biowaste recycling, in order to assure that the process won't cause any harm.

Still, according to Baum und Wagner (2000), waste can be classified according to the various motivations for dealing with it in closed loop systems. Good waste either remains in the economic circulation directly or indirectly via recycling.

According to the "Federal Ministry for Environment, Nature Conservation, Building and Nuclear Safety", through the "Circular Economy Act", Germany has successfully developed a modern circular economy. At the same time that, resources are becoming scarcer and climate change has become a global priority issue, the closed-loop economy is making a significant contribution to climate action (BMUM). Over the last years, the emissions of GHG related to waste management activities, in particular methane (the main component of landfill gas), have decreased significantly.

7.2.2.2 Legislation on bio waste recovery

The recovery from bio waste has already been regulated since 1998, year in which the "Bio-waste Ordinance (BioAbfV)" came into force.

The Ordinance brings a serie of sanitary requirements in order to control the possible appearance of pathogens, which is possible, both in composting and in the fermenation of this type of waste. Besides that, the Ordinance set limit values for some pollutants, which may occur in the compost and fermentation residues, produced during treatment and used mostly as fertilizer or soil amendment. A little further on this work, will be presented, the maximum values for the concentration of heavy metals in the compost.

In April 2012, the amendment "Ordinance on Biowastes" was published and entered in August from the very same year fully into force. Through the Ordinance, a standard delivery note was introduced and the documentation and record keeping obligations were revised.

In order to assure a uniform enforcement of the Ordinance at national level, the various feredal units drew up guilines focusing the enforcement authorities. Those are to be found under the name: "Guidelines on the Enforcement of the Amended Ordinance on Biowastes (2012)". This should be understood as a supportive tool for the local authorities, responsible for the introduction and application of the "rules of biowaste" on the enforcement of the ordinance in a legally binding way. The guidelines should be significant helpful to operators of biowaste treatment plants, manufactures of mistures containing biowaste and also to farmers applying biowaste and mixtures to land.

7.2.2.3 Landfilling of biodegradable municipal waste

The landfilling of Biodegradable Municipal Waste (BMW) is of big environmental concern. First of all, the decomposition of BMW results on the production of landfill leachate, which can contaminate groundwater, if not enclosed and still, GHG are also produced, contributing to Global Warming. Besides that, landfilling of BMW represents a potentially valuable resource being wasted. By redirecting BMW away from landfilling to recycling and recovery practices such as composting or anaerobic digestion or material recycling, valuable resources can be produced and the exploitation of virgin resources and energy and the amount of land required for landfill can be reduced.

EU Landfill Directive required from all its members to reduce a certain porcentage of its biodegradable municipal waste (BMW) that was been landfilled. Specific percentages were established as targets for the years of 2006, 2009 and 2016. The targets were calculate based on the generated amount of BMW in Germany in the year 1995, which was 28.4 million tonnes.

Technical intructions on waste from human settlements were established in 1993. Requirements on the location, design and operation of landfill and also the composition of waste accepted for landfilling, were defined and every stakeholder involved had some time for the transition, providing legal and plannig certainty. At that time the organic content in waste going to landfills had been limited at 3% total organic carbon (TOC), with transition period till 1st June 2005.

After that, “Landfill of Waste Ordinance” established that after 1st June the maximum carbon content should not exceed 18% for municipal waste, which has been mechanically/biologically pre-treated.

Aiming to meet composition requirements, waste with high carbon content stopped been landfilled and Germany has reported that zero tonnes of BMW (Biological Municipal Waste) hadn’t been landfilled in 2006, 2007, 2008 and 2009 (Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety, 2006).

8 ANAEROBIC DIGESTION – THE TECHNOLOGY AND ITS TECHNICAL ASPECTS

8.1 Introduction

The anaerobic digestion is a natural process found in mature in oxigen-free environments.

During anaerobic digestion organic matter is transformed to methane through different steps by a conglomerate of microorganisms. In the course of the hydrolysis, complex materials such as proteins, long chain carbohydrates and lipids are broken into their components: amino acids, sugars and long chain volatile fatty acids, respectively. These components are then converted into acids, characterizing the so-called acidification. After that, the products of acidification are converted into acetate, hydrogen and carbon dioxide during acetogenesis and these subsequently feed the last step of the process, known as methanogenesis, when finally, biogas is produced.

This biological process occurs in the absence of oxygen. A combination of microorganisms working synergistically, decomposes organic matter, producing so biogas and a nutrient rich digestate, which is composed of a liquid portion known as liquor and a solid fibrous material.

Typically, the biogas produced during the process, consists of around 60% methane (CH_4), around 30% of carbon dioxide (CO_2) and still, small amounts of hydrogen sulphide (H_2S) and ammonia (NH_3). The methane is a great source of energy and can be used for the production of heat and even electricity (Deublein and Steinhauser, 2008).

During the process some factors have to be monitored in order to ensure a stable manner for optimal biogas production. The most important conditions to be considered when designing an AD are: pH, temperature, DS content, retention time, organic loading rate and the ratio between carbon and nitrogen.

The principal features of an AD system are illustrated in the Figure 24.

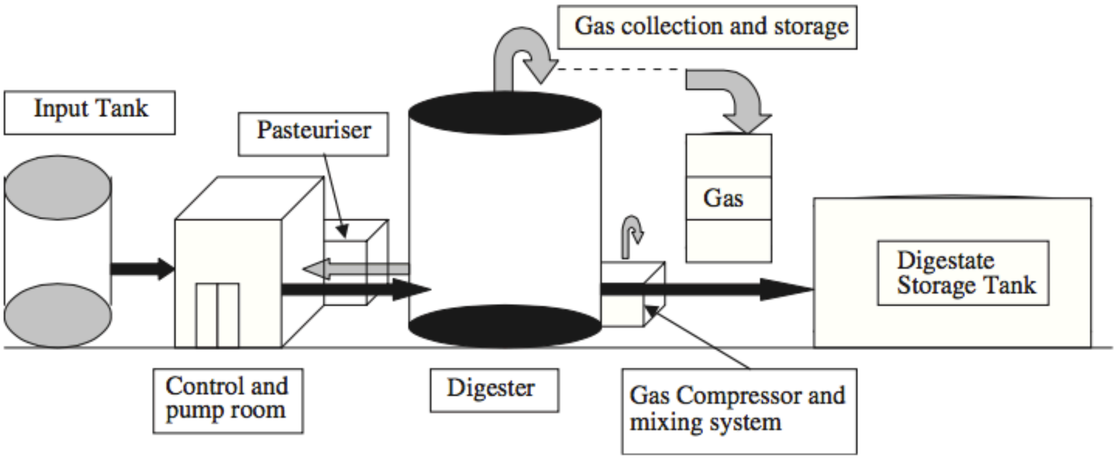


Figure 24: General layout of an AD.

Source: Duerr, M., Gair, S., Cruden, A., McDonald, J. (2007).

8.2 Biochemical reaction

To understand how methane and carbon dioxide are produced a knowledge of a biochemical and microbiological breakdown of organic matter in soil is required.

In nature, methane-forming archaeas are found by the decomposition of biogenic-organic material, in an environment characterized by oxygen deficiency. These microbes, also known as "obligate anaerobes", can only survive in the absence of oxygen.

The formation of methane from biomass normally acts in accordance with the equation, shown below:

$$C_cH_hO_oN_nS_s + y\ H_2O \rightarrow x\ CH_4 + n\ NH_3 + s\ H_2S + (c - x)\ CO_2$$

Where: $x = 1/8 \cdot (4c + h - 20 - 3n - 2s)$

$y = 1/4 \cdot (4c - h - 20 + 3n + 3s)$

The ratio of CO_2 to CH_4 is driven by the reduction ratio of the organic raw material.

In practice, the convertion to biogas is not complete. The volume o biogas, which can be produced through the fermentation of the substrates, depends on some factors, among them:

- Portion of material with a high-energy content in the organic mass;

- Matter of organic dry material in the entire dry biomass;

- Dry matter content of the substrate;

- Actual grade of decomposition observed in the biogas plant.

8.3 Phases of degradation

The metabolism of methane-forming archaea depends on the preparatory work of the “metabolism-environment” and the symbiosis with other microorganisms.

The methane fermentation is a complex process, which can be divided up into four phases of degradation. These phases are known as hydrolysis, acidogenesis, acetogenesis, and still, methanation, according to the main process of decomposition that takes place in this phase. Each of these phases are carried out by different groups of microorganisms, which partly remains in cross-feeding interrelation, i.e. one microorganism that lives off the product of another specie, and place different requirements on the environment.

The formation of methane respects an exponential equation, in principle.

Both the first in relation to the second and the third in relation to the fourth phase are intimately linked. As a result, one can carry out the process well in two steps. In both of them, the rates of degradation have to be equal in size.

In case that, the hydrolytic stage runs too fast, the CO_2 share in the biogas increases, consequently the acid concentration goes up and the pH value drops below 7.0 and finally, the acid fermentation is then realized in the second stage as well. In the case the second stage takes place too quick, then the methane productionshould be reduced. There are still many microorganisms of the first stage in the substrate and the archaea of the second stage have to be inoculated.

Figure 25 shows the fourth different stages that are observed during the fermentation conducive to the production of methane.

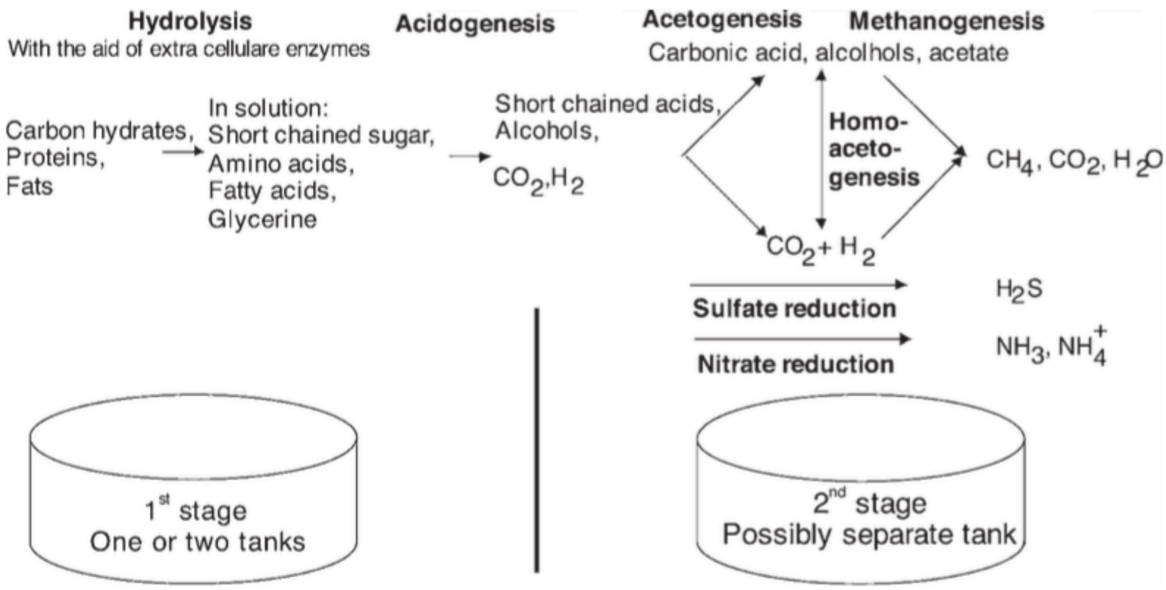


Figure 25: Anaerobic decomposition.

Source: Deublein, D., Steinhauser, A. (2008).

8.3.1 Hydolysis

During the first one, also knows as "Hydrolysis", high-molecular compounds (between them, lipids, carbohydrates and proteins) react with water, forming sugar, fatty acids and amino acids. Hydrolysis is actually the name of any chemical decompostion in which a compound is split into other compounds, which have a simpler structure, by reacting with water.

Figure 26 demonstrates the formation of monomers (R-Rest), in chemical reaction with water.

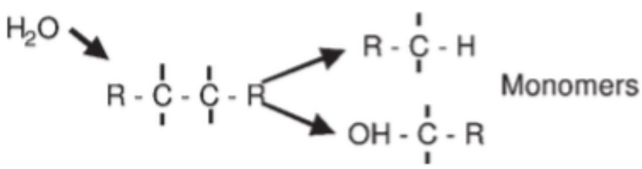


Figure 26: Formation of monomers (R-Rest).

Source: Deublein, D., Steinhauser, A. (2008).

The hydrolysis of carbohydrates occurs within a few hours, while the hydrolysis of lipids and proteins takes a bit longer, in a period of a few days. Woody materials show a greater resistance to decomposition, due to the presence of lignine, the lignine are degraded very slowly and yet incompletely.

The microorganisms present in this phase, which are only facultative anaerobic, capture the oxygen dissolved in the water and so cause the low redox potential necessary for the other microorganisms, the obligatorily anaerobic ones (Deublein and Steinhauser, 2008).

8.3.2 Acidogenesis

Acidogenesis means acid formation.

During this phase, the monomers formed when the hydrolysis, are degraded to short-chain organic acids, alcohols, hydrogen, and carbon dioxide, by the action of different facultative and obligatorily anaerobic bacteria. The organic acids formed comprises butyric acid, propionic acid, acetate and acetic acid.

The concentration of the intermediately formed hydrogen ions influences the nature of the products of fermentation (Deublein and Steinhauser, 2008).

8.3.3 Acetogenesis

The products from the acidogenesis provide the necessary substrate for other bacteria, present on the the acetogenic phase.

The reaction of the phase, now discussed, are endergonic, which means, they are heat absorb nonspontaneous reaction. In this type of reaction, the Gibbs free energy increases.

During this phase, homoacetogenic microorganisms (strictly anaerobic microorganisms) continually reduce exergonic H_2 and CO_2 to acetic acid, as it is shown below:

$$2\,CO_2 + 4\,H_2 \leftrightarrow CH_3COOH + 2\,H_2O$$

The acetogenic bacteria are essentially H_2 producers. The oxydation of long-chain fatty acids forming acetate performs on its own and so only by low hydrogen partial pressure is it thermodynamically possible. Therefore, acetogenic bacteria depends on very low H_2 concentration for its survival.

Meanwhile, methanogenic organisms survive exclusively by higher hydrogen partial pressure. They continually consume the products of the metabolism of the acetogenic bacteria from the substrate and hence keep the hydrogen partial pressure at a low level, just appropriate for the acetogenic bacteria.

For that reason, acetogenic and methanogenic microorganisms have to live in symbiotic interaction.

In the case of low hydrogen partial pressure, H_2, carbon dioxide and acetate are essentially formed by the acetogenic bacteria. On the opposite side, when the partial pressure of H_2 is higher, above all, butyric, capronic, propionic and valeric acids, as well as, ethanol is formed. From all what is produced, no more than acetate, H_2 and CO_2 can be processed by methanogenic microorganisms.

A very peculiar phenomenon happens involving the hydrogen, which is called "interspecies hydrogen transfer". The hydrogen moves directly from the acetogenic microorganisms to the methanogenic ones, without being dissolved in the substrate. This explaining the fact that, around 30% of the absolute CH_4 production in the anaerobic sludge is attributed to the reduction of CO_2 by H_2, on the other hand, just 5 to 6% of the entire methane formation can be attribute to the dissolved hydrogen. The Figure 27 reveals, how this phenomenon works.

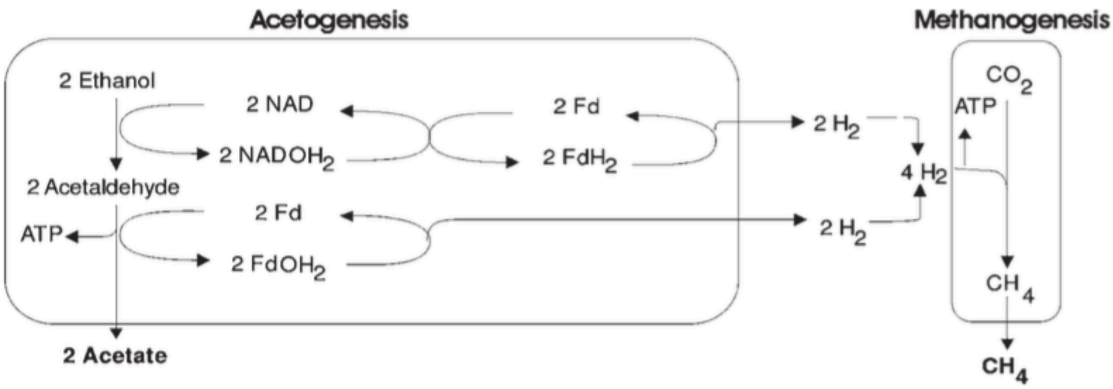


Figure 27: "Interspecies hydrogen transfer".

Source: Deublein, D., Steinhauser, A. (2008).

The conversion of alcohols and fatty acids occurs thanks to the energy coming from the methanogenics, which in return, receive the necessary substrate (H_2, CO_2, acetic acid) for the growth of the acetogenic bacteria.

The acetogenic phase limits the rate of degradation in its final stage. It is possible to estimate the rate of activity of the acetogenic bacteria by measuring the quantity and the composition of the biogas produced.

Still on this phase, organic nitrogen and sulfur compounds can be mineralized to hydrogenic sulfur through the production of ammonia (Deublein and Steinhauser, 2008).

8.3.4 Methanogenesis

During this stage, the formation of methane occurs under stricly anaerobic conditions. The methane formation reactions are without exceptions exergonic, that means, a reaction that realeases energy in the form of work. Each of the methanogenic species are not able to degradate all substrates. One can divide adequate substrates for the methanogenesis into the following three groups:

CO_2 type: CO_2, $HCOO^-$, CO

Methyl type: CH_3OH, CH_3NH_3, $(CH_3)_2NH_2^+$, $(CH_3)_3NH^+$, CH_3SH, $(CH_3)_2S$

Acetate type: CH_3COO^-

When the formation of methane works properly, the acetogenic phase also works without problems. However, if the formation of methane is disturbed, overacidification occurs.

As mentioned before, acetogenic archaea present on the reaction are inhibited by their own product, the hydrogen, and therefore these bacteria depend on other microorganisms, the methane-forming ones, to detoxify their environment, setting a symbiotic relationship. Therefore, it is a problem, when the acetogenic bacteria live in symbiosis with other organisms, but the methanogenic ones. In waste water technology, a simbiotic relationship may occur with other microorganisms, which reduce sulfate to hydrogen sulfide. Consequently, they demand hydrogen, competing with the methanogenic ones. Methanogenic archaea have then restricted offer of hydrogen and hence form less methane. Additionally, hydrogen sulfide can be toxic to methanogenic archaea (Böhnke, Bischofsberger and Seyfried, 1993).

Each of the reactions where methane is formed present different energy yields.

The reaction of oxidation of acetic acid if compared with the rection of reduction of $CO_2 + H_2$, producing CH_4 is much less exergonic, as it can be ssen below:

$CH_3COOH \leftrightarrow CH_4 + CO_2$ at a $\Delta G^o = -31$ kJ/kmol

$CO_2 + 4\ BADH/H^+ \leftrightarrow CH_4 + 2H_2O + 4NAD^+$ at a $\Delta G^o = -136$ kJ/kmol

However, just 27 to 30% of the methane arises from this reduction, in the time that about 70% derives from acetate during its methanation.

The methane-forming archaea, which use acetate, proliferate in acetate very slow, with regeneration time of at least 100 hours in theory, whereas CO_2 has showed up to be essentialfor the growth. It is important to take into account that, in practice, the regeneration time observed can be much longer (Deublein and Steinhauser, 2008).

8.4 Substrate requirements

The best feedstock is one, which is a wet slurry with high volatile solids and low nonbiodegradables.

For a stable decomposition process, the substrate should consist of sufficient biogenic-organic substance. Easily digestible, low-molecular compounds are the perfect substrate for this type of decomposition. The disintegration of high-molecular biopolymers takes much longer time to be done, making the process an unattractive alternative for municipal waste treatment, thus plant matter is a poor substrate for biochemical processes unless some pretreatment system is used to separate or solubilize the lignin.

The anaerobic microorganism need “nutritive salts” and trace elements to proliferate. There are some substances that are capable of decreasing or stopping completely the reaction, so called “Inhibitors”. In the fermantation of household waste, these are oft discarded antibiotics or desinfectants.

Besides that, household waste can also present heavy metals and salts that generally inhibits the process and are toxic above certain concentrations, thus, a pre-treatment is necessary for the efficiency of the process.

The ratio C/N of the substrate should be among the ratios 16:1 and 25:1. But this is only an indication, considering that nitrogen can likewise be in lignin structures bound. Substrates presenting low C/N ratio drives to increased ammonia production and restriction of methane formation. On the other hand, a too high C/N proportion drives to difficulty on the formation of protein (Deublein and Steinhauser, 2008).

8.5 Pre-treatment

Biowaste has to pass through an intensive pre-treatment in general.

This pre-treatment is intended to remove unwanted matter and posteriorly to fragment and homogenizate the material to be digested.

Besides that, the treatment steps and the combined to be treated for biowaste have to be adapted according to the plant specific conditions.

It begins with the removal of certain materials from the input material, such as plastics and textiles, which should not be treated in anaerobic fermenter. They are not biodegradable and, still can wrap around moving parts, destroying mixing action. Despite technological advances, separation techniques have high separation rates but still cannot guarantee 100 percent efficiency.

After the removal of such matter, the comminute is to take place. The material suffers intense mechanical treatment been divided into small parts, leading to the enlargement of the specific surface area and hence improving the capacity of water absorbency. This part is essential to prepare the substrates for an efficient fermentation process.

Subsequently the material is to be mixed. As a result, a homogeneous material is to be find, that means, an aggregate with property that vary very little from one point to another. This step is therefore reasonable especially if the consistency of substrates is varying.

Mixing is essential for biogas production and has to be controled. Too much mixing stresses the microorganisms and the absence of mixing drives to foaming. Proper mixing leads to a faster degradation due to improved transportation processes (Deublein and Steinhauser, 2008).

8.6 Process parameters

As it happens with any other biological process, the constancy of the living conditions during the anaerobic decomposition of solid waste is of vital importance for the microorganisms, involved in the process. A simple variation in temperature or in the substrate may lead to shutdown of the gas production. It can take up to a few weeks, so that the ecological system inside the anaerobic reactor adapts to the new conditions and starts to produce gas again.

The microbial metabolism processes are determined by many parameters, thus, in order to optimize the fermenting process, numerous parameters, such as temperature and pH value, have to be taken into account and be controlled. Furthermore, there are different species of methane-forming archaea, each of them with different preferences of temperature. In waste treatment, there are two prefered temperature ranges with an increased gas production. The first one is called "Mesophilic" range, in which the temperatures are between 32 and 50 °C and the other one is called "Thermophilic", in which the temperatures are between 50 and 70 °C (Weiland, 2001).

If we compare the two periods, there are less types of microorganisms working in the hottest temperature range, and therefore the thermophilic fermentation is biologically less stable. Due to the greater technological efforts and bigger energy input required to maintain thermophilic temperatures in the reactor, most reactors operate at mesophilic temperatures.

During the hydrolysis and the acidification phase, bacterial activities require slightly pH values, while during the methane-forming stage pH should be around neutral.

Some of the above mentioned and other environmental conditions required for the metabolic processes that take place during the biogas fermenter are listed and pointed on the Table 5.

Parameter	Hydrolysis/acidification	Methane fermantation
Temperature	25 - 35 °C	mesophilic: 35 - 40 °C
		thermophilic: 52 - 57 °C
pH - Value	5.2 - 6.3	6.7 - 8.2
C:N - Ratio	10 - 45	20 - 30
Solid matter content	< 40 % dry matter	< 30 % dry matter
Redox potential	+400 - -300 mV	< -250 mV
Nutrient demand C:N:P:S	500 : 15 : 5 : 3	600 : 15 : 5 : 3
Trace elements	no specific requirements	essential: Ni, Co, Mo, Se

Table 5: Environmental requiremens.

Source: Weiland (2001).

As a consequence of what is being shown in the table above, it can be concluded that, the only way to set optimum environmental conditions for all microorganisms involved in the digestion is by using a two-stage plant, where hydrolysis and acidification take place in one tank and the acetogenesis and the methanation take place in another tank.

Contrarily, if the entire process has to take place in a single tank, a 1-stage-system, priority should be given, so that the requirements of methanogenics are repected, otherwise these microorganisms would have not a chance of survival, inside the mixed culture, on account of their lower growth rate and higher sensibility to environmental factors, in comparison with other microorganisms.

There are still some specific situations, where greater attention is demanded.

In the case of the existence of substrates containing lignin, what limits the process is the hydrolysis, deserving therefore greater attention.

For substrates presenting high protein value the ideal pH does not present significant variation and therefore, the use of a single stage for the digestion is sufficient for satisfactory results to be reached.

Still, in another disparate situation, in case of a high fat content, the hydrolysis progesses quicker than usual, emulsification increases, bioavailability likewise also increases and thus the acetogenesis is limiting. In those cases, preference should be given to a thermophilic catabolism of fat.

8.7 Variations of biogas techniques

An essential feature for the classification of the fermentation processes is the model of operation, whereby a distinction can generally be made between continuous and discontinuous processes.

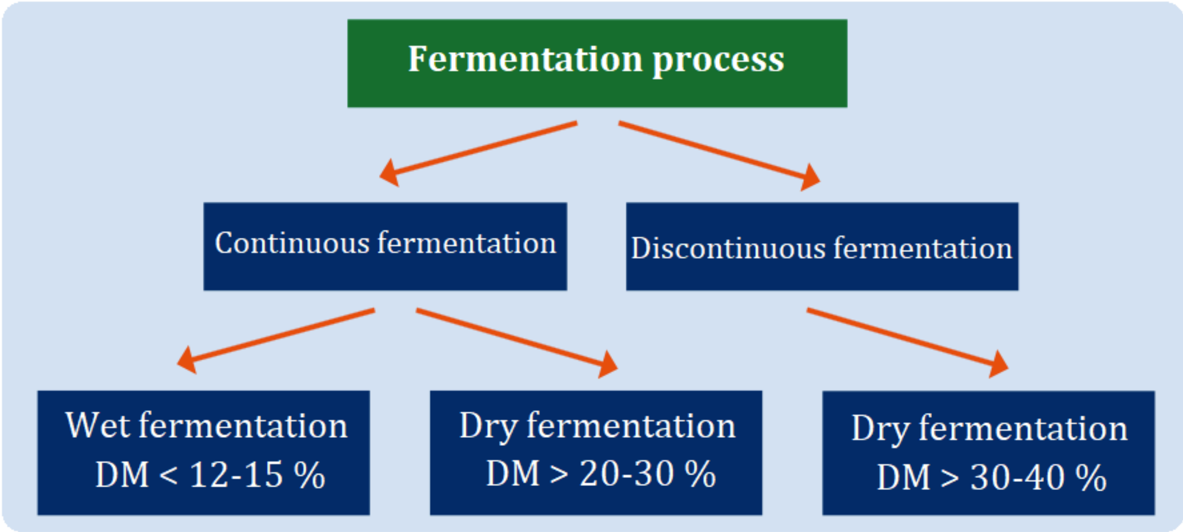
In the continuous processes the organic waste is added regularly to the fermentation reactor (also known as "digester"), which promotes continuouus biogas production with constant quality.

In constrast to that, in the discountinuous process, the digesters are filled by wheel loaders, emptied after a couple of weeks and then refilled (batch operation). The biogas production is not continuous, but a parallel connection of several delayed-acting digesters can largely compensate for this.

Discontinuous processes have advantages over continuous processes due to their technically simpler reactor systems. On the other hand, because of their higher space-time yields, they require a smaller reactor volume and are generally easier to automate than discontinuous processes.

Besides all that, the processes still differentiate between dry and wet fermentation, each of which is more suitable, depending on the degree of moisture of the mixture.

The possible variations of the process are indicated in Figure 28.



** DM is the abbreviation for "Dry Matter".*

Figure 28: Possible variations of Anaerobic Digestion.

Adapted from: Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit (BMU) (2012).

The values presented in Figure 28, should be understood as values for comparison and do not have an exact character.

The variations mentioned here will be further discussed in the next items.

8.7.1 Dry and wet fermentation

Microorganisms do not flourish in dry conditions, so biodegradation starts only when waste is moist.

What distinguish dry from wet fermentation is the water content of the substrate. In dry fermentation the water content is of about 70 to 80% of weight and in the wet fermentation, whereby water is still added to form a sludge, the percentage is of 85 to 90% of weight. In the dry fermentation substrates are not pumpable, as in the wet alternative, which also makes the transport and mixing of the material with the fermenter a bit harder.

In both of them, during microbiological transformation processes, in the fermenters, dry matter will be degraded and water is developing (Schüsseler, 2004).

The dry technique is most done single-stage. These systems are less susceptible to foreign matters, and therefore are increasingly used for the treatment of biowaste. Still, dry fermentation requires less water and the full capacity of the digester can be utilized.

On the other hand, wet fermentation permits the removal of floating and siking matter and still, allows for sludge recirculation (Schlwin, Gattermann, 2005).

8.7.2 Single and multi-stage systems

Biogas plants can operate on single or multi-stage.

In the first one, all microbiological steps of degradation happen simultaneously in one digester at the very same time. Thus, it is impossible to guarantee that all microorganisms involved in the process, work under their specific ideal conditions, which vary from one another. Therefore, there might be longer retention times needed in single-stage systems. In addition, substrates that are easy to degrade can be problematic, since organic acid accumulation (coming from the Acidogenesis) leads to process instability.

In multi-stage processes, hydrolysis and acidogenesis take place in one digester while acetogenesis and methanogenesis take place in othe digester and hence, process conditions, as pH and temperature, can be adapted according to the requirements of microorganisms (Fricke and Franke, 2002). As a result, the spacial separation of these stages of the process provide better stability and higher degradation rates of the organic matter (Weiland, 2001).

Nevertheless, many high-rate one-phase systems deveped in recent years habe been increasingly installed and has showed great efficiency, such as the DRANCO system. Due to higher investiment and operating costs for running two different processes, there is a tendency for the operation of single stage treatment plants (De Baere, L., Mattheeuws, B., 2012).

8.7.3 Mesophilic and thermophilic processes

As mentioned before, anaerobic degradation of municipal waste can be efficiently realised in mesophilic and thermophilic temparature range. The determination of the temperature range in which the process is to take place determines the microbiological flora present during the process and with that also the gas production rates. Usually, with similar hydraulic retention times, high temperatures lead to higher degradation and gas yield rates. At the same time, higher energy input is necessary to maintain thermophilic conditions.

Some of the advantages observed by Kaltschmidt, for mesophilic and thermophilic operation of biogas plants, are pointed on Table 6.

Mesophilic	Thermophilic
- Lower water vapour content of biogas	- Higher growth rates
- Less energy needed to heat fermenters	- Lower solubility of oxygen in the substrate and therefore fast development of anaerobic conditions
- High variety of microorganisms and therefore higher process stability	- Greater efficiency by killing pathogen germs
- Lower CO2 solubility in the liquid and therefore lower CO2 content of biogas	- Reduction of sludge volume
	- Shorter retention times

Table 6: Some advantages for mesophilic and thermophilic operation of biogas plants.

Source: Kaltschmidt (2009).

Mesophilic digestion has always been predominant, due to the smaller need for heating and greater stability (De Baere, L., Mattheeuws, B., 2012).

9 COMPOST

9.1 Use of the compost produced in the digestion process

Besides the energy recycling observed in the anaerobic digestion process, there is a second output from the process, the compost.

Compost is basically a soil-like material, rich in organic substances (carbon storage in the soil by the compost), as well as in nutrients, mainly: N, P, K, Ca and Mg (Favoino and Hogg 2008; Hermann et al. 2011). It increments the humus content, increases the erosion resistance and the activity of living organisms, present in the soil. It also strengthens the soil structure and enhances the water and nutrient balance of the soil.

Due to all these properties above mentioned, the compost is widely used to prevent structural degradation of agricultural soils and to maintain and improve long-term soil fertility.

The presence of nutrients causes compost to have a promising potential to be used as soil amendment. This valuable organic fertiliser can be returned to the land thereby displacing chemical fertilisers currently in wide spread use.

Still, for soil with low porosity, the mixture with compost provides the soil a higher concentration of pores and therefore allows air and water to flow and within reduces surface erosion. For sandy soils, the mixture with compost boosts the capacity of the soil of retaining water and reduces therefore the desiccation of this.

Finally, the presence of compost allows roots to grow deeper and to loosen the soil structure, contributing to a more stable soil structure.

According to Deublein and Steinhauser (2008), the retention time of the biomass in the anaerobic reactor is about 20 days, in most biogas plants and within this time, only part of the organic matter is degraded, remaining therefore certain amount of residue. The values of some of those are showed on Table 7.

Dry Matter	480
Organic dry matter	240
Total nitrogen (N)	6.2
Phosphate (P_2O_5)	3.2
Potassium (K_2O)	4.6
Calcium (Ca)	20
Magnesium (Mg)	3.6

Table 7: Some components of the residue of bio wastes (kg/Mg).

Source: Deublein and Steinhauser (2008).

The anaerobic digestion redisposes nutrients. Table 8 makes this clearer, indicating the values of some of the major nutrients found in the compost produced through the anaerobic digestion of organic waste.

Total nutrients	**Avarage values found for compost made from biowaste 2007**
Total nitrogen (N) [% DM]	1,5
Total nitrogen (N) [kg/t WW]	9,5
Organic nitrogen (N) [% DM]	1,4
Organic nitrogen (N) [kg/t WW]	8,8
Total phosphate (P_2O_5) [% DM]	0,8
Total phosphate (P_2O_5) [kg/t WW]	4,9
Total potassium [% DM]	1,3
Total potassium [kg/t WW]	8,0
Total magnesium [% DM]	0,7
Total magnesium [kg/t WW]	4,6
Soluble nutrients	
Nitrogen soluble in $CaCl_2$ (N) [% DM]	0,1
Nitrogen soluble in $CaCl_2$ (N) [kg/t WW]	0,6
Nitrogen soluble + 5% Norg (N) [% DM]	0,2
Nitrogen soluble + 5% Norg (N) [kg/t WW]	1,1

Table 8: Avarage value for nutrients found in the compost.

Source: Bundesgütegemeinschaft Kompost (2008).

9.2 Processing of the compost

The residue of anaerobic fermentation contains more or less water depending on the technologie applied. Residues from mesophilic or dry processes have naturally lower water content than residues from a wet thermophilic fermentation.

Before the distribution of this residue as valuable fertilizer, it must be adequately dehydrated, and in many cases sanitized, deodorized, and still, rotted.

A desinfection process can be avoided in the case high temperatures are applied during fermentation and the residue is discharged in sufficiently clean conditions. However, such conditions do not represent the majority of the cases and such procedure is indispensable, especially if the residue is discharged after the second phase of degradation at a temperature no higher than 30º C.

Usually, after 12 to 24 hours after fermentation, the residue loses its typical smell and endures without smell afterwards, and therefore does not need additional deodorization. This process should not be necessary, when fermentation process is adequate.

The aerobic decomposition of the residue names rotting, i.e. its decomposition in presence of oxygen. This process can take from 2 to 6 weeks, depending on how long the matter was subjected to the anaerobic fermentation and the degree of degradation wanted (Deublein and Steinhauser, 2008).

9.3 Marketing opportunities and application of compost

The range of applications for the compost is wide.

Despite a certain range of data and the disparity observed in the use of compost in different regions of Germany, it is really clear that, the application of compost as fertilizer and soil improvers in agriculture figures as the biggest market field for it. In this area, mainly fresh compost is used, while ready-made campost is preferred for landscaping and horticulture (BGK - Bundesgütegemeinschaft Kompost e.V., 2008).

Still, according to BGK (2008), the respective regional structure significantly influences the marketing of the products. If in the rural markets the biggest demand for compost is for its use as fertilizer, what is observed in urban areas is a growing demand for its use in landscaping and in gardening as hobby.

Table 9 gives an example of the marketing field of the bio waste compost produced in Sachsen and in whole Germany.

Market sector	Germany[1)]	Sachsen[2)]
Agriculture	55	34,4
Private households / Gardening	10	7,9
Conservation of landscape / Landscape architecture	11	49,2
Soil substrate	15	--
Other	9	8,5

Table 9: Marketing field of the produced composts in %.

Source: 1) Bundesgütegemeinschaft Kompost (BGK) (2011).

2) Statistisches Landesamt des Freistaates Sachsen (2008).

9.4 Conditioning of solid residues and its use as soil amendment

It is important to mention that, caution must be taken in the use of the produced compost, since it may contain heavy metals, resulting from the presence of those in the MSW.

The maximum values allowed, for the concentration of some metals in the compost to be used, are defined by german law and must be respected.

Table 10 contains such values.

Heavy Metal	Avarage value for compost from Bio - Mix Waste [mg/Kg DM]	Limit values
Pb	38,0	150,0
Cd	0,4	1,5
Cr	22,0	100,0
Cu	48,7	100,0
Ni	13,7	50,0
Zn	181,0	400,0
Hg	0,1	1,0

Table 10: Maximum values allowed and mean value of heavy metals for the compost.

Source: Bilitewski, B., Härdtle, G., Marek, K. (1994).

Besides that, if the residue is to be used as landfill, some characteristics of the residue should be controled, as it is showed on Table 11.

Parameter[2)]		Unit	Limit value according to regulations[3)]	Value after 7 weeks rotting	Value after 10 weeks rotting
Breathing activity	**AT_4**	mg O_2/g DM	5	3.0	2.6
Gas formation	**GB_{21}**	Nl/kg DM	20	n.a.	9.2
TOC in the eluate		mg/L	250	240	220
Upper calorific value	**H_0**	MJ/kg DM	6000	9700	9700[4)]
TOC in the residue		% DM	18.0	15.2	14.8

1) Limits determined by Abfallablagerungsverordnung (AbfAblVO), 2001;

2) Either the values for AT4 or GB21 respectively either H0 or TOC in the residue are to be guaranteed;

3) without considering the possible exceedance;

4) in fraction <20 mm after 10 weeks 8800 MJ/kg DM.

Table 11: Characteristic figures for aerobically rotted residue after 3 weeks anaerobic degradation in one stage under quasi-dry and mesophilic conditions compared with prescribed limits.[1)]

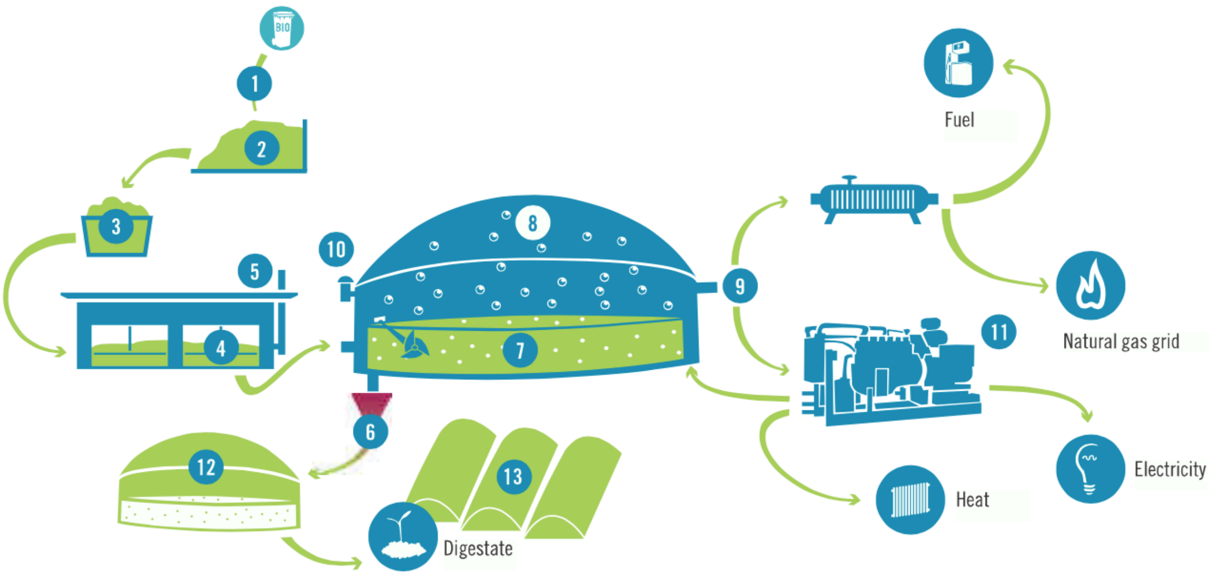
Source: Deublein and Steinhauser (2008).

Still, it is important to remember, that the improvement of waste quality is the most important measure to ensure the provision of high-quality soil amendments. Which means, the quality from the waste collected and from the soil produced are closely related. The better the separation of waste at home, the better the expected quality of the compost.

10 PROPOSAL OF CHANGES IN THE WASTE MANAGEMENT IN DRESDEN

Based on what was previously presented in this paper, here, a new handling for the organic portion of household waste is going to be proposed, in an attempt of enabling the practice of basic waste management principles by preventing or reducing the adverse impacts of resource use and improving the efficiency of such use.

Figure 29 illustrates the adjustment proposed in the present work, with regard to the treatment of waste in Dresden.



1. Feedstock (biowaste)
2. Reception and waste storage (bunkers, tanks, vessels, collection point, silos)
3. Preparation, processing, sorting and cleaning of the feedstock
4. Enclosed building for the acceptance, storage and preparation of putrescible waste with air collection system
5. Biofilter to reduce smells and organic compounds by passing the collected air through a bed or container of wood shavings, bark chips and compost layers
6. Sanitation unit (either in front of or after the digester), during the digestion at thermophilic temperatures (> 55°C) or while post composting
7. Digester (could be one or several vessels operating in row or in parallel), equipped with heating system
8. Gas storage for the produced biogas available hermetically sealed on top of the digester and other vessels or as external gas storage
9. Gas cleaning system for desulphurization and dewatering
10. Safety equipment: pressure relief devices, safety valves, gas flares as well as instrumentation and control equipment for the entire plant
11. Combined heat and power unit (CHP) for generating power and heat (Alternatively biogas can be upgraded and fed into the natural gas grid or used as fuel for vehicles)
12. Digestate storage for the digested feedstock to collect digestate for times (e.g. winter) when it cannot be applied
13. Digestate upgrading e.g. separation, drying, pelletizing, post composting

Figure 29: System proposed in the current work.

Adapted from: Fachverband Biogas e.V. (2017).

The next item of this chapter is dedicated to the theorical support, in favour of the new handling concerning the organic portion of household waste, shown above. Furthermore, in this chapter, some secondary matters, also susceptible of improvement, will also be presented and briefly discussed.

10.1 Anaerobic digestion of the organic waste

First of all, based on the work of Deublein and Steinhauser (2008), a brief comparison is made between the technology currently in use for the treatment of organic waste (composting) and the technology that it is intended to institute in Dresden (fermentation). This comparison is made and illustrated in the Table 12.

Parameter	Fermentation	Composting
Biological degradability	Not all org. matter can be fermented	Not all org. matter compostable
	Material with high water content can be treated	
Energy yield	Energy production more than 700 kWh/Mg	Energy-consuming
Compliance with legal requirements	Ignition loss often >5%*	Odor, toxic exhausts (NH_3, CH_4)
	Residue odourless	
Residues resulting from the processing	Little amount of residue	
	Shorter time for rotting	Long time for rotting
	Residue to be used as fertilizer	Residue to be used as fertilizer
Impurities in the residues	Reduction of germs. Elimination of infectious agents (Salmonella)	Savings on fertilizer and energy (about 90 kWh/Mg)
Exhaust	Little greenhouse effect due to CO_2	Little greenhouse effect
Waste water	Proportional to the amount of waste	Water remains in the residue
Investment costs	Medium	Low

**According to German laws the ignition loss of waste for landfill has to be <5% - this value can only be attained by combustion.*

Table 12: Comparison of processes for the disposal of bio waste.

Source: Edelmann, W., Ilg, M., Joss, A., Schleiss, K., Steiger, H. (2007).

Due to the conviction that the technology presented (anaerobic fermentation) may be the most appropriate solution to encompasse questions of waste management and of energy demand together, hereby it is defended the construction of a biogas plant in the city.

10.2 Improvement of waste source separation

Source separation of waste and subsequent recycling processes are promissing solutions on the road to a circular economy. They reduce waste disposal and the need for resource deployment, while also producing secondary raw materials; as such, they have a significant effect on climate protection.

When it comes to biowaste, a previous study, conducted by the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU in German), points two main reasons in favor of source separation. Those are pointed below:

- The bio waste, separately collected, can be materially and energetically used and thus contributes to the preservation of mineral fertilizer reserves, peat and fossil energy sources;

- The amount of “Rest waste” with comparatively higher treatment costs is to be reduced.

Still, according to the BMU (2012), in 2011, the residual waste treatment costs were between 70 and 150 Euros per tonne of waste, while biowaste treatment, that is, composting or fermentation, usually requires expenses between 30 and 80 Euros per tonne. Such numbers demonstrate that, the expanding of the collection of biological waste makes economic sense indeed.

For the reasons here pointed, this part of the work is dedicated to the promotion of proper source separation.

10.2.1 Public participation and information dissemination

In addition to technical requirements, the rate of material and energy recovery from the organic portion of household waste is also determined by the willingness of households to sort and separate the bio waste from the rest of their garbage.

The situation, previously described on section 4.4.1 from the current work shows that, it still exists a considerable quantity of organic waste being discarded into the “Rest waste” bins. The presence of “impurities” is an indication of inadequate separation and sorting behavior.

It is crucial therefore, to consider how the residents of Dresden can be approached and persuaded to participate more actively, even beyond current participation levels, in order to increase source separation rates and thus also the recovery rates.

As it was mentioned on the antecedent section from the current work, the improvement of waste source separation leads to several benefits. However, the lack of understanding about these benefits, acts as barries to greater engagement of the population and therefore education plays an essential role in determining participation in source separation.

Informative material in respect to the collection of bio waste should be produced and distributed. It should include:

- The goals of the “bio waste recycling” program;

- Detailed information on the program, including pick-up schedule;

- Type of system used;

- Guidance on how to separate materials – which materials should be disposed of in the bio waste bin;

- Data regarding the impact that the recycling of organic waste has on municipal waste collection;

- Information about the collection agency;

- Periodic information with numbers concerning the recycling of organic waste – the amount of methane produced, amount of energy generated, emissions avoided etc.

As soon as the population starts to understand the benefits of source separation of household waste, they should play a more active role in this regard.

Adapted public work to the target groups is perhaps also a good way of approaching the subject. The target group-oriented information includes, for example, certain action days, cooperation with the local press, foreign language brochures, educational activities in schools, among other things.

10.2.1.1 Presence of immigrants and the production of material available in more languages

According to the Census 2017 from Statistische Ämter des Bundes und der Länder, almost 7% of all Dresden citizens are foreigners, which means a bit more than 37.000 people. Those are 37.000 people that may have limited-German-proficiency, but that still produce waste. It is important that informative material, with instructions about the correct disposal of waste into the bins, is available in more languages, reaching so a bigger number of people.

On the website from Landhauptstadt Dresden, basic material is available, with information such as the emptying frequency of waste bins or how to classify certain materials dispensed in order to ensure the best destination for waste. Nevertheless, although Dresden becomes more and more people from all over the planet, these materials are still available just on German, which hampers an understanding from the population as a whole.

Figure 30 illustrates the material found on the official website from the city of Dresden. Despite the quality of the material, it only reaches people with proficiency in the German language.

Figure 30: Informativ material concerning the waste management in Dresden.

Available at: https://www.dresden.de/de/stadtraum/umwelt/abfall-stadtreinigung/abfall-abc.php (accessed in June 2017).

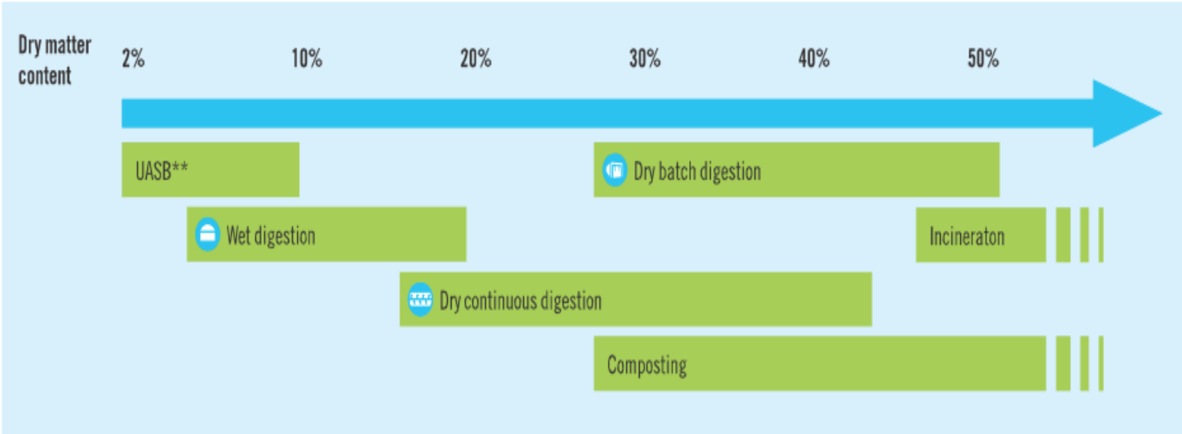
Furthermore, the public agency should provide continuously available guidelines (written, web-based, hotline) for exisiting waste management activities, such as collection, recycling of various streams, separate collection of bulky wastes, etc, contributing to reduce the distance that still exists between population and their waste, converting the local people into more active actors, when in respect to waste management.

10.3 Anaerobic digestion – choice of the most appropriate technology

Considering the range of alternatives previously seen on section 8.7 of this document, the first step on this part of the work has to be the choice of the most appropriate digester technology, the most suitable one in view of the reality found in Dresden.

For this election, will be taken into account the amount of water found in the organic waste that is collected in Dresden, even though the feedstock can be diluted to the proper dry matter content of each digester technology.

The Figure 31 indicates different digester technologies and the dry matter content associated with each of these technologies.



***Upflow anaerobic slugde blanket technology is a form of anaerobic digestion designed for materials with high water content (e.g. sewage sludge).*

Figure 31: Overview of technologie depending on dry matter content for the possible operating mode.

Source: Fachverband Biogas e. V. (2016).

Taking into consideration that, the biowaste from households presents dry matter around 45% in Dresden, as it was already mentioned, previously on section 4.4.2 from the current work, the technology indicated as the most appropriate one for the digestion of this kind of waste is the “dry batch digestion”. In case the percentage dry matter content exceeds 45%, the material still can be diluted. At the same time, the technologie also works with lower percentages, being able to treat waste with just 30% of dry matter content.

11 ENERGY YIELD AND PAY BACK OF THE INVESTMENT

As a result of this work, it is aspired to produce compost and energy coming from the biowaste from household in Dresden. The energy produced can be distributed both in the form of heat and in the form of electric energy, being thus possible to supply many households in the city with this energy.

That would contribute to the construction of a more sustainable Dresden.

For a primary, basic evaluation of the amount of methane produced and of the energy yield, the German Biogas Association suggests some numbers, illustrated in Figure 32, that vary according to the feedstock used in the plant.

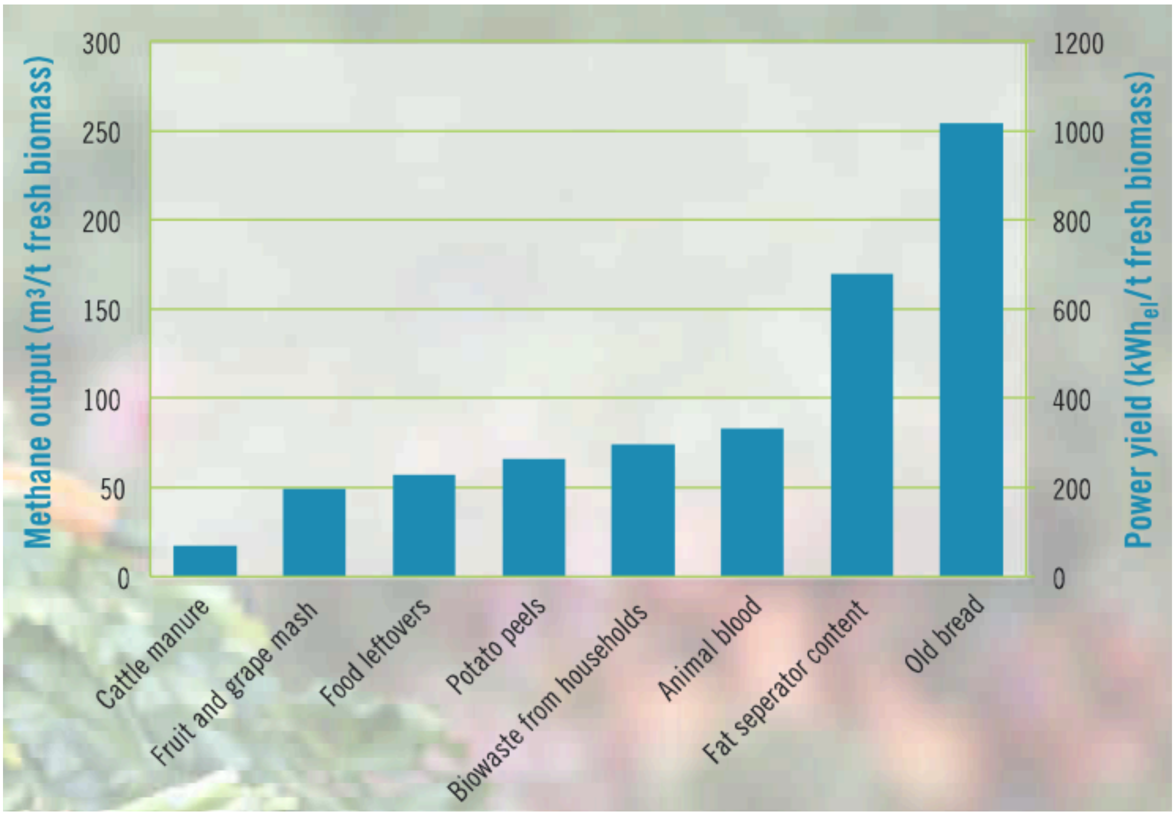


Figure 32: Energy yield of possible feedstock.

Source: Fachverband Biogas e. V. (2016).

From Figure 32, it is possible to predicate that, using biowaste from households as feedstock for a biogas plant, around 75 m^3 per tonne of biowaste is to be produced and about 300 kWh per tonne of biowaste is to be generated.

But, in the real world, the energy yield observed in anaerobic digestion plants may vary greatly from the expected theoretical value for the energy production of a plant. And precisely for this reason in the this work it was considered pertinent to refer to values already observed in other anaerobic digestion plants, which are fed with biowaste from household in other cities in Germany.

Using the avarage energy consumption that is consumed in a residence in Germany, it is possible to establish a number of houses that could be supplied with such energy.

Under, some practical examples found in the Biogas-Atlas 2014/2015 (Witzenhausen, 2015).

Vergärungsanlage Deisslingen:

The Deisslingen digestion plant utilizes the separated bio waste from the Schwarzwald-Barr-Heuberg region. The project is considered an example of successful intercommunal cooperation. The selected fermenataion technology was only economically viable on the basis of all the quantities of the three counties been digested together.

The plant was built conveniently next to the sewage treatment plant “Oberer Neckar” and near the highway, simplifying the transport of bio waste and also compost.

The operations started in 2005. About 25,000 tonnes of bio waste are processed every year in the plant. The resulting biogas is supplied in a combined heat and power (CHP) unit and once into electricity transformed, it is fed into the public electricity grid.

Still, the excess of heat from the CHP is used at the site to dry municipal sewage sludge. Which means, the energy that would be lost during this process is also used and thus the “actuall lost” of energy during its transformation in the generator is satisfactory. Almost the complete use of energy is realized and sawage can be introduced into the adjacent sewage system on a short path.

All input materials of the fermentation are pasteurized. The solid fermentation residues are delivered to the farmers of the region as high-quality fertilizer.

Table 13 shows a few important facts about this plant.

Capacity	25.000 t Biowaste
Opening	2005
Electrical power	950 kW
Production of biogas	~3.300.000 Nm^3/year
Generation of current	~6.300.000 kWh/year
Energy use	Feeding into the public electricity supply system; sludge drying
Use of fermentation residues	Fertilizing compost for agriculture

Table 13: Numbers and data concerning the biogas plant in Deisslingen.

Source: Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit (BMU), Umweltbundesamt (UBA) (2012).

Trockenfermentationsanlage Erfurt:

In 2009, a new plant for the recycling of organic matter was open near the Landfill Erfurt-Schwerborn, replacing the open composting of Erfurt bio waste. There, 18.200 t of bio waste can be convert into clean energy every year by a dry fermentation process. The energy produced is enough to feed 1.000 houses from Erfurt.

Dry Fermentation technology differs from traditional “wet digester” tank systems that utilize liquid feedstock and physically stir and agitate materials with moving parts.

In Erfurt the technology uses a batch-style approach, where waste remains stationary during the digestion.

Organic waste with high dry substance contents can only be added to the conventional wet-digestion process to a limited extent. The dry fermantaion process in the other hand, makes it possible to methanize almost any kind of organic waste, without converting the material into a pumpable, liquid substrate. This fact makes this system resistant against contaminants such as films, woody or fibrous components.

The fermentation plat still produces certified compost, used on the local agriculture.

Table 14 shows some important number about the plant.

Capacity	23.500 t Biowaste
Opening	2009
Electrical power	660 kW (2 x 330 kW)
Thermal power (usable)	800 kW (2 x 400 kW)
Production of biogas	1.761.714 Nm^3/year (2011)
Generation of current	3.424.772 kWh/year (2011)
Heat generation	4.305.630 kWh/year (2011)
Heat use (CHP - Combined heat and power)	3.104.270 kWh/year (2011)
Difference	1.201.360 kWh/year (2011)
Energy use	Feeding into the public electricity supply system from Erfurt
Use of fermentation residues	Production of compost

Table 14: Numbers and data concerning the biogas plant in Erfurt.

Source: Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit (BMU), Umweltbundesamt (UBA) (2012).

Vergärungsanlage Kirchstockach:

The fermentation plant, located on Munich district, started its operations in 1997. The plant, which works with wet fermentation, achieves an annual throughput of more than 30,000 tonnes bio waste.

After early attempts to store the energy over chemical storage systems, using microporous aluminum silicate, i.e. absorbing minerals, that at high temperatures can store energy, in 2009 the heat produced started been transferred to commercial buildings located near the plant. The electricity produced in the combined heat and power unit (CHP) is fed into the public electricity grid.

Part of the residues is transformed into compost.

Table 15 shows some facts about this plant.

Capacity	30.000 t Biowaste
Opening	1997
Electrical power	1 MW
Production of biogas	2.300.000 Nm^3/year
Generation of current	5.000.000 kWh/year
Energy use	Own supply and feeding into the public electricity supply system
Use of fermentation residues	Production of compost

Table 15: Numbers and data concerning the biogas plant in Kirchstockach.

Source: Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit (BMU), Umweltbundesamt (UBA) (2012).

11.1 Energy generation

Different scenarios were taken into account to demonstrate possible forecasts. Basically, this work intends to present the potential and significant increase in clean energy production if some of the organic waste from households, today selectively collected, happened to be treated in the plant, which the construction is in this work defended.

In November 2012 the government of Dresden published a document called "Integrated Energy and Climate Protection Concept Dresden 2030". After analysis of some data, such as the percentage of renewable energy in its energetic matrix and comparing those with national standards, the Environment Secretary of Dresden, propose some goals for the future of the city, concerning the use of energy and its sources, seeking to align the city with national targets imposed by the Energiewende program, already mentioned in section 6.2 of the present work.

In addition to setting targets for the reduction of GHG emissions and for a greater participation of renewable sources of energy, the government of Dresden also propose measures in order to increase energy efficiency in the city and a more rational use of it. As results of the line of action designed, the city should be able to reduce the energy consumption in coming years, despite the expected population increase.

In this part of the paper, a quantitative analysis takes place, demonstrating the share of energy coming from the suggested biogas plant, which shall be expected. For this analysis, two values for energy consumption will be used, a value admitted as trend and a more optimistic value, which consider better results for the municipal program. Both values were taken from this document.

Besides that, the estimate amount of energy production, in form of heat and electricity, is based on a comparison of expected values, taking into account the values pointed in Figure 32, and the ones observed for the biogas plant in Erfurt, given the similarities between the two plants. The biogas plant in Erfurt is a modern plant (its opening was in 2009) and uses a dry-batch-digestion technology for the digestion of the organic waste, the most appropriate technology for the digestion of the organic waste from Dresden, as it was already pointed in the section 9.4 from the current work.

After that, the results found will be discussed and compared with national targets.

11.1.1 Estimation of energy generation

First a comparison between the values observed in practice and the theoretical values for energy generation, will be made in order to calculate the deviation between the two.

If we take into account the estimation given in Figure 32, that for each ton of domestic organic waste, the generation of 300 kWh is expected, for the plant in Erfurt, the production of energy to be expected, is:

18.200 [t/year] of organic waste x 300 [kWh/t] = 5.460.000 [kWh/year]

But instead, what is observed in reality is the production of:

3.424.772 [kWh/year] + 1.201.360 [kWh/year] = 4.626.132 [kWh/year]

This being the sum between the electricity production in 2011 and the heat production for the very same year, respectively, as it can be observed at the beginning of this chapter.

The observed difference between the two values is: 833.868 [kWh/year].

But taking into account that the plant in question was built in 2009 and that the document is from the year 2016 (most recent), and even assuming the advance of technology in this period, as can be observed in section 5.2 from the current work, for calculation purposes, in this paper, only half of the observed difference between the theoretical value and the actual value will be considered.

The expected difference between theoretical values and actual values is:

(833.868 [kWh/year] / 2) / 5.460.000 [kWh/year] ≈ 7,6 %

Still, taking into account the values for the heat and electricity production of the plant in Erfurt, the percentages of heat and electricity generated in a plant using CHP (combined heat and power plant), will be estimated.

For heat: 3.424.772 [kWh/year] / 4.626.132 [kWh/year] ≈ 26 %

For electricity: 1.201.360 [kWh/year] / 4.626.132 [kWh/year] ≈ 74 %

Now, given the difficulty of implementing changes in an already consolidated system, such as the implementation of a new technique for the treatment of the organic waste, the implementation of the plant in the current system must go through a test phase and the treatment of the organic portion of household waste in the biogas plant should take place gradually. In this sense, two different scenarios will be considered, where different amounts of waste are treated in the plant. First, 15.000 tons of household organic waste and still, 25.000 tons, which represents 100% of the organic waste from household suffering anaerobic digestion, observing the amount of organic waste which is collected separately in the city, as pointed out in section 4.4 from this work.

The expected values for energy generation in a future anaerobic digestion plant, working with a dry-batch-digestion and CHP, having the capacity to treat 25.000 tons of organic waste per year, are:

Energy:

<u>For 15.000 tons of organic waste been treated in the plant per year:</u>

Energy [kWh/year] = 15.000 [t/year] x 300 [kWh/t] x 92,4%* = 4.158.000 [kWh/year]

* 92,4% (100% - 7,6%) refers to the possible disparity between theoretical and practical values.

<u>For 25.000 tons of organic waste been treated in the plant per year:</u>

Energy [kWh/year] = 25.000 [t/year] x 300 [kWh/t] x 92,4% = 6.930.000 [kWh/year]

Isolating such values, for heat and electricity generation, are to be expected:

<u>For 15.000 tons of organic waste been treated in the plant per year:</u>

Heat: 25% of 4.158.000 [kWh/year] = 1.039.500 [kWh/year] ≈ 1,04 [GWh/year]

Electricity: 75% of 4.158.000 [kWh/year] = 3.118.500 [kWh/year] ≈ 3,12 [GWh/year]

<u>For 25.000 tons of organic waste been treated in the plant per year:</u>

Heat: 25% of 6.930.000 [kWh/year] = 1.732.500 [kWh/year] ≈ 1,73 [GWh/year]

Electricity: 75% of 6.930.000 [kWh/year] = 5.197.500 [kWh/year] ≈ 5,2 [GWh/year]

The values here estimated are organized in Table 16, in order to make the information clearer for the reader.

Quantity of organic waste to be treated	Estimated energy generation [kWh/year]	Estimated electricity generation [kWh/year]	Estimated heat generation [kWh/year]
15 tons of organic waste	4.158.000	3.118.500	1.039.500
25 tons of organic waste	6.930.000	5.197.500	1.732.500

Table 16: Estimated values for energy production through the fermentation of organic waste in Dresden.

Source: Table of own authorship (2017).

11.1.2 Share of renewable energy in Dresden and the joining in from anaerobic digestion of the organic waste

In this section, a comparison of the expected values for two different scenarios in the year 2030 and the values found in the previous section, substracted from the probable losses, that should occur from the generation to final consumption, is going to be made for the production of heat and electricity from the biogas plant, which should start to treat the organic portion of the household waste in Dresden.

For the losses above mentioned, the value 0,64 will be used (46% of losses). This indicator expresses the relationship between the energy available to end-users and the energy that enters the system. 0,64 was the value registered in Germany for the year 2013, according to IEA, the Internacional Energy Agency (2014).

This comparison is intended to point out the significance of the energy to be produced from the organic portion of domestic waste, in relation to national targets for the production of renewable energy. That means, it is intended to show the contribution with which this technology can collaborate, so that the city happens to fit into what is a national trend, helping Dresden to obtain position of prominence among other cities from Germany.

The values that will be presented here for the year 2030 were removed from a study made by the Environmental Agency from Dresden (2013).

The first of these values indicates a trend, cconsidering the serie of values found for energy production between 2005 and 2012. The second value takes into account a change in the computed trend, where municipal authorities act more actively in favor of increasing the generation of energy from renewable sources, influencing the future scenario.

Table 17 presents these values.

Year	2005[1]	2030[2]	2030[3]
Final energy consumption [TWh]	10,35	9,9	8,8
Share of heat coming from renewable sources [%]	1	6	19
Share of electricity coming from renewable sources [%]	2	7	22

1) Gross final energy consumption in Dresden in 2005.

2) Estimated value for final energy consumption in Dresden in 2030, trend scenario.

3) Estimated value for final energy consumption in Dresden in 2030, efficient scenario.

Table 17: Contribution of the energy produced through the fermentation of organic waste in relation to the final energy consumption.

Source: Table of own authorship (2017).

For the year 2030, targets were set by the German government with regard to the share of the final energy consumption in Dresden, coming from renewable sources.

According to Eurostat (2017), *"the final energy consumption is the total energy consumed by end users, such as households, industry and agriculture. It is the energy which reaches the final consumer's door and excludes that which is used by the energy sector itself."*

In 2008, the German government published a document, called *"Ausbau erneuerbarer Energien im Strombereich bis zum Jahr 2030"*, where some new national targets for the production of renewable energy were established. Between those targets, the German government has set its goals for the participation of renewable energy within the final energy consumption. The government has set up the share of 50% of the final energy consumption in the national territory coming from renewable sources, until the year 2030.

Observing the numbers from Table 14, it can be seen that, despite government efforts, Dresden should have numbers well below those defined as national targets, set by the German government.

In this sense, any and all energy recovery initiatives have the power to transform this scenario and should be encouraged in order to align Dresden with a national trend. The use of a biogas plant for the handling of the organic waste has the potential to contribute to a cleaner energy matrix of Dresden, seeking to cover the numbers established by the German government for the final consumption of energy from renewable sources and so, supporting the establishment of a more sustainable city.

11.2 Financial analysis of the plant

The aim of this part of the current work is to analyze the economic performance of the biogas plant, which construction is suggested, throught the computing of payback of the plant.

Payback period is the time in which the initial cash outflow of an investment is expected to be recovered from the cash inflows generated by the investment, in this case, by the sale of energy and compost, produced in the plant. For the measure of this value, focus was given to the German framework conditions concerning payment for electricity produced as well as the production costs.

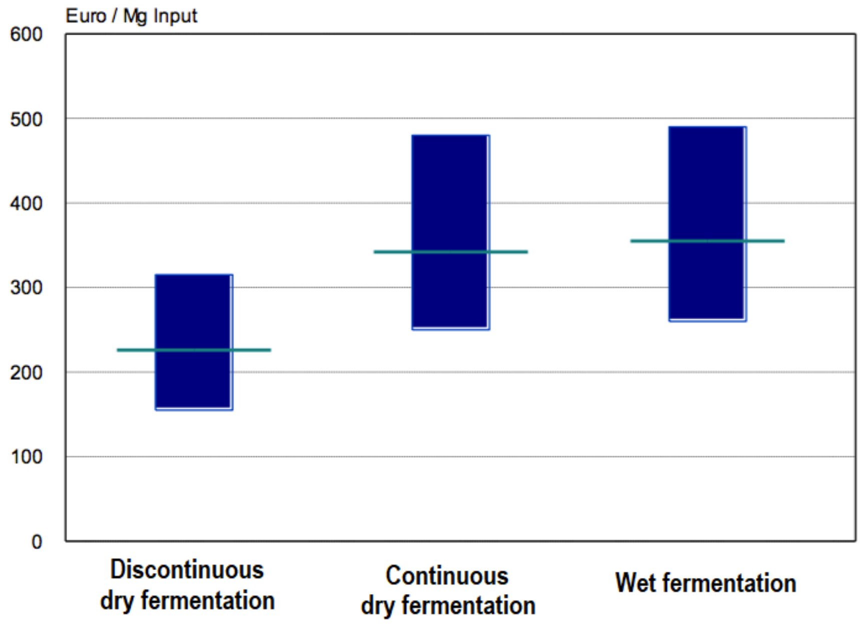
11.2.1 Costs

Batch fermentation processes require lower investment than continuous wet or dry fermentation plants, but also presents lower gas yield.

Here, it must be taken into account whether the fermentation plant can be integrated as an upstream substation into the existing composting facility and thus be able to use essential process stages for digestate treatment or whether it is a new, independent plant, which requires a bigger investment.

For the specific operating costs, an additional from 40 to 50 € per tonne of biowaste should be assumed, whereby there is a cost degression as the plant capacity increases.

Figure 33 and Figure 34, illustrate, typical specific costs (avarage and deviations) of different biowaste fermenattion processes based on the previous experience in Germany. While Figure 33 shows specific investment costs, which should be expected, Figure 34 exhibits the specific operating costs, for the various fermentation processes.

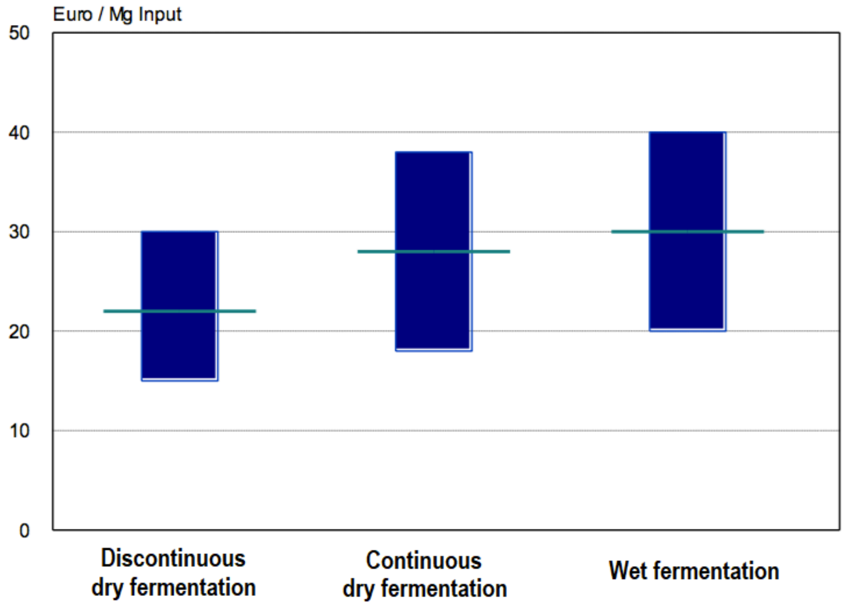


** the values refer to the average values found for plants with capacity of 20.000 tons per year*

Figure 33: Specific investment costs of various biowaste fermentation processes.

Source: Witzenhausen-Institut (2008).

Usually, for the concrete works shall be taken around 60% of the investment costs and the remaining 40% for technical equipment, according to Deublein and Steinhauser (2008).



** the values refer to the average values found for plants with capacity of 20.000 tons per year*

Figure 34: Specific operating costs of various biowaste fermentation processes.

Source: Witzenhausen-Institut (2008).

The specific operating costs consist of costs for the maintenance for concrete works and for techniques and still for the CHP, besides costs related to personnel costs.

Another important cost to be accounted concerns the payment of an insurance, which should amount around 0,5% of the investment costs.

11.2.2 Revenues

The revenues are essentially determined by the sales of energy produced, in form of heat and electricity and also the sales of compost.

The fermentation of biowaste is explicitly recognized as an innovative technology by the amendment of 2008 to the Renewable Energy Sources Act (EEG) and remunerated accordingly (if solid fermentation residues are recycled).

According to a previous amendment of 2004, also to the EEG, granted a technology bonus of 2 cents per KWh_{el}, for the basic allowance for dry fermentation, which was the case of most biowaste fermentation plants.

A further increase in remunaration for the electricity fed in can be achieved through sensible heat utilization in accordance with Annex 3 of the amended EEG. Thus, the use of process heat for the treatment of digestate for the purpouse of fertilizer production is called as an option.

Further revenues are to be generated by the remuneration from the use of the waste heat generated during power generation (by the use of a CHP – combined heat and power unit). Often, the use of heat is a decisive factor for the profitability of concepts.

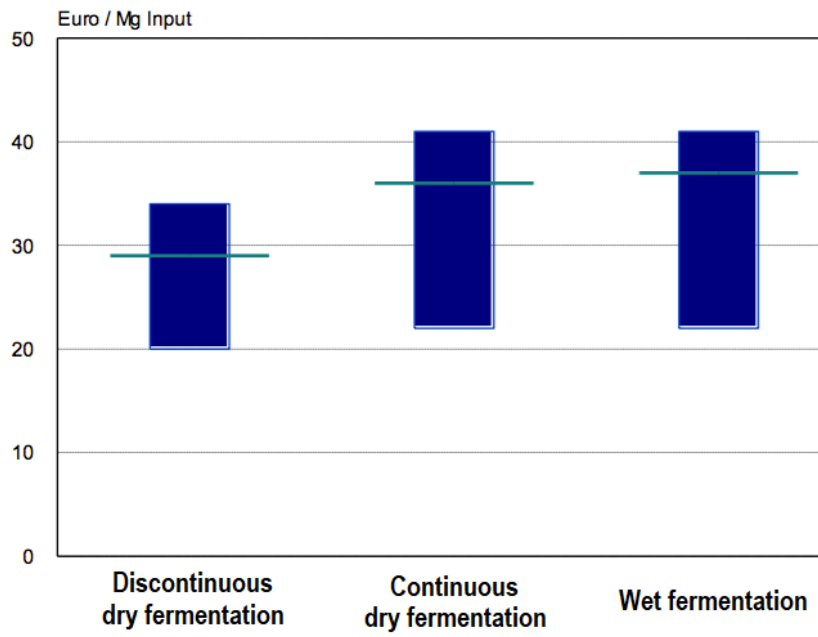
The profit from a biowaste fermentation plant are influenced by the following factors:

- Biogas yields and methane content;

- Utilization and distribution of the fermentation residues (sales as fertilizer);

- Suitable heat concepts and sale of excess heat.

Figure 35, brings the different expected revenues for each of the fermentation processes pointed.



** the values refer to the average values found for plants with capacity of 20.000 tons per year*

Figure 35: Specific revenues of various biowaste fermentation processes.

Source: Witzenhausen-Institut (2008).

For the estimation of the payback, the values brought in the figures above will be used just as a simple reference. Different scenarios will be taken into account for the calculation of different payback periods, since this may vary according to the amount of garbage that is treated in the plant.

The following values shall be taken into account for such calculation:

5.000.000 Euro as the initial investment of the plant is to be considered.

According to Marco Böning (personal communication, October 17, 2017), the manager of the biogas plant in Erfurt, 4.700.000 Euro were spent for the construction of the plant. When dividing the value by the capacity of the plant (23.500 tons) it can be noticed that this value is below the value indicated in Figure 33. There is a logical explanation for this. According to Deublein and Steinhauser (2008), the smaller numbers (investment per input capacity) stand for large plants, the higher numbers for small ones.

Following the same logic for general costs in the plant, 20 Euros per ton of material is going to be defined as the operating cost of the plant;

And finally, 30 Euros per ton of treated material, for the expected gain.

Here, three different scenrios are going to be examined. On the first one, it is going to be calculate the payback for the situation where the plant treats only 15 tons of organic waste per year. The second scenario takes into account the treatment of 20 tons of organic waste. And finally, in the third scenario will be considered 25 tons of organic waste, ie in which case all the organic garbage from household in Dresden, currently selectively collected, being sent to the anaerobic digestion plant.

Hereby, a very simple calculation of payback is going to be conducted, where capital costs are not going to be considered. For the estimation of the payback time, first the expected gain with the plant is to be calculated, per unit of time. As soon as the initial investment for the construction of the plant is well known, this value has to be divided by the first value found. The result of this division illustrates the time required for the initial investment to be recovered.

In the line below, an example is given for the calculation of this period, taking into account the values already mentioned above, for the case where only 15 tons of organic waste are to be treated in this plant.

Revenue per time unit: 15.000 [t/year] x 10 [Euro/t] = 150.000 [Euro/year]

Initial investment: 5.000.000 [Euro]

Payback: 5.000.000 [Euro] / 150.000 [Euro/year] ≈ 33 years.

The value found is relatively high, but since the initial cost of construction is fixed and the value gained periodically is linked to the input quantity to be treated, the closer to its maximum capacity, the plant should present lower payback periods.

Table 18 brings the payback values for each one of the three proposed scenarios.

	Initial investment [Euro]	Revenues per time unit [Euro/year]	Payback [year]
15 tons of input	5.000.000	150.000	33,3
20 tons of input	5.000.000	200.000	25
25 tons of input (maximum capacity)	5.000.000	250.000	20

Table 18: Payback calculation for the biogas plant.

Source: Table of own authorship (2017).

Despite the relatively high values found, the fact that the German government provides low-interest credit for this type of venture ends up making this time shorter and enabling the development of technology in the country.

12 CONCLUSION

At a time when resources are becoming scarcer, petroleum prices are greatly rising and climate change is one of the great challenges of our age, especially the concentrations of carbon dioxide (CO_2), laughing gas (N_2O) and uncontrolled methan (CH_4), the circular economy is making a significant contribution to climate action.

Renewable energy is a key concept for the 21st century. As outlined at the beginning of this paper, based on the work of Goldenberg, the development of a matrix based on renewable energy and less dependent on fossil fuels, should support the construction of a more sustainable Dresden. But the implementation of any new technology in an existing market requires some preconditions.

First of all, there has to exist a demand for this new technology by means of an added value in terms of economic, social and environmental benefits or comfort.

Second, the introduction of renewable energy technologies depends on how affordable it is, if compared with the income or investment.

At last, but not least, a structure of support for this new technology needs to exist, that means, presence of information, quality standards and research, in order to bring improvement.

The present work sought the solution of a matter of both solid waste treatment and cleaner energy production.

As shown by practical examples presented on Section 5.3 and also on Chapter 11, biogas plants for the treatment of the organic portion of domestic waste are already used in other cities in Germany, which indicates that the technology is already known and yet, that the technology is very efficient as a solution capable of solving, the need of treatment and disposal of the organic waste and the increase of renewable energy production in Germany, as it was demanded by the government, as presented on item 6.1.

However, as evidenced by the financial analysis made, which can be seen in item 11.2, if the decision-making takes into account purely financial factors, the biogas project risks failure. Yet, when choosing a technology for local energy production, cost should not be understood as a uniquely financial variable. The purely financial analysis is poor and ignores important factors that should be considered carefully in decision making. Tha calculation of the cost must take into account non-measurable variables, such as social and environmental costs or still, security suplly, and thus, the "cheapest technology" is not necessarily the most attractive one. Thinking this way, well-design subsides provided up front can be very efficient to close the gap between renewables and conventional energy systems.

The establishment of an energetic matrix based on renewable energy sources, depends on political will and action. As illustrated and discussed previously on this work, in section 6.2, the promotion of an energy transition at the national level is only possible through the establishment of policies promoting the development and use of RE sources and technologies, enabling investments in this field. If biogas projects are to be successful and the market still has to maturate, it is crucial to assist the companies and organisations that promote and deliver biogas projects and to benefit them with financial incentives and technical support.

The German government proved to work for the implementation of this technology. The Chapter 6 describes the country's politically supervised shift in direction from nuclear and fossil fuels to renewable sources of energy.

About the capacity of the technology to produce energy, in section 11.1 it was made clear, that a single plant for the treatment of the organic portion from household waste is capable of producing large amount of energy, contributing positively for the achievement from the national goals set.

Besides the energetic recovery, the material output from the fermentation redisposes nutrients and produces a valuable material, which can be used in the agriculture or gardening or still, in the recovery from contamined sites, as it was presented on section 9.1 from this work.

For the reasons above mentioned, the use of the technology in question must be able to count on long-term political and social support, allowing the technology to mature and undergo development, so the price of the technology should decrease, and the population can thus enjoy the advantages associated with social, environmental and still, economical aspects from it.

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