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Research Article

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Biogas Plant Installation in the Region of Brandenburg, Germany: Environmental Impacts-Safety Aspects and Risk Application

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Abstract

A significant renewable source nowadays is biomass that covers the 12 % worldwide of the energy needs. The national German market belongs to one of the world leaders regarding the biogas use and production. Around 7800 biogas power plants are located in the Germany in a corresponding capacity of 3.5 GW.

The World Bioenergy Association supports that up to 90% of the total bioenergy consumption is going for traditional uses like cooking and heating. The main biomass resources are mainly used for heat and electricity production or for generating secondary energy barriers such as biogas or biofuels.

We have a variation of biomass residues that main categories are agricultural, waste, forestry and industrial residues. All the types of the residues have the ability to be used as input in biogas power plants for biogas generation.

In the production of biogas the technological process which is used is known as anaerobic digestion. The process is microbiological and during operation the organic material is decomposing in oxygen limited environment. In the biogas generation technologies are given several difference substrates that all have a different environmental performance.

The construction of a biogas power plant and its operation results in plenty of safety issues, possible risks and impacts in the human health, animals and the ecosystems. It is highly significant the biogas power plants to provide a safe environment for the employees.

The regional state of Brandenburg has been developing regarding the renewable sources of energy. The Ministry of Environment, Health and Consumer Protection has been focused in an innovative policy considering the energy efficiency and energy conservation, however there has been emphasized the production of renewable energy.

Keywords: Biogas, Anaerobic Digestion, Safety, Brandenburg, Bioenergy

Introduction

The constant need for the reduction of greenhouse gas emissions leads to the use of alternative energy sources for energy generation. A significant renewable source nowadays is biomass that covers the 12 % worldwide of the energy needs. The national German market belongs to one of the world leaders regarding the biogas use and production. Around 7800 biogas power plants are located in the Germany in a corresponding capacity of 3.5 GW [1, 2].

The biogas is used as a renewable energy fuel. In more detail, the carbon dioxide (CO_2) in the atmosphere gets absorbed by the vegetation during the process of photosynthesis. A basic indicator for the climate protection is the development of the energy related CO_2 emissions. On behalf of the Ministry of Economy and European Affairs, ZAB Energie monitors the development of the energy strategy targets in the region of Brandenburg [3, 4].

Overview of the Biogas Production Today

A versatile renewable source which plays a high significant role in the energy policies worldwide and is one fundamental restructure in the power supply systems in Europe as well as in Germany is the biofuel known as biogas-biome thane. Main input use for biogas production is organic wastes such as biomass and main intention is the replacement of the fossil fuels. Biogas contributes actively in the climate protection and belongs to one very reliable source of income. In addition, the biogas generation is independent from any kind of weather conditions and has the advantage that is storable and as power supply can be used in several ways [5-7].

Biogas has been in first place became the research interest in countries such as China, India, Nepal as well as Asian areas and additionally in Europe and USA has been applies in large scale biogas applications. Several observations have been outlined that research has been accomplished in Saharan countries with main objectives the technical aspects of the production. In more detail, the anaerobic digestion technologies, operating power plant design and research about the temperature effect and fermentation [8].

Aim and Objectives of the Research

The present research paper aims to present the biogas production developed industrial applications in the region of Brandenburg in Germany and introduce the safety aspects and risks that may occur in the operating units.

The one objective of the research investigation is based in the three key targets of the European Commission "20-20-20", about the 20% mitigation of the greenhouse gas emissions, the 20% increase of the energy consumption from renewable sources and the 20% progress of the European Union´ s energy efficiency. The case study of Brandenburg will present the status of the biogas energy production and the greenhouse emissions reduction. In addition, there will be explored scientifically the biomass residues used in the anaerobic digestion technologies in the operating units which refer to the environmental aspects and will be examined the main input used in the region.

Furthermore, the second objective regarding the safety aspects and risks of the industrial applications of biogas operating units will be investigated based in indicators regarding the operation, educational profile of the operators, the possible accidents and already existing legal framework that is established and we can evaluate what needs to be improved and taking care of.

Material and Methods

The research methods that have been adapted for the accomplishment of the present research study were a scientific review from data bases and personal questionnaires/ interviews with experts, who are working in biogas plants, academic institutes and energy centers in the region of Brandenburg.

Moreover, the main detailed data collection for the regional status was accomplished and preceded with the collaboration of the Energy Technology Initiative (ETI) in Potsdam and the Ministry of Environment, Health and Consumer Protection Land Brandenburg, referring to the operating biogas production plants in the region of Brandenburg of Germany. In addition, the present thesis has been based on presentations and reports from the European Biogas Association conferences material that has hosted experts, scientists and high level policy makers discussing about anaerobic digestion and gasification from several countries that biogas production is applied.

Structure of the Thesis

The research study begins with the introduction of what will be discussed and examined in the paper. It takes place the definition of the objectives together with the methodology that has been applied for the accomplishment of the research.

In the Chapter 2 is described and introduced the theme of the Renewable Energies, in which baselines and the development worldwide that has been established through the years. Moreover, it takes place the first mention of the biogas production which belongs in one of the continuously growing renewable energy source.

The Chapter 3 follows with the analysis of the biogas production such as the detailed description of the process, the anaerobic technologies which apply in the operating power plants and the environmental impacts of the biofuel regarding the climate change.

Furthermore, in the Chapter 4 is examined the case study of the regional status of Brandenburg in Germany regarding the biogas operating units, the uses of the produced biogas, as well as the installed capacity existing in the area. Furthermore, the regional status refers to the environmental impacts regarding to the production of the greenhouse gas emissions that connect with the climate change.

The Chapter 5 explores another significant point that is under consideration in the production power plants. More specific there is given the scientific view regarding the safety aspects and risks applying in operating units.

Moreover, the Chapter 6 outlines after the research process what the representative operation is regarding the production of biogas in the region of Brandenburg referring to the production of CO_2 emissions. According to questionnaires there has been examined the point of view of experts and academics that are experiencing and working in the biogas sector during operation.

Bioenergy: Biomass, Biogas and Biomethane

The present chapter aims to introduce us to the most popular form of Renewable Energies concept of bioenergy, where there is a big range of products and technologies applied. In our case main focus is the uses of biomass in order to generate biogas and the clarification of the difference of biome thane and biogas.

The Renewable Energy known as Bioenergy

Bioenergy is concerned as a highly attractive, low carbon energy source. This results in the environmental friendly character of the conversion of biomass residues into energy products which are characterized with low CO_2 emissions. Moreover, bioenergy is used for daily human needs such as heating, cooking and lighting and main expectation refers to the goal that bioenergy will cover the 30% of the world's needs globally [9, 10].

According to Alhaleh et al., bioenergy is characterized as the biggest contributor of sustainable and renewable energy source worldwide and plays a key role in many industrial and power sectors [11]. Biomass belongs to the main resource to produce bioenergy. Furthermore, the authors point out that on 2014 Europe has been announced as the region with a very high bioenergy developed industry by the World Bioenergy Association.

In order to achieve and install efficient bioenergy sustainable systems main ingredient as starting point is the biomass feedstock. Using the appropriate biomass residues leads us to a bit potential of high level bioenergy systems which contribute in energy production with low levels of released greenhouse gas emissions (GHG) [12].

Bioenergy is simply the energy, which is produced by using biomass or with other words organic matter and currently belongs to the basic renewable energy source for transportation. Moreover, a high quality of the bioenergy is referring to its versatile character which makes it appealing [13].

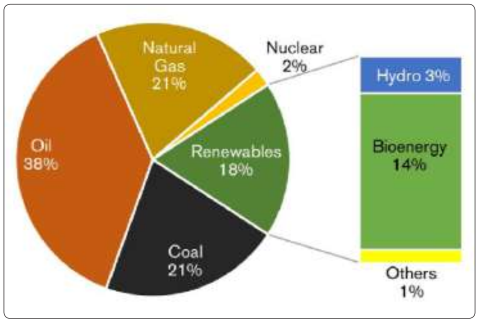

Figure 2.1: Global Energy Consumption on 2013, based on World Bioenergy Association [14].

The World Bioenergy Association supports that up to 90% of the total bioenergy consumption is going for traditional uses like cooking and heating. However, comes the need of change since there coming environmental impacts such as deforestation, climate change which leads to the "modern" conversion technologies and the use of the bioenergy products such as biogas, biofuels etc [14].

The Energy Efficiency and Conservation Authority describe simply the concept of bioenergy. More specific, the plants during the process of the photosynthesis absorb the sun's energy and they store it for their growth. Eventually bioenergy results from the energy content as well as byproducts such as animal manure, bedding materials etc [15].

According to the European Biomass Association, bioenergy has four significant benefits which refer to the economical, social and environmental factors. In addition, the most important of all the green energy produced which decrease our dependence of the use for fossil fuels. Regarding the economic sector there are new investments supported and we have affordable energy. Furthermore, socially it contributed to the creation of jobs which benefit the communities and the well being improvement. Last but not least, the environmental advantages which are related are connected with the mitigation of the greenhouse gas emissions and the improved waste management practices for the good of the ecosystems [16].

Biomass Residues in Energy Production

Bioenergy or biomass energy is coming after the burning of wood, twings, straw, dung etc. Biomass is used as input for being burnt either directly for heat or generating electricity, as well as to produce high energy gas. Usually biomass is available in raw form and most of the times burn inefficiently, where much energy is wasted. In the bigger picture there is an enormous potential around the biomass resource in upgraded uses of existing forests and other resources provided from the land for higher productivity [17].

Regarding the substrates the industrial applications use as input in the biogas production are three main types such as residues (fruit & berry trees, bedding material), livestock products (poultry manure/litter, pig & cattle manure) and energy crops (cultivated especially for biofuel production such as biogas and ethanol-typical energy crops also are known as maize and sweet sorghum) [18].

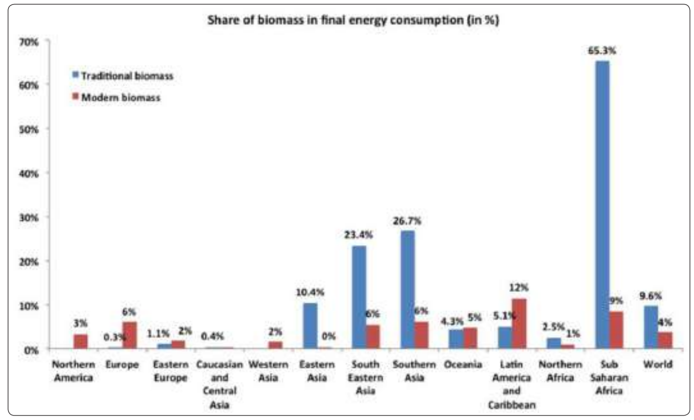

Figure 2.2: Share of Biomass Utilization covering the Energy Consumption Worldwide on 2015, based on World Bioenergy Association [14].

According to World Bioenergy Association, on 2013 we had 462 TWh of electricity produced from biomass feedstock. The energy consumption globally is shown in the figure 2.2 regarding the biomass share based on traditional biomass and modern biomass.

The main biomass resources are mainly used for heat and electricity production or for generating secondary energy barriers such as biogas or biofuels. We have a variation of biomass residues that main categories are agricultural, waste, forestry and industrial residues. All the types of the residues have the ability to be used as input in biogas power plants for biogas generation. For the substantial future in Europe regarding biogas production is the availability of biomass feedstock. More specific the availability is based on key indicators concerning financial, technological and environmental factors like production costs, the types of the residues, location of available waste (transportation costs) and the applied technologies for waste processing and production of energy crops [18].

The figure 2.3 shows the energy demand worldwide and biomass demand from forest and agricultural residues with their future potential for 2030 and 2050. The traditional biomass such as wood or charcoal has been used in the households for cooking since the very past times. On the other hand, with the term modern biomass we talk about the progressive technological applications used today in the energy sector generating alternative sources for energy consumption to meet our needs [14].

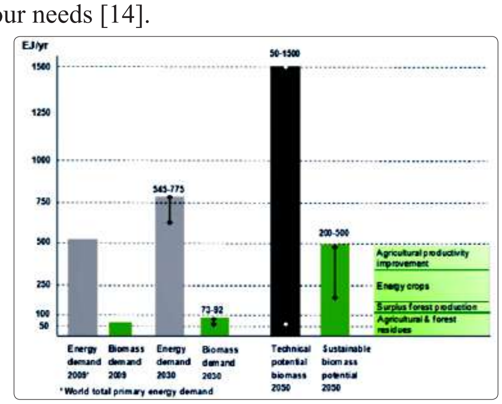

Figure 2.3: Energy Demand and Biomass Demand Worldwide with Future Potential [18].

Biogas Production

Biogas is defined as the primary product from the technological process of anaerobic digestion. It is a methane rich renewable gas with composition of methane 50% - 65% and carbon dioxide 35% -50%. Biogas has a significant characteristic regarding the substrate flexibility that can be source. More specific, we can produce biogas from agricultural residues, animal manure, energy crops, sewage sludge, household and industrial waste and more. During the operation of the anaerobic digestion simply the bacteria reacting with the organic matter in the absence of oxygen produce biogas.

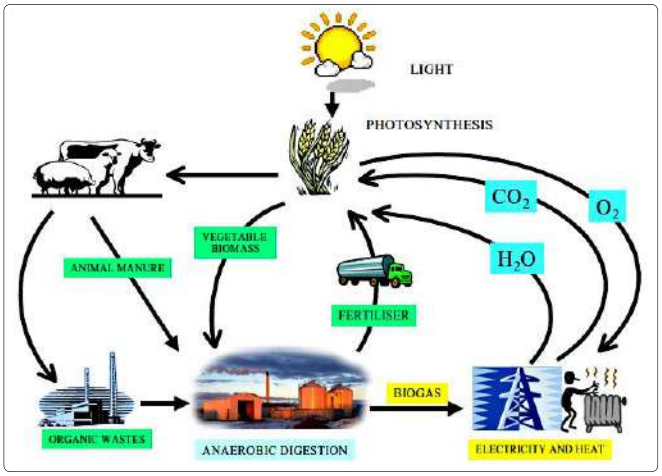

Figure 2.4: Biogas Cycle from Anaerobic Digestion Technological Process [3].

The figure 2.4 shows the life cycle of biogas and the interrelations, staring with the sunlight and the photosynthesis phenomenon and continues. The figure 2.5 below represents a characteristic biogas product use.

The capture of the sunlight as fixed carbon in biomass via photosynthesis, during which carbon dioxide (CO_2) is transformed to organic compounds, is the key step in the generation of virgin biomass and is described from the equation below:

$CO_2 + H_2O + light + chlorophyll \rightarrow (CH_2O) + O_2$, where carbohydrate is represented by the building, block (CH_2O), is the primary organic product [19].

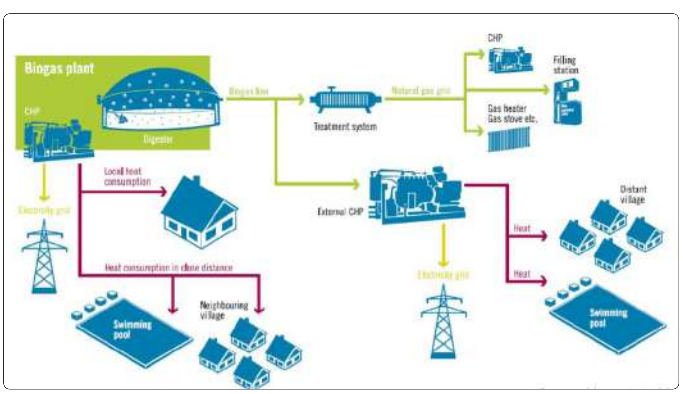

Figure 2.5: Biogas End Use Products [20].

Regarding to uses of the biogas, it is possible to be converted energy in many ways. The most common is the utilization of combined heat and power (CHP), where the produced energy is aiming for heating and electricity. Moreover, we have also the case of the storage of the biogas in appropriate installations [21].

What is Biomethane?

Biomethane is the upgraded biogas produced through anaerobic digestion or from biomass gasification for cleaned syngas. In addition, according to European Biogas Association, the Power-to-Gas process methane product if the electric power is a renewable energy source and the hydrogen is converted into methane in CO_2 digester.

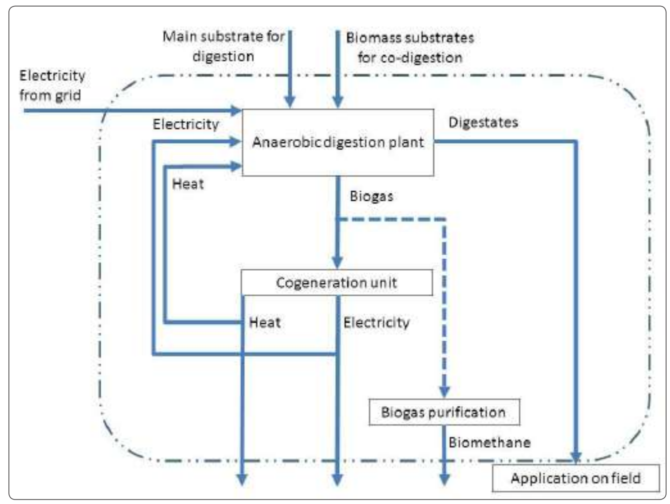

Figure 2.6: Flow chart: biogas production from substrates of the purification to bio methane and generation of heat and electricity in biogas co generation unit [22].

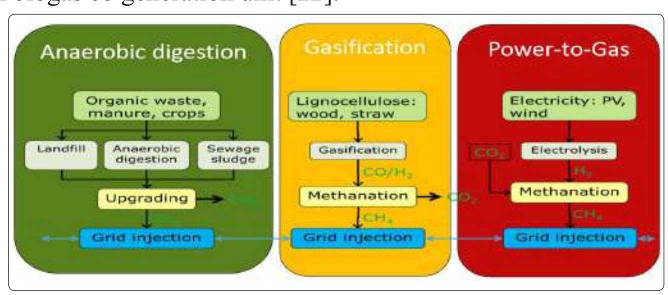

Figure 2.7: Biomethane Production Technologies [20].

Chemical Composition and Physical Properties of Biogas

In this part, according to Biogas Renewable Energy, the tables 2.1 and 2.2 present the chemical composition of biogas depending on the feedstock used such as household waste, wastewater treatment sludge, agricultural residues and food waste. Depending on the substrates utilized we are able to observe below the variation in the values of the product regarding the chemical composition and the physical properties, which differentiate again, depending on the input that has been used.

Table 2.1: Composition of Biogas, based on the Waste Input [6].

Elemental Components	Household Residues	Wastewater Sludge	Agricultural Residues	Industrial Food Waste
CH_4 % vol	50-60	60-75	60-75	68
CO_2 % vol	38-34	33-19	33-19	26
N_2 % vol	5-0	1-0	1-0	-
O_2 % vol	1-0	<0.5	<0.5	-
H_2O % vol	6 (à 40 ° C)	6 (à 40 ° C)	6 (à 40 ° C)	6 (à 40 ° C)
Total % vol	100	100	100	100
H_2S mg/m^3	100-900	1000-4000	3000-10000	400
NH_3 mg/m^3	-	-	50-100	-
Aromatic mg/m^3	0-200	-	-	-
Organochlorinated or organofluorated mg/m^3	100-800	-	-	-

Table 2.2 Physical Characteristics of Biogas [6].

Types of gas	Biogas 1 Household waste	Biogas 2 Agri-food industry
Composition	60% CH_4 33 % CO_2 1% N_2 0% O_2 6% H_2O	68% CH_4 26 % CO_2 1% N_2 0% O_2 5 % H_2O
PCS kWh/m^3	6.6	7.5
PCI kWh/m^3	6.0	6.8
Density	0.93	0.85
Mass (kg/m^3)	1.21	1.11
Index of Wobbe	6.9	8.1

Biogas Production Systems: Anaerobic Digestion Technologies and Environmental Impacts

A biogas installation plant is a complex concept that contains plenty of several elements. More specific, the layout of an industrial application which produces biogas depends on the type and amount of feedstock and regarding to the type, desirable size and operation conditions we have a big variety of technologies for conditioning, storage [3].

The Process of Biogas Production: Anaerobic Digestion Technologies in Biogas Operating Units

In the production of biogas the technological process which is used is known as anaerobic digestion. The process is microbiological and during operation the organic material is decomposing in oxygen limited environment. Main products which come from the anaerobic digestion are biogas and digestate. During the process we have low amounts of heat produced to the aerobic decomposition, similar to the biomass combustion [3].

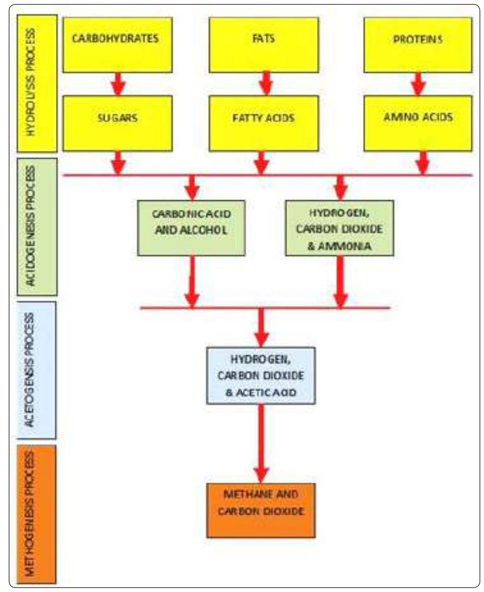

Figure 3.1: Process Flow Diagram for a typical Biogas Reactor Process [23].

In the anaerobic digestion technological process, we have four stages known as: hydrolysis, acidogenesis, acetogenesis and methanogenesis (figure 3.1). In hydrolysis, the microorganisms which occur in the substrates excrete enzymes to break in smaller units the organic compounds of carbohydrates, lipids and nuclear acids to glucose, glycerol, purines and pyrinides. Then, in the acidogenesis follows the hydrolysis products are fermented into fatty acid intermidiateries. The third stage of the acetogenesis is the critical part of the process. The volatile fatty acids and alcohol get oxidized to acetate, hydrogen and carbon dioxide before the conversion into methane. The final phase of the process is methanogenesis, where the methanogens generate methane gas from acetate or H2 and CO_2 [24].

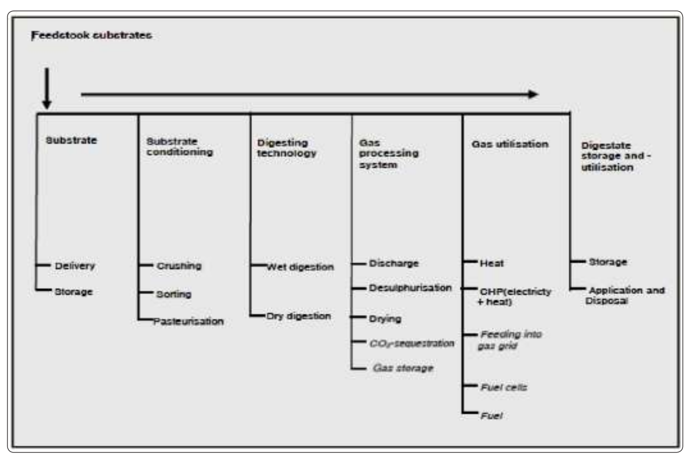

Figure 3.2: Process Steps of Biogas Technologies [3].

The concept of biogas production contains some process steps for the complete operation from receiving the feedstock, to store and maintain it due to certain conditions depending on the substrate. It follows the digesting technology depending on the form of the input to move on to the conversion and eventually to the utilization of the product (biogas) as presented in the figure 3.2 [3].

Anaerobic digestion technology is highly advantageous for the following reasons. In first place the biogas is produced from raw materials which wouldn't be used such as animal manure or agricultural residues like leaver or sugar beets. Moreover, the indirect environmental impacts like the decreased emissions of methane and ammonia (during manure storage) and lower emissions of ammonia because of waste composting. Last but not least, the replacement of fossil fuels from biogas that could limit the greenhouse gases and emissions of particles [25].

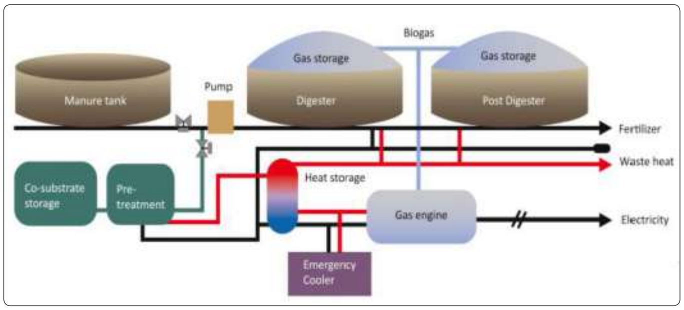

Figure 3.3: Functioning Principles of a Biogas System [24].

In this part, regarding the figure 3.3 we observe the main functioning principles of the biogas system and it s parts such as the manure tank, the gas storage, the pre treatment and storage of the feedstock, the engine, heat storage and emergency cooler.

Additionally, the schematic representation in the figure 3.4 shows in a biogas system how the material flow applies before and after the process.

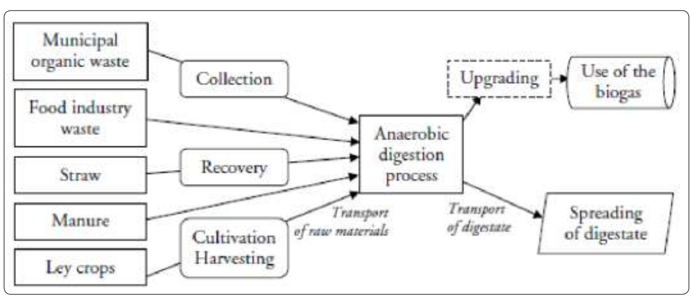

Figure 3.4: Biogas System: Material Flowing [25].

Strategies in Biogas Operating Units installed in Different Capacities

Table 3.1: Biogas Plants Strategies with Three Scaled Capacities, retrieved from Gerlach et al. [24].

BIOGAS PLANTS	SMALL< 100kW	MEDIUM 100 - 500 kW	LARGE SCALE>500kW
Suitable for	Small scale farms Farms with only animal Farms with mainly perennial cultures like fruit and wine	Big farms Farms with more arable crop production (with green manure) Larger horticulture production	Several bigger organic farms with short distances in between potential for a common biogas plant in cooperation
Disadvantages	High specific cost for biogas plant (e per kW) Management lies on the farmer him selves Lower electric efficiency in CHP	Dependency of external biomass supply Waste heat utilization can be a challenge Transportation cost may occur Appropriate cooperation agreements with biomass suppliers must be foreseen	Higher cost per kW Transportation costs More costly and time demanding approval process Cooperation agreements must be developed Enough biomass necessary in relation to plant size
Advantages	Closely integrated with the farm setting Only own biomass (no dependencies) No transportation cost Waste heat allocated locally	Lower specific cost for biogas plant (e per kW) Higher electric efficiency in CHP Employed people can take part in the operation	More optimal energy sales can be developed, like upgrading for the gas grid Specialized operator can be employed
Strategies	Do it your selves Concept appropriator simple turnkey concepts	Turn key plant appropriate Organic biomass must be secured through agreements from suppliers Import of conventional biomass for a transition period Convert neighboring Farms to organic	Customized biogas plant setting can be afforded Alternative marketing strategies can be analyzed

Environmental Impacts in Biogas Production Technologies

The use of the organic waste effects significantly in the productivity of the agriculture and forestry and additionally in a successful biofuel production system has both economic, as well as environmental beneficial results. From the biogas production the indirect environmental impacts are referring to the acidification and eutrophication potentials [25, 26].

In the biogas generation technologies are given several difference substrates that all have a different environmental performance. A significant element that needs to be considered is the release of the emissions of carbon dioxide (CO_2) and methane. High interest presents the methane regarding it s environmental aspects [22]. The release of greenhouse gas emissions belongs to the high scale impact which brought the policy strategies to request the reduce rate of the CO_2 emissions. The potential of the global warming is a value which gives us the ability to talk about the heat which is trapped by certain mass of the gas and question the heat amount of heat trapped in the atmosphere by a similar mass of CO_2 [27, 28].

Furthermore, biogas contains approximately 50-60 % by volume methane which makes it valuable fuel. A serious concern regarding the treatment of the sludge refers to the concentration of the heavy metals, poor biodegradable organic compounds, as well as pathogenic organisms like bacteria in the wastewaters. The materials mentioned can be dangerous for the environmental ecosystems and this can happen since they can leach from the soil and reach the groundwater and spread. Through the food chain, entering in the crops which are food of animals can threat also the human health since they are toxic [21].

Since 1980 has been identified in Europe a general reduce of acidifying substances. The definition of "acidification" is established as "the effects of the introduction of acidifying substances into the environment by means of atmospheric deposition". More specific the basic pollutants that create the environmental issue are: Sulphur dioxide (SO_2), (produced basically from coal combustion processes). Additionally, we have nitrogen oxides (NOx), (produced from mobility vehicles and combustion processes). Last but not least, ammonia (NH_3), (coming from fertilizers, animal manure and agricultural applications) [29].

According to Pöschl, Germany's main goal is to raise the frequency of the biofuel use to meet the human needs and to be more dependent in imports so this way the released greenhouse gas emissions to be generated elsewhere and not be counted officially for the German country [30]. In the Brandenburg region the greenhouse gas emissions coming from the biogas production vary and the mitigation of the GHG has the possibility to be decreased up to 75%, when biogas will replace the oil fuels, petrol [31, 25].

The environmental impacts of the biogas stations which concern the scientific communities and the governments are: atmospheric pollution, noise from the biogas stations, risk of groundwater and surface waters contamination, soil pollution, impacts on the landscape and other [32].

Greenhouse Gases (GHG)

During the biogas production we have often the release except of carbon dioxide (CO_2), additionally NOx and SO_2. The life cycle emissions are substantially reduced when biogas from tops and leaves of sugar beets, manure and organic waste are utilized mainly to the reduced emissions of NO_3- and NO_3 [33].

Table 3.2: Contribution of the main Greenhouse Gases to the Greenhouse Effect [28].

Gas	Formula	Contribution (%)
Contribution (%)	H_2O	36-72%
Carbon Dioxide	CO_2	9-26%
Methane	CH_4	4-9%
Ozone	O_3	3-7%

The most significant greenhouse gas emissions are the carbon dioxide (CO_2) and the water vapor. On the other hand the N_2 and O_2 do not have any impacts on the Earth. The highlighted greenhouse gases directly influenced by the human activities are: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), the chlorofluorocarbons (CFSs) (a group of gases containing fluorine, chlorine and bromine) and ozone [28].

Biogas Installation Plants: Europe, Germany and the Brandenburg Region

In this chapter will be presented the biogas and biome thane development of the power plants through the years from the past till the recent future in Europe. It will follow the historical milestones of the biogas production development in the world leader of the biogas sector in Germany and it will be introduced briefly the region of Brandenburg transition network and installed capacities, as well as the description in more detail of the region regarding the energy–biogas market.

European Status of Biogas and Biomethane Installation Plants

According to European Biogas Association, is given the current status and the future expecting operating plants which apply in Europe. The figure 4.1 introduces the biogas plant evolution the last decade and then follows the European status about the biogas installation plants existing as well as the new plants expected, as presented in figure 4.2.

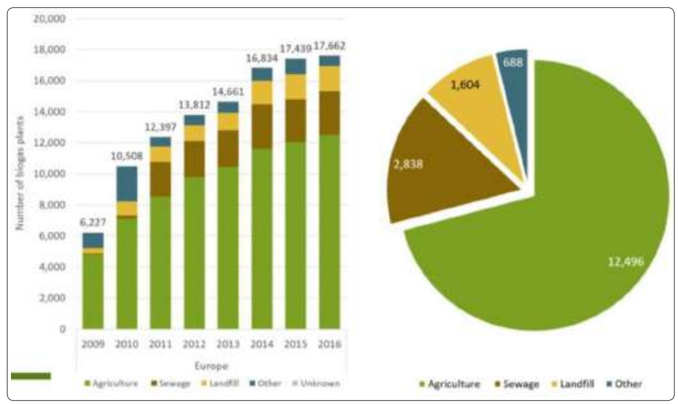

Figure 4.1: Number of Biogas Plants in Europe since 2009 [20].

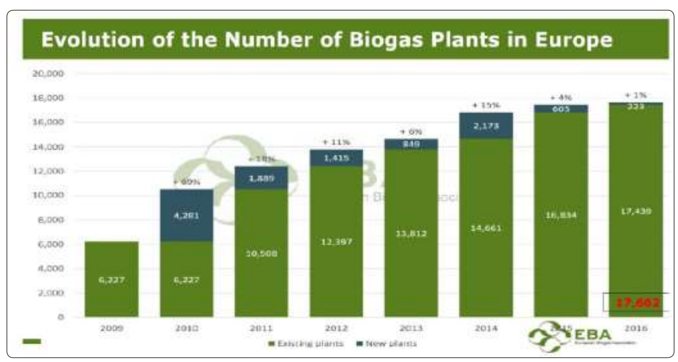

Figure 4.2: Biogas Plants in Europe from 2009 till 2016 [34].

The European market regarding the biogas operating units is showing a major increase considering the development of the installation of production plants. On 2010 we had a rapid increase +69% biogas installation plant applications comparing the number of the plants from 2009.

The European status of the biome thane plants is shown in the figure 4.3. The tendency of the development of the installation plants is increasing from 2011 till 2016. On 2014 we had a +30% increase in new installation power plants.

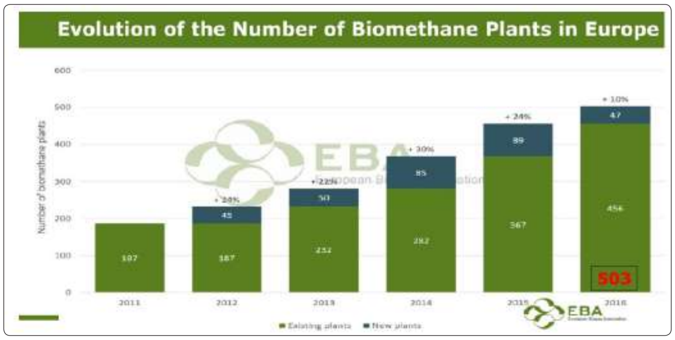

Figure 4.3: Biomethane Plants in Europe from 2011 till 2016 [34].

Electricity Production and Future Targets in EU 28

In the European Union the historical development since 1990 is shown in the figure 4.4.We are able to observe a continuous tendency of increasing energy supply of electricity from the produced biogas.

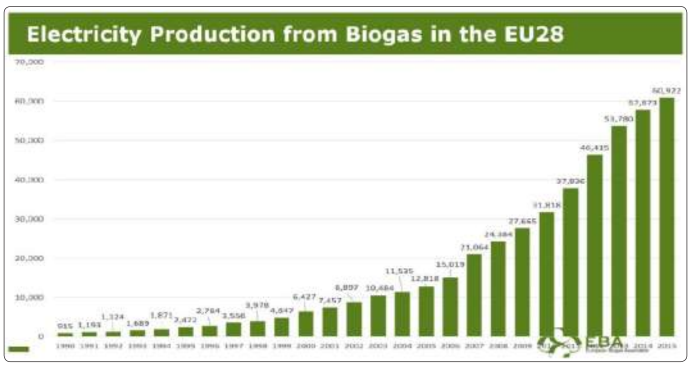

Figure 4.4: Electricity produced from Biogas since 1990 [34].

Figure 4.5: Targets and Forecast for the European Union, based on the International Electro technical Commission and the National Renewable Energy Action Plan [34].

Greenhouse Gas Savings from Biogas and Biomethane

The greenhouse gases savings remain an official rationale of EU policy, as well as basic criteria for evaluating whether a bio fuel source qualifies for the targets. The European governments are concerned about environmental benefits. However, their assumptions are contradicted by national bio fuel practices. The country of Germany in the bio fuel usage reduces the greenhouse gas emissions, but some potential savings have been lost by more intensive agricultural practices [30].

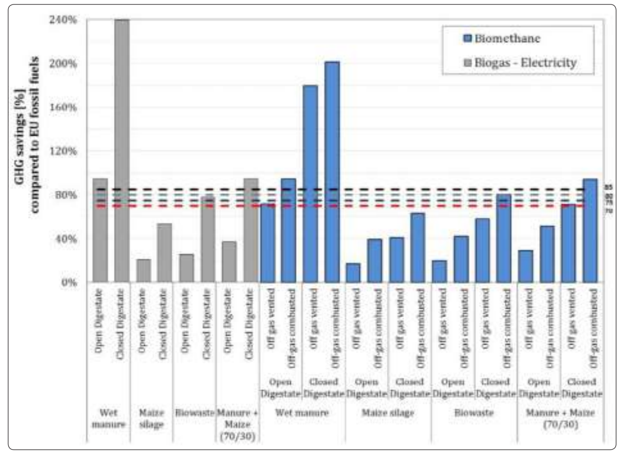

Figure 4.6: Greenhouse Gas savings from Biogas and Biomethane in Europe

According to the European Biogas Association (2018) regarding the concerns if there will be accomplished the key targets by 2020, based on the feedback of operators, researchers and policy decision makers the general attitude is positive with the condition that more can happen in order to reach the goals.

Biogas in Germany: Historical Milestones and Market Development

According to the German Society for Sustainable Biogas and Bioenergy Utilization the biogas productions in Germany start already since 1930 with the first appearance of the generation of sewage gas in sewage treatment plants. The production peak is taking place during the 2nd World War and more specific right after the currency reform on 1950. Between the years 1935 and 1955 biogas has been treated in some sewage plants in order to be used in transportation vehicles and households. A farmer known as Berhaloth in Hesse was the owner of one agricultural biogas plant in Germany on 1948 and used the manure of two horses and eight cows for daily production of 8-10 m3 (the biogas was used in the household). Later on the 70s German farmers started to produce their own biogas in order to be independent from the energy supplies. The feed in "tariff" for electricity is introduced on the 90s and it is replaced later on 2000 from the Renewable Energy Sources Act with main goal to apply a sustainable plan and raise by 30% the energy supply from renewable energies. According the Clean Energy Wire (2016) the figure 4.7 presents the biogas installed plants in Germany since 2000 and the installed capacities in MWh.

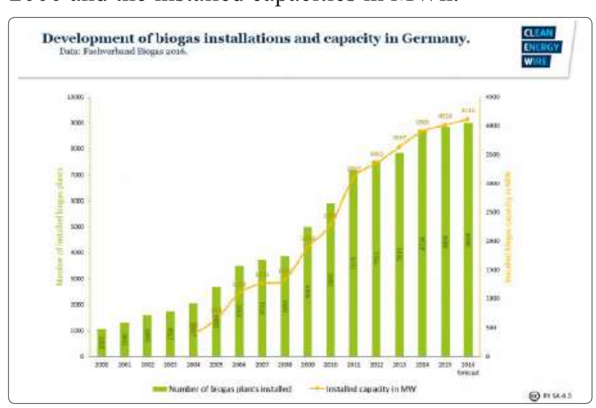

Figure 4.7: Biogas Market Developments in Germany [35]

Energy Production and Biogas in Brandenburg

The research area that is investigated comprehends 30,377 km2 and includes two German Federal states, the capital of Germany Berlin and Brandenburg, as shown in the figure 4.7 [36].

Figure 4.8: Map of Germany [36].

The figure 4.10 presents the installed capacities in the region and the transition network map where we are able to observe that there is an important fossil fuel capacity more specific in Lusatia. The grid in the region as shown in the figure 4.9 outlines the interconnection of the Berlin – Brandenburg area and a high amount generation capacities from Lusatia has been existing since 1894 as a significant lignite power generation source. The table 4.1 shows the installed capacities of the regional area of Berlin – Brandenburg for the year late 2011 – early 2012 [37].

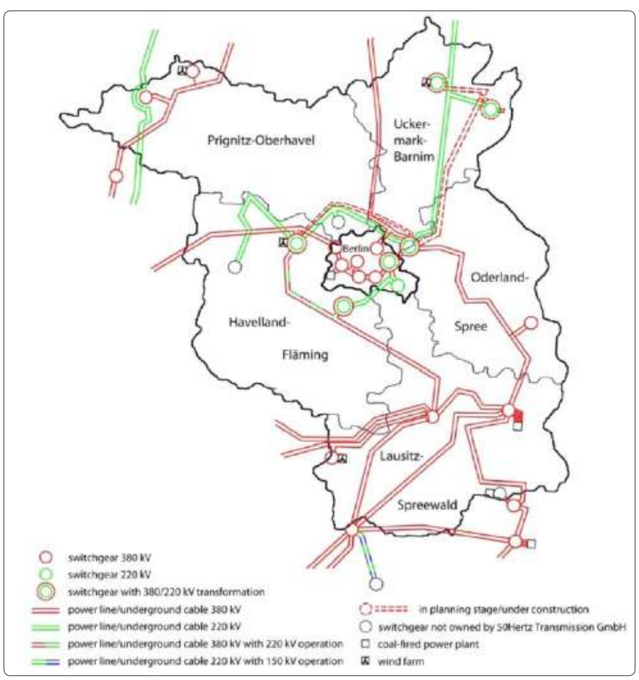

Figure 4.9: Berlin – Brandenburg Transition Network [37].

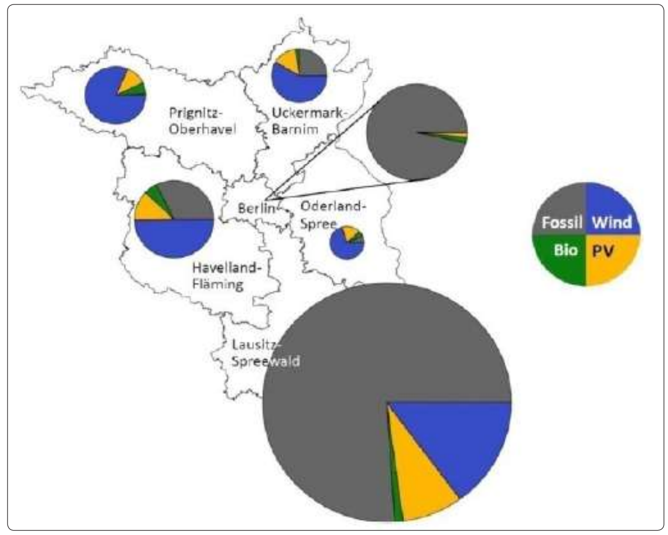

Figure 4.10: Installed capacities of fossil fuels (grey), wind (blue), bioenergy (green) & photovoltaic (yellow) [37].

The regional state of Brandenburg has been developing regarding the renewable sources of energy. The Ministry of Environment, Health and Consumer Protection has been focused in an innovative policy considering the energy efficiency and energy conservation, however there has been emphasized the production of renewable energy. Main purpose is based in the reduction of the greenhouse emissions, the conservation of the natural resources, as well as the strengthening of the Brandenburg region. Another significant goal is referring to the expansion of the renewable energy [38].

For three times the region of Brandenburg has been awarded from the German Renewable Energies Agency with the LEISTERN prize on 2008, 2010 and 2012 for being the best state in Germany comparing to the other regions for using renewable energies such as biomass, solar and wind, as well as geothermal and hydroelectric power [38].

	Biogas/MW	Biomass/MW
Prignitz-Oberhavel	36	57
Uckermark-Barnim	12	19
Oderland-Spree	18	28
Lausitz-Spreewald	25	39
Havelland-Fläming	41	65
Total Brandenburg	**132**	**208**
Berlin	**0**	**45**

Table 4.1: Berlin – Brandenburg Installed Capacities of Biogas and Biomass [37].

In Brandenburg the energy strategy, according to ZAB, says the energy policy guidelines and the associates apply measures in order to achieve the challenges of the global climate change [4]. The three key indicators to meet the desirable outcomes are the energy efficiency, the energy saving and the CO_2 emissions. Regarding the energy related CO2 emissions development it is important to point out that is one central indicator concerning the climate change. They arise significantly in the combustion of coal, gas and oil. The brown coal has the largest total energy related CO_2 emissions.

Safety Aspects and Risk Applications in Operating Power Plants

The fifth chapter will describe the point that focuses in the safety and the possible risks which occur in the biogas power plants. The legal framework that is established will be given below, the hazards – risks and accidents which took place in Germany. The construction of a biogas power plant and its operation results in plenty of safety issues, possible risks and impacts in the human health, animals and the ecosystems. It is highly significant the biogas power plants to provide a safe environment for the employees. The application of measures in order to prevent risks and hazards has been mandatory [39].

Hazards and Risks in Biogas Plants

Biogas is a promising energy resource in the context of the new European Energy Strategy 2020. The wastes (water or biomass) that are used for biogas generation have a versatile character and it can be produced all over Europe for a great variety of applications: transport, stationary energy use, heat and combustion. The basic risk issues regarding to the quick development of biogas, which is flammable, toxic, and possibly pathogen (microbiological hazard) are described below:

- The variety of the applicable technological processes (from waste water treatment to solid waste treatment or biogas valorization by farmers) without reference document clearly defining at worldwide level the state of the art regarding safety;
- The lack of clear regulations and standards regarding the safety of biogas production and use, and the lack of enforcement of the existing occupational health and safety regulation (including ATEX);
- The lack of organized communication channels to share the experiences (near misses, accidents and also positive experiences) between the industry players, but also with the usual stakeholders such as authorities and insurance companies [40].

For the safe operation of the production plants there is necessary the fulfillment of some significant safety issues and appropriate measures for controlling and monitoring the unit and ensure the safety of the employees. According to the authors Seadi et al., the measures for hazard prevention need to cover the following areas [3].

- Explosion prevention
- Fire prevention
- Mechanical dangers
- Sound statically construction
- Electrical Safety
- Lightning protection
- Thermal Safety
- Noise emissions protection
- Asphyxiation, poisoning prevention
- Hygienic and veterinary safety
- Avoidance of air polluting emissions
- Prevention of ground and surface water leakages
- Avoidance of pollutants release during waste disposal
- Flooding safety

The hazards which may occur in biogas production plants can be related to health and the environment. The health hazards are possible to be categorized in hazardous substances, for example dermatological infections, viruses, bacteria, acids etc. Furthermore, there are potential hazards which could be dangerous in the human health regarding to electrical hazards, mechanical hazards, fire, noise and gas hazards. A case for a possible fire could come from hot surfaces, high amounts of heat and noise could come from the operation of the CHP. The gas hazards refer to the gases released during operation which could effect to explosions, suffocation and intoxication. The dangerous elemental components of biogas are the CO2, methane (CH4) which has an explosive range between 4. 4 % - 16.5 %. Last but not least, oxygen can be also dangerous when its concentration is below 18Vol - % [41].

Accidents in Biogas Plants in Germany

The high safety standards result from the fact that accidents take place in the industrial applications. The accidents can be caused due to mechanical reasons, chemical, radiation or the noise hazards that occur. However, as shown in the figure 5.4 the highest percent up to 90% of the accidents are caused from mechanical reasons.

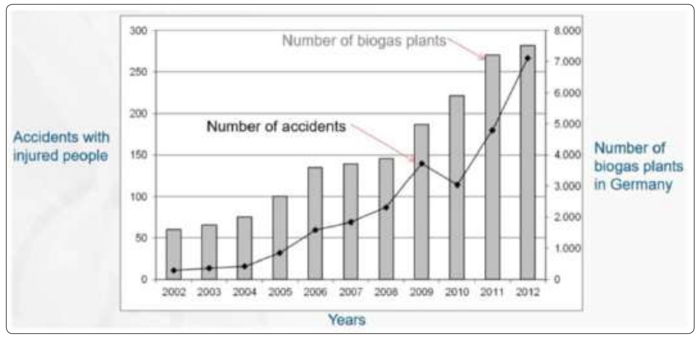

Figure 5.1: Accidents on Biogas Production Plants in Germany [41].

In Germany the installation plants are increased which means the possibilities for accidents also does. In the figure 5.3 we have the status of the accidents with injured people regarding the number of the biogas plants.

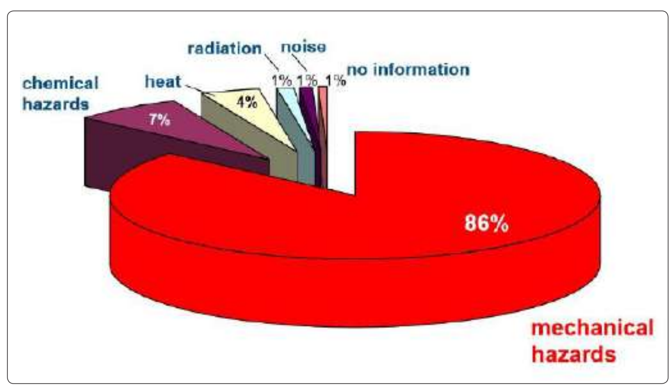

Figure 5.2: Rates of Accidents depending on the Hazards [41].

Legal Framework "ATEX"

The ATEX Directives have been established from the European Union with main goal to prevent accidents and their approach prioritizes safety, which should be adapted as main priority during operation. Furthermore, we need to point out that before the implementation of the ATEX there were other references considered such as the IEC standards unable to provide though certification [42].

The legal framework regarding the possible explosion risks which occur in operating plants is known as ATEX. More specific, ATEX includes two directives, known as: Directive 92/92/EC (alternatively ATEX 137 or ATEX Workplace Directive) and Directive 94/9/EC (alternatively ATEX 95 or ATEX Equipment Directive). The Directive 92/92/EC relates with minimum requirements for health improvement conditions and safety protection for the employees in explosive areas. The second Directive 94/9/EC is about the systems/ equipment of which may be used in explosive environments [43, 44].

Figure 5.3: Connections of ATEX 95 & ATEX 137 [42].

ATEX is based in the European standards; however it is recognized and accepted outside Europe too. In the other countries is adapted the IECEx concept to ensure safety which similar to ATEX [42].

In the figures 5.3 and 5.4, based on the content of the directives of ATEX the connections and a schematic representation of the established areas/ zones characterized for high attention regarding the explosive risks.

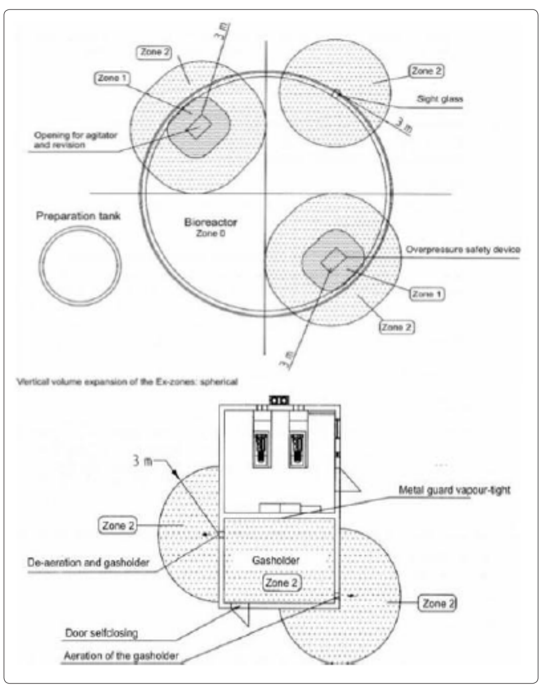

Figure 5.4: Explosive Areas in Biogas Plant

we have three zones on the schematic representation of biogas plant, where: the zone 0-the bioreactor contains an explosive area due to the release of gases, vapors or mists [43]. The zone 1 covers areas where we have sometimes risk for explosive atmospheres (we have also in the areas of zone 1 release of gases, vapors, mists). The zone 2 covers the areas in the biogas plant that is relatively safe and has no danger for gas mixtures releases [43].

Discussion and Results

The present chapter outlines the regional status of Brandenburg in Germany concerning the industrial applications of biogas production plants based on the number and the installed capacity of the operating plants, as well as the connection with the produced carbon dioxide (CO_2) emissions and the future tendency. In addition, we are able to see the concerns and indicators that play a significant role in the safety and risk aspects of the operating plants.

The figures below are produced from data provided from the Ministry, Environment, Health and Consumer Protection Land Brandenburg to show the regional development industry and ZAB Energie for the information concerning the carbon dioxide (CO2) emissions in the region.

Furthermore, the table 6.1 aims to present the aspects of health and safety in operating units based on answers of academics and engineers working on the field.

Regional Status of Biogas Production in Brandenburg, Germany

The operating units of biogas production in the region from the available data use substrates of agricultural residues like corn, grass, sugar millet and sorghum. Moreover, the second feedstock input comes from the livestock such as poultry manure, droppings and litter. Main source of biomass residues additionally used in the region are pig manure and cattle manure.

Regarding the regional status of the Brandenburg developed biogas industry the figure 6.1 and 6.2 present the number of the industrial applications of biogas production regarding to the uses of the produced biogas for 2015. The highest number of the power plants it mainly used for combined heat and power (CHP). In total we count on 2015 more than 300 biogas operation units, where approximately the 70% of them are combined heat and power units (CHP).

The figure 6.3 and 6.4 outlines the biogas operating units regarding the installed capacity. We are able to observe that we have an equal number of biogas plants operating with installed capacity up to 600kWh and between 600kWh to 1000 kWh.

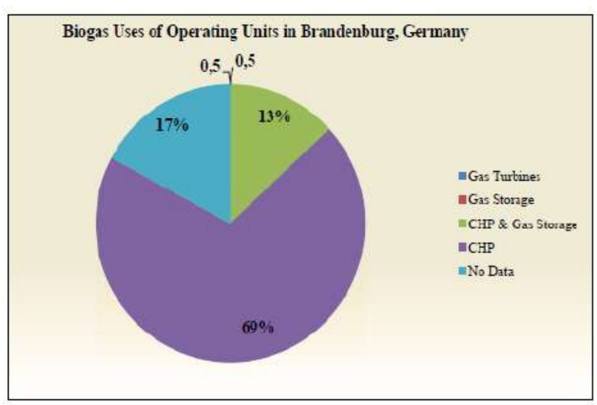

Figure 6.1: Number of Biogas Production Plants in the region of Brandenburg, based on the Ministry of Environment, Health and Consumer Protection [38].

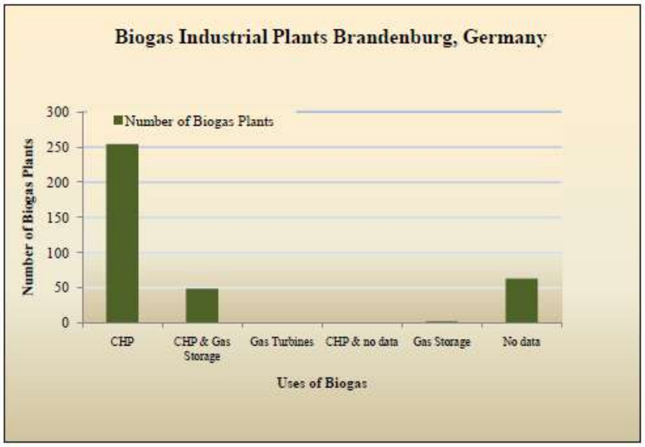

Figure 6.2: The Biogas Uses of the Biogas Operating Units, based on the Ministry of Environment, Health and Consumer Protection [38].

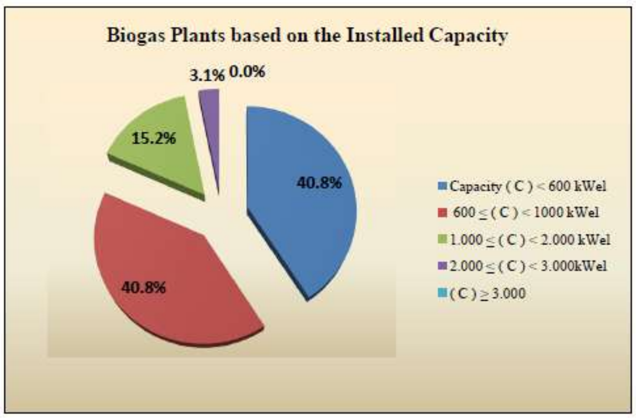

Figure 6.3: Biogas Operating Units regarding the Installed Capacity, based on the Ministry of Environment, Health and Consumer Protection [38].

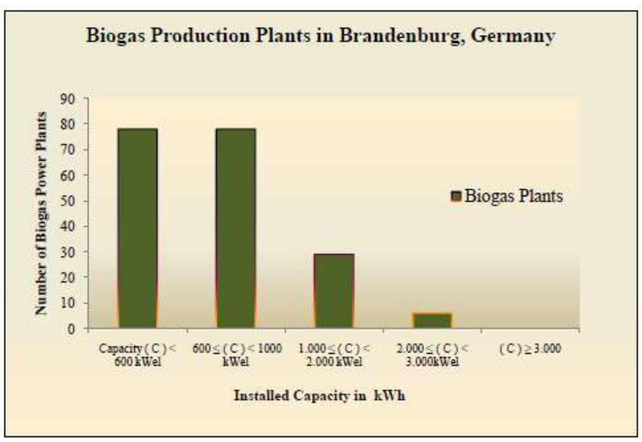

Figure 6.4: Biogas Industrial Applications in the Brandenburg Region with their Installed Capacity on 2015 (Appendix; Table 8.1)

Carbon Dioxide (CO_2) Emissions and Future Trend in Brandenburg, Germany

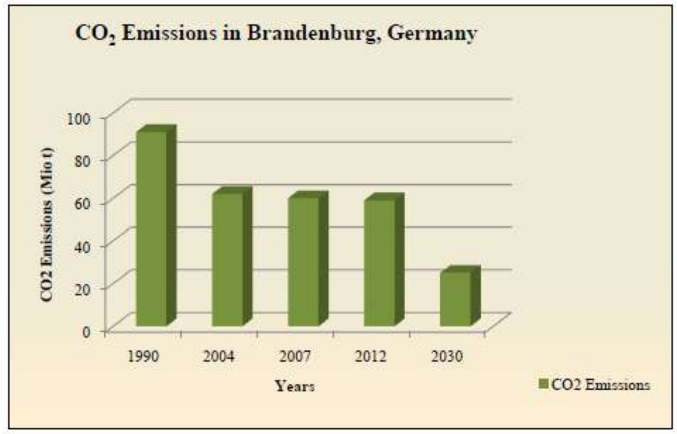

Figure 6.5: Carbon Dioxide (CO_2) Emissions in Brandenburg, based on ZAB Energie (2014) (Appendix; Table 8.2)

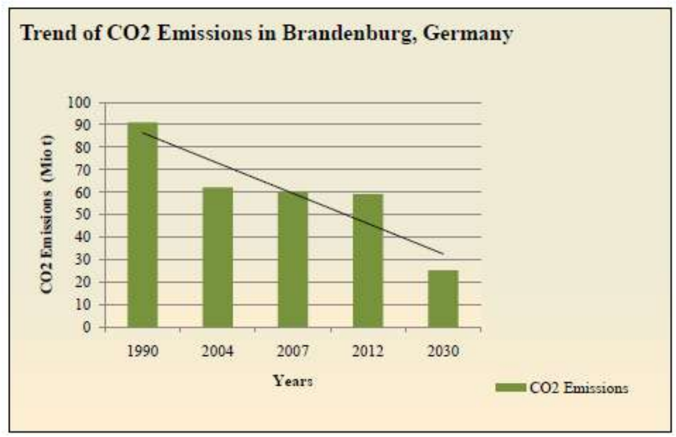

Figure 6.6: Trend of the release of Carbon Dioxide (CO_2) Emissions, based on ZAB Energie [3].
(Appendix: Table 8.3)

Safety and Risks in Operating Biogas Units

Table 6.1: Health and Safety Aspects in the Industrial Biogas Installation Plants

Operation of Biogas Production Plants	• Preliminary planning of processes and plant dimensioning, economic study • First evaluation of approvability, preliminary talk with authority for approval • Approval planning and application for approval • If necessary process of public participation (depending on plant size and application) • Process of approval, clarification of queries from authorities • Approval • Plant erection and commissioning, interim acceptance procedures by authorities • Final acceptance by authorities

Educational Profile of the Employees in Operational Procedures	• Process Engineering • Environmental Engineering • Biotechnology
Safety of Anaerobic Digestion Technologies Main Hazards and Relevant Parameters	Safety of Anaerobic Digestion Technologies Main Hazards and Relevant Parameters
Possible Accidents During Operation of Biogas Power Plants	The number of possible failures is limited. Risks are well-known, and measures for the avoidance as well. Main problems: individual ignorance of operational and safety instructions, poor technological discipline.
Safety & Regulations	All equipment in the EU is tested for safety. Most important: individuals have to obey existing concepts, instruction etc. Maintenance of equipment, like sensors for flammable or toxic gases, proves of the functionality of safety equipment. That's sufficient.

Conclusions

The present research thesis explored the biogas production development and the aspects of safety and risks that may occur in the operation units in the industry. Regarding the biogas development there is an overview taking place for the European status and the German market development through the years. The case study that has been examined is the region of Brandenburg (Germany).

The Chapter 2 is introducing bioenergy and a worldwide overview regarding the energy production share. Furthermore, the biomass residues in the energy production are described and important point is the big variety of organic substrates is used for biogas generation.

In the Chapter 3 follows the description of the technological process of anaerobic digestion, the most popular biogas technology applied in the industry and the environmental impacts which result from the biogas technologies.

The Chapter 4 presents the European status of biogas, the German market development and the general picture of the energy consumption in Brandenburg. Furthermore, the greenhouse gas savings evaluated from the European Biogas Association are reported, as well as the future targets of EU28.

The Chapter 5 outlines the concerns that relate to the operating units for the safety and the risks that occur, the legal framework around it and the accidents that took place in Germany the past years.

Based on the first objective of the research to examine the region of Brandenburg, we have the developed biogas industry status for 2015 and the status of the carbon dioxide (CO_2) emissions evaluated for the case study area and the future trend. In addition, the biogas production plants we counted to be more 300 with main feedstock use animal manure and agricultural residues.

Regarding the safety and the risk application objective, after personal interviews with operators and academics we end up in the conclusion that main problems in the industrial plants come from the individual ignorance of the instructions and measures and the poor technological discipline of the employees.

Last but not least, concerning the key targets of the European Union if they will be accomplished based on the progressive evolution of the biogas development surely we tend to and there is positive attitude that we might reach them if more will be done (based on debate in European Biogas Association Conference on January 2018).

Appendixes

Questionnaire
Health and Safety Conditions in Biogas Production & Technologies

Biogas Production – Employees Profile

1. How long have you been working in the biogas production sector?
2. How is the process of obtaining a permit to operate a plant? Please explain briefly in short, why
3. For the operators which education or kind of training is appropriate?

Anaerobic Digestion

4. In the biogas production, are the processes of anaerobic digestion such as hydrolysis- acidogenesis -acetogenesis and methanogenesis equivalent regarding safety? If yes, please give a short description:

Relevant Parameters and Main Hazards

5. What are the safety critical parameters according to your experience? Please note briefly.

a)
b)
c)

1. Are the safety management systems in place adequate? Please explain in short why:

Accident Issues

7. From your experience is it necessary to establish permanent network sharing information on causes of accidents? Please note briefly why.
8. Are occurring accidents and risks discussed openly among biogas working sites?
9. In your experience in power plant technologies were there any kinds of accidents according safety? If yes how did you face it?

Regulations and Safety

10. Can we define some minimum regulations standards regarding safety?
11. Are there any actions needed to support the implementation of safety regulations?

Tables

The tables below show the data used in order to outline the results on the chapter 6, after collection, process and evaluation.

Table 8.1: Number of Brandenburg Operating Units regarding the Urban District, based on the Ministry of Environment, Health and Consumer Protection [38]

Urban District	Number of Plants	(C) < 600 kWel	600 ≤ (C) < 1000 kWel	1.000 ≤ (C) < 2.000 kWel	2.000 ≤ (C) < 3.000 kWel
PR	20	13	5	2	
OPR	13	9	3	1	
OHV	9		4	5	
UM	16	5	9	2	
BRB	1	1			
HVL	14	8		2	4
MOL	15	5	9	1	
EE	7	3	2	2	
FF	2	2			
LDS	9	4	2	3	1
LOS	9	2	6		1
OSL	9	5	2		
PM	21	8	9	4	
SPN	5	3	1	1	
TF	26	5	17	4	
UM	16	5	9	2	
TOTAL	192	78	78	29	6

The table 8.1 presents the information data available of the biogas plants regarding the urban districts and the installed capacity of the power plants. The urban districts mentioned above are the following: Brandenburg/ Havel (BRB), Elbe/ Elster (EE), Franfurt/ Oder (FF), Havelland (HVL), Dahme – Spreewald (LDS), Oder – Spree (LOS), Märkish – Oderland (MOL), Oberhavel (OHV), Ostprignitz – Ruppin (OPR), Oberspreweald – Lausitz (OSL), Potsdam – Mittelmarkt (PM), Prignitz (PR), Spree Neiße (SPN), Teltow Fläming (TF) and Uckermark (UM).

Table 8.2: Amounts of Carbon Dioxide Emissions in Brandenburg, [3].

Year	CO_2 Emissions (Mio t)
1990	91,0
2004	62,0
2007	60,3
2012	59,5
2030	25,0

Table 8.3: Biogas Operating Units in Brandenburg, Germany, based on the Ministry of Environment, Health and Consumer Protection [38].

Number of Biogas Plants	Uses of Biogas
1	Gas Turbines
2	Gas Storage
49	CHP & Storage
254	CHP
63	No data

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