MSc Program
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Examination of Agricultural Biogas Application Options in Turkey

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AFFIDAVIT

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ABSTRACT

Biogas has a unique position among all renewable energy sources for it can address many different demands; electricity, heat, vehicle fuel, fertilizer, waste treatment. Biogas can be combusted in a gen-set to generate electricity and heat or after upgrading to bio-methane it can be used as vehicle fuel or feed into gas grid as a substitute of natural gas. Due to these flexible application possibilities, biogas is an advantageous option among all energy technologies particularly in the developing countries which are dependent on imported fossil fuels and facing waste management problems.

In this thesis, anaerobic digestion technology and utilization methods of biogas are discussed. The status of biogas production and utilization in Turkey is examined along with the legal background. It was expressed that agricultural wastes represent a high potential for biogas production. The key study addressing the vehicle fuel demand of the farms resulted to be economically feasible. However, biogas market in Turkey is still initiating and there are some legal barriers restricting the penetration of biogas energy.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABBREVIATIONS

AD: Anaerobic Digestion
APCAEM: Asian and Pacific Centre for Agricultural Engineering and Machinery (of United Nations)
BG: Biogas
BIWARE: Biomass and Waste for Renewable Energy (Project of Bremen University)
CAGR: Compound Annual Growth Rate
CAPEX: Capital Expenditure
CBA: Canadian Biogas Association
CHP: Combined Heat and Power
CCHP: Combined Cooling Heat and Power
CRF: Capital Recovery Factor
CSTR: Continuous Stirred Tank Reactors
d: Day
DEFRA: Department for Environment, Food and Rural Affairs (U.K)
DM: Dry Matter
EMRA: Energy Market Regulatory Authority (of Turkey)
EML Electricity Market Law
EU: European Union
EPDK: please refer to EMRA
ETKB: The Ministry of Energy and Natural Resources of Turkey
equiv.: Equivalent
FAO: Food and Agriculture Organization (of United Nations)
FLH: Full Load Hours
GDP: Gross Domestic Product
GHG: Greenhouse Gas
GVA: Gross Value Added
h: Hour(s)
HP: Horse Power
HRT: Hydraulic Retention Time
IRR: Internal Rate of Return
ISPAT: Investment Support and Promotion Agency of Turkey
l: Litres
m: Meters
MMO: Chamber of Mechanical Engineers (of Turkey)
Mtoe: Million tonnes oil equivalent
NG: Natural Gas
NGV: Natural Gas Vehicle
NPV: Net Present Value
OFMSW: Organic Fraction Municipal Solid Waste
OLR: Organic Loading Rate
O&M: Operation and Maintenance
P.A: Per annum
PBP: Payback Period
pH: Power of Hydrogen

ppmv: Parts Per Million by Volume
RE: Renewable Energy
REL: Renewable Energy Law
RES: Renewable Energy Sources
R&D: Research and Development
SME: Small - Medium Enterprise
SRT: Solids Retention Time
t: tonnes
TARMAKBİR: The Turkish Association of Agricultural Machinery & Equipment Manufacturers
TL: Turkish Liras
TURKSTAT: Turkish Statistical Institute
TR: Turkey
TSWL: Turkish Solid Waste Legislation
TVT: Thermische Verfahrenstechnik und Simulation
UN: United Nations
USDA: United States Department of Agriculture
VFA: Volatile Fatty Acid
VS: Volatile Solids
WACC: Weighted Average Cost of Capital
y: year

1 Introduction

In the fight against the biggest threat to our planet's future – global warming; all the 195 countries adopted to the Paris Agreement on 12 December 2015 for reducing their carbon emissions. Since burning fossil fuels is responsible for around 2/3 of the global greenhouse gas emissions, renewable energy will take an even more important role in this legally-binding action plan. In additional to environmental problems; fossil energy sources have sustainability and security problems in developing countries.

Biogas is an environment-friendly, sustainable energy carrier produced from anaerobic digestion of biomass sources. Even though there can be carbon based gas emissions – mainly CO_2 – during energy production from biomass, biomass sources are considered as "carbon neutral". Carbon neutrality indicates that there is no net carbon release to the atmosphere considering the growing plants counterbalance the same amount of carbon by capturing it within their life-cycle unlike fossil fuels.

Every other year production and use of biogas are getting popular worldwide. In the last decades, thousands of biogas plants are successfully established in European countries leading by the European countries such as Germany, Sweden, Austria and Italy. In 2006 there were estimated to be 18 million family-sized plants in China, 5 million in India. However, even though there is significant bio-waste potential especially from agricultural wastes due to growing economy and population, modern biogas energy technologies are not yet commonly utilized in many other developing countries such as in Turkey.

The core objective is to investigate the possibilities of alternative biogas utilization in agriculture sector of Turkey.

2 Biogas Energy Technology

This chapter focuses on the technological background of biogas production and utilization for practical uses.

2.1 Anaerobic Digestion for Biogas Production

Anaerobic digestion (AD) is a biotechnological process which is used for the treatment of organic materials by the help of microorganisms' activities under the exclusion of oxygen and light in certain temperatures. In nature, anaerobic activities take place in swamps, marshes, wetlands, marine sediments, rice soils, peat bogs and digestive system of animals and some insects (Palmisano & Barlaz, 1996). Basically, AD technology replicates this natural conversion process of organic substrates. AD is a mature and reliable technology for the treatment of organic waste, wastewater or slurry not only for the reduction of organic load of the wastes and but also for biogas production. A well-managed anaerobic biomass digestion system can easily results into high levels of purification and biogas output. The two final results of AD are biogas and digestate.

"AD is today standard technology for stabilisation of primary and secondary sewage sludge, for treatment of organic industrial waste from food-processing and fermentation industries as well as for the treatment of the organic fraction of municipal solid waste." (Al Seadi, 2008)

Numerous organic materials can be a source for anaerobic digestion-biogas production. Commonly bio-wastes like sewage sludge, manure and agricultural wastes are used for anaerobic digestion.

"*The most common biomass categories used in European biogas production are listed below (...):*

- *Animal manure and slurry*
- *Agricultural residues and by-products*
- *Digestible organic wastes from food and agro industries (vegetable, fruit and animal origin)*

- *Organic fraction of municipal waste and from catering (vegetable, fruit and animal origin)*
- *Sewage sludge*
- *Dedicated energy crops (e.g. maize, miscanthus, sorghum, clover).*" (Al Seadi, 2008)

Please refer to Appendix A for the complete list of bio-wastes suitable for biological treatment as it was mentioned in European Waste Catalogue (2007).

AD process can be defined as the continuous degradation of complex organic material into smaller and simpler units. As a result, the most of the chemical energy content in the substrate are conserved in produced methane gas except a minor proportion is used for bacteria growth (Murphy & Thamsiriroj, 2013:105).

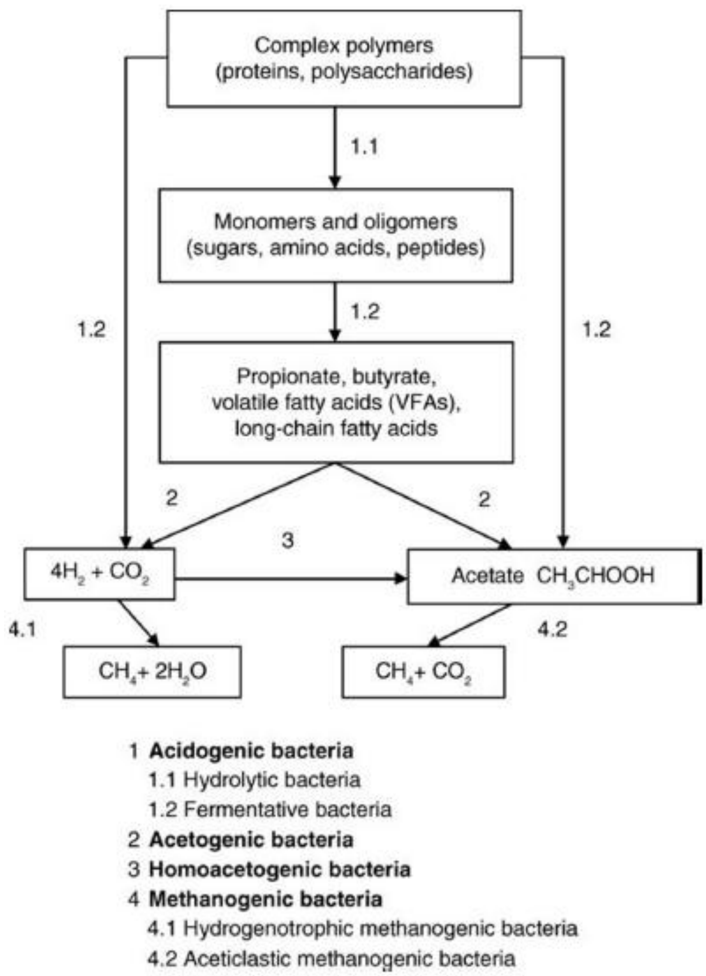

Figure 1. Anaerobic Digestion Process. Source: Murphy & Thamsiriroj (2013)

The conversion of raw biodegradable feedstock into biogas and digestate is achieved through biochemical syntrophic reactions performed by various groups of microbial population namely acidogenic, acetogenic, homoacetogenic and methanogenic bacteria. These bacteria groups compose the substrate produced by another type of bacteria in previous stage. Although the microbial population mainly consists of anaerobic bacteria, the other types of bacteria, protozoa and fungi can also play minor roles.

Bio-chemical reactions performed by these different types of micro-organisms are explained below:

Hydrolysis

Hydrolysis is the first stage of the continuous degradation process of the organic material. During this step, hydrolytic enzymes excreted by hydrolytic and fermentative bacteria play the main role by decomposing the polymers such as proteins, carbohydrates, lipids, into monomers and oligomers. The produced smaller units are in simpler formation and soluble in water. The main reactions during hydrolysis can be simplified to three: degradation of polysaccharide to monosaccharide, fatty acids and glycerol production from lipids by lipase enzyme and production of amino acid from proteins by protease enzyme (Al Seadi, 2008).

Acidogenesis

During this stage fermentative bacteria convert soluble end-products of hydrolysis into methanogenic compounds. Simple sugars, amino acids and fatty acids are transformed into acetate, CO_2, H_2, VFAs (Volatile Fatty Acids: propionic acid, formic acid, butyric acid, valeric acid) and alcohols. The products of acidogenesis are mainly alcohols and VFAs with high carbon content like propionate and butyrate (Murphy & Thamsiriroj, 2013).

Acetogenesis

At this stage, methanogenic compounds such as hydrogen, carbondioxide, acetate are produced by the oxidization of intermediate products from acidogenesis and fermentation of carbohydrates. Later on these methanogenic substrates will be digested by methanogenic bacteria. The significant reactions of this step are acetate formation from glucose, ethanol, propionate and bi-carbonate (Al Seadi, 2008).

During acetogenesis, increasing hydrogen concentration can inhibit the acetogenic bacteria. Therefore, the presence of H_2 consuming bacteria is important to keep hydrogen presence in acceptable levels. Methanogenesis runs parallel with acetogenesis as symbiosis.

Methanogenesis

Methanogenesis is the slowest and the most crucial step of the whole AD process. The fluctuation of the operation conditions like temperature, feeding rate, pH can easily influence it. Any slight increase of O_2 levels in the digester can completely terminate CH_4 formation.

There are 2 different groups of active methanogenic bacteria during this stage; hydrogenotrophic methanogenic bacteria and aceticlastic methanogenic bacteria.

The hydrogenotrophic methanogenic bacteria work together with acetogens in principle of syntropic mutualism and digest the hydrogen acetogens produced. Hydrogenotrophic methanogens have faster reproduction rates compared to aceticlastic methanogens (Pfeffer, 1979 cited by Murphy & Thamsiriroj, 2013).

The Advantages and Disadvantages of AD

AD has many advantages compared to other organic waste treatment methods like landfill, incineration, gasification, pyrolysis, composting etc.

The general *advantages* of anaerobic digestion are: (Ayberk, 2010), (Mes et al., 2003)

- Mature, well-tested and relatively simple technology
- Efficient organic waste pollution control
- Reduction of high organic loads and volumes of bio-wastes
- Possibility to generate power, heat, fuel from wastes with good predictability and versatility
- Possibility to achieve income through electricity, heat and fertilizer sale or savings
- Energy savings compared to other waste treatment methods, the required energy ranges from 0,05 to 0,1 kWh/m^3 depending on the demand for pumps and effluent circulation

- Closed system without any air emissions or land pollution
- Low viscosity digestate that can be used as high quality organic fertilizer
- Prevention of pathogens, less attraction to flies / pests, less odor compared to waste storage methods
- Complete nutrient cycle of nitrogen, phosphorus and potassium
- GHG reduction (CH_4 from manure and CO_2 by fossil fuel replacement)
- Suitable for rural electrification
- Relatively lower O&M and construction costs
- Less space requirement than conventional systems

The **disadvantages** (Mes, et. al, 2004):

- Tight control requirement of many parameters (temperature, pH, mixing, chemical compounds)
- Methanogenic microorganism are very sensitive to a various chemical substances
- proper seed sludge need for process start-up
- Odor caused by H_2S formation
- Long retention time

In practice, AD in applied in several different methods as Figure 2 summarizes below. Anaerobic Digestion systems can be categorized depending on the operating parameters (Arsova, 2010):

1. Organic Load rate
    - Wet digestion (TS <15%)
    - Dry digestion (25% < TS)
2. Operating temperature:
    - Psychrophilic = <25^{o}C
    - Mesophilic= 25^{o}C – 45^{o}C
    - Thermophilic= 45^{o}C –70^{o}C
3. Number of reactors used in series:
    - Single stage systems
    - Multi stage systems
4. Substrate input to the reactor:
    - Batch reactors
    - Continuous feeding reactors
    - Plug flow reactors

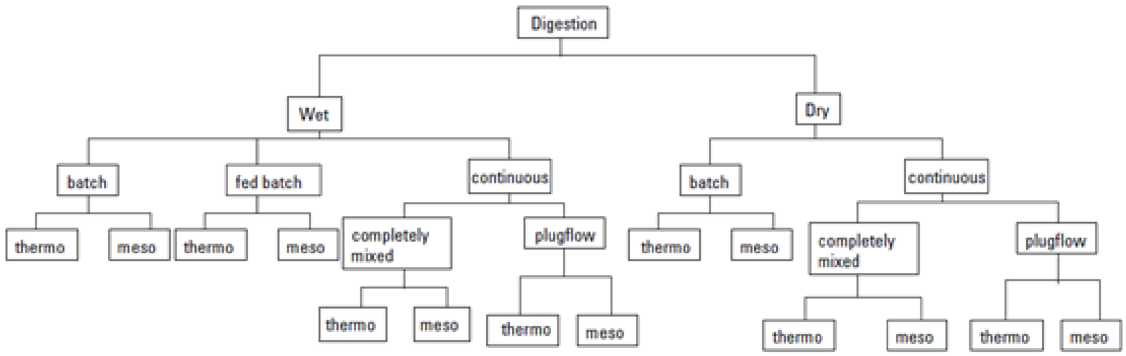

Figure 2. Classification of Anaerobic Digestion Methods. Source: Mes et al., (2003)

2.1.1 Important Parameters

Anaerobic digestion processes are affected by some environmental conditions and operating parameters such as oxygen, temperature, mixing, nutrients, pH, alkalinity, toxic compounds and so on. The most crucial parameters and their influences on anaerobic bacteria are explained in this chapter.

Temperature

Temperature is a critical factor for the operation of AD digesters since it determines the performance and grow rate of the bacteria consortia. Even though methanogenic bacteria can withstand to a wide range of temperature, they perform in the maximum rate in three different ranges. Thus, AD processes can be divided into;

- Psychrophilic = <25^{o}C
- Mesophilic = 25^{o}C – 45^{o}C
- Thermophilic = 45^{o}C –70^{o}C

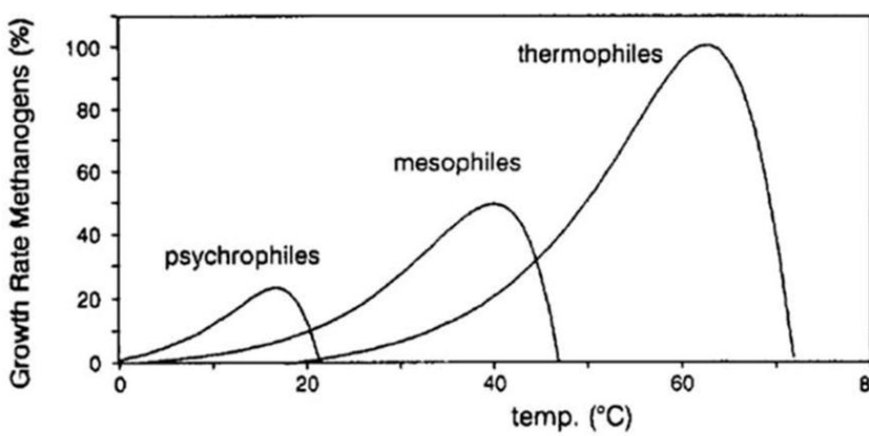

Figure 3. Relative Growth Rates of Methanogens. Source: Angelidaki (2004) cited by Al Seadi (2008)

Nowadays, most of the biogas plants are operated at thermophilic temperatures for CH_4 production can be 25 to 50% higher than in mesophilic ones and also shorter retention time (Banks & Heaven, 2013). Process temperature should be chosen according to feedstock.

"*Thermophilic operation temperature results in faster chemical reaction rates, thus better efficiency of methane production, higher solubility and lower viscosity. The higher demand for energy in the thermophilic process is justified by the higher biogas yield*." (Al Seadi, 2008: 25)

The important kinetic parameters influenced by temperature are:

- Bacteria growth rate and yield
- Bacteria decay rate
- Half saturation constant

Other than these parameters, operation temperature has a direct impact on hydraulic retention time (HRT). Lower the operation temperature, higher the minimum retention time. Digestate viscosity also varies inversely with temperature; the digestate is more liquid in higher temperatures and more solid at lower temperatures. Lastly, NH_3 toxicity is influenced proportionately by temperature changes (Banks & Heaven, 2013).

Therefore it is crucial to maintain a constant temperature in the digesters during AD process. Even minor changes like 1^{o} C can influence the sensitive thermophilic bacteria negatively to achieve expected CH_4 yield. The less sensitive mesophilic bacteria can tolerate +/- 3°C without any negative effect. Usually, the heat from Combined Heat and Power Plants (CHP) is used for maintaining process temperature through interior floor and wall heating in the reactor (Al Seadi, 2008: 25).

pH and Alkalinity

pH is another important factor for the different stages of AD process since the acidity/basicity of the solution (substrate) effects microorganisms activity and decomposition of some compounds crucially. Methanogenic bacteria are very sensitive to pH value likewise to temperature. Bacteria grow rate and methane formation performance reduce when pH of the substrate decreases to lower values (acidic). The breakdown of the compounds such as NH_3, S^{2-} and organic acids are influenced by pH value. On the other hand, pH is a function to the concentration of VFA and dissolved CO_2. The correlation of VFA and $CaCO_3$ concentrations has to be adjusted well to keep the pH constant during process (Arsova, 2010). The proportion of VFA/$CaCO_3$ = 1/6 shows that the process works well also in terms of alkalinity (Uğurlu, 1994 cited by Ayberk, 2006). Sudden increase in VFA growth can decrease pH value (Al Seadi, 2008).

While biogas can be produced at pH value range 5,5 to 8,5 during AD, the optimum value for maximal biogas yield is depending on the feedstock and digestion type pH value varies in different steps of AD process and there is an optimal pH value known by experience for the most efficient performance of each stage. However, the optimal pH value for methanogenesis – the most important stage of AD – is accepted to be 7 to 8. As mentioned in the chapter before, the process temperature of mesophilic digestion is lower than thermophilic digestion which increases the CO_2 dissolution in water. As a result, pH value of mesophilic digestion is lower than thermophilic digestion, between 6,5 and 8,0 (Arsova, 2010), (Al Seadi, 2008).

During the acetogenesis stage, the organic acids over-production risks reactor failure by decreasing pH to the lethal level (5) for methanogenic bacteria which are supposed to consume the produced acids can no longer function. On the other side, over-production of methanogenic bacteria cause excess NH_3 concentration which rises pH value over 8 and inhibit acidogenesis stage where acidogenic bacteria need lower optimal pH-value. (Lusk 1999), (Arsova, 2010).

Mainly, a bi-carbonate (HCO_3-) buffer system controls pH value in the digester.

Volatile Fatty Acids (VFA)

During hydrolysis stage of AD, the digestion of complex organic molecules by saprophytic bacteria results in short-chain fatty acids with low molecular weight. These acids (acetic, propionic, butyric, valeric, isovaleric, caproic) are defined as volatile fatty acids (VFA). In cases where system does not have high pH buffering capacity, a strong increase in the amount of VFA can lower the pH value and dysfunctions the AD process. In general VFA consumed by acetogenic bacteria and do not accumulate in digester.[1]

Schnaars (2012: 82) asserts that in normal conditions VFA concentration in the AD reactors ranges from 50 mg/l to 300 mg/l and upon exceeding this limit may cause problems related to pH.

VFA tests which evaluate the VFA concentration in the reactor in the unit of mg acedic acid equiv. are essential to determine the health of digestion (Schnaars, 2012: 82).

Mixing

Even though, there are discussions going on how the mixing should be performed and on its contribution to biogas yield, general agreement is that the mixing increase the reaction rate in the digester [2]. Field experiments show mixing of the slurry continuously not only prevents; crust formation, scum accumulation, foaming and stratification but also helps the fresh feedstock to circulate around after entering into the digester (Banks & Heaven, 2013). These benefits of mixing facilitate the biogas release from slurry.

Lack of proper mixing can cause problems related to deposition of inert mineral-based materials in large scale tanks (Banks & Heaven, 2013).

Trace Elements and Toxic Compounds

1- Ammonia

Ammonia is produced in hydrolysis stage and beneficial for anaerobic fermentation only below concentrations of 80 mg/L. Especially excess free ammonia (unionized NH_3) concentration in the digestate is harmful for methanogenic bacteria. In manure slurry digesters, free NH_3 originated from urine in the feedstock may cause such a problem. The increase of pH-value and temperature in the reactor proportionally increases the ammonia inhibition effect (Al Seadi, 2008).

Schnaars, (2012: 83) suggests that; if NH_3 concentrations rise continuously, the OLR has to be decreased.

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[1] http://www.cevremuhendisleri.net/konu/ucucu-yag-asiti-tayini.1696/ - accessed on 20.07.2016
[2] (Stroot et al., 2001), (Kaparaju et al., 2008), (Banks & Heaven, 2013)

2- Sulfide

Sulfides can cause inhibition in two ways; firstly, by creating a competing with methanogenic bacteria for the common substrates and secondly, by its toxic effect to some anaerobic bacteria (Nayono, 2010).

3- Nutrients

The bacteria in the digester need trace amounts of some essential nutrients such as N and P to live and reproduce. Other than essential nutrients, Ni, Co and Mo are known to have positive effects to methane production (Ayberk, 2010).

Macro-nutrients such as C, H, N, O, S are essential for bacteria reproduction. Most of carbon, hydrogen and oxygen which are already present are consumed and formed into methane and carbondioxide. However, nitrogen and sulfur can be converted into potentially harmful ammonia and sulphides. The easiest solution for this potential problem is keeping the C/N ratio in the range of 20 - 30/1. Other optimal macro-nutrient ratios are; C/P = 120/1 and C/S = 600/1.

4- Heavy Metals, Light Metal Ions, other Toxic Compounds

Heavy metals (Cu, Cd, Zn, Hg, Pb), phenolic compounds (phenol, chlorophenol, nitrophenol), disinfectant and some pesticides can create toxic effects on bacteria and decrease microbial growth and performance when their concentrations are above limits. For instance the inhibition limit of copper is 0,5 mg/l (Schnaars, 2012: 83).

Light Metal Ions (salts such as Na, Ca, Al, Mg) usually can be found in the digestate as they are the products of organic substrate degradation or remains of pH control additives. The moderate amounts are beneficial to stimulate bacteria reproduction. Nevertheless, excess concentrations have adverse effect and even can be inhibitory or toxic (Nayono, 2010).

Heavy metals are not degradable thus they can easily accumulate in the digester and reach to dangerous levels. According to some researches heavy metal toxicity is one of the main reasons of reactor failure (Nayono, 2010). Metals spotted in the digester can be originated from the feedstock coming from the industrials (Schnaars, 2012: 82).

2.1.2 Wet & Dry Digestion

Depending on the moisture content of the feedstock, anaerobic digestion can be distinguished into wet and dry digestion types (Lissens et. al., 2001), (Nayono, 2010).

- Wet digestion: total solid concentration of the substrate: <15%
- Dry digestion: total solid concentration of the substrate: 20 - 40%

"*In wet digestion processes, the solid waste has to be conditioned to the appropriate solids concentration by adding process water either by circulation of the liquid effluent fraction, or by co-digestion with a more liquid waste.*" (Nayono, 2010)

In general, for wet digestion CSTR (continuous stirred tank reactors) with integrated mixing applications are preferred (Banks & Stentiford, 2007).

Energy crops and silages are typical substrates for dry fermentation. Garden wastes, grass, straw, solid animal manure and solid household bio-waste are another examples for dry digestion. Common feature of dry digestion feedstock is its pumpable form.

In dry digestion tanks, mechanical stirring is not applied. Produced biogas or leachate can be circulated in tank to provide some mixing but complete mixing is not possible. Bacteria groups in different parts of digester contact less and their cooperation weakens. As a result, microbial activity is limited.

The advantages of both dry and wet digestion are summarized below according to several studies[3] can be found below:

The advantages of dry digestion:

- Less complicated pre-treatments
- Higher organic loading rate
- Greater flexibility in the type of feedstock accepted
- Shorter retention times
- Less consumption of water and energy for heating

[3] (Angelonidi & Smith, 2015: 549), (Nayono, 2010), (Vandevivere et al., 2002), (Banks & Stentiford, 2007), (Lissens et. al., 2001)

The advantages of wet digestion:

- Less sophisticated mechanical equipment
- Possibility to dilute inhibitory substances
- Improved energy balance and economic performance

2.1.3 Digester Types

Digester - also called reactor or bioreactor - is the core unit of a biogas facility where the anaerobic digestion is taking place. Depending on the climate, digesters may need to be heated. The size of reactor indicates the size of biogas system, while family size ones have the capacity of few m^3, commercial facilities can have few digesters with thousands of m^3. Usually, the biogas reactors are constructed with steel or concrete, in shape of silo or ponds on the ground or underground.

Batch Digesters

Batch reactors are the simplest type of digesters used for dry fermentation of substrates with solid content of 30 – 40%, such as energy crops, green cutting, silages and solid manure. The feedstock is carried and fed into the reactor by typical agriculture or construction vehicles. After biogas production starts, increases, reaches its peak, decrease and stops, the reactor is opened and roughly half of the digestate is taken away. The remaining half is left for to be inoculums for next operation. The batch then is completed and the process is repeated (Nizami & Murphy, 2010). The mechanical mixing is not applied in batch digester. In general, the leachate drained from the reactor is sprayed continuously from the top in a closed circulation system (Murphy & Thamsiriroj, 2013:116).

The biggest benefit of batch reactor is the simplicity. The solid content in the digester is high thus the energy need for heating is low which presents another significant advantage. On the other hand, due to lack of proper mixing, the biogas yield is not optimized. This the most important disadvantage of the batch digesters. (Murphy & Thamsiriroj, 2013:116) The most common batch digester type is the concrete "*garage* *type*” digesters. The capacity of a batch reactor can vary from 2.000 up to 50.000 tonnes/year (Al Seadi, 2008).

Continuous Digester

The continuous digester (CSTR) is the most common and well-known reactor type which is used for wet digestion of feedstock with 2 – 12% DS e.g. sewage sludge, animal slurries. Contrary to batch type reactors, substrate is continuously pumped to the tank and biogas is produced constantly and predictably without any interruption for loading or unloading. The mixing is the most important feature of this type. Usually HRT equals to SRT thus the retention time cannot be less than the time that bacteria needs to double their population to prevent a failure. OLR value is in the range of 1 to 4 kg VS/m^3/d. Often, the continuous digesters are designed as two-step systems, includes all the microbial groups in each tank (vessel). The effluent recirculation from the second tank to the first one stimulates to dilute the feedstock and balances the system. In the two step system, most of the biogas is collected from the first tank. Continuous reactors can be vertical or horizontal shape (Murphy & Thamsiriroj, 2013).

Plug Flow Digesters

For dry continuous digestion usually plug flow systems are preferred.

The substrate enters to the plug-flow reactor from one side and flows towards to the end without exposure to any mixing or stirring. The fresh substrate is inoculated by circulating liquor. According to the working principle of plug flow reactors, degradation of VS is completed during the flow of substrate through the tube. Also the effluent at the outlet has less VFAs concentration and the system has better degradation efficiency. Even though, there is no mechanical mixing, in practice stirring occurs due to convection currents, friction on the walls and produced gas movement.

Plug flow tanks can be vertical or horizontal.

2.1.4 Biogas Fertilizer

It is widely known that biogas fertilizer applications increase the crops yields significantly. Additionally it improves the soil conditions for useful microorganism to develop.

"Most vegetable crops such as potato, radish, carrot, cabbage, onion, garlic, etc., and many types of fruit (orange, apple, guava, mango, etc.), sugar cane, rice and jute appear to react favourably to sludge fertilization." (GIZ, 2005 cited by APCAEM, 2007)

The bio-fertilizer has superiority over chemical fertilizer for several reasons:

- Completely organic and does not include any chemical additives.
- Low viscosity which helps to penetrate better into ground.
- Higher fertilizer value including many essential nutritious.
- Less intensive odor.
- In addition to N, K, F; organic nutrient such as protein, cellulose and lignin which increases soil permeability and hygroscopicity are present. These organic compounds also supply the needs of beneficial microorganisms in the soil.
- Erosion prevention due to rapid humification feature of humic substances (humus, humate, humic acid) content.
- Reduces nitrogen washout.
- Desirable in the market.

Fertilizer consumption per hectare in Turkey has increased in the last years though the total consumption remains constant. The fertilizer sector in Turkey is being dominated by four companies with their total share of 80% in the market. However, the raw materials of fertilizer production (nitrates, P, K) cannot be supplied from national market. This leads fertilizer producing companies to import through joint ventures (ISPAT, 2013).

Ideally agricultural soils should have at least 5% share of organic nutrient which is crucial for plant cultivation. When the organic matter content drops below 2%, the structure of soil is deteriorated, root growth is negatively affected and plants can not benefit from the soil efficiently. In Turkey, the overall ratio of organic nutrient in the soil has fallen below 1% (Baytekin, 2013a).

Organic-nutrient-rich biogas fertilizer can address this agricultural problem in Turkey.

Within the scope of DBFZ (2011) project, there has been two applied research on the effects of composted organic biogas fertilizer in the southern Turkey in 2013. Improvements on the yield and product quality were observed on tomato, pepper, maize, barley and wheat (Baytekin, 2013b).

By applying fertilizer produced in a biogas plant on the agriculture fields where it initially taken from, the nutrient cycle would be completed thus the ecology balance is preserved. This is the major environmental benefit of using biogas fertilizer from an ecological point of view.

2.2 The Properties of Biogas

Biogas is a gas mixture dominated by CH_4 and CO_2. The composition of produced biogas is generally depending on digestion type and digested feedstock. The main components of biogas and their ranges are 45–75% CH_4, 25–55% CO_2, <1% H_2S (0–2000 ppmv) and <1% NH_3 (0–590 ppmv). Other than CH_4, CO_2, H_2S and NH_3, biogas might also contain over five hundred various contaminants such as hydrocarbons, siloxanes and aromatic compounds. In addition, trace amounts of hydrogen, nitrogen, oxygen, carbon monoxide, and carbohydrates can be found in trace amounts in biogas. Typically the gas mixture is saturated with water vapor (2% - 7%) (Al Seadi, 2008), (Petersson & Wellinger, 2009), (Murphy & Thamsiriroj, 2013).

The energy content of biogas directly relies upon the methane content. Since the energy content of 1 Nm^3 bio-methane is approx. 10 kWh, typical biogas (methane content of %60) can be accepted to have an energy content of 6 kWh per normal m^3. This amount is equal to energy content of 0,6 litres fuel-oil (BIWARE, 2005), (SGC, 2012). In joule units the energy content of biogas is the range of 19 - 26 MJ/m_n^3 (Murphy & Thamsiriroj, 2013: 105).

The higher methane content indicates better quality of biogas since the CH_4 is the main combustible gas in the mixture. CO_2 does not have any energy value associated with it.

The amount of hydrogen sulphide in the gas mixture is depending on the characteristics of the digested biomass. Usually, the biogas obtained from livestock wastes has a higher hydrogen sulphide content compared to the biogas from the digestion of crops (Murphy & Thamsiriroj, 2013: 105). Desulfurization (particularly removal of H_2S), is crucial for not only it is extremely toxic for human health, but also it has a corrosive impact on the materials and structures of the biogas systems (KRONOS, 2014).

Siloxane content in the biogas from landfill and sewage sludge fermentation can cause serious problems in down-stream utilizations.

Table 1. The Characteristics of Biogas from Landfill and Anaerobic Digestion Source: derived from Persson et al., (2006)

		Landfill gas	Biogas from AD
Lower heating value	MJ/nm^3	16	23
	kWh/nm^3	4,4	6,5
Density	kg/nm^3	1,3	1,2
Higher Wobbe index	MJ/nm^3	18	27
Methane number		> 130	>135
Methane	vol-%	45	63
Methane, variation	vol-%	35-65	53-70
Carbon dioxide	vol-%	40	47
Carbon dioxide, variation	vol-%	15-50	30-47
Nitrogen, variation	vol-%	5-40	–
Oxygen, variation	vol-%	0-5	–
Hydrogen	vol-%	0-3	0
Hydrogen sulphide, variation	ppm	0-100	0-10000
Ammonia	ppm	5	<100
Total chlorine (as Cl^-)	mg/nm^3	20-200	0-5

Biogas Safety

"*While most of the secondary components in the biogas cause no trouble (...) Hydrogen sulfide imposes particular demands as regards occupational health and safety.*" (KRONOS, 2014)

The safety issues related to biogas production and management similar to those of NG. The common risks to be aware of are summarized below (SGC, 2012):

- Inflammability and explosion risks
- Poisoning related to H_2S
- Suffocation
- Risks related to high pressure
- Thermal danger

On the other hand, biogas has the advantage of having lower density than air, in an event of gas leaking it tends to rise up. Another safety asset is that the biogas has higher auto-ignition temperature than petroleum based fuels under normal conditions. These features indicate that biogas is safer in terms of explosion risks in traffic accidents compared to potential of traditional fuels such as petrol and diesel (SGC, 2012).

2.3 Biogas Utilization

While the most common utilization of biogas is to burn it to produce heat and electricity, biogas upgrading technologies for grid injection and for vehicles are also becoming interesting in the last decades (Persson et al., 2006).

2.3.1 Generation of Power and Heat

As mentioned before, biogas can be utilized in stationary applications options for heat & power generation. Traditional utilization of biogas is heat generation by burning it in a boiler and simultaneous electricity and heat generation by burning it in a CHP gen-set with waste heat recovery (Kaparaju & Rintala, 2013).

In addition, when biogas combusted in a boiler, the produced steam can be used to operate steam engines (such as steam piston, steam screw engine) or steam turbines.

Moreover biogas theoretically can be used as fuel for gas turbine, micro gas turbine Stirling motor and fuel cell (low or high temperature) (Al Seadi, 2008).

This chapter will focus on the most common biogas utilization; CHP.

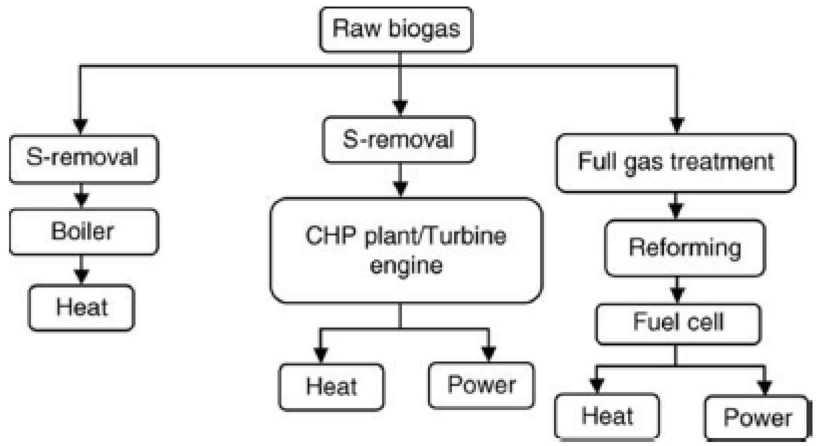

Figure 4. Stationary Biogas Utilization Options. Source: Al Seadi (2008)

Co-generation (heat and power)

Co-generation also called CHP (combined heat and power) refers to the system that produces thermal and electric energy at the same time. In cogeneration plants, the heat resulted from combustion is collected from the engine's exhaust in hot water or steam form (Kaparaju & Rintala, 2013).

The energy content of methane in biogas is converted into mechanical energy through the engine pistons moved by the power of the combustion. The mechanical energy then turns the rotor (electromagnets) within stator (conductor) in electric generator and electricity current (AC) is generated according to Faraday's Law. The electric motors which generate alternating current also named as alternator. Electricity production with a gen-set of combustion engine and generator is a well-known and relatively easy-to-operate technology.

Full gas treatment of biogas is not a necessity for CHP utilizations. However, before biogas fed to the engine, it has to be dried and H_2S content has to be lower than the limit engine requires (typically < 500ppm). CO_2 is not required to be removed (Hingerl, 2001 cited by Mihic, 2004). The engines can have different limits for the concentrations of H_2S, halogenated hydrocarbons and siloxanes in biogas.

The chemical features of biogas make it convenient for internal combustion engines. Since CH_4 and biogas is reliable against knocking, it can be used in high compression ratios than petrol engines (Mihic, 2004). Converted spark-ignited NG engine is the most common engine type for stationary biogas applications. Four stroke diesel and petrol (gasoline) engines can be also converted for biogas (Kaparaju & Rintala, 2013). Commonly co-generation systems have spark-ignition engine or diesel engine with integrated waste-heat recovery unit. In Europe, about the half of the cogeneration systems in biogas power plants have 4 stroke gas engines while the other half has diesel engines with pilot fuel injection (Deublein & Steinhauser, 2008).

Four-stroke biogas engines

Four-stroke engines are originally produced to burn natural gas. Today, converting four stroke natural gas engines into a biogas engine needs little modification work. Four-stroke biogas engines can be preferred for applications from 100kW to 1 MW. Their electricity efficiency rate ranges from 30% to 40% and they have a lifetime of ca. 60.000 hours. The feeding-biogas should contain minimum 45% CH_4 to prevent engine knocking (Deublein & Steinhauser, 2008: 370).

After the biogas and air mixture taken to the engine, it is combusted by spark ignition in compression rate of 8:1 to 12:1. Since biogas includes CO_2, the compression rate can be technically increased. Higher compression ratio results in 1% to 2% increased efficiency. The ignition is controlled digitally which provides precise combustion timing, longer lifetime of spark-plugs and low exhaust emissions (Deublein & Steinhauser, 2008), (APCAEM, 2007).

Diesel engines with pilot fuel

In diesel engines the injected fuel is compressed until self-ignition. The compression ratio is much higher than gas engine, around 15:1 to 20:1. The injected fuel mixture is adjusted to control the power output (APCAEM, 2007), (Deublein & Steinhauser, 2008).

Since biogas needs high temperatures to be self ignited, small amounts of secondary fuel is injected to engine to promote ignition. This secondary fuel is called pilot fuel and it is usually a fuel with high cetane number such as diesel, biodiesel, vegetable oils, mineral oils. The share of ignition oil to total amount of fuel is recommended to be in the range of 10 – 18%. If CH4 share is low in the biogas, ignition oil should be mixed more. The efficiencies of diesel engines are approximately 15% higher than four stroke gas engines in small capacity range. They are also more economical. On the other hand, diesel engines have higher NO_x emission and shorter lifetime (35.000 h) in comparison to gas engines (Deublein & Steinhauser, 2008: 371), (Ray et al., 2013).

There are **some technical points** which are important for the utilization of biogas in the CHP engines:

Ignitability properties of CH_4 indicates that the air-gas mixture should consist of; 5% to 15% of CH_4 and 85% to 95% of air of the total volume to achieve the best combustion behavior in the engine. If the share of methane in the mixture drops down than 5% or increase higher than 15%, CH_4 cannot be properly ignited with spark plug (Mihic, 2004).

The other important technical parameter is the *combustion velocity* of CH_4 with air. Combustion velocity (Cc) directly depends on the volume share of methane. The maximum Cc value is achieved just below the stoichiometric air / fuel ratio, (0,8 - 0,9). The combustion velocity of a mixture with 10% methane is 0,38 m/s (Mihic, 2004).

The ignition temperature of methane with air is in the range of 918 K to 1023 K. (Mihic, 2004).

The compression rate of engine for CH_4 to self-ignite with air: e=15 – 20. (the ratio, e, increases proportionally with carbondioxide content) (Mihic, 2004).

Tri-generation (cooling, heat and power)

When some part of the useful thermal energy generated in CHP plant is utilized in a heat exchanger for cooling purposes, it is called tri-generation or CCHP (combined cooling heat and power). If there are refrigeration needs in the facility, a tri-generation biogas system results in even higher overall energy efficiency, economic incomes through electricity savings and further GHG emission reduction.

Quadgeneration (cooling, heat, power and CO_2)

Quadgeneration is a new term that can be seldom encountered in the literature which defines CO_2 production besides tri-generation of cooling, heat, electricity.

CO_2 which is removed from upgraded biogas or obtained from engine exhaust can be an alternative to CO_2 produced from fossil sources for the needs of chemical industry. CO_2 can be also utilized in greenhouses to act like fertilizer (Al Seadi, 2008). Quadgeneration offers the highest possible environmental performance.

Clarke Energy[4] states that "*Carbondioxide recovered and scrubbed from gas engines is widely used in the horticultural industry, most notably in greenhouses across the Netherlands*."

2.3.2 Biogas Upgrading to Biomethane

Raw biogas is upgraded to be suitable for feeding into grid or to be used as fuel in vehicles. The upgrading process mainly involves the removal of CO_2 and undesired compounds (e.g. hydrogensulfide) to increase the methane share of biogas to more than around 95%. Upon successful gas upgrading utilisation, the product biogas almost fully consists of methane which was derived originally from biomass source therefore it is named as "biomethane".

Urban (2010) comments on the features of biomethane: "*It is easily storable and is an ideal option for flexible power generation in cogeneration plants.*"

CO_2 removal is carried out to meet the Wobbe index requirements of biogas. The Wobbe index which explains the relations of the heating value of the gas with its specific gravity is an important aspect for most gas applications (Persson et al., 2006).

[4] https://www.clarke-energy.com/gas-engines/quadgeneration/ - accessed on 26.07.2016

Table 2. The Components of Biogas and their Effects. Source: Deublein & Steinhauser (2008)

Component	*Effect*
CO_2	– Lowers the calorific value – Increases the methane number and the anti-knock properties of engines – Causes corrosion (low concentrated carbon acid). if the gas is wet – Damages alkali fuel cells
H_2S	– Corrosive effect in equipment and piping systems (stress corrosion); many manufacturers of engines therefore set an upper limit of 0.05 by vol.%; – SO_2 emissions after burners or H_2S emissions with imperfect combustion – upper limit 0.1 by vol.% – Spoils catalysts
NH_3	– NO_x emissions after burners damage fuel cells – Increases the anti-knock properties of engines
Water vapour	– Causes corrosion of equipment and piping systems – Condensates damage instruments and plants – Risk of freezing of piping systems and nozzles
Dust	– Blocks nozzles and fuel cells
N_2	– Lowers the calorific value – Increases the anti-knock properties of engines
Siloxanes	– Act like an abrasive and damages engines

There are various available biogas upgrading technologies. 4 of them are explained in this chapter:

1. **Absorption**

This method is taking advantage of solubility degree difference between CH_4 and CO_2. Biogas is sent through counter-flowing absorbent; only CO_2 dissolves and stays absorbed in the liquid while the biogas leaves the column with increased methane content. There are mainly 3 types of absorption techniques differ from each other by active the liquid absorbent: *water scrubbing* is the most popular one. In *organic physical scrubbing*, organic solvents which absorb CO_2 more efficiently than water are used. In *chemical scrubbing*, amine solutions absorb CO_2 with a very low CH_4 loss by the help of chemical reaction (Petersson & Wellinger, 2009: 10).

2. **Pressure Swing Adsorption (PSA)**

PSA technology separate CO_2 by absorbing it on surface of a solid material (activated charcoal, zeolite) in high pressures. After the absorption is done in the first vessel, biogas is fed to the next one and so on. Before the round of several vessels is completed the process starts all over the absorbents in the first vessel are regenerated with a consecutive pressure decrease (Petersson & Wellinger, 2009: 9), (Deublein & Steinhauser, 2008).

3. **Membrane Separation (Gas permeation)**

In gas permeation technology, biogas is fed to the hollow fiber membranes which are permeable to CO_2, H_2O and NH_3 but not CH_4 (Petersson & Wellinger, 2009: 11). Pretreatment of biogas is necessary for protecting the membranes from harmful impurities (Makaruk et al., 2010).

"The most important advantages include safety and simplicity of operation, easy maintenance and operation without hazardous chemicals. Gas permeation plants can be operated unattended." (Makaruk et al., 2010)

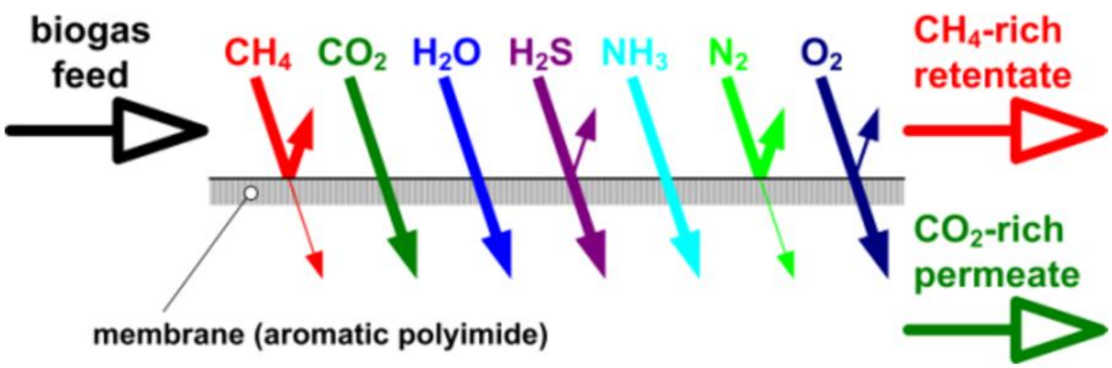

Figure 5. Schematic Scheme of the Membrane Separation of Biogas. Source: TVT (2013) [5]

4. **Cryogenic upgrading**

Cryonic upgrading is a developing technology works in principle of liquefaction of gas components with different boiling points. Even though it can result into biogas with high concentration levels of methane, it is an expensive and high energy consuming method (Deublein & Steinhauser, 2008).

[5] http://bio.methan.at/en/gaspermeation

Table 3. Comparison of Biogas Upgrading Technologies. Source: Deublein & Steinhauser (2008)

Technology	Costs		Removed Contamination	Temp. (°C)	Press. (bar)
	Invest.	Operat.			
Absorption					
In Water	+	+	Dust, CO_2, H_2S	5-25	10 - 12
Physically	+	+	CO_2	<40	10 - 20
Chemically	+	+ +	CO_2, H_2S	<40	20 - 30
PSA					
Zeolite	+ +	-	CH_4, N_2	<40	10 - 12
Carbon	+ +	-	CO_2, H_2S, COS, H_2O, O_2, NH_3,Hg	<40	10 - 12
Membranes	+ +	+ +	All	<40	30
Cryogenic	+ +	+ +	CH_4	<-80	200

Al Seadi, (2008) comments on the cost of biogas upgrading plants: " *(...) investment per unit of installed capacity is lower for larger plants, compared to small ones. In the case of operation costs, the most expensive part of the treatment is the removal of carbondioxide*"

According to International Energy Agency's (IEA) biogas upgrading plant list in Task 37 member and non-member countries, the most preferred upgrading methods can be seen in the graph below:

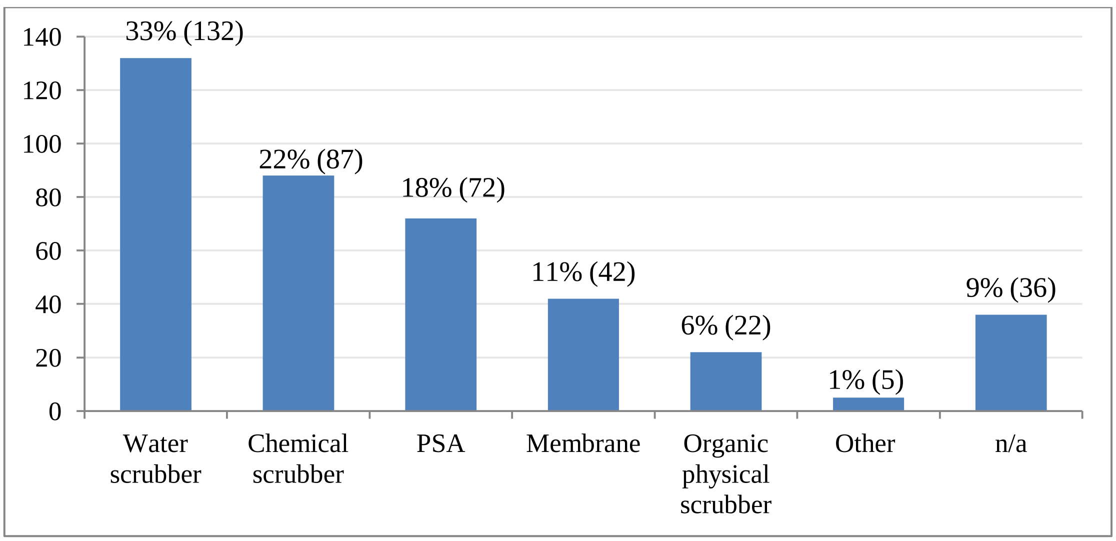

Figure 6. The Current Share of Installed Biogas Upgrading Methods. Source: derived from IEA Task 37 plant list[6]

[6] http://www.iea-biogas.net/plant-list.html (accessed on 10.08.2016)

2.3.2.1 Biomethane for Grid injection

Bio-methane (upgraded biogas) is mainly composed of CH_4 similarly to natural gas. Thus it can be directly used either on the site or to be injected and distributed in an existing natural gas grid or to be transferred to external consumers through separate pipelines. Persson et al., (2006) asserts "*Injecting biogas into the gas grid improves the local security of supply. This is an important factor since most of the countries consume more gas than they produce.*"

The distance of the biogas plant to the gas grid connection is crucially important for the investment costs which increase significantly with the length of the pipe line need to be constructed.

"*The design and operation of biogas injection equipment depend on the operating conditions of the natural gas grid (pressure, gas composition and combustion characteristics of the locally distributed natural gas, length of the pipeline connecting to the supply network) and the type of biogas upgrading facility.*" (Urban, 2013)

Contrary to raising concern in recent years, some studies[7] demonstrate that there is no risk of transmitting infection via biogas; the amount of micro-organisms in biogas equals to the natural gas levels (ELSEVIER, 2006 cited by Persson et al., 2006).

2.3.2.2 Biomethane for Vehicle Fuel

After upgrading to CH_4 proportion of more than 95%, biogas can be used as clean transportation fuel for vehicles in the same way as natural gas is used. Bio-methane meets all the technical necessities of vehicle manufacturers and NG vehicle engines.

In addition to waste treatment, odor and pathogen prevention benefits of anaerobic digestion, an integrated biogas upgrading system can bring further air quality improvements by replacing in-use fossil vehicle fuels especially in cities. Biomethane as

[7] The Swedish Institute of Infectious Disease Control, National Veterinary Institute and the Swedish University of Agricultural Science

a vehicle fuel with one of the lowest carbon footprint can make a significant contribution to the de-carbonization of the transport sector in the near future.

"*The technology is advancing year upon year, making the growing number of upgrading units more cost-efficient. Unlike the electric transport, the mature technology of gaseous transport does not require further big investments and innovation in order to be deployed. CNG and LNG can provide a bridge technology for passenger cars and an ultimate solution for heavy duty vehicles and maritime transport*." (EBA, 2013)

Biomethane is used in vehicles in 2 different forms to suit different type of vehicles:

1- CNG (Compressed Natural Gas) is more commonly used in personal cars and light duty vehicles such as tractors and pick-ups.
2- LNG (Liquefied Natural Gas) has higher energy content per volume thus it is preferable to fuel long-distance large vehicles such as marine vessels and trucks.

CNG is basically compressed form of natural gas, therefore compressed bio-methane is often called as bio-CNG as the same way LNG produced bio-methane is often called as bio-LNG.

CO_2 is not harmful for IC engines but it does not have any energy value in the mixture thus the purpose of CO_2 removal is saving energy by volume reduction at compressing process (Evergreen Gas, 2012). After the removal is done, bio-methane is sent to 4-stage gas compressor to be compressed and stored under 20 – 25 MPa in a cascade filling system to form into CNG (Ray et al., 2013). CH_4 is in liquid form only at temperatures below -160^{o}C under atmospheric pressure. Therefore, biomethane has to be compressed to high pressures to become suitable for vehicle fuel. After the cylinders are finished, they can be refueled from cascade filling system. Another option is direct compressing of biomethane into the fuel tank integrated to vehicle (Ray et al., 2013). Inlet biogas quality may have effects on operation cost of upgrading system but not the quality of the bio-CNG. For LNG production, bio-methane is not compressed but liquefied. LNG is produced by cooling biomethane down to the temperatures -160^{o}C in a liquefier through cryogenic treatment in a pressure range of 0 – 20 bar.

The most vehicles in the market can be converted into biomethane vehicles by simple engine modification with affordable costs. Although, factory-manufactured natural gas vehicles are advantageous to converted ones in terms of warranty, spare-parts and maintenance support.

Besides high investment costs and lack of infrastructure, another significant disadvantage of biomethane applications on vehicles is the space requirement for cyclinders. However in trucks, tractors and other large vehicles this is not a significant problem. Viking Strategies (2013)[8] indicates that the dairy sector is looking forward to supply fuel to their milk/milk products trucks from the biomethane which is produced from the manure of their plant.

"As the Natural Resources Canada Natural Gas Vehicle Deployment Roadmap indicates, the most suitable current applications for natural gas in vehicles, given engine technology, fueling infrastructure, and vehicle availability, is the heavy duty tractor trailer and return to base fleets." (Natural Gas Use in Transportation Roundtable, 2010)[9]

A 3-year long research[10] in Europe on biomethane as vehicle fuel concludes to the points below (Viking Strategies, 2013):

- Bio-methane is renewable replacement of natural gas.
- Bio-methane does not influence the engine performance negatively (based on observation during 4,5 million km).
- Drivers have positive approach towards biomethane.
- Biomethane powered car sale in Sweden, Switzerland and Italy are increasing with the help of government subsidies.
- Advertisement advantage, increasing environmental concerns and incentives can influence further growth.
- High purchase costs, limited vehicle supply and lack of fuel station infrastructure can limit further penetration of biomethane.

[8] http://biogasassociation.ca/bioExp/images/uploads/documents/membersOnly/DeveloperGuide-BiomethaneVehicleFuel.pdf - accessed on 30.08.2016
[9] https://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/oee/pdf/transportation/alternative-fuels/resources/pdf/roadmap.pdf - - accessed on 23.08.2016
[10] Biomethane Vehicle in Five European Cities, Biogasmax, 2010

The further market penetration of biomethane among all other low-carbon fuels is depending substantially on public policies and assurances at international and national levels (EBA, 2013).

2.3.3 Biogas Appliances

Biogas is a lean gas that can run off all natural gas appliances with no need of change on equipment design to provide heating, lighting, cooking and cooling in households and for commercial purposes. This is a valuable feature for supplying energy services through small applications especially in the rural areas without electricity access such as Africa. For instance, biogas from a simple family or farm size digester can feed gas stoves or lambs and improves life quality standards significantly. Another example is powering brooders or incubators with biogas to provide / increase production in poultries. Biogas applications in rural areas without municipal waste management can also prevent pathogen spread risk from stored organic wastes. Usually, biogas is utilized in engines only if the output of the plant is more than 10 m^3/d.

The range of appliances that can work with biogas (APCAEM, 2007).

1. Gas stoves/cookers
2. Lamps and brooders
3. Radiant heater
4. Incubator
5. Refrigerator

3 Agricultural Biogas Applications in Turkey

Turkey is accepted to be among the world's largest emerging economies named "E7" bloc. Together with growing economy and increasing population, energy demand is rapidly increasing in the country. Turkey is dependent on imported fossil sources; %70 of all energy fuels is imported gas, hard-coal and oil (MMO, 2015).

DBFZ (2011) asserts "*Turkey's energy consumption had been growing faster than its own energy production, which makes Turkey a rapidly growing energy importer".*

Table 4. Turkey's Energy Balance Change, 1990 – 2013. Source: ETKB (2014)

	1990	**2013**	**Increase**
Total Energy Demand (Mtoe)	52,9	120,3	127 %
Total Energy Import (Mtoe)	30,9	96,3	211%

Turkey's average annual energy demand growth was 4,6% from 1990 to 2013, in comparison; the average annual energy demand growth of EU was just 1,6% whilst the same time period. The energy sector in Turkey still searches for the solutions to the problems such as; rapid demand increase, dependence on foreign sources and fossil fuel pollution. It was indicated by ETKB (2014) that the share of RES in gross final consumption was 13,5% in 2012.

In the Global Status Report of REN21 (2016), Turkey is ranked 1st on geothermal power capacity increase, 2nd on solar water heating capacity increase, 3rd on hydropower capacity increase and 10th on wind power capacity increase in 2015 in the world. However energy production from biomass sources could not follow up this trend as much as other renewable energy sources.

3.1 The Status of Agriculture & Food Sector and Future Assumptions

In Turkey, the quarter of the total population lives in rural areas and almost the quarter (23,6%) of all the employment is in the agricultural sector in 2014 (TOBB, 2013).

Even though the national economy is in transition from agricultural based economy towards to industrial and service based economy, traditionally Turkey is self sufficient in terms of meeting its food demand by the advantage of suitable agro-climate conditions. Only a minor part of agricultural goods are imported (FAO, 2012).

"*Agriculture has an important impact on the social and economic development of Turkey since it meets the majority of the population's food requirements domestically and prevents Turkey from being dependent on international sources. (...) According to the UNIDO Industrial Development Report agriculture is of high importance in Turkey and agriculture is fragmented to a normal extent."* (FAO, 2012)

According the TURKSTAT data[11] in 2014, approximately 50% (38.558 thousand ha.) of total land area of Turkey is "utilized agricultural land" which is suitable for production of wide range of agricultural goods like cereals, fruits, vegetables and poultry and dairy products.

Agriculture in Turkey mainly based on crop cultivation and animal farming, 67% of all agricultural products are supplied from crops and livestock. Also there is an increasing fruit and vegetable demand from the region. Besides agriculture, aquaculture and sea-food production is another strong sector which contributes to GDP by 26% (FAO, 2012).

The most produced 15 food and agricultural commodities in Turkey can be seen in the table below. The world ranking is added to the table to show that Turkey is among top 10 countries in the production of most commodities and keep its place as an important agriculture country.

[11] www.tuik.gov.tr/PreIstatistikTablo.do?istab_id=53

Table 5. The 15 Most Produced Agricultural Commodities in Turkey with their Ranking in the World. Source: FAOSTAT (2013) [12]

Commodity	Production (tonnes) in 2013	World Ranking
Wheat	22.050.000	4
Milk whole fresh cow	16.655.009	n/a
Sugar beet	16.489.000	5
Tomatoes	11.820.000	4
Barley	7.900.000	5
Maize	5.900.000	19
Grapes	4.011.409	6
Potatoes	3.948.000	19
Watermelons	3.887.324	4
Apples	3.128.450	3
Chilies and green peppers	2.159.348	3
Onions dry	1.904.846	6
Oranges	1.781.258	8
Meat indigenous chicken	1.758.477	n/a
Cucumbers and gherkins	1.754.613	2

There are some other agriculture products which are not on the top 15 list but they are produced much more than in the rest of the countries due to high national demand. These are hazelnut, fig, cherry, poppy seed and apricot which are produced the most in Turkey (world ranking of 1st). Also olive (world ranking of 4th) and tea (world ranking of 6th) production carries an importance for the agriculture in the country.

The leading agro-industrial sectors in Turkey are meat production (cattle and chicken), dairy farming, sugar industry (sugar beet processing) and olive & olive oil production (DBFZ, 2011). The agro-industry has a high growth potential due to growing population coupled with urbanization and trend of consumption behavior to processed food.

In Business Monitor International (BMI) Research[13], these future estimations for the agro-industry in Turkey are made until the year 2020:

- a continuous growth of cereal production driven by increasing human consumption
- a resilient growth of livestock market supported by government

[12] FAO statistics: http://faostat3.fao.org/browse/rankings/commodities_by_country/E - accessed on 08.08.2016:
[13] http://www.bmiresearch.com/turkey- accessed on 11.08.2016

- a firm growth of sugar market due to the effective implementation of reforms
- an increase in rice consumption in parallel to population growth
- an increasing demand for beef
- the poultry production will rise by benefitting from governmental subsidies and regional export opportunities

Table 6. Growth of Some Food and Beverage Subsectors, 2005 – 2011. Source: derived from ISPAT (2013)

Product	Growth % 2005 - 2011
Fish	22%
Bovine/ovine meat	18%
Bread	17%
Wheat flour	16%
Poultry	12%
Oil	11%
Spirits	11%
Ice-cream	10%

According to the analysis of The Economist (intelligence unit)[14] there are 3 major challenges Turkish agro-food sector is facing today:

- Not enough public spending on agricultural research & development
- Low GDP value per capita
- The future risk of political stability

3.2 Agro-waste Potentials, Availability and Limitations in Turkey

Ministry of Energy and Natural Sources, ETKB (2014) estimates the total theoretical biogas energy potential of Turkey to be between 1,5 - 2 Mtoe (62,8 - 83,7 PJ) which equals to 2.512.080.000 - 3.349.440.000 m^3 biogas [15] per year.

After working on the most recent statistics of TURKSTAT, FAOSTAT and BEPA[16] and examining the common points of national and international studies, reports and

[14] http://foodsecurityindex.eiu.com/Country/Details#Turkey - accessed on 12.08.2016
[15] 1 m^3 biogas is assumed to represents 25 MJ energy. 1 Mtoe = 41,868 PJ. 1 PJ = 1.000.000.000 MJ.
[16] (BEPA, 2016): http://bepa.yegm.gov.tr/ - accessed on 17.08.2016

researches [17] on biogas potential in Turkey, the sectors and bio-wastes with the most potential are estimated to be:

1. Meat production, meat processing / Slaughterhouse; bone, blood, grease, fat
2. Poultry Farm; manure, bedding
3. Cattle Farms; manure
4. Dairy Farms; manure, milk, cheese, whey waste water and
5. Sugar beet factories; sugar beet press cake, molasses
6. Olive and olive oil production; olive press cake, olive mill waste water
7. Vegetable processing; pomace of tomato, eggplant
8. Fruit processing and juice production; pomace of oranges, apples, pomegranate
9. Fish processing; fish wastes

Table 7. Overall of Biogas Potential in Turkey. Source: derived from DBFZ (2011)

Sector	Feedstock	Technical Biogas Potential [PJ/year]
Livestock	Cattle manure	42,1
	Poultry manure	36,2
Agricultural residues	Straw of cereals	27,7
	Sugar beet leaf	4,4
	Tomato waste	4,1
Agro-industrial residues	Meat production and slaughterhouse	0,2
	Dairy (cheese wastewater)	2,4
	Sugar beet press cake and molasses	4,5
	Olive press cake and wastewater	2,4
	Juice industry residue pomace	1,6

Livestock

In Turkey, 1/3 of agriculture activity is in the livestock sector with around 2,5 million active enterprises and farms (DBFZ, 2011).

From 2008 to 2012, the dairy sector in TR has grown at the rate of 7% - 8%, particularly in the sub-sectors of cheese and milk production while the cattle population ascended steadily. Turkey becomes the regional exporting country of dairy products (ISPAT,

[17] (DBFZ, 2011), (Eastern Research Group, 2012) (Deniz et. al, 2014), (ETKB, 2014), (ISPAT, 2013), (FAO, 2012)

2013). The beef meat production which was 435.778 tonnes in 2001 has reached to 1.149.261 tonnes in 2015 with a sharp increase (TURKSTAT, 2016). The cheese waste-water is estimated to be more than 3 million tonnes per year (DBFZ, 2011).

"*The potential for the production of biogas from milkprocessing waste water in Turkey is 54.2 million cubic meter per year (m^3/yr). This production is worth $ 15.1 million per year in terms of energy costs.*" (Coskun et al., 2012)

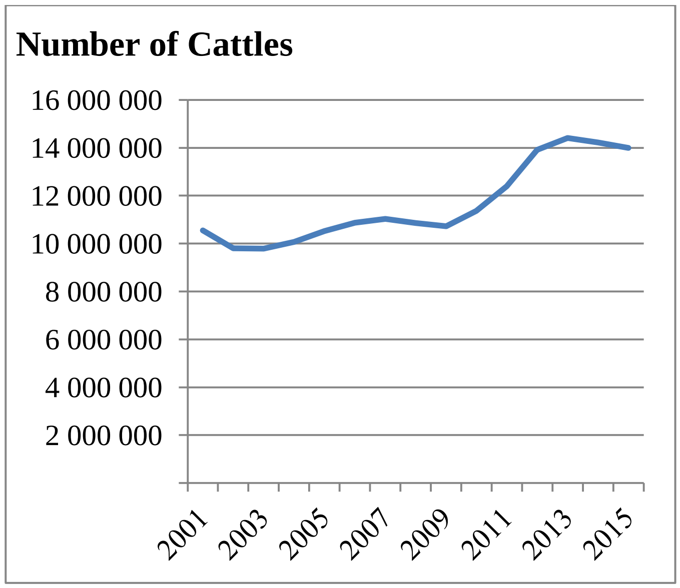

Figure 7. The Trend of the Number of Cattles in Turkey, 2001 – 2015. Source: derived from TURKSTAT (2016)

The livestock farms in Turkey are smaller in comparison to the farms in Europe. Only around 0,8% (1.000) of the total farms have more than 50 animals; for the comparison, this number equals to 66 % in the Netherlands (ISPAT, 2013). However the investments for establishing modern farms with more than hundred cattle are increasing.

ISPAT (2013) forecasts this growth to continue in the upcoming years due to:

- "*Local per capita demand below developed country levels*
- *Growing population*
- *EU bans lifted – now Turkey can target many markets in Europe*
- *Raw milk costs expected to go down due to growing capacity into the sector*"

Turkish poultry sector had an overwhelming growth in the last decade by the local investments to meet the increasing national and regional demand. Chicken meat production has almost quadrupled in the last 15 years. The regional export of poultry products is increased by 60% over the years 2008 – 2012 (ISPAT, 2013).

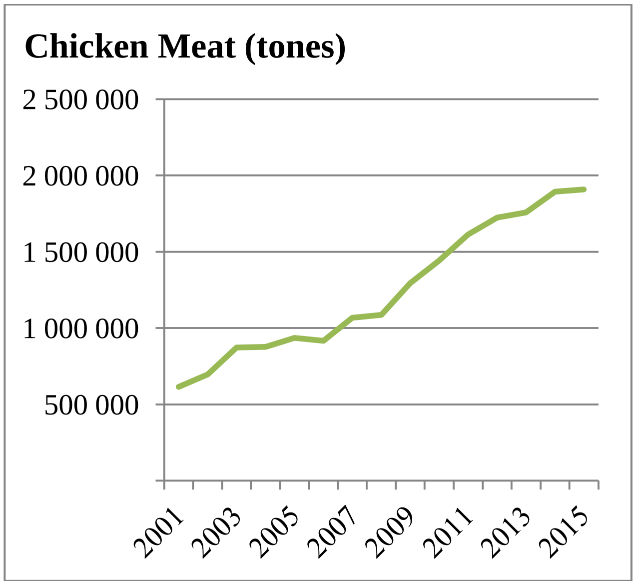

Figure 8. The Trend of Chicken Meat Production in Turkey, 2001 – 2015. Source: derived from TURKSTAT (2016)

Total population of poultry animals (laying hens, broilers, turkeys, geese, ducks) is 316.332.446 with higher potential in the western part (TURKSTAT, 2016).

In the more industrialized western part of Turkey, the cattle farms have more animals and animals are not grazing outside unlike in the eastern regions. Thus the bovine manure in eastern part of Turkey is considered to be less collectable. On the other hand, in poultry facilities almost all of the manure is available to collect. The best examples of vertical integration production system are practiced in poultry sector.

When calculating the technical energy potential, the assumption made that; in the western regions, the 50% of the cattle manure, in the eastern region 15% of the cattle manure and in both regions %99 of poultry manure can be available to be used for biogas production according to the data obtained from Ekinci et al., (2010) and DBFZ (2011).

The manure in the animal farms is not handled properly. Many farmers in rural areas have lack of waste management awareness. There are not sufficient structures to collect manure either. Most of the time, manure is disposed randomly to the surrounding environment, spreading on the fields or discharged to water bodies. If not, farmers remove the manure out of the barn with water and store in trenches which are sometimes leaking. This kind of utilization results in land, water, ground water pollution, contamination risks and odor (Ekinci et al., 2010).

According to RE Action Plan of ETKB (2014), 20% of the cattle manure is estimated to be available for biogas production and the total energy potential equals to 0,58 Mtoe while energy potential from poultry waste is assumed to be 0,3 Mtoe. These potentials represent 971 million m^3 and 502 million m^3 biogas per year.

Ekinci et al., (2010) has calculated the potential for biogas plants at 2 different capacities and their energy production from manure as it was summarized in Table 8.

Table 8. The Potential of Methane, Electricity and Heat Production from Manure in Turkey. Source: derived from Ekinci et al., (2010)

	The number of biogas plants with capacity of 200000 tons/year	The number of biogas plants with capacity of between 10000 and 200000 tons/year	Production			
			Methane (Million m^3/year)	Electrical energy (GWhe/year)	Heat energy (GWht/year)	Digestate (Tons/year)
Total	27	74	365.33	1270.97	1452.53	2256961.16

Sugar Beet Industry

The amount biodegradable wastes produced by the 33 sugar factories in Turkey are calculated by (DBFZ, 2011) as 394.250 t/y molasses and 2.778.544 t/y pulp&press cake. Not only the residues of sugar industry but also the sugar beet plant itself is available for AD including the leaves and the beet. The Middle-Anatolian region has the highest potential in this term.

Olive and Olive Oil

As a Mediterranean country, olive and olive oil production and consumption is very important for Turkey. Turkey is responsible for nearly 95% of the world-wide olive oil production. 70% of the total cultivated olives are processed in oil-mills. There are around 1.000 small sized olive oil mills located near to western and north-western sea cost of the country (DBFZ, 2011).

DBFZ (2011) further indicates some points on using olive residues for biogas production: "*According to the data from the ministry of industry, 2011: when 5kg olives are being used, 1kg oil and 2 kg oil press cake could be obtained. (..) The press cake as well as the oil mill waste water (OMWW) contains phenol (carbolic acid) which can influence the biogas process negative."*

Turkey is among of the top ten producers of many different fruits and vegetables in the world. **Fruit and vegetable processing** industry is already developed especially the sub-sectors of tomato paste, fruit juice and frozen vegetables. Turkey is also a significant exporter of processed fruits and vegetables products, for instance, globally ranked as 1st in jam, 5th in canned food, 4th in dried fruits.

Pomace which produced during juice production is suitable and available for AD although in cases of high mounts of citrus content, pre-treatment of feedstock might be necessary.

Table 9. Bio-waste Amount in Juice Industry in Turkey. Source: Deniz et al., (2014)

Juice Industry in 2010		
Fruit	**Pomace (%)**	**Pomace Amount (1000 tonnes)**
Apple	18	67,7
Pomegranate	55	43,3
Orange	55	29,6
Sour cherry	28	20,6
Peach	14	13,3
Apricot	14	5,1
Grape	28	4,8

Aquaculture and fishery sector in Turkey grows to become the fourth largest producer in Europe. The annual production volume is increased by 8% which now represents the 7,2% share of total European market. Compound Annual Growth Rate (CAGR)[18] of the sector was 29% while the global aquaculture has increased by 6,4% over the years 2005 - 2011 (ISPAT, 2013).

Functional food is a substantial sector with average rate of growth on production of baby food, baby milk formula, energy and sport drinks, probiotic yoghurts, and breakfast cereals (ISPAT, 2013).

Even though there are continuous local investments for **greenhouse agriculture**, the share of modern greenhouses is behind of the national potential. In Turkey greenhouses are most commonly used for vegetable cultivation (typically tomato, cucumber, pepper, eggplant). Greenhouse heating potential from renewable energy sources such as solar thermal, geothermal and biomass are present for saving high energy cost (ISPAT, 2013).

3.3 Current Status of Biogas Energy in Turkey

The waste management awareness of agro-businesses in Turkey is rising due to increasing public concerns on the disposal of agricultural wastes (such as poultry manure) into the surrounding environment.

In the rural areas of Turkey, biomass is only used in traditional ways to generate heat by burning; wood wastes, crop residues or dried animal manure. Modern biogas systems are introduced only in the last decades after the improvements on the legislations

After the year 2000, the biological wastewater treatment plants in manufacturing industry in Turkey have doubled in number (in 2000: 526, in 2014: 1094). The increasing trend of the wastewater treatment in the industry is shown in the graph below.

[18] CAGR (Compound Annual Growth Rate) refers to the average rate (%) of yearly market size growth during the specific period of years (2007-2011). The data is obtained from (ISPAT, 2013)

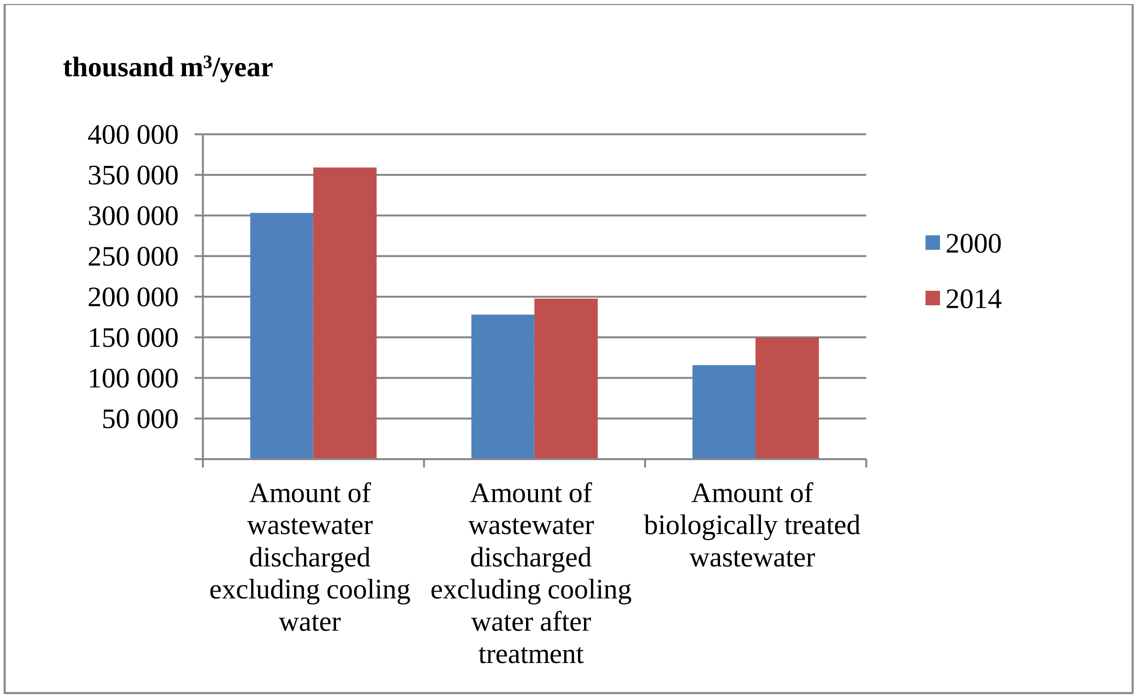

Figure 9. Manufacturing Industry Wastewater Indicators, 2000 – 2014. Source: prepared according to TURKSTAT (2016) [19]

Today, the biogas market in Turkey is in the initiating level. The biogas plants in the country are investigated by the license search engine[20] of Energy Market Regulatory Authority (EMRA - *EPDK in Turkish*) and the information on the feedstock is obtained from companies' and local news websites. There are 19 installed biogas plant in agriculture and food sector with total capacity of 42 MW. While most of them are collective agricultural biogas plants with their feedstock mainly consists of manure (cattle & poultry), cultivation residues and silage coming from several farms and fields, only 3 of them agro-industrial applications using vegetable oil & food processing waste. The types of biogas plants currently present are:

- 22 landfill-gas
- 19 agricultural & food industry
- 3 plants using municipal organic waste after the separation in the landfill
- 6 municipal waste-water plant

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[19] http://www.turkstat.gov.tr/PreTablo.do?alt_id=1019

[20] (EMRA, 2016c): http://lisans.epdk.org.tr/epvys-web/faces/pages/lisans/elektrikUretim/elektrikUretimOzetSorgula.xhtml

The full list of all licensed AD biogas plants in Turkey can be found in the Appendix B. Besides of few AD plant there are 2 power plant using chicken manure as feedstock for pyrolysis in Turkey and 1 large scale one 12 MW is planning by the company *ZGC BES* in the city of Bolu.

There were 24 biomass energy projects at different stages of “license application process” with a total capacity of 131 MW_e at the date, 04/11/2014 (MMO, 2015).

The total capacity of unlicensed biomass energy plants was 21,4 MW_e in 2015. In the same year these plants imported 37.094 MWh surplus electricity which equals to 16,6% of all unlicensed electricity imported to the grid (EMRA, 2016d).

It is not clear how many of these biomass based project are biogas project since EMRA statistics does not have option to search only for biogas. This issue is addressed in the Conclusion and Recommendations chapter.

3.3.1 Reference Examples

The two successful biogas plants in Turkey are explained below; Efeler dairy farm and Sütaş Aksaray dairy farm, which were commissioned in 2015 and 2013 respectively. In both facilities, biogas is obtained from cattle manure and utilized in co-generation plant. The examples of biogas plants are explained in the form of “factsheet” which was derived from companies’ official technical reports.

1- Efeler Biogas Plant

Name of the Biogas Plant: *Senkron Efeler Biyogaz Santrali*
Location: *İncirliova / Aydın (100 km to İzmir)*
License date: *03.10.2012 - 03.10.2027*
Company: *Senkron Grup Ltd.Co.*
Total Investment: *6.250.000 € (20 M TL)*
Investment Horizon: *25 years*
Capacity:
Electricity: *2,4* MW_e
Heat: *2,875* MW_{th}
Cooling: *1,625* MW_{th} *(optional)*
Electricity Generation: *19.200.000 kWh/year*

Heat Generation: *23.000.000 kWh/year*
FLH: *8.000*
Feedstock:

%100 Cattle Manure
6.000 livestock for milk production
400 tonnes/day

Organic Solid Fertilizer: *3.000 tonnes/year*, Liquid Fertilizer (Optional): *3.000 tonnes/year*
Fertilizer Packaging Plant was financially supported by a regional development agency
Greenhouse Heating (Optional): *3.000* m^2
Water Consumption: *50 - 60* m^3 *water/day*
Operation is done by 7 workers in 3 shifts
Biogas Engines: *2 x 1,24* MW_e *Guascor HGM 560* [21]

2- SÜTAŞ Enfaş Aksaray Biogas Plant[22]

The company "Sütaş" owns 2 milk processing facility in Turkey; one in Bursa (Karacabey) and the other one in Aksaray, with the total capacity of 950 million litres milk per year. Both dairy farms have biogas plants and produced biogas is used in CHP, electricity fed to the grid and thermal energy is used for the processes in the plant. Here, the biogas plant in Aksaray is explained:

Name of the Biogas Plant: *Enfaş Aksaray Biyogaz Tesisi*
Company: *ENFAS Enerji Elektrik Üretim A.Ş. subsidiary under SÜTAŞ Group*
Location: *Aksaray (250 km to Ankara)*
Commissioning Date: *2013*
Capacity:

Electricity: *2,134* MW_e
Heat: *2,2* MW_{th}

GOLD Standard Certificate
Biogas Production: approx. *3.800.000* m^3/y
Electricity Generation: *14.938.000 kWh (as in the power purchase agreement)*
11.925.000 kWh (exported to grid in year 2014)
Heat Generation: *7.617 tonnes of steam / y*

Heat is used for bioreactor heating and dairy plant s processes

FLH: *7000* [23]

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[21] https://www.dresser-rand.com/products-solutions/guascor-gas-diesel-engines/guascor-hgm-engines/
[22] https://www.sutas.com.tr/uploads/images/Sutas-Faaliyet-Raporlari-2014.pdf
[23] Own calculation

Feedstock: *128.659 tonnes Cattle Manure in year 2014*

450 tonnes/day from 3 cattle farms (150 t/d each) in 10 km away

Organic Solid Fertilizer: *is planning to be used in nearby agricultural land*

GHG emission reduction: *54.533 tonnes* CO_2 *equivalent*

Excess methane (to be flared if there is any a flare is installed

Financial:

Capital Investment: *5.799.000 $*

FIT: *$13.3 Cent/kWh*

Income Tax Rate: *20%*

O&M Cost: *509.000 $*

Carbon Revenue: *not until 2023*

IRR: *16,1%**

**"This IRR value represents the most optimistic scenario in terms of capital investment and electricity generation. For the proposed project, in order to reach the benchmark IRR values, average electricity tariff must be above 14$ c/kWh so that the investment will become reasonable."*

The Future Goals:

Sustainability Report, 2014[24] of the company defines the goal for meeting the 100% of all electricity by new investment and new possible feedstock (production wastes) by 2020. Also Sütaş Group aims to supply 100% of their fertilizer need of the forage fields. The company ENFAŞ is currently working on increasing the capacity from 2,1 MW to 6,2 MW.

3.4 Turkey's Bio-Energy Policy and Legal Framework

Today Turkey's energy strategy is based on reducing the dependence on foreign sources and energy supply security. The policy is giving priority for using domestic renewable resources but also coal and nuclear energy to ensure the diversification of energy sources. The 2023 targets related to biogas energy as mentioned in Renewable Energy Action Plan by ETKB (2014):

- *"(...) an increase of the share of renewable energy in electricity generation of at least 30% of the total.*
- *Target of energy from renewable sources in gross final consumption of energy in 2023: 20,5%*
- *(...) 1.000 MW of biomass (the biomass target is not yet included in the official documents)."*

[24] https://www.sutas.com.tr/uploads/images/sutas-surdurulebilirlik-raporu.pdf

In National Renewable Action Plan, the utilization of biomass sources are less promoted in comparison to other RES such as hydropower, wind, geothermal. The biomass target for 2023 is mentioned but not added to the official documents. DBFZ (2011) states that; "*The implementation of biomass utilization facilities which might contribute to the energy demand is often not part of political strategies*."

The Turkish waste legislation is compatible with the EU directives on the goal of reducing biodegradable waste by 30 percent in 50 years. Other than this and FIT scheme, there are not any other policy remarked in REN action plan for promoting the use of biogas such as district heating, biogas grid or natural gas grid integration. Currently there are no technical specifications, requirements or payment tariffs for biogas injection to the grid. Furthermore there are no plans for creating an infrastructure for RES district heating/cooling in near future (ETKB, 2014). Only in recent years, improvements in the support legislations made renewable energy technologies more competitive in the energy market of Turkey.

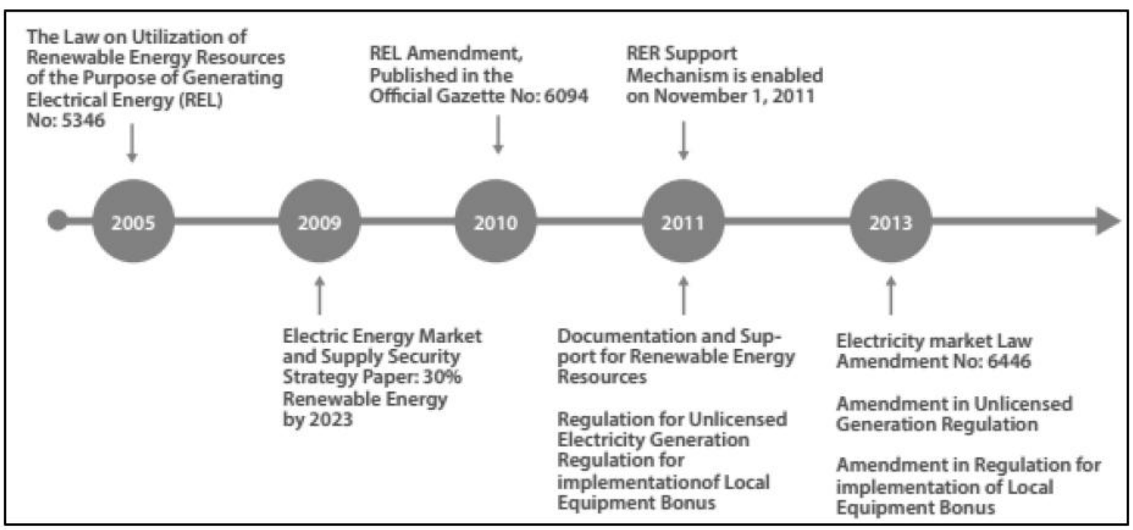

Figure 10. Timeline of Improvements on RE Legislation Related to Biogas Energy. Source: derived from ETKB (2014)

Even after the Renewable Energy Law (law no: 5346) is put in force on 10.05.2005, there was not any significant attraction due to lack of secondary regulation and very low FIT (5,5 $ cent/kWh), until the Regulation on 08.01.2011 (law no: 6094) which increased FIT rates and bringing more non-monetary subsidies. On 30.03.2013, the license exemption capacity limit is increased to 1 MW from 500 kW by the regulation on the Electricity Market Law (Law no: 6446) resulting more opportunities for investors.

In Turkey, the main promotion scheme for renewable energy production is the guaranteed feed-in-tariff (FIT).

Table 10. FIT Schedule I. Source: EMRA (2016a) [25]

Schedule I (Provision of the law dated 29/12/2010 and numbered 6094)	
Type of Production Facility Based on Renewable Energy Resources	Prices Applicable (US Dollar cent/kWh)
a. Hydroelectric production facility	7,3
b. Wind power based production facility	7,3
c. Geothermal power based production facility	10,5
d. Biomass based production facility (including landfill gas)	13,3
e. Solar power based production facility	13,3

Table 11. FIT Schedule II. Source: EMRA (2016a)

Schedule II (Provision of the law dated 29/12/2010 and numbered 6094)		
Type of Facility	Domestic Production	Domestic Contribution (US Dollar cent/kWh)
E- Biomass power based production facility	1- Fluid bed steam tank	0,8
	2- Liquid or gas fuel steam tank	0,4
	3- Gasification and gas cleaning group	0,6
	4- Steam or gas turbine	2,0
	5- Internal combustion engine or Stirling engine	0,9
	6- Generator and power electronics	0,5
	7- Cogeneration system	0,4

The Renewable Energy Law (YEK-Law) differentiates the amount of the FIT (schedule I) depending on the technology and also defines an additional FIT (schedule II) for each domestically manufactured component of the power plant. The FIT (schedule I) is limited to 10 years and the bonus FIT (schedule II) is limited to first 5 years of

[25] Law on Utilization of Renewable Energy Sources for the Purpose of Generating Electrical Energy; http://www.emra.org.tr/en/documents/electricitymarket/Legislation - accessed on: 10.08.2016

operation. The amount tariff for local-content varies from 0,4 ¢$ to 2 ¢$ depending on the equipment. The amounts are given in the currency of US dollars ($) by the law.

According to the Electricity Market Law, another important incentive mechanism is the exemption from Energy Market Regulatory Authority (EMRA) license in the terms of:

1. RE power plants with a capacity lower than 1000 kWe. (This capacity limit can be further increased by the authorization of the Council of Ministers)
2. RE power plant which consumes all of their energy production without giving to energy transmission/distribution system (These plants can sell the electricity which exceeds their consumption to the grid according to table of tariffs explained in FIT schedule I and FIT schedule II).
3. Cogeneration facilities with the overall efficiency of at least 80%.
4. Micro cogeneration facilities with a capacity lower than 100 kWe
5. Electricity generation facilities from municipal landfills and municipal wastewater sludge

Unlicensed generation has the advantages of *not being obliged to:*
- pay license or service fees
- form a company
- provide the documents; “letter of guarantee”, “resource use right” etc.

These benefits not only decrease the investment costs significantly but also help investors to avoid the complicated license obtaining procedures. In addition to the two main incentives - FIT and license exemption – other incentives for RE investments provided by REL and EML are explained below:

1. *Purchase Guarantee:* Electricity distribution companies are indirectly obliged to procure the electricity produced from renewable sources.
2. *Priority for Grid Connection:* Upon competition or conflict with other application, RE plants have the priority from EMRA.
3. *License Fee Advantage:* The RE facilities wishing to obtain EMRA license, pay 10% of the total license fee. In addition, these companies do not pay the annual license fee for the first 8 years after construction.
4. *Land-use Utilization:* The rental and use right costs of the lands belonging to the State or Treasury are discounted by 85% for 10 years for RE investments.
5. *Additional Capacity Advantage:* If the planned full capacity cannot be reach due to technical problems, another power plant can be constructed within the permissions of the license.

The current existing legal framework related to biogas applications in Turkey can be found in the Table 12 below:

Table 12. Turkish Legal Framework Related to Biogas. Source: DBFZ (2011)

Law on Utilization of Renewable Energy Sources for the Purpose of Generating Electrical Energy (Renewable Energy Law - REL)
Electricity Market Law (EML)
Environmental Law
Animal Side Products Unused For Human Consumption Regulation
The Protection of Waters Against Pollution Caused by Nitrates from Agricultural Sources
The Solid Waste Control Regulation
General Rules for the Regulation of Waste Management
The Production, Importation and Placing on the Market of Agricultural Organic, Organomineral Fertilizers, Soil Regulators and Other Microbial Product with Enzyme Content Regulation

3.5 Barriers to Biogas Investments in Turkey

Barriers to the biogas investments in Turkey are listed below;

1. No official government biogas target: The government's energy strategy focuses less on biomass in comparison to other renewable energy sources. The biomass energy installed capacity target mentioned in the Renewable Energy Action Plan is included to the official documents.
2. Neither any policy program nor any targets for specific amount of biowaste utilization/management. Lack of specific legal regulations for manure management (DBFZ, 2011).
3. Complicated and time-consuming bureaucracy of admission process.
4. Inadequate biomass potential assessment studies: Infrequent statistics on solid waste by Turkish Statistical Institute (TURKSTAT). There are only a few up-to-date assessment studies and databanks on the bio-waste energy potential in the country. The academic research papers often ignore the technical and economic potential and rather focus on rough theoretical potential. Lack of guidelines for municipal data collection on wastes from households and city.
5. Drivers for organic waste management investment are not strong; Violations of the environmental regulations such as agricultural waste disposal are not always enforced with necessary punishments (financial penalty). The public complaints are often completely ignored.

6. Insufficient human resource with technical experience of biogas investment economics and project developing.
7. Lack of biogas knowledge: No public awareness-raising and capacity-building programmes for politicians, investors, farmers, industries, financers etc., to address the end-uses of biogas and environmental and economic aspects.
8. Not enough information on current and expected future costs of biomass energy utilizations.
9. Inadequate financing possibilities especially for small-scale investments; conservative approach of the finance suppliers.
10. Presence of only *one* biogas association.
11. Insufficient Feed-In-Tariff; FIT (13,3 USD cent/kW_hel) is low compared to European countries such as Germany, Austria, Spain, Italy [26]. 10 years of FIT period is not long enough to make long-term income predictions during economic evaluation stage of project planning. In addition, as FIT is given in the currency of U.S dollars by the law, the fluctuation of $ / TL exchange rate also creates uncertainty of the expected incomes.
12. Lack of legal regulations and technical infrastructure for bio-methane injection to natural gas grid and no bio-CNG subsidies for users except tax reduction.

[26]http://www.seai.ie/Renewables/AD_In_Ireland_22nd_October/A_Biogas_Roadmap_for_Europe.pdf page: 11

4 Key Study:

In this chapter, a key study of small-scale agricultural CNG - CHP biogas plant is studied according to the conditions of Turkey. Energetic and economic considerations are made by referring to previous researches and publications in the field as well as author's personal experiences.

Today, there is not any biogas upgrading plant in operation in Turkey. Neither there is any research or pre-feasibility on farm-scale bio-CNG production published yet. In the Turkish literature on biogas, vehicle fuel expense of the farms is often an ignored issue. The key study tries to address this missing part of initiating biogas market in the country. The drivers for examining an agricultural bio-CNG - CHP model are:

- The availability of agro-wastes as explained previously in the Chapter 3.1
- Manure management needs of agricultural sectors
- All sizes CHP systems and efficient use of excess thermal energy are supported clearly in the government strategies and policies
- High vehicle fuel costs caused by obsolete agricultural machinery
- Lack of legal and technical basis/framework for bio-methane injection to the national natural gas grid

For these reasons above, the key study is perform on a collective biogas facility near to cattle farms with 700 cattle in total and surrounding maize silage fields. Biogas is produced from the anaerobic co-digestion of cattle manure and maize silage and it is upgraded to CNG for to be used in the farm vehicles while CHP provide necessary energy for the process.

Various biogas calculator tools on the web are examined and BIWARE DSS[27] and RETScreen[28] software are taken as an example. A calculation tool (an excel spreadsheet) is prepared which combines energetic and economic output of biomass feedstock.

[27] http://www.biware.hs-bremen.de/
[28] http://www.nrcan.gc.ca/energy/software-tools/7465

TVT (2013)'s Biomethane-Calculator[29] is used for bio-methane production calculations. The snapshot of the results of Biomethane-Calculator and excel calculation tool and can be found in the Appendix D and Appendix E respectively.

Table 13. Summary Table of the Key Study (own calculations)

Feedstock	9.893	t/year
Biogas Upgrading Capacity	35	m^3/h
Electrical Power Capacity	33	kWe
Thermal Power Capacity	48	kWth
Electricity Generation	272.057	kWh/y
Heat Generation	395.776	kWh/y
CNG Production	166.434	m^3/y
CHP Efficiency	85%	
GHG Reduction	304	t CO_2 equiv./year
Total Initial Investment Cost	1.002.020	€
Total yearly O&M Costs	92.698	€/year
Diesel Fuel Cost Savings (23 Tractor)	193.063	€/year
Fertilizer Sale & Savings	96.866	€/year
Electricity Cost Savings	14.244	€/year
Heating Cost Savings	-	€/year
Net Present Value (NPV)	1.466.750	€
Annuity (a)	172.284	€
Payback Period (PBP)	6	years
Internatl Rate of Return (IRR)	14%	

Table 13 summaries the main features of the key study. The detailed explanations can be found done below in several sections; energy demand, feedstock, design capacities and parameters, energy outputs and economics.

4.1 Energy Demand

In the key study, the energy demand of the farms is aimed to be met by their own agro-wastes to reduce their economic expenses. Energy is an indispensable need of agricultural activities and agro-industry to run agricultural vehicles and machines, to illuminate & heat barns and greenhouses, to manufacture agro-chemicals, to process

[29] http://bio.methan.at/en/download_biomethane-calculator

food and products, to store products under refrigeration etc. The main energy inputs of the agriculture are vehicle fuel, fertilizer and electricity.

"*For all farm types, either red diesel or electricity is the biggest contributor to energy use from fuel. Red diesel* [30] *accounts for 67% of energy use from fuel on specialist cereal farms."* (DEFRA, 2013:1)

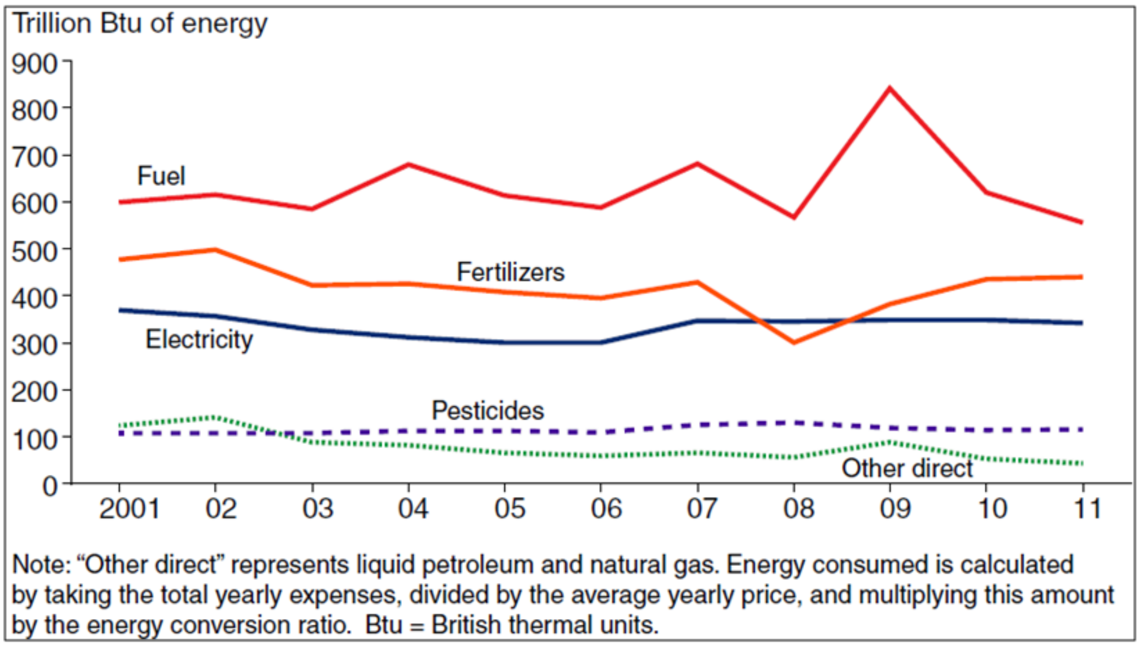

Figure 11. Consumption of Energy Inputs in the Farms in USA. Source: Miranowski (2005) cited by Beckman et al., (2013:10)

Figure 11 indicates that the fuel is the leading energy need of farms. It is followed by fertilizers and electricity. Heating (shown as "other direct" in the figure) is the least demanded component, around 1/3 of electricity. On contrary to these, traditional CHP utilization of biogas produces more thermal energy than electricity and no vehicle fuel at all. Thus, from an energetic point of view, CHP biogas plants are *not the perfect* models to address the demands of agricultural enterprises compared to their biogas potential especially in warm countries or in countries without district heating infrastructure, like Turkey. It is the theoretical reasoning behind working on a CNG-CHP key study rather than only-CHP plants.

[30] red diesel: diesel fuel dyed to red color for agricultural uses in the UK.

In a 1.000 cattle farm the CNG demand for agricultural vehicles[31] is defined to be 141.805 m^3 annually (Krich et al., 2005: 102). Within this perspective, in the key study, the produced CNG (166.434 m^3/y) is accepted to replace the fuel need of 2 – 3 farms including the vehicles that will transport the feedstock to the plant. This would also provide the flexibility of bringing different substrates for the AD system to increase the efficiency by co-digestion without extra transportation costs.

Yearly working hours of tractors is 500 – 550 in Turkey (TARMAKBİR, 2015). The hourly diesel consumption of a typical tractor on the road can be calculated according to the formula below (Özçelik & Özer, 2006):

0,12 x HP = diesel l/h

Therefore, during road driving 75 HP tractor would consume;

0,12 x 75 = 9 l/h

And during field work of 75 HP tractor would consume[32];

0,23 x 75 = 17,25 l/h

If it is assumed 225 hours road driving and 225 hours field work a 75 HP tractor would consume;

(17,25 l x 225 h) + (9 l x 225 h) = 7.150 litres diesel per year.

From an economic point of view, this would cost to a farmer:

7.150 l/y X 1,16 €/l = 8.294 €

This calculated amount is valid for new model vehicles; however, in practice the tractors are not efficiently consumes diesel fuel by the time they get older. This issue is addressed below.

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[31] 1 large tractor, 1 medium tractor, 1 small tractor, 1 feeder truck, 2 pickup trucks
[32] http://www.fuel-economy.lubricants.total.com/tr/tarim/eko-verimlilik.html - accessed on: 01.09.2016

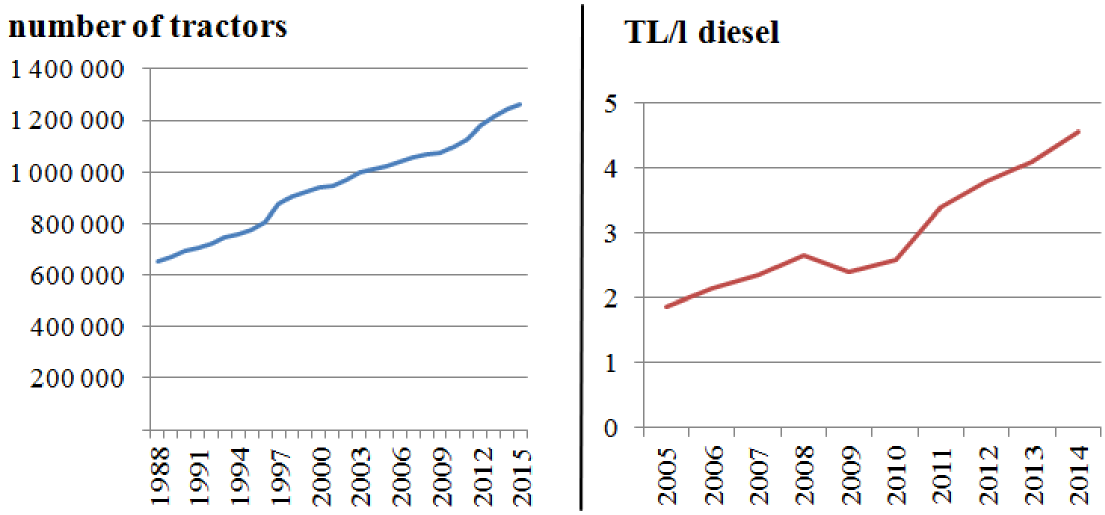

Figure 12. The Trend of Number of Tractors along with Diesel Prices in Turkey. Source: TURKSTAT (accessed on 01.09.2016)

In Turkey, the number of tractors in the country is constantly increasing because of the ones which completed their life cycle are kept in operation. In 2014, there were 1.612.310 tractors with average age of 23 years. Almost 50% of these tractors are over-aged, 25+ years in operation (TURKSTAT, 2014). Old tractors consume 30% more fuel compared to the new ones. This results into 700 – 1000 litres of extra diesel consumption and 100 - 150 working hour loss per tractor per year (TARMAKBİR, 2015). From an economic point of view, this would cost for each tractor extra;

1000 litres x 1,16 €/l = 1.160 € per year.

If this extra cost added to one year diesel fuel expense calculated above:

8.294 € + 1.160 € = 9.454 € per year.

Calculations show that a farmer in Turkey spend nearly 10.000 € for fueling a light tractor (75 HP) per year.

Constantly increasing fuel prices can worsen this economic loss. Diesel fuel prices per litre are in increasing trend in the last decade. It is calculated during the period 2006 – 2015 average yearly raise was 7,5%. However, in key study calculations it is assumed to be 5% per year with a safer approach.

4.2 Feedstock

It is assumed t1 cattle produces 50 kg manure in a day and 70% of it is available Maize silage commonly used for animal feeding assuming there are 100 ha of maize silage fields and %20 of it is produces silage to be collected for biogas plant with an availability of 95% silage yield 50 t/ha (Karakuz, 2015: 19). Since the feedstock belongs to the farmer, there are no feedstock costs.

Table 14. Feedstock of the Key Study (own calculations)

			Source	
	Cattle	Maize Silage		
Feedstock (t/y)	8.943	950		
DM (t/y)	903	292	Online European Feedstock Atlas	
VS (t/y)	717	279		
Biogas (m3)	291.157	163.216		
Methane Content	55%	53%	Finsterwalder, 2008	
Total Feedstock		9.893	t/y	
Total Produced Raw Biogas		454.373	m^3/y	
Average Methane Content of Biogas		54,28%		

4.3 Installed Capacities and Design Parameters

Table 15. Design Capacities and Parameters of the Key Study (own calculations)

			Source
Methane Content of Raw Biogas	54,28%		
Raw Biogas Production	454.373	m^3/y	
Biogas sent to CHP unit	153.905	m^3/y	34%
Biogas sent to Upgrading Plant	300.468	m^3/y	66%
Bio-methane Production (CNG)	166.434	m^3/y	Biomethane-Calculator
Biogas Upgrading Capacity	35	m^3/h	Biomethane-Calculator
Elec. Installed Capacity	33	kW_{el}	
Thermal Installed Capacity	48	kW_{th}	
CHP Efficiency	85%		
FLH	8.300	h/year	Typical data

Around 450.000 m3 of biogas is calculated to be produced after AD according to Al Seadi (2008: 99). The share of 34% of produced raw biogas is estimated to be used in CHP unit while the rest of the biogas (approx. 300.000 m^3/y) is sent to the upgrading unit. FLH is estimated to be 8.300 hours. Heating value of both bio-methane and fossil natural gas is rounded to be 10 kWh.

CHP unit supplies electricity to BG upgrading and AD plant and thermal energy for digester heating and drying fertilizer. CHP is scaled according to thermal energy need by taking Kalmari bio-CNG plant[33] as an example. A spark plug Otto engine is planned to be preferred since they are the most suitable option for the engines with installed capacity lower than 100 kW_{el} (Al Seadi, 2008). Electrical efficiency of the engine is 35% and thermal efficiency is 50% (BIWARE DSS, 2005).

The upgrading unit is chosen as gas permeation with high recovery as it is the most cost-efficient option in Biomethane-Calculator tool. Methane recovery of 99,5% is expected to be achieved.

4.4 Energy Outputs

The biogas plant produces CNG, electricity, thermal energy and fertilizer. This section explains their production and self consumption in the facility.

Table 16. Electricity Output and Consumption of the Key Study (own calculations)

			Source
Electricity Generation	272.057	kWh/y	
Consumed in AD plant	80.319	kWh/y	10% of theoretical production
Consumed in BG Upgrading	46.602	kWh/y	0,28 kWh/m^3 (Harasek, 2011)[34]
Consumed in fertilizer plant	32.975	kWh/y	(Berg, 2011)
Consumed in the farms	112.161	kWh/y	Remaining electricity
Electricity imported to grid	-	kWh/y	

[33] (Kallio, 2011): http://www.biomasscounts.eu/wp-content/uploads/2014/10/vtt_01_kalmari-biogas-farm-in-laukaa_en.pdf
[34] https://nachhaltigwirtschaften.at/resources/iea_pdf/events/20110331_bioenergieforschung_6_2_harasek.pdf?m=1469660713

The excess electricity is assumed to be used in the facility rather than to be sold to the national grid to gain more economic benefits. FIT for biomass energy in Turkey is 0,120 €/kWh_{el} (13,3 cent USD/kWh_{el}) while grid electricity price is = 0,127 €/kWh. Another benefit is reducing service fees and technical costs to connect electricity grid is also avoided.

Usually 10 % - 30 % of the brutto produced electricity and heat is used for the self - consumption of the plant. Electricity is used for the operations such as mixing, pumping, etc.) (Al Seadi, 2008) (BIWARE DSS, 2005). After supplying electricity to BG upgrading unit too, the surplus produced electricity is used in the farm and provide energy bill savings.

Table 17. Thermal Energy Output and Consumption of the Key Study (own calculations)

			Source
Heat Generation	395.776	kWh/y	
Consumption for digester heating	233.689	kWh	30% (BIWARE DSS, 2005)
Consumption for fertilizer drying	162.087	kWh	Remaining thermal energy
Consumption in the farms	-		

%20 of produced heat is planned to be consumed for digester heating. The remaining thermal energy is used for fertilizer dryer (or space heating depending on the needs of the farms). Other than this there is no excess thermal energy left except summer season.

Table 18. Vehicle Fuel Demand of the Key Study per year (own calculations)

			Source
Number of Vehicles	23	tractor	Assumed
Yearly tractor working hours	550	h/y	(TARMAKBİR, 2015:22)
Average diesel consumption per hour	13	l/h	(Özçelik & Özer, 2006)
Diesel consumption per vehicle	7.150	l/y	
Total replaced diesel by CNG	164.450	l/y	

It can be seen that produced CNG can replace the fuel of 23 agricultural tractors with 75 HP. Three (3) of these tractors are assumed to be used for feedstock transportation from farms to the biogas facility. (1 litre diesel is accepted to be replaced by 1 m^3 CNG and their efficiencies in the engine are assumed to be the same).

There are only 19 CNG filling stations[35] across the country; therefore selling CNG is not a practical option. Thus private filling station for the use of return-to-base fleet is seen as the most efficient method. Agricultural enterprises are good examples since tractors are used around the farms most of the times. Please refer to Appendix C for the location of the CNG filling stations in Turkey.

Table 19. Fertilizer Output of the Key Study per year (own calculations)

			Source
Digestate after AD (15% solid, 85% liquid)	9.398	t/y	95% of feedstock
Liquid Fertilizer to be sold	5.592	m^3/y	(Berg, 2011)
Solid Fertilizer to be sold	705	t/y	(Berg, 2011)

95% of feedstock is converted into digestate after AD. This digestate (15% solid and 85% liquid form) is sent to the fertilizer processing unit to be separated. It is assumed that %30 of liquid fertilizer, %50 of solid fertilizer is lost during separation process. After separation and drying solid fertilizer is expected to have 88% DM. The digestate is assumed to be used as high-quality fertilizer on the maize fields and provide income by avoiding purchase costs or to be sold in the open market. Upon self-consumption of fertilizer, the yields of the maize fields are expected to increase.

4.5 Economics

Criteria of Net Present Value (NPV), Internal Rate of Return (IRR) and Payback Period (PBP) are examined for economic feasibility of the investment through the calculations done according to the formulas below. WACC is accepted as 10%, in literature and investment reports it varies, big energy companies in Turkey have 5% to 8% [36].

PBP is calculated by dividing Total Investment Cost by Annuity.

[35] http://cngeurope.com/countries/377-2/ - accessed on: 02.09.2016
[36] https://www.sabanci.com/ca/docs/8D192F67466740379238C5B20DBA79/487A9B6D3F244B7794BDB930F4146329.pdf

Net Present Value	Capital Recovery Factor	Annuity
$NPV = \sum_{t=1}^{T}\left(\frac{C_t}{(1+r)^t}\right) - C_0$	$CRF = \frac{r \times (1+r)^T}{(1+r)^T - 1}$	$\alpha = NPV \times CRF$
T: Investment horizon (y) t: Year-count C_t: Cash flow in year t (€) r: Weighted Average Cost of Capital (WACC) C_0: Initial investment (€)		

Figure 13. Formulas Used for Economic Evaluation. Source: Weißensteiner (2014)

IRR is also calculated via NPV formula mentioned above. NPV is set to zero and the discount rate "r" is solved which equals to IRR. In general, the higher the IRR, the more feasible is the project although IRR should always be evaluated together with NPV to have a clear overview of the project value (Geylan, 2015).

Other Assumptions:

- TL/€ = 3,3
- US $/€ = 1,1
- Current Diesel Price [37] = 3,84 TL/l = 1,16 €/l
- Current Natural Gas Price [38] = 1,02 TL/m3 = 0,3 €/m^3
- CNG price in Turkey [39] = 0,74 €/m^3
- Investment horizon = 20 years

Table 20. Initial Investment Costs of the Key Study (own calculations)

Initial Costs			Source
AD Plant	414.952	€	(Deublein & Steinhauser, 2008)
Upgrading Plant	368.626	€	Biomethane-Calculator
Fertilizer Plant	84.755	€	(Berg, 2011)
Engine Conversion Cost of 23	60.000	€	2.609 € per vehicle
Filling Station	40.909	€	(Viking Strategies, 2013:8)
CHP Unit	32.778	€	(Deublein & Steinhauser, 2008)
Total Investment Cost	1.002.02	€	

[37] Shell diesel price in Ankara/Merkez: http://www.shell.com.tr/products-services/on-the-road/fuels/fuel-pricing.html accessed on: 31.08.2016
[38] http://www.igdas.istanbul/SatisTarifesi?lang=en accessed on: 01.09.2016
[39] http://cngeurope.com/countries/377-2/ accessed on: 08.09.2016

Specific Cost of AD plant is (8.000 €/m^3/h biogas which equals to 4.150 €/kWe) and CHP (1.000 €/kW) are derived from Deublein & Steinhauser (2008: 273). Filling Station Costs includes low pressure piping, storage, compressor etc. for six vehicles (Wilkinson, 2013 cited by Viking Strategies, 2013:8).

The investment costs are cross-checked with IRENA (2012).

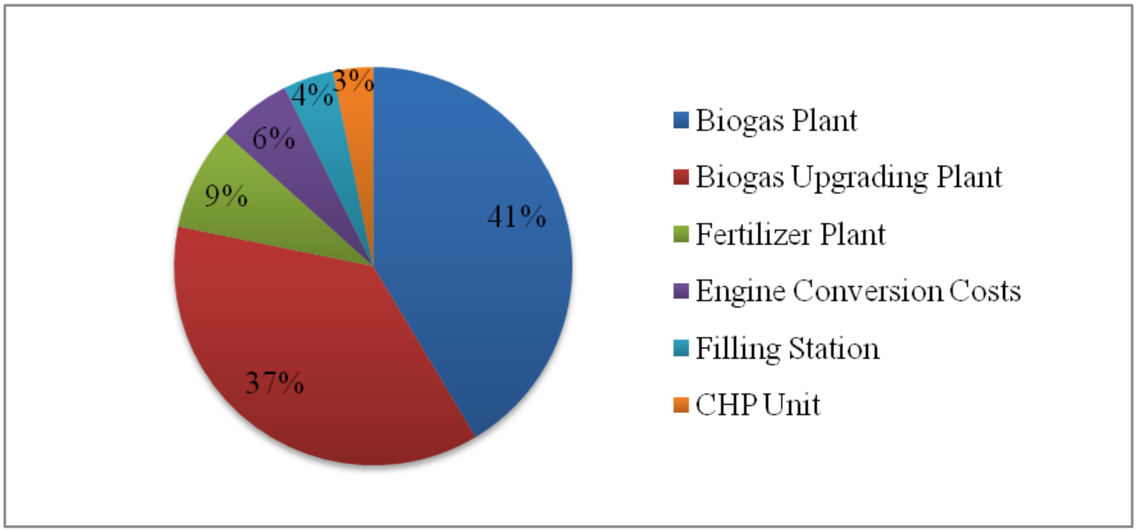

Figure 14. Share Distribution of Initial Costs (own calculations)

Table 21. O&M Costs of the Key Study (own calculations)

O&M Costs			Source
Biogas Upgrading Plant	53.582	€/y	Biomethane-Calculator
AD Plant	22.387	€/y	(IRENA, 2012)
Fertilizer Plant	12.713	€/y	(Berg, 2011)
Total O&M Costs	92.698	€/y	

Total O&M Costs includes the variable O&M Cost of 4.016 € (0,005 $/kWh). O&M Costs of fertilizer plant includes marketing expenses. O&M of AD plant accepted to be equal to 5%. Typical cost ranges from %1 - %6 of the CAPEX (IRENA, 2012).

Biomethane-Calculator calculated the specific costs per m^3 biomethane as 0,55 €/Nm^3 (Appendix D).

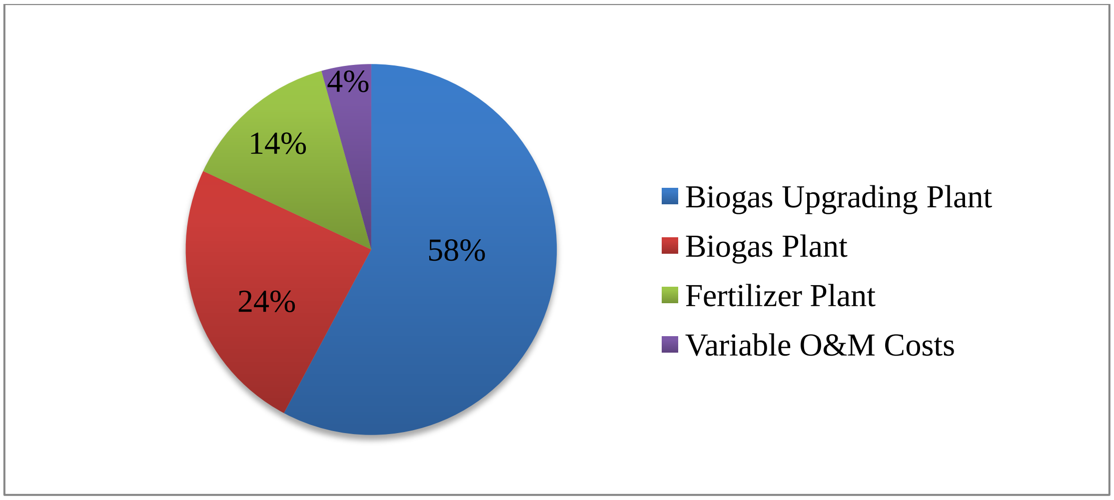

Figure 15. Share Distribution of O&M (own calculations)

Table 22. Incomes of the Key Study per year (own calculations)

			Source
Diesel fuel cost savings	193.063	€	1,16 €/l
Fertilizer Sale & Savings	96.866	€/y	Calculated based on (Berg, 2011)
Electricity Savings	14.244	€/y	
Heating Costs Savings	0	€/y	
CO_2 Savings Income	0	€/y	No market yet in Turkey

After electricity consumed in the biogas plant's facilities, the remaining produced electricity is used in the farms to achieve electricity bill savings.

It is projected that all the heat is used for digester heating and fertilizer drying thus there no income is expected from heat sales.

Electricity price escalation is taken as 3% and diesel price escalation is 5% as it was mentioned before to have more accurate income estimation in the upcoming years.

Berg, (2011) stated that liquid fertilizer market price is 9,76 €/m^3 and solid fertilizer market price is 60 €/t in Turkey. Thus, it is calculated that the income from liquid fertilizer would be 54.575 €/y while income from solid fertilizer would be 42.290 €/y.

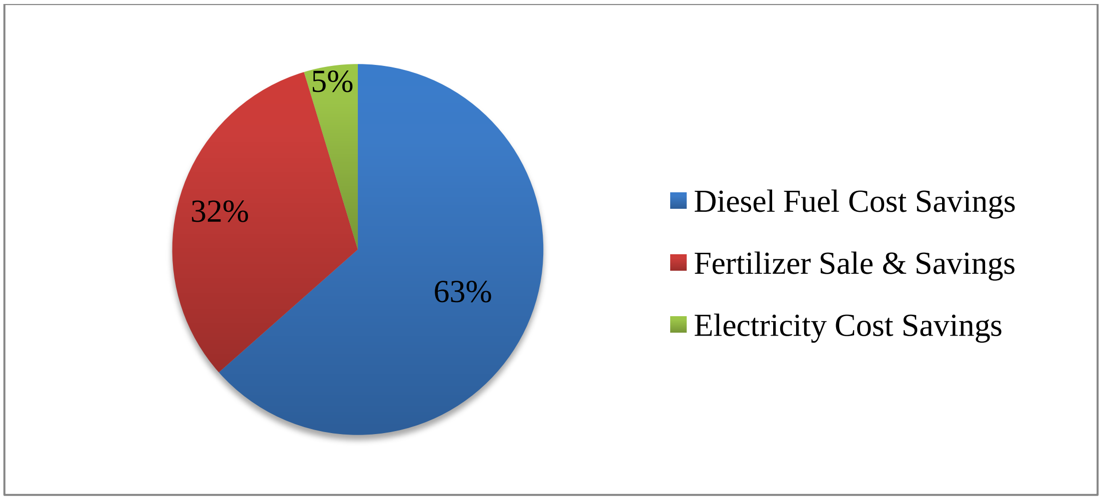

Figure 16. Share Distribution of Yearly Incomes (own calculations)

GHG Emission Reduction

The biogas facility is calculated to reduce 304 t/CO_2 equivalents every year by replacing fossil fuel of vehicles and power generation from fossil fuels. Electricity generation assumed to reduce 0,42 kg CO_2 per kWhel [40] generated from biogas and replacing diesel with bio-CNG reduces 2,63 kg CO_2 per l [41] on the other hand the amount CO_2 separated from biogas during upgrading is causing emission of 247 t CO_2 each year, thus this amount is subtracted from savings to calculate the net amount.

4.6 Comparison to Other Models

Two different variations of the key study are also prepared with same efficiencies, same type and amount of feedstock and same reference data but different biogas utilizations to show the difference of the economic performance. The different aspects three different models are explained below:

Only CHP:

- 100% of raw biogas is utilized in CHP
- Grid connection costs of 30.000 € is added to the total investment cost
- Heat use is needed of the year (maximum 75% of it assumed to be used)

[40] (IEA, 2015:129): "CO_2 Emissions From Fuel Combustion" in 2013 Appendix I countries
[41] http://www.sunearthtools.com/tools/CO2-emissions-calculator.php#txtCO2_7

- Diesel fuel costs of 3 tractors which will be used feedstock transportation (250 hours/year per vehicle, 9 l/h consumption) is added to yearly expenses
- There are no mechanisms for heat sale such as district heating to utilize excess heat which is produced by only-CHP model

Only CNG:

- Even though there are only few thousand CNG vehicles in the country, the best scenario is assumed, and all the CNG is accepted to be sold.
- The amount of vehicle fuel equal to consumption of 23 tractor is avoided and the rest of the CNG is sold in the open market with the price of 0,74 €/m^3.
- Filling station investment cost is assumed to be higher due to larger storage need
- Marketing costs are included to O&M cost of CNG filling station
- Since there is no CHP unit, electricity and natural gas (for heating) purchase costs are added to the expenses

The summary comparison table of all the three studies can be examined below:

Table 23. Comparison of the Key Study (CNG-CHP) to other Models (own calculations)

	only CNG	CNG - CHP	only CHP	
Feedstock	9.893	9.893	9.893	t/year
Share of BG sent to CHP	0%	34%	100%	
BG Upgrading Capacity	53	35	-	m^3/h
Electrical Power Capacity	-	33	97	kWe
Thermal Power Capacity	-	48	141	kWth
Electricity Generation	-	272.057	803.190	kWh/y
Heat Generation	-	395.776	1.168.446	kWh/y
CNG Production	252.029	166.434	-	m3/y
CHP Efficiency	-	85%	85%	
GHG Reduction	290	304	341	tCO_2/y
Initial Investment Cost	971.481	1.002.020	626.477	€
Total yearly O&M Costs	103.314	92.698	50.145	€/year
Diesel Fuel Cost Savings	218.500	193.063	-	€/year
Fertilizer Sale & Savings	96.866	96.866	96.866	€/year
Electricity Cost Savings	-	14.244	91.084	€/year
Heating Cost Savings	-	-	23.183	€/year
NPV	1.171.971	1.466.750	904.821	€
Annuity	137.659	172.284	106.280	€
Payback Period	7	6	6	years
IRR	11%	14%	15%	

4.7 The Result of the Key Study

The key study shows that farm-scale bio-CNG production is feasible in Turkey. Economic evaluation underlines that bio-CNG-CHP is already competitive with mature CHP model. In comparison to only-CNG model, bio-CNG-CHP clearly has the advantage of process energy costs savings. CNG-CHP system seems to have the optimum installed CHP capacity to get the most efficient use of both electricity & thermal energy while supplying the number 1 need of the farms: vehicle fuel.

On the other hand there are some barriers to overcome such as; lack of public knowledge on biogas technologies, conservative approach to NG vehicles, lack of field experience on biogas upgrading, lack of financing possibilities and low investment capacity of farmers. The barriers to biogas investments in Turkey are explained with detail in "Conclusion and Recommendations" chapter.

Economic feasibility of the project is highly dependent on diesel fuel costs per litre. It was mentioned before that; in the last years diesel prices in Turkey has increase 7% of yearly average and in the key study it was assumed to be 5% for the future. If the diesel price escalation of 7% was considered, the project would be much more feasible. On the other hand, if diesel price escalation would be 1%, the IRR of the investment would fall down to 10% from 14% and payback period increase to 10 years from 6 years.

Demonstrative research in the field is needed to determine the optimum performance and scale of this kind of investments.

5 Conclusion and Recommendations

Currently biogas production through anaerobic digestion is an attractive option for the agricultural sector in Turkey to provide energy and fertilizer savings while managing the growing organic waste problems. The other benefits of biogas energy to Turkey could be: supplying energy security, decreasing energy import, creating rural employment, contribution to GHG emission reduction, improvements on soil fertility and underground water quality.

Agriculture sector in Turkey has almost untapped and available biogas potential in particular on cattle and poultry manure. The wastes of agro-industry are also considered to be promising, especially in the olive-olive oil, sugar beet and fruit processing sectors.

The key study shows that agricultural bio-CNG utilization coupled with a CHP unit is a feasible model in Turkey which has a very efficient energetic performance in terms of meeting the most demanded energy inputs of the farms; vehicle fuel, fertilizer, and electricity. Bio-CNG investments can be highly competitive against traditional CHP utilizations with the current trend of increasing vehicle fuel prices in the country.

Today in Turkey biogas is facing mostly legal based barriers to catch up with the increase of other renewable energy sources. Some recommendations are listed below for promoting biogas energy to overcome the barriers on its way to represent a share in national energy mixture of the future.

Recommendations:

1. Official renewable energy targets should include biogas (biomass energy as mentioned in the regulation). In action plans, biomass energy should be emphasized as much as other renewable energy sources.
2. Biogas energy roadmap and long-term national strategy should be put in action.
3. Periodic inspections of organic waste disposal should be enforced strictly as described in the Environmental Law.
4. The obstacles in the bureaucracy should be reduced especially for foreign investors. English translation of informative documents is needed (e.g. official websites of Renewable Energy Directorate, Turkish Biogas Association, the biomass energy map of Turkey, EMRA license research engine)

5. Detailed biomass potential data banks should be created and the assessment should include technical and economic potentials. The existing one - the biomass energy map of Turkey (BEPA) of Energy Ministry should include technical potential rather than theoretical assumptions.
6. FIT should be increased to competitive levels. In the regulation, FIT is defined under the title of “biomass sourced energy” for all source of energy production including not only biomass but also combustion, landfill-gas etc. FIT for biogas should de higher to have a better competition with relatively simpler applications such as landfill gas similar to European regulations.
7. Credit providers and banks should be informed on biogas energy economics through seminars and voluntary education programmes.
8. The missing parts in the regulations should be detected by comparing to successful frameworks such as German biogas regulations.
9. Manure management regulations on how the animal manure should be treated, stored and transported should be prepared.
10. Turkish Solid Waste Legislation (TSWL) should be improved with concept definition of wastes and hierarchy of waste utilization measures.
11. There should be a basic policy for the production of biogas energy equipment domestically such as boilers and co-generation systems.
12. Legal basis for bio-methane injection grid and bio-CNG use should be created.
13. The efforts towards creating a carbon market should be accelerated.
14. Waste management associations and institutions should be strengthened for creating improved strategies to determine the polluted and over-capacity disposal sites. The coordination between biogas association and other stakeholders should be built up. The responsibilities of each stakeholder should be established and shared within specified limits.
15. Municipalities need guidance/guidelines on data collection of waste with source categorization (municipal, commercial, household, SMEs etc.)
16. The development strategies in the future should include modernization of the agriculture. Efficient, sustainable production measures and modern manure management systems should be promoted.
17. More pilot biogas projects should be implemented and results should be published in order to improve the knowledge of biogas plant operation.
18. Farmers and SMEs should be educated / trained on the benefits of biogas production, bio-CNG utilization, nutrient cycle, AD process, collection of liquid manure and using digestate as fertilizer. Public acceptance and awareness should be increased through media campaigns.

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APPENDIXES

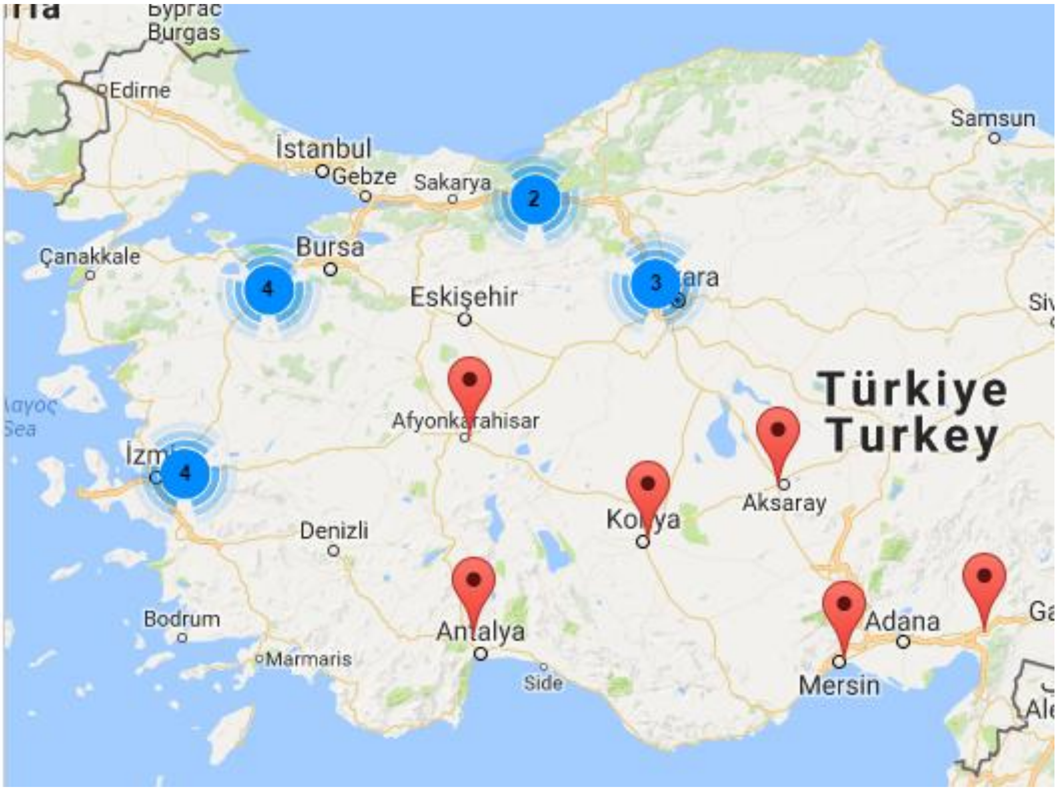
Appendix A: Biowaste Suitable for Biological Treatment. Source: European Waste Catalogue (2007)

Waste description	
Waste from agriculture, horticulture, aquaculture, forestry, hunting and fishing, food preparation and processing	Waste from agriculture, horticulture, aquaculture, forestry, hunting and fishing
	Waste from the preparation and processing of meat, fish and other foods of animal origin
	Wastes from the fruit, vegetables, cereals, edible oils, cocoa, tea and tobacco preparation and processing: conserve production; yeast and yeast extract production, molasses preparation and fermentation
	Wastes from sugar processing
	Wastes from the dairy products industry
	Wastes from the baking and confectionery industry
	Wastes from the production of alcoholic and non-alcoholic beverages (except coffee, tea and cocoa)
Wastes form wood processing and the production of panels and furniture, pulp, paper and cardboard	Wastes from wood processing and the production of panels and furniture
	Wastes from pulp, paper and cardboard production and processing
Waste from the leather, fur and textile industries	Wastes from the leather and fur industry
	Wastes from the textile industry
Waste packing; absorbents, wiping cloths, filter materials and protective clothing not otherwise specified	Packaging (including separately collected municipal packaging waste)
Waste from waste management facilities, off-site wastewater treatment plants and the preparation of water intended for human consumption and water for industrial use	Wastes from anaerobic treatment of waste
	Wastes from wastewater treatment plants not otherwise specified
	Wastes from the preparation of water intended for human consumption or water for industrial use
Municipal wastes (household waste and similar commercial, industrial and institutional wastes) including separately collected fractions	Separately collected fractions (except 15 01)
	Garden and park wastes (including cemetery waste)
	Other municipal wastes

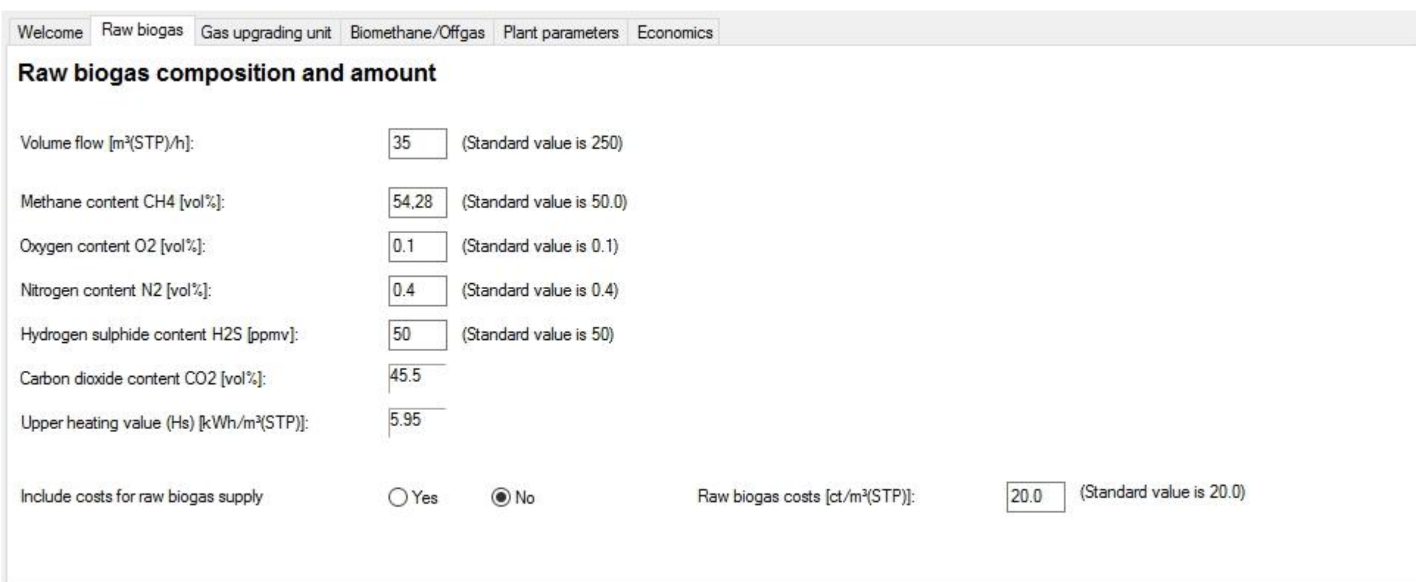
Appendix B: List of Agricultural Biogas Plants in Turkey. Source: EMRA (2016c)

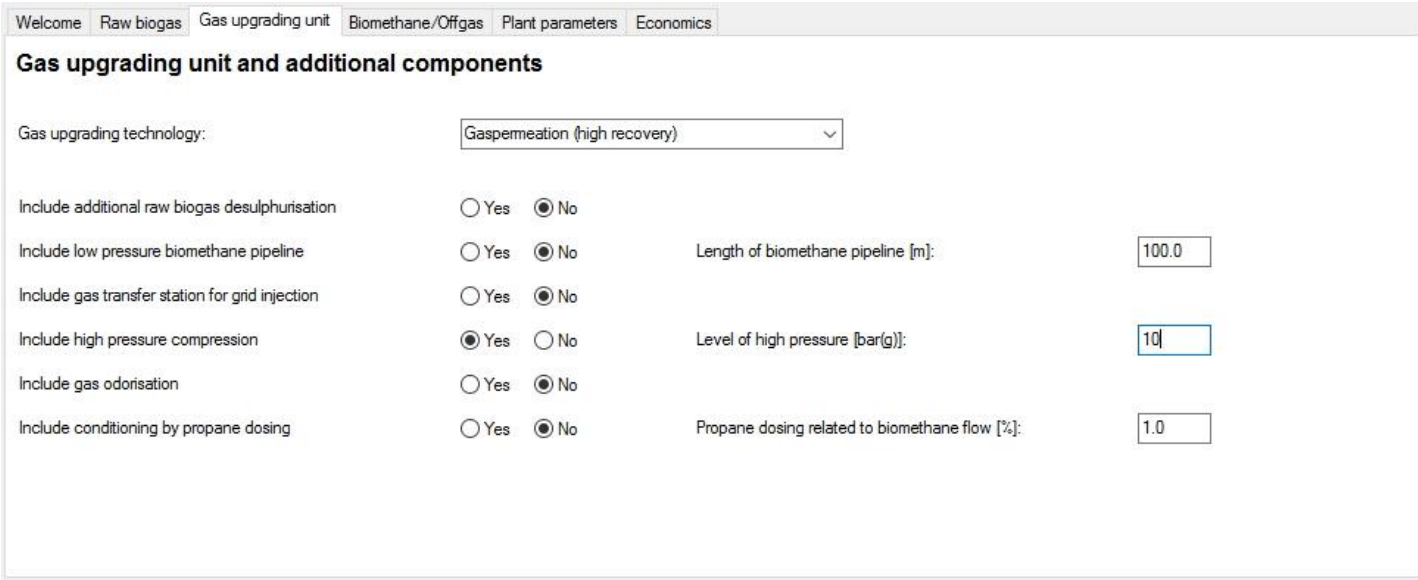
Commissioning Date	Feedstock	Name of the Plant	City	Installed Capacity (MWm)	Licensed Electricity Generation (kWh)	Last year's electricty generation (kWh)	FIT USD cent
n/a	Manure + Agricultural residues	Afyon-1 Biyogaz Santrali	Afyon	1,2	n/a	n/a	n/a
28.10.2015	Manure + Agricultural residues	Ovacık Biyogaz Enerji Santrali	Kırklareli	5,0	33.600.000	0	13,3
25.10.2014	Manure + Dairy waste	Karacabey 2 Biyogaz Tesisi	Bursa	4,4	22.407.000	1.881.482	13,3
n/a	Wastewater from maize	Cargill Bioenerji Tesisi	Bursa	0,1	n/a	n/a	n/a
24.10.2014	Manure + Agricultural residues	Polatlı BES	Ankara	1,6	10.297.000	441.920	13,3
28.08.2013	Manure + Dairy waste	Aksaray OSB Biyogaz Tesisi	Aksaray	6,6	22.407.000	11.925.499	13,3
24.10.2014	Manure + Slaughterhouse	Albe-I Biyogaz Santrali	Ankara	1,9	12.691.000	1.492.030	13,3
26.02.2014	Manure + Agricultural residues	Gönen Biyogaz Tesisi	Balıkesir	3,7	25.347.000	14.218.675	13,3
16.01.2015	Vegetable oil waste	Hayat Biyokütle Projesi	Kocaeli	1,0	6.685.000	0	13,3
12.06.2014	Manure + Slaugtherhouse	Edincik BES	Balıkesir	2,2	14.938.000	0	13,3
24.10.2014	Manure + Agricultural residues	Afyon Biyogaz Santrali	Afyon	4,1	28.070.000	0	13,3
16.02.2013	Food waste ind.	Karma 1 BES	Sakarya	1,5	10.490.000	3.321.640	13,3
31.10.2013	Manure + Dairy waste	Senkron Efeler Biyogaz Santrali	Aydın	2,5	20.000.000	9.715.485	13,3
29.10.2015	Manure + Agricultural residues	Karaman Biyogaz Tesisi	Karaman	1,5	9.898.000	0	13,3
17.08.2012	Manure + Dairy waste	Sezer Bio Enerji Biyogaz Tesisi	Antalya	0,6	3.500.000	1.917.090	13,3
30.10.2012	Manure + Agricultural residues	Ekim Grup Biyogaz Tesisi	Konya	1,2	9.936.000	0	13,3
31.10.2012	Manure + Agricultural residues	İzaydaş Biyogaz Enerji Ürt. Tes.	Kocaeli	0,3	2.640.000	139.035	13,3
Under construction / Partly Operation							
20.10.2014	Manure	Sigma Suluova Biyogaz Tesisi	Sakarya	1,0	14.000.000	218.270	13,3
25.05.2016	Manure	Akıncı Enerji Sandıklı Biyogaz	Afyon	1,4			
			Total	42			

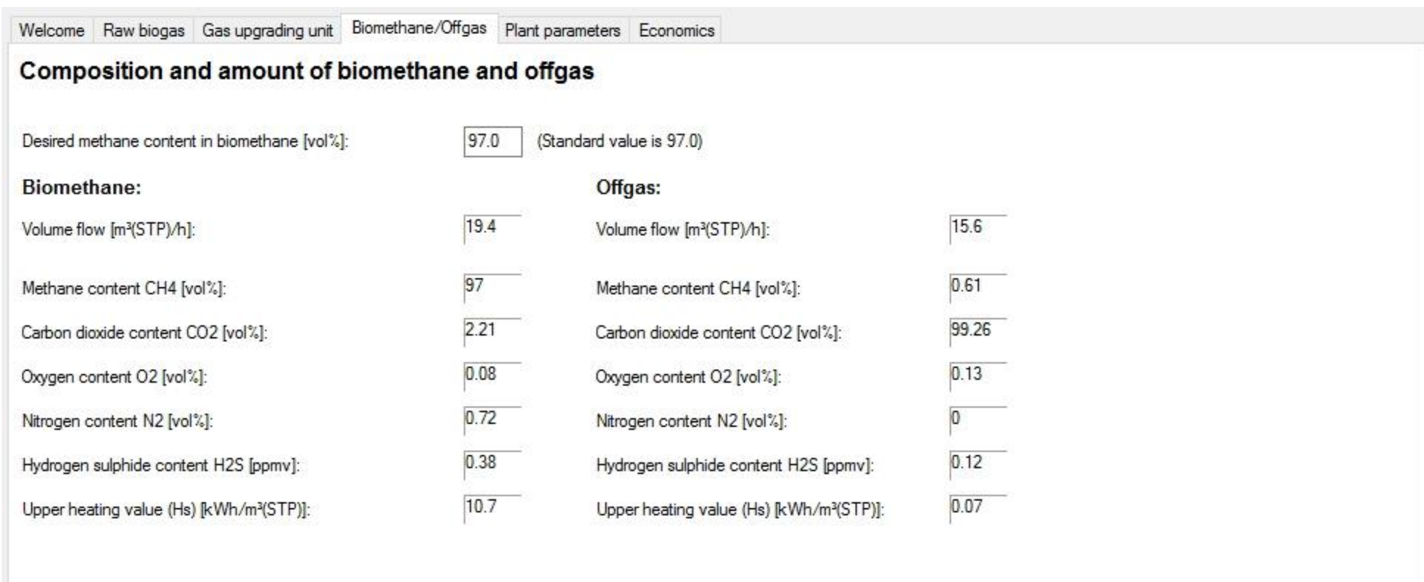
Appendix C: The Location of all the CNG Stations in Turkey. Source: derived from http://cngeurope.com/countries/377-2/ , (red sign indicates 1 station)

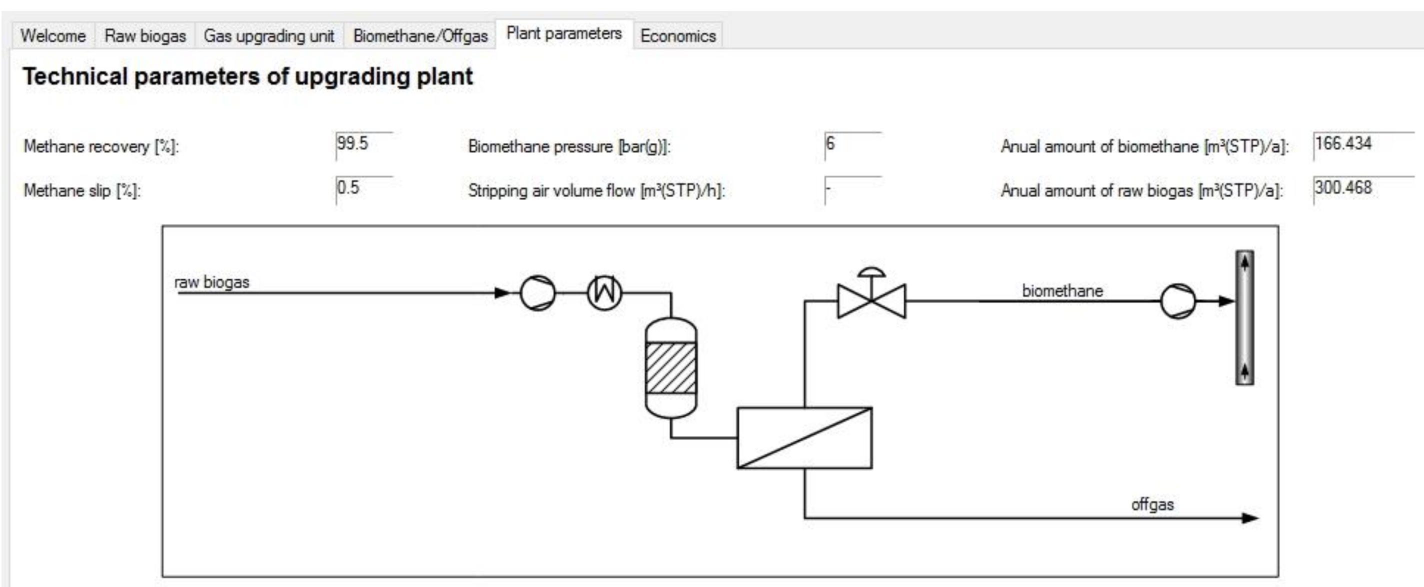


Appendix D: The Results of Biomethane-Calculator Software (following 5 snapshots). Source: own calculations




Welcome
Raw biogas
Gas upgrading unit
Biomethane/Offgas
Plant parameters
Economics
Gas upgrading unit and additional components
Gas upgrading technology:
Gaspermeation (high recovery)
Include additional raw biogas desulphurisation
Yes
No
Include low pressure biomethane pipeline
Yes
No
Length of biomethane pipeline [m]:
100.0
Include gas transfer station for grid injection
Yes
No
Include high pressure compression
Yes
No
Level of high pressure [bar(g)]:
10
Include gas odorisation
Yes
No
Include conditioning by propane dosing
Yes
No
Propane dosing related to biomethane flow [%]:
1.0


Welcome
Raw biogas
Gas upgrading unit
Biomethane/Offgas
Plant parameters
Economics
Composition and amount of biomethane and offgas
Desired methane content in biomethane [vol%]:
97.0
(Standard value is 97.0)
Biomethane:
Volume flow [m³(STP)/h]:
19.4
Methane content CH4 [vol%]:
97
Carbon dioxide content CO2 [vol%]:
2.21
Oxygen content O2 [vol%]:
0.08
Nitrogen content N2 [vol%]:
0.72
Hydrogen sulphide content H2S [ppmv]:
0.38
Upper heating value (Hs) [kWh/m³(STP)]:
10.7
Offgas:
Volume flow [m³(STP)/h]:
15.6
Methane content CH4 [vol%]:
0.61
Carbon dioxide content CO2 [vol%]:
99.26
Oxygen content O2 [vol%]:
0.13
Nitrogen content N2 [vol%]:
0
Hydrogen sulphide content H2S [ppmv]:
0.12
Upper heating value (Hs) [kWh/m³(STP)]:
0.07


Welcome
Raw biogas
Gas upgrading unit
Biomethane/Offgas
Plant parameters
Economics
Technical parameters of upgrading plant
Methane recovery [%]:
99.5
Methane slip [%]:
0.5
Biomethane pressure [bar(g)]:
6
Stripping air volume flow [m³(STP)/h]:
-
Anual amount of biomethane [m³(STP)/a]:
166.434
Anual amount of raw biogas [m³(STP)/a]:
300.468
raw biogas
biomethane
offgas

Welcome | Raw biogas | Gas upgrading unit | Biomethane/Offgas | Plant parameters | Economics

Investment and operational costs, specific production costs

Investment costs [€]:	368.626	Specific costs per m³ raw biogas [ct/m³(STP)]:	30.46
		Specific costs per m³ methane in raw biogas [ct/m³(STP)]:	56.42
Annual capital costs [€/a]:	37.955	Specific costs per kWh methane in raw biogas (Hs) [ct/kWh]:	5.12
Annual operational costs [€/a]:	53.582	Specific costs per kWh methane in raw biogas (Hi) [ct/kWh]:	5.68
Annual raw biogas costs [€/a]:	0		
Annual propane costs [€/a]:	0	Specific costs per m³ biomethane [ct/m³(STP)]:	55
Annual chemicals costs [€/a]:	0	Specific costs per m³ methane in biomethane [ct/m³]:	56.7
Annual overall costs [€/a]:	91.537	Specific costs per kWh methane in biomethane (Hs) [ct/kWh]:	5.14
		Specific costs per kWh methane in biomethane (Hi) [ct/kWh]:	5.71

(Hs ... Upper heating value Hi ... Lower heating value)

Appendix E: The Result of Excel Calculation Tool of the Key Study. Source: own calculations

SOURCE		Dry matter g/kg FM	organic matter (VS) g/kg DM	biogas yield LN/kg VS	methane yield LN/kg VS
European Feedstock Atlas	Cattle slurry	101	794	406	181
European Feedstock Atlas	Maize Silage	307	955	586	310

Feedstock

Number of Cattle	700
Manure (kg/animal/d)	50
Maize field ha	100
Maize field used for silage	20%
Silage Yield (t/ha)	50

	Cattle Slurry	Maize Silage
Theoretical Biomass (t/y)	12.775	1.000
Availability	70%	95%
Feedstock (t/y)	8.943	950
DM (t/y)	903	292
VS (t/y)	717	279
Biogas (m3)	291.157	163.216
Methane Content	55%	53%
Methane Amount (m3)	160.136	86.505

Total Feedstock	9.893	t/y
Total Produced Raw Biogas	454.373	m3/y
Total Methane	246.641	m3/y
Average Methane Content	54,282%	

Installed Capacities

Raw Biogas Production	454.373	nm3/y
Methane Content	54,28%	
Methane Loss in CHP	1,8%	
Energy value of methane	10	kWh
Share of Biogas used in CHP	34%	
Biogas sent to CHP unit	153.905	nm3/y
Biogas sent to Upgrading unit	300.468	nm3/y
Upgrading Capacity	35	nm3/h
Biomethane Production (CNG)	166.434	m3/y
FLH	8.300	h/year
Elec. Installed Capacity	33	kWe
Thermal Installed Capacity	48	kWth
Electrical Efficiency	35%	
Thermal Efficiency	50%	
CHP Efficiency	85%	

CO2 emission factor elec.	0,42	kgCO2/kWhel
CO2 emission factor veh.	2,63	kg/diesel l
Total CO2 Savings	304	t CO2/year

(Outputs) Electricity, Heat, Fuel & Fertilizer

Electricity Generation	272.057	kWh/y
Cons. factor of upgrading unit	0,28	kWh/Nm3
Consumed by upgrading unit	46.602	kWh
Consumed by fertilizer plant	32.975	kWh
Consumed by AD plant	80.319	kWh
Electricity used in the farms	112.161	kWh
Electricity imported to grid	-	kWh

Heat Generation	395.776	kWh/y
Heat used for digester heating	233.689	kWh
Heat used for fertilizer drying	162.087	kWh
Heat used in the farm	-	kWh
Displaced NG Boiler Eff.	75%	
Replaced Natural Gas	-	m3/y

Number of Vehicles	23	tractor
Power of the Tractors	75	HP
Yearly Tractor Working Hours	550	h/y
Litre diesel per hour	13,12	
Diesel cons. per vehicle	7.216	l/y
Total Replaced Diesel cons.	165.968	l/y

Digestate after AD	9.398	t/y
Liquid Part %85	7.988	m3
Solid Part %15	1.410	t/y
Separation loss (liquid)	30%	
Separation loss (solid)	50%	
Liquid Fertilizer to be sold	5.592	m3
Solid Fertilizer to be sold	705	t/y

Economics

Investment Horizon	20	year
WACC	10%	
CRF	0,1174596	

Spec. Invest. Costs of AD plant	8.000	€/m3/h biogas
Invest. Cost of Biogas Plant	414.952	€
Invest. Cost Upgrading	368.626	€
Spec. Invest. Cost CHP	1.000	€/kW
Investment Cost CHP	32.778	€
Spec. Cost for Eng. Conv.	2.609	€
Total Engine Conversion Cost	60.000	€
Filling Station incl. Storage	40.909	€
Fertilizer Plant Invest. Cost	84.755	€
Total Investment Cost (CAPEX)	1.002.020	€

Variable O&M Costs	4.016	
O&M Cost to Invest.	5%	
O&M Costs of Biogas Plant	22.387	€/year
O&M Costs BG Upgr. unit	53.582	€
O&M Cost of Fertilizer Plant	12.713	€/y
O&M Costs Escalation	1%	
Total O&M Costs	92.698	€

Electricity Price in Turkey	0,127	€/kWh
Elec. Price Escalation	3,0%	
Electricity Savings	14.244	€/y

Natural Gas Price	0,30	€/m3
NG Cost Escalation	1,0%	
Yearly Replaced NG Cost	-	

Diesel price	1,16	€/l
Diesel price Escalation	5,0%	
Total Diesel Fuel Cost Savings	193.063	€

Liquid Fertilizer Market Price	9,76	€/m3
Solid Fertilizer Market Price	60	€/t
Income from liquid fert.	54.575	€/y
Income from solid fert.	42.290	€/y
Total Fertilizer Sale Income	96.866	€/y

Year	Discounted CF	Nominal CF	O&M Costs	Total Investment Cost	Vehicle Fuel Savings	Fertilizer Cost Sale	Heating Cost Savings	Electricity Cost Savings	Discounted Costs
			1%		100%		1,0%	3,0%	
0	-€ 1.002.020	-€ 1.002.020		-€ 1.002.020					€ 1.002.020
1	€ 192.251	€ 211.476	-€ 92.698	€ -	€ 193.063	€ 96.866	€ -	€ 14.244	€ 84.271
2	€ 182.338	€ 220.629	-€ 93.625	€ -	€ 202.717	€ 96.866	€ -	€ 14.672	€ 77.376
3	€ 173.005	€ 230.269	-€ 94.561	€ -	€ 212.852	€ 96.866	€ -	€ 15.112	€ 71.045
4	€ 164.210	€ 240.420	-€ 95.507	€ -	€ 223.495	€ 96.866	€ -	€ 15.565	€ 65.232
5	€ 155.917	€ 251.106	-€ 96.462	€ -	€ 234.670	€ 96.866	€ -	€ 16.032	€ 59.895
6	€ 148.093	€ 262.356	-€ 97.426	€ -	€ 246.403	€ 96.866	€ -	€ 16.513	€ 54.995
7	€ 140.707	€ 274.197	-€ 98.400	€ -	€ 258.723	€ 96.866	€ -	€ 17.009	€ 50.495
8	€ 133.729	€ 286.660	-€ 99.384	€ -	€ 271.660	€ 96.866	€ -	€ 17.519	€ 46.364
9	€ 127.134	€ 299.775	-€ 100.378	€ -	€ 285.243	€ 96.866	€ -	€ 18.044	€ 42.570
10	€ 120.896	€ 313.574	-€ 101.382	€ -	€ 299.505	€ 96.866	€ -	€ 18.586	€ 39.087
11	€ 114.995	€ 328.093	-€ 102.396	€ -	€ 314.480	€ 96.866	€ -	€ 19.143	€ 35.889
12	€ 109.407	€ 343.368	-€ 103.420	€ -	€ 330.204	€ 96.866	€ -	€ 19.718	€ 32.953
13	€ 104.116	€ 359.435	-€ 104.454	€ -	€ 346.714	€ 96.866	€ -	€ 20.309	€ 30.257
14	€ 99.101	€ 376.335	-€ 105.499	€ -	€ 364.050	€ 96.866	€ -	€ 20.918	€ 27.781
15	€ 94.347	€ 394.111	-€ 106.554	€ -	€ 382.252	€ 96.866	€ -	€ 21.546	€ 25.508
16	€ 89.838	€ 412.804	-€ 107.619	€ -	€ 401.365	€ 96.866	€ -	€ 22.192	€ 23.421
17	€ 85.560	€ 432.462	-€ 108.695	€ -	€ 421.433	€ 96.866	€ -	€ 22.858	€ 21.505
18	€ 81.500	€ 453.132	-€ 109.782	€ -	€ 442.505	€ 96.866	€ -	€ 23.544	€ 19.745
19	€ 77.644	€ 474.866	-€ 110.880	€ -	€ 464.630	€ 96.866	€ -	€ 24.250	€ 18.130
20	€ 73.982	€ 497.716	-€ 111.989	€ -	€ 487.862	€ 96.866	€ -	€ 24.978	€ 16.646
NPV	**€ 1.466.750**							**NPV of Costs**	€ 1.845.185
Ann.	**€ 172.284**							**Annuity Of Costs**	€ 216.735
IRR	**14%**								
PBP	**6**	*years*							