UNIVERSITA' DEGLI STUDI DI PADOVA

FACOLTÀ DI AGRARIA

Dipartimento Territorio e Sistemi Agro-Forestali

TESI DI LAUREA MAGISTRALE IN SCIENZE E TECNOLOGIE AGRARIE

ECONOMIC FEASIBILITY AND ENVIRONMENTAL BENEFITS OF FARM-SCALE BIOGAS PLANTS

Relatori:

Prof. Davide Matteo Pettenella

Dr. Stefano Guercini

Correlatori:

Dr. Mattia Cai

Dr. Tuomo Pesola

Laureanda: Martina Boschiero

Matricola n. 586297

Anno Accademico 2009–2010

“In una società in cui «si conosce il prezzo di ogni cosa e il valore di nessuna»”

“In a society where «the price of everything is well-known but not the value»”

Enzo Bianchi

Index

Acknowledgements ... 3

Summary ... 4

Riassunto ... 5

Introduction ... 6

Chapter 1: Anaerobic digestion and biogas ... 8

1.1 A renewable energy ... 9

1.2 Short history ... 13

1.3 Biogas and anaerobic digestion process description ... 15

1.3.1 Microbiological process ... 15

1.3.2 Operational and biological process parameters ... 18

1.3.3 Biomasses for use in anaerobic digestion ... 24

1.3.4 System description and components ... 31

1.4 Final utilization of biogas ... 40

1.4.1 Heat generation ... 40

1.4.2 Electrical generation and CHP ... 41

1.4.3 Vehicle fuel generation ... 42

1.4.4 Injection into the grid ... 43

1.5 Final utilization of the digestate ... 43

1.6 State of the art of biogas ... 46

1.6.1 In Europe ... 46

1.6.2 In Italy ... 52

1.7 Overview of European and Italian legislation concerning biogas production ... 55

Chapter 2: Costs and benefits of farm-scale biogas plant 60
2.1 Costs and benefits to the farmer 64
2.1.1 Costs to the farmer 64
2.1.2 Benefits to the farmer 72
2.2 External costs and benefits 84
2.2.1 Odour reduction 86
2.2.2 GHG emission reduction, contribution to global change mitigation and improvement of air quality 89
2.2.3 Other externalities 93
Chapter 3: The model and its application 99
3.1 Input biomasses worksheet 103
3.2 Energy production worksheet 107
3.3 Transport worksheet 109
3.4 CO_2eq. avoided emission worksheet 111
3.5 Costs worksheet 113
3.6 Benefits and externalities worksheet 117
3.7 Financial analysis and economic analysis worksheets 121
3.8 Results worksheet 126
Chapter 4: Results and discussion 128
4.1 Results concerning the financial and economic analysis 128
4.2 Evaluation and appraisal of the externalities 133
4.3 Sensitivity analysis of the incentive for electricity production 138
Chapter 5: Conclusions 142
References 145
Websites looked up 162

Acknowledgements

I would like to thank my supervisors and co-supervisors for their guidance and support throughout this research.

Special thanks go to Tuomo Pesola, Principal Lecturer of Oulu University of Applied Science: School of Renewable Natural Resources (Finland), who have been so helpful and supportive. He has always made himself available to answer any questions and provide valuable feedback. He also went out of his research field to help me in collecting useful information and to permit me to visit in person some biogas plants in Finland. His encouragement and advice during my staying in Oulu have been invaluable.
Juha-Pekka Snäkin, Senior Researcher of Turku University, deserves special thanks as well for involving me with his model, which has been a fundamental support for the development of the model used in this dissertation.

I also would like to thank all the people that have been close to me and supported me, thing not always easy to do.

Summary

The agricultural biomasses constitute a prominent part of the renewable energy that have a key role in the energy policy of European Union. In the last years the electricity production from biogas generated by anaerobic digestion of biomasses has been considerably supported at national level. In this study a financial analysis of farm-scale anaerobic digestion plants has been carried out to evaluate the profitability of the projects from a private point of view, and an economic analysis have been carried out to underline the projects' social and environmental benefits that affect the community on the whole. The results of the financial analysis show the determinant and necessary role of the incentive to guarantee the financial profitability of the projects. Whereas the economic analysis highlights a lack of data in the literature about the appraisal and monetization of the potential externalities generated by the farm-scale biogas chain; moreover it proves that the feed in tariff applied is overestimated respect the tariff that make the projects economically feasible.

The anaerobic digestion plants fed only with animal manure and sewage present higher externalities than the once fed exclusively with energy crops.

However the adopted feed in tariff support both the plant typologies without distinction, but for the plants that use only energy the financing is not justified because the non-equivalents social and environmental benefits.

Riassunto

Tra le fonti energetiche rinnovabili che rivestono un ruolo chiave nelle politiche energetiche dell'Unione Europea rientrano le biomasse di origine agricola. Negli ultimi anni, a livello nazionale, è stata incentivata considerevolmente la produzione di energia elettrica da biogas derivante dalla digestione anaerobica delle biomasse. Il presente lavoro effettua un'analisi finanziaria dell'installazione di impianti di digestione anaerobica a livello di azienda agricola con una valutazione della profittabilità del progetto da un punto di vista privato e un'analisi economica in cui invece vengono valutate le componenti dei benefici sociali ed ambientali dei progetti che ricadono sull'intera società. I risultati dell'analisi finanziaria dimostrano come l'incentivo sia determinante e necessario per rendere gli impianti finanziariamente convenienti. L'analisi economica invece evidenzia la carenza di dati presenti in letteratura circa la valutazione e la monetizzazione delle potenziali esternalità generate dalla filiera aziendale del biogas e, inoltre, dimostra come l'incentivo sia ampiamente sovrastimato se confrontato con la tariffa limite che rende i progetti economicamente attuabili.

E' emerso inoltre che gli impianti che utilizzano soltanto reflui zootecnici presentano esternalità maggiori rispetto a quegli impianti che utilizzano esclusivamente colture energetiche. Tuttavia la tariffa onnicomprensiva promuove indistintamente entrambe le tipologie di impianti, non giustificando però il ritorno sociale ed ambientale di tale finanziamento nel caso di impianti alimentati esclusivamente a energy crops.

Introduction

The current environmental issues concerning the increase of greenhouse gasses emissions with the consequent climate change, and the current energetic questions related to the utilization of fossil fuels, which are running out and their supply depends on the extra-European countries even more limiting the energy self-sufficiency of the European Community, prompting governments and international authorities to adopt specific policies to favour the use of renewable energies.
The Kyoto Protocol, the UE Renewable Directive 2001/77/CE, the European Biomass Action Plan and the recent National Action Plant for Renewable Energies, are example of political goals fostering the development of energy conversion technologies based on renewable energy sources.
The agricultural sector could play a fundamental role to cope with those issues making available several biomasses utilizable as renewable energy sources, especially those that are considered rejects of the zootechnical or agricultural process, such as animal effluents and crop residues.
The farm-scale anaerobic digestion plants that generate biogas fuel from livestock and crops biomasses could help in mitigating the GHG emission reducing the livestock methane emissions (FAO, 2010) and it represents a viable alternative to the traditional manure management systems, which are considered source of pollution for air, soil and water resources.
The Italian government is supporting the production of electricity from biogas fuels in accordance with the communitarian policy, guaranteeing to the farmer higher business income. Anyway farm-scale biogas plants produce also social and environmental benefits that should be taken into account when national supporting schemes are developed.
In order to apprise the external benefits that affects the whole society and internalize them in the support scheme, it is necessary to carry out an economic analysis that differs from the traditional financial analysis, going beyond the private benefits.

The scope of this dissertation was to carry out an economic analysis of the anaerobic digestion technology at farm level. A bibliographic research has been carried out to outline the component parts of the private benefits to the farmers and of the external benefits which interest the whole society. Then a model was developed with the support of Microsoft Excel program to obtain the data necessary to bring to completion the financial analysis and the economic analysis that have been carried out with the costs-benefits analysis approach. Finally, the results have been compared with the national supporting scheme of the feed in tariff, the "*tariffa onnicomprensiva*".

This work is divided in five different chapter relating to the subjects analyzed.

Chapter 1 represent an introductory section about anaerobic digestion technology and biogas fuel. The technology is briefly contextualized in the renewable energy sector, the processes and the final utilization of the biogas and the digestate are described. Moreover an overview of the state of the art and of European and Italian legislation concerning biogas production is given.

In Chapter 2 the micro-economic effects at farm level and the environmental and social implications related to the installation of an anaerobic digestion farm-scale plant are discussed. A detailed description of the costs and benefits of farm-scale biogas plants is carried out and models and economic analyses present in literature are described. The chapter is subdivided in two different section to distinguish the costs and benefits in accordance to the different level of beneficiaries involved: the individual farmer (private level) and the whole community (social level). The attention is focused especially on the latter, since it is the fundamental components for determining the economic feasibility of a project.

Chapter 3 consists of a detailed description of the component parts of the research Microsoft Excel tool developed to set the financial and economic analysis.

Results are reported and discussed in Chapter 4 where, in addition, other potential externalities are calculated and internalized, and a sensitivity analysis is carried out to examine the effects of changing the value of the incentive on the financial profitability and to verify the correctness of the electricity incentive tariff.

The last chapter relates the conclusion about the whole study.

The information reported hereafter have been elaborated on the basis of data published in specialized scientific journals and reviews, congress proceedings, results derived from international and national research programs, and information available at communitarian, national and regional institutional and research websites.

Chapter 1: Anaerobic digestion and biogas

Anaerobic digestion is a biological process carried out by anaerobic microorganisms in oxygen absence condition. The final products of their metabolism are a mixture of gas (biogas), composed mainly by methane (CH_4) and carbon dioxide (CO_2), and a reject part (the "*digestate*"), more or less moist depending on the initial substrate and on the technology used (Albuzio and Paparelli, 2008).

As methane has high energy value, anaerobic digestion can be exploited to produce methane fuel.

Potentially all organic matters can be transformed in biogas. In Europe dominant share of biogas production is accounted for by the collection of biogas in landfills (EurObserv'ER, 2008), but in recent times interest has increased in agricultural sources of biomass, like manures, energy crops and crops residues. Also the use of slurry, organic municipal solid waste and agro-industrial waste is becoming more widespread.

Beside the production of energy, anaerobic digestion is a very promising solution for the treatment of agricultural waste (Karellas et al., 2010), reducing unpleasant odours, controlling greenhouse gas emissions, preventing water and soil pollution, improving agriculture multifunctionality and, very often, increasing farm income, especially if governments adopt specific support policies (Yridoe et al., 2009).

Farm scale biogas plants usually work in the following schematic way: manures (and other agricultural residues) are collected and sent to the digester tank. Here, in the absence of oxygen and carefully controlled conditions, anaerobic microorganisms start the transformation and the decomposition of substrates and anaerobic digestion takes place. The resulting biogas is collected, stored and it can be transformed in heat energy, or power electric energy or can be used directly as a gaseous fuel. The digestate, the solid reject part coming out from the digester, can be stored and used as a fertilizer or a soil conditioner.

Anyway, several different solutions are applicable in anaerobic digestion technology: each plants differ to the other depending on the farm needs, the location, the scattering of the primary sources (Karellas et al., 2010), the governmental economic supporting tools, the farm's financial possibilities and the final aim of the farmer.

Because of the variety of possibilities, farmers and the actors of the agro-energy sector need supporting decision model, that help them to identify the operation that are more economically profitable and environmentally appropriate.

This chapter provides a general overview of the anaerobic digestion process and of the available technology.

1.1 A renewable energy

Renewable energies are energy sources derived from natural processes that are replenished constantly. The Unified Bioenergy Terminology paper terms the *renewable energy* as "…energy produced and/or derived from sources infinitely renovated (hydro, solar, wind) or generated by combustible renewable (sustainably produced biomass)…" (FAO, 2004).
Thus renewable energies can derive directly or indirectly from the sun, from heat generated deep within the earth or they are generated from solar, wind, geothermal, biomass, hydropower and ocean resources, biomass, biogas and liquid biofuels (Eurostat, 2009b).
In 2005, renewable energy accounted for 6,7 % of total primary energy consumption in the EU‑27, compared to a share of 4,4 % in 1990. Over the period, the share of renewable energy in final consumption has also increased from 6,3 % in 1991 to 8,6 % in 2005 (EEA, 2008). The share of renewables in primary energy consumption is expected to increase, to a value between 10 % in 2020 and 18 % in 2030. In scenarios where more stringent policies to reduce GHG emissions, and promotion of RES and energy efficiency are assumed, higher shares of renewables in primary energy consumption are envisaged ranging from 13 % in 2020 to over 24 % in 2030 (EEA, 2008).
Achieving the proposed new target for renewable energy will require a substantial effort, to fill the gap between the current levels (8,5 % in the final energy consumption in 2005) and the objective of 20 % of renewable energy in the final energy consumption in 2020. To meet the proposed targets, 15 Member States will have to increase their national share of renewables in the final energy consumption by more than 10 percentage points compared to 2005 levels. Substantially reducing final demand for energy will help Europe achieve the target for renewable (EEA, 2008).

Biomass and wastes are the main renewable sources of energy production in the EU. In 2006 they reached the 68% of the primary energy production derived from renewable energy

(Figure 1) (Eurostat, 2009b). Hydro ranked second with a share of 21%, while wind, geothermal and solar accounted for less significant proportions: 6%, 4% and 1% respectively.

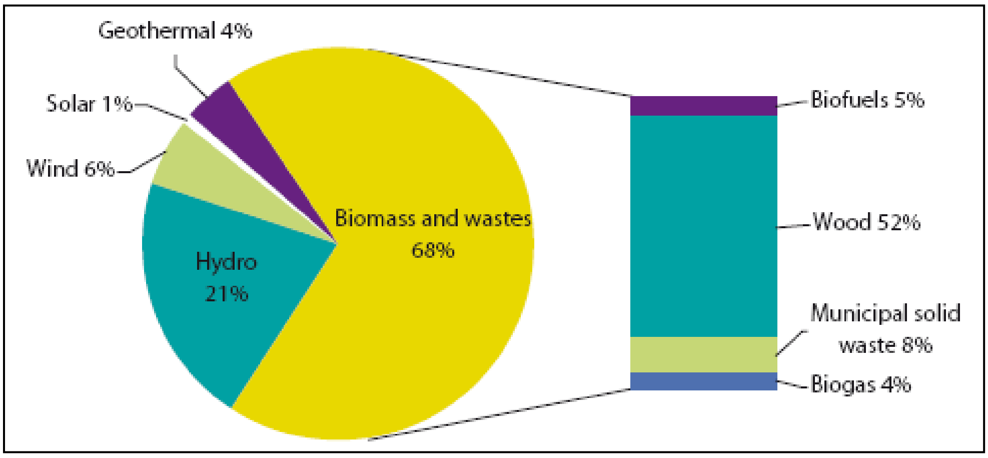


Figure 1: EU-26 primary energy production from renewable energy sources- breakdown by individual sources in 2006 (Eurostat, 2009b).

The term biomass identifies with the "material of biological origin excluding material embedded in geological formations and transformed to fossil" (FAO, 2004). Biomass may be considered as a form of transformed solar-energy, as all the biomass is linked in some way to the sun and to photosynthetic process. From this point of view bioenergy is a renewable energy sources (Figure 2) (FAO, 2004).

Within biomass category, wood and wood wastes accounted for three quarters, i.e. its share represents 52% of the total energy production from renewable; municipal solid wastes[1] represented the 8% while biofuels and biogas accounted for 5% and 4% respectively, in 2006 (Eurostat, 2009b).

[1] It should be mentioned that, in this Eurostat statistic publication (2009b), municipal wastes also includes the non-biological fraction as many Member States are unable to split municipal wastes into biological and non-biological content; but the latter is supposed to be excluded from renewables.

Biogas is the result of microbial anaerobic degradation of carbon-containing compounds. It is formed mainly by methane, and for this reason it has been consider as a potential energy source.
All the organic matters can be transformed in biogas; in recent times most part of the studies and plants are turned to agricultural sources, like manures, energy crops and crops residues. Also slurry, organic municipal solid waste and agro-industrial waste are used more and more.
By definition, biogas production and utilization, as the other renewable, can offer a series of benefit that tackles and gets near the European Union's problems and objectives regarding to climate change, the increasing extra-EU dependence on oil and soil fuels, the soaring energy costs and the strengthening of agriculture sector (Eurostat, 2009b).
Furthermore, the EU can be considered a leader in renewable energy applications, boosting high-tech industries, offering new economic opportunities and constituting a non-negligible source of industrial development and employment (Eurostat, 2009b).

In any case, it is important to underline, that the renewability of these forms of energy should be always linked with the sustainability of their production and exploitation. In order to respect completely the meaning of renewable energy, rational, environmental respectful, future looking and appropriate solutions for each specific case reality should be applied, overcoming the mere profit point of view.

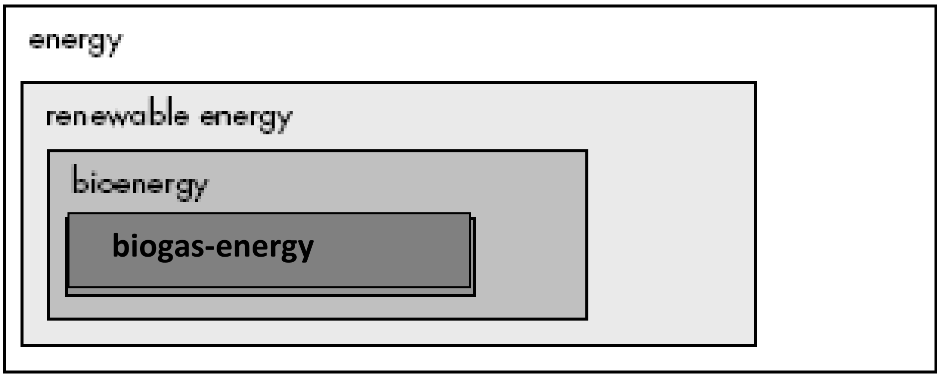


Figure 2: Bioenergy in the energy statistic field (modified from FAO, 2004).

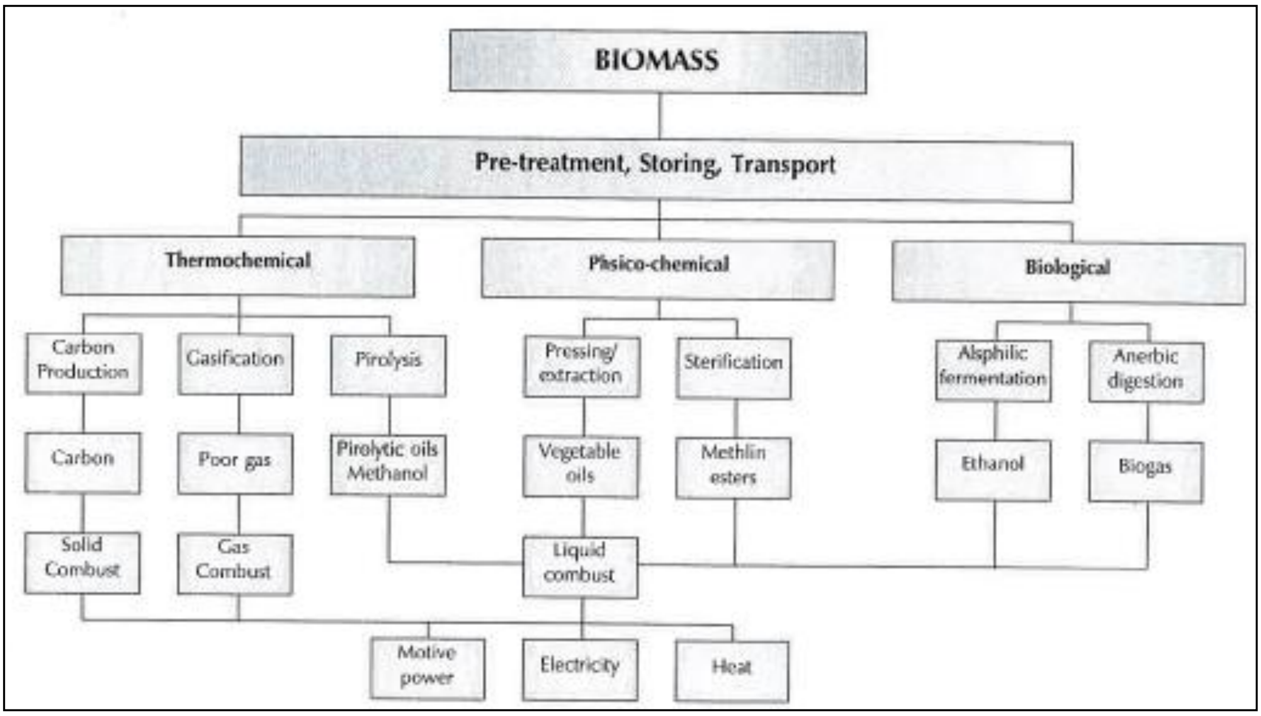


Figure 3: Simplified and schematic main ways of energetic exploitation of biomass (Grover et al., 2002).

1.2 Short history

Historical evidence indicates that biogas was used for heating bath water in Persia during the 16th century B.C. and in Assyria during the 10th century B.C. (Lusk, 1998).

Moreover methane gas produced when stagnant water is combined with decaying organic matter, was already known to the alchemists of the Middle Ages as “swamp gas” (Klaus, 2009).

The systematic study of AD begun around the same time as modern scientific research and involved many prominent scientists. As early as 1764 Benjamin Franklin described the possibility to light a large surface of a shallow muddy lake in New Jersey. The results of this experiments were reported in a letter to Joseph Priestly in England, who some years later published his own experience with the inflammable air (Titjen, 1975).

The first scientist to describe the formation of inflammable gasses at low temperature in marshes and lake sediments, was Alessandro Volta, who published in Italy the letter “*Aria inflammabile native delle Paludi*” in 1776. In 1804, John Dalton gave the correct chemical formula for methane (Wellinger, 1999).

Methane was first produced in the laboratory by French scientist Marcellin Berthelot in 1856, and methane-producing bacteria were discovered by Dutch biologist Nicolaas Louis Söhngen in 1906 (Klaus, 2009).

The earliest publication on the influence of temperature on methane formation was written by Popoff (1859), who found that river sediments could form biogas at temperature as low as 6 °C and that increasing the temperature up to 50°C could stimulate gas production while leaving gas composition unchanged (Wellinger, 1999).

The first digestion plant was built in a leper colony in Bombay (India) in 1859. In the same period Gayon, a student of Louis Pasteur, experimented with the production of biogas from animal manure and concluded that anaerobic manure fermentation might supply gas for heating and illumination under special circumstances (Titjen, 1975).

In 1895 biogas recovered from a slurry treatment in England was used to fuel street lamps.

Based on the findings that higher temperatures stimulates the biogas formation, heating systems were developed to increase the digester temperature. In particular, Imhoff and Blunk patented between 1914 and 1921 a series of procedures.

One of the most significant scientific developments in agricultural biogas goes back to the thirties, when Buswell made his basic experiments on manure digestion in combination with others possible types of organic waste (Buswell and Hatfield, 1936), launching the co-digestion.

The first full-scale agricultural biogas installation was developed in 1938 by Isman and Ducellier, in Algeria. Albeit small (10 m^3 approximately), the plant was running with solid waste (van Brakel, 1980). Unfortunately, the outbreak of the Second World War interrupted the further developments and studies on the solid waste system.

In Europe, towards the end of the Second World War, the fuels supply limitation urged all those involved in the energy sector to develop other technologies, and AD of liquid manure and slurry regained some popularity. In fact, in France more than 40 small-scale plants, mostly batch digesters, were operated; the number increased to 800 in the fifties (van Brakel, 1980). In Germany some 48 facilities of rather large size and high technical standard operating mainly on slurry were established (Titjen, 1975). It is interesting to point out that already at that time, half of the gas was utilized to run vehicles.

In Italy, during and after the war years, amateur and artisan biogas plants were built (ENEA, 1983), especially for domestic and cooking needs.

As the census taken by ENEA underlines, in Italy the AD, both farm-scale and large-scale (or industrial-scale), received little attention until the energy crisis of the 1970's, that revived the interest in these technologies. In 1983, indeed, there were already 56 biogas plants operating on animal waste, at various locations in northern and central Italy.

In the United States of America, during and immediately after the energy crisis caused by the oil embargo in 1973, many anaerobic systems were built to produce energy. Al least 71 were installed on commercial livestock or poultry operations, but as energy prices declined after the crisis, many of those systems were abandoned (Lusk, 1998).

While energetic crisis of the Seventies increased interest in alternative energy resources, across the World, the lack of understanding and overconfidence in those technologies resulted in numerous failures. Poor system design, improper system installation, unsatisfactory system management could be the causes of the limited long-term success in the United States (Lusk, 1998).

Nowadays biogas production has become a successful technology to produce energy from agriculture and livestock source and to treat biowaste or slurry from household and industrial plants.

The developments of the last 20 years, due to the increased interest in energy self sufficiency, the more sensitive attention to environmental and pollution problems, the technological

progress and the contribution of a promoting and incentive policy for renewable energies, allow more reasonable biogas production costs, its upgrading and efficient utilization to produce electricity, heat, vehicles fuel and soil amendments.
For example the European Union adopted several legislative instruments to promote the utilization and the development of AD and all the other renewable energy technologies, allocating funds, incentives and refunds. Research programs were supported to optimize, improving and understand deeply AD process and its economical and environmental implications.
Generally the investment costs decreased, as the dissemination of AD plants in EU increased considerably and improvements of the process efficiency occurred (Kaisto, 2010).
Moreover, the success of biogas production come from the availability of low costs substrates, as several agro-industrial rejects, manure, slurry, and organic urban waste (Weiland, 2010).
The present resurgence of interest in anaerobic digestion is due also to its potential to solve some actual problems: greenhouse gasses reduction, manure stabilization, sludge reduction, odour control and energy production (Cantrell, 2008).
It is considered to be a technically proven and commercially attractive way to produce renewable energy (DGS and Ecofys, 2005).

1.3 Biogas and anaerobic digestion process description

1.3.1 Microbiological process

Anaerobic digestion (AD) is a biological process, occurring in asphyctic conditions, where some anaerobic microorganisms in the process of carrying out their biosynthesis, transform organic substances in energy and secondary metabolites (Albuzio and Paparelli, 2008), including a gas mixture, called “biogas”.
It is a process found in many naturally occurring anoxic environments including watercourses, sediments, waterlogged soils and the mammalian gut (Ward et al., 2008).

Biogas generation can be described in the following schematic way:
organic matter + H_2O + nutrients → new cells + residue matter + CO_2 + CH_4 + NH_3 + H_2S (Albuzio and Paparelli, 2008).

Biogas is composed primarily by methane (50-80% of the volume) and carbon dioxide (50-20% of the volume), then volatile aromatic molecules, ammonia and trace compounds, such as hydrogen, oxygen and hydrogen sulphide (DGS and Ecofys, 2005) (Table 1). The latter is highly corrosive and can cause damage to engines, boilers and other mechanical and structural components. It is recommended to separate it early in the biogas upgrading process (Persson et al., 2006).
Usually biogas is saturated by water vapour and could contain fine dusts and silicate organic compounds (e.g. siloxanes) that, during the last phases of the process and during the utilizing of the gas, could cause some serious problems (Albuzio e Paparelli, 2008).

Only the methane content of biogas has energy value, and for this reason biogas can be exploited for energetic purposes.
From 1 m^3 of methane it is possible to obtain 1,8-2 KWh approximately of electricity and 2-3 KWh approximately of heat, that could be used for different purposes (Piccinini, 2007).

Component	**Volume percentage**
Methane (CH_4)	50-80%
Carbon dioxide (CO_2)	50-20%
Nitrogen (N_2)	<1%
Hydrogen (H_2)	<1%
Ammonia (NH_3)	<1%
Hydrogen sulphide (H_2S)	<1%

Table 1: Biogas composition (DGS and Ecofys, 2005).

The overall process of AD involves the synergic action of a complex community of bacteria, that decompose complex organic waste in biogas, chiefly methane and carbon dioxide (Cantrell et al., 2008).

The AD process occurs in three main stages: hydrolysis, fermentation and methanogenesis (Cantrell et al., 2008). Some authors call the fermentation stage “acidification” (Albuzio and Paparelli, 2008), and others further divide it in two different phases: acidogenesis and acetogenenis (DGS and Ecofys, 2005).

Different categories of microorganisms succeed each others, in the different corresponding process phases (Figure 4).

Hydrolytic microorganisms, including common food spoilage bacteria, start the hydrolysis phase, breaking down complex organic molecules into simple ones: sugars, fatty acids and amino acids. These subunits are then transformed into carbon acid alcohols, ammonia, carbon dioxide, and hydrogen gases by the acidogenic bacteria, during the acidogenesis phase (Cantrell et al., 2008).

Acetogenesis is the following phase, where acetogenic bacteria convert the complex mixture of short-chain fatty acids to acetic acid with the release of more carbon dioxide, and hydrogen gases. Methanogenic bacteria (like *Methanobacterium*, *Methanococcus*, *Methanospirillum*, *Methanosarcina)* are active in the final phase (methanogenesis), which produces mainly methane and carbon dioxide (Albuzio and Paparelli, 2008).

Usually methanogenic bacteria carry out their metabolic activity satisfactorily at temperatures in the range from 35C° to 55 C° (Gerardi, 2003).

Indeed, very often, to ensure the highest biogas production and maintain constant and high enough the temperature, heated plants are resorted to.

The methanogenic microorganisms are also sensitive to pH change: when the pH falls below 6,3 pH the methanogenic population could be destroyed (Chen et al., 2002).

For an anaerobic digestion to be effective in biogas production, a balance among the cidogens/acetogens and methanogens is crucial (Cantrell et al., 2008), as the metabolism of the first influenced enormously the development of the latter.

Therefore, to achieve efficient biogas production, the development and metabolism of all the bacteria strains involved have to be studied and monitored carefully, measuring constantly temperature, pH, volatile fatty acid concentration, and giving the microorganisms adequate feeds reflecting their needs.

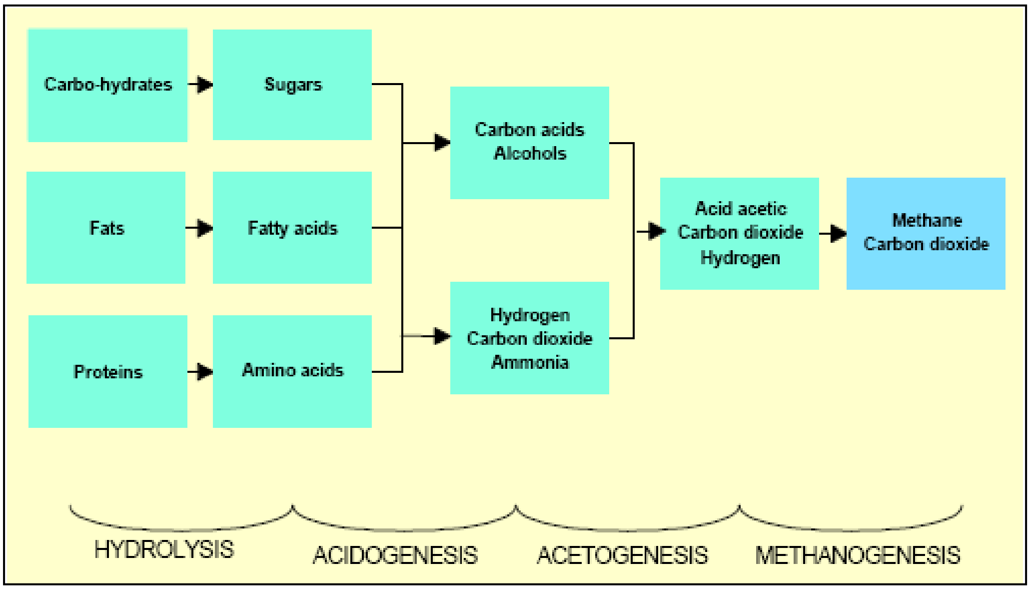


Figure 4: Schematic diagram showing the main theoretical stages of the anaerobic digestion process (Al Seadi, undated).

1.3.2 Operational and biological process parameters

The rate of methane biogas production is sensitive to changes in influent materials and relating metabolic substrates, temperature, pH, organic loading rate and hydraulic retention time. Therefore these variables must be controlled in order to maximize methanogenic biogas production (Cantrell et al., 2008).

The main parameter for managing the anaerobic digestion process can be divided in two groups: the operational parameters of the reactor and the stability parameters of the biological process (Cecchi et al., 2003).

The operational parameters of the anaerobic reactor are the following:

- A digester's *hydraulic retention time* (HRT) value is the average time the liquid is held in the digestion process and is calculated as the ratio of the digester volume to the effluent's volumetric flow rate (Cantrell et al., 2008).

Therefore it is the time that a fluid element spends in the reactor. This is strictly true for ideal reactors (Cecchi et al., 2003).

It is defined by the following equation (Wellinger, 1999):

$$HRT = \frac{V}{Q},$$

where HRT = hydraulic retention time (day);

V= reactor volume (m^3);

Q= flow rate (m^3/day).

If manure or other substances pass through a digester too quickly, then the microorganisms do not proliferate fast enough; leading to digestion failure (Cantrell et al., 2008).

The minimal HRT depends on the type of material to be digested and also the digester's temperature (Wellinger, 1999), influencing also the production costs. At the planning stage the retention time should also be calculate so as to avoid the bacterial losses and permit an efficient biogas conversion (Albuzio and Paparelli, 2008).

HRT is inversely proportional to the temperature: usually low HRT value are related with high process temperatures. The lower the degradation rate, the slower the doubling time of the bacteria, the higher is the HRT (Wellinger, 1999).

Average minimum HRT, in mesophilic digestion condition, is about 10-15 days for swine sludge, between 12 to 18 days for cattle manure and 18-36 days for cattle manure with straw bedding (Wellinger, 1999).

In general, HRT could range between a maximum value of 100 days in a pshycrophil condition, to 15 days or less in thermophilic plants (DGS and Ecofys, 2005), always depending by the substrate that is degraded (Figure 5).

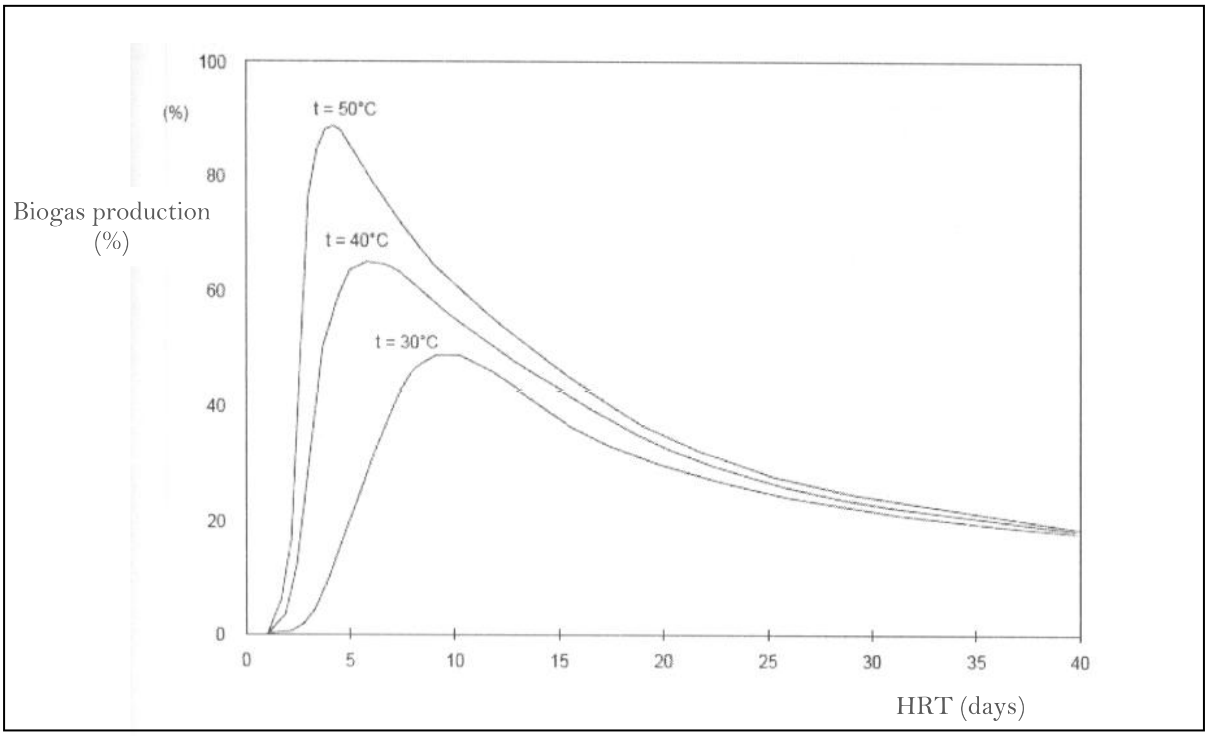


Figure 5: Percentage of biogas production related to HRT and temperature (30°C, 40°C and 50°C) of the process (Albuzio and Paparelli, 2008)

- The *solid retention time* represents the average residence time of solids in the reactor and it is the ratio between the content of total solids in the reactor and the solid flow rate extracted from it. If the quantity of biomass extracted from the reactor is equal to the biomass produced in it, the solid concentration in the reactor (as biomass) will be constant in a given time and it can be said that the reactor is operating in a steady-state condition (Cecchi et al., 2003).

Analytically:

$$SRT = \frac{V * X}{W},$$

Where: SRT= solid retention time (day);

V= reactor volume (m^3);

X= volatile solids concentration in the reactor (Kg TVS/m^3); and

W= flow rate of the extracted matter from the reactor.

- The *organic loading rate* (OLR) is defined as the amount of substrate (expressed as volatile solids (VS) or total volatile solids (TVS) or chemical oxygen demand (COD) or biological oxygen demand (BOD) components) fed per day per unit digester volume, as explained in the following formula:

$$OLR = \frac{Q * S}{V},$$

Where: ORL = organic loading rate (Kg substrate / m^3 reactor day);
Q= substrate flow rate (m^3/day);
S= substrate concentration in the inflow (Kg/m^3) and
V= reactor volume (m^3) (Cecchi et al., 2003).

Higher loading rates can reduce the digester's size and consequently the capital costs (Cantrell et al., 2008). However enough time should be permitted for the microflora to break down the organic material and convert it to gas.
The OLR should be between the extremes of 0,5 kg and 5 kg of organic matter per m^3 per day (kgOM/m^3/day/). A healthy situation would be between 1 and 3 kgOM/m^3/day. In order to avoid too high organic load at the feed-in point of the digester, feeding fresh substrate into the digester should be done at least daily (DGS and Ecofys, 2005).

Another property of fermentation is the *volume load* (VL) that denotes the quantity of substrates supplied daily per unit of volume of the digester (Bauer et al., 2009).

- The *specific gas production* (SGP) is also a crucial parameters as it measures the amount of biogas produced by a unit of mass of substrate, in terms of total volatile solids (TVS), as m^3 of biogas per Kg of substrate feed (Albuzio and Paparelli, 2008). This parameter is strictly linked with the biodegradability of the substrate and to the process typology. The SGP value is often used to compare the performance of different anaerobic process (Cecchi et al., 2003). Obviously the SGP depends primarily on the type and composition of the feedstock, as well as on the processing conditions in the digester (Bauer et al., 2009).

$$SGP = \frac{Q_{biogas}}{Q * S},$$

where: Q_{biogas}= biogas flow rate (m^3/day);
Q=inlet flow rate (m^3/day) and
S= substrate concentration in the influent (Kg substrate/m^3).

Obviously SGP is higher when low digested materials are inserted in the anaerobic digester (Albuzio e Paparelli, 2008). Hence, when only manure and sludge are fed to the plant, the resulting biogas production is limited. In this case, it is possible to add some biomass crops, or crop residues or extra-agricultural products to increase biogas production.

- *Gas production rate*, the rate of gas produced to reactor volume, is another parameters to be taken into account. It is given by the formula:

$$GPR = \frac{Q_{biogas}}{V},$$

where: Q_{biogas}= biogas flow rate (m^3/day), and
V= digester volume (m^3).

- The efficiency of anaerobic digestion can be affected also by the *particle size* and the *subdivision of feedstock* and the *degree of mixing* that takes place in the reactor (Albuzio e Paparelli, 2008; Ward et al, 2008).

Some parameters are of particular importance in affecting the biological processes occurring during anaerobic digestion:

- *Temperature*: the reaction environment has to represent a compromise between the microorganism groups' needs and the plant's characteristics, in order to allow a balanced growth of microbial populations (Albuzio and Paparelli, 2008). Anaerobic digesters operate basically in three temperature ranges: psycrophilic temperature are lower than 30 °C, mesophilic temperature cover a range between 30 °C and 45 °C, and a temperature between 45 °C and 60 °C is defined as thermophilic temperature (DGS and Ecofys, 2005). Variation of 2-3 °C in temperature can give rise to a change of the system (Cecchi et al, 2003).

- *pH* represents one of the most important parameters for the development of biogas reactions. The ideal pH for anaerobic digestion is very narrow: 6,8-7,2 pH (Ward et al., 2008).

As already mentioned, each bacteria strains need a specific and limited range of pH to optimize their metabolic functions.

Methanogenic bacteria are particularly sensitive to pH. Their optimum is around pH 7, and their grow rate is greatly reduced below pH 6,6 (Mosey and Fernandes, 1989).

During the digestion, pH is influenced mostly by the acidogenic, that increment the pH value because of the organic acid volatilization process.
The optimum pH of hydrolysis and acidogenesis has been reported as being between pH 5,5 and 6,5 (Ward et al., 2008).
This is an important reason why some designers prefer to separate the hydrolysis/acidification and acetogenesis/methanogenesis process in a two-stage process (Ward et al., 2008). In the mono-stage plants, where all the anaerobic phases are carried out in the same tank, pH values around 6,8 need to be maintained in order to facilitate methanogenic bacteria.

- *Buffer capacity* is often referred to as *alkalinity* in anaerobic digestion, which is the acid-neutralizing capacity of a medium (Cecchi et al., 2003). It is the equilibrium of carbon dioxide and bicarbonate ions that provides resistance to significant and rapid changes in pH, and the buffering capacity is therefore proportional to the concentration of bicarbonate (Ward et al., 2008). In turn, this results from the presence of hydroxides, carbonates and bicarbonates of elements such as calcium, magnesium, sodium, potassium and ammonia. In the case of anaerobic digestion the presence of volatile fatty acids, beside borates, silicates and phosphates, also contributes to alkalinity (Cecchi et al., 2003).
Buffer capacity is a more reliable method of measuring digester imbalance than direct measurements of pH, as an accumulation of short chain fatty acids will reduce the buffering capacity significantly before the pH decreases. Increasing a low buffer capacity is best accomplished by reducing the organic loading rate, although a more rapid approach is the addition of strong bases or carbonate salts to remove carbon dioxide from the gas space and convert it to bicarbonate, or alternatively bicarbonate can be added directly. Direct bicarbonate addition is more accurate as converting carbon dioxide to bicarbonate will require a time lag for gas equilibrium to occur which could result in over-dosing. It has also been demonstrated that the inoculum-to-feed ratio can be modified to maintain a constant pH (Ward et al., 2008).

- *Volatile fatty acids* (VFA). Short chain fatty acids represent a key intermediate step in the process of anaerobic digestion and are also capable of inhibiting methanogenesis in high concentrations. Anaerobic processes will alter the pH, particularly the production of fatty acids, and it has been shown that fermentation of glucose is inhibited at total VFA concentrations above 4 gl/l (Ward et al., 2008). Monitoring of fatty acids, particularly butyrate and isobutyrate, has been demonstrated to contribute to process stability, as an increase in fatty acids can be indicative of an overload of the organic loading rate. Essentially, the reason is that the methanogens will not be able to metabolise the acetate produced by the acetogenic organisms until the number of methanogenic organisms has increased sufficiently (Ward et al., 2008). This is especially true of feedstock which are rapidly hydrolysed. With poorly-degradable feedstock, the hydrolysis stage is more likely to be the limiting step. Inhibitors of methanogenesis such as excessive fatty acids, hydrogen sulphide, and ammonia are toxic only in their non-ionised forms. The relative proportion of the ionised and non-ionised forms (and therefore toxicity) is pH-dependant. Ammonia is toxic above pH 7; volatile fatty acids and hydrogen sulphide are toxic below pH 7 (Mata-Alvarez, 2003).

- *Metabolic substrates*: carbon, nitrogen, phosphorous and sulphur are the elements that never can lack in the digester (Albuzio and Paparelli, 2008). Carbon is fundamental because, along hydrogen, it forms methane itself. The presence of nitrogen in the substrate is necessary because it is an essential element for the production of proteins during the bacteria's metabolism and if there is nitrogen deficiency methane production will be low. Nitrogen helps also to maintain the pH (when converted to ammonia it neutralizes acids). However too much nitrogen in the substrate can lead to excess ammonia formation, resulting in toxic effects (DGS and Ecofys, 2005).

Carbon-to-nitrogen (C/N) ratio is an important parameter that affect AD. A healthy C/N ratio is between 20:1 and 40:1, although more extreme values can still result in efficient digestion (DGS and Ecofys, 2005). The optimal C/N ratio is around 30:1 (Albuzio and Paparelli, 2008). But often C/N ratios of feedstock don't respect the optimum, and some are considerably lower than this ideal level. Is for this reason that sometimes co-digestion is suggested.

1.3.3 Biomasses for use in anaerobic digestion

Biogas production can make use of a variety of different biomasses: organic fraction of solid municipal waste (SMW or biowaste), slurry from urban and industrial water treatment, biological waste and wastewater from agro-industries (e.g. milk serum, alcoholic distillery waste, liquid waste from fruit juice factories, etc.), animal slaughtering and butchering rejects (e.g. fats, blood, stomachal content, entrails, etc.), animal defecations (manure and sewage, mainly from bovine, swine and poultry sectors), energetic crops (especially silages and sorghum) and crops residues (fodders, low quality and non-saleable fruits and vegetables, silos and straw percolations) (IEA Bioenergy, 2001).

As with all biotechnological processes there are a few limits to the AD process. The biggest limitation is the processes inability to degrade lignin, a major component of wood. Despite this inability, several research programs have successfully used crops including aquatic and marine plants, grasses like Napiergrass, and woody biomass as potential feedstock for the AD process (IEA Bioenergy, 2001).

However, it is important to underline that AD gives the opportunity to recover, transform and dispose of biomasses that otherwise are considered only as wastes and end-refuses.

Some authors (DGS and Ecofys, 2005; Gebrezgabher et al., 2009; Ragazzoni et al., 2010) assert that feedstock choice is one of the most important step in the development of the project. The biomass typology is the element that primarily affects the costs and the returns of the plant. Therefore it is essential analyze every possible alternatives, in order to minimize the costs and maximize the positive return (Ragazzoni et al., 2010).

It is necessary to verify the concrete availability of different types of biomass and their real technical-environmental compatibility, to avoid unsteady biogas production during the year due to unexpected shortage of co-substrates supply. It is recommended to develop a thorough analysis of the regulatory regime they are subjected to (Kaisto, 2010; Ragazzoni et al., 2010): indeed, some materials can be used as feed for biogas plant only after specific treatments (e.g. sanitization or pasteurization process), and others are not recommended, as explained in the European Regulation 1774/2002[2]. If the latter are used, the digestate can’t be considered as a fertilizer for agronomic scopes, and it has to be identified as a waste and sent to landfills or to appropriate disposal places.

As it is possible to see in the table 2, the feedstock used affects enormously the biogas methane content and certainly exerts a dominant influence on the input digester costs and the overall profitability of the plant (Ragazzoni et al., 2010).

On farm level digesters, the basic substrate is usually manure or sludge (depending on the type of livestock bred and manure management), but other organic materials, like crop

[2] The Regulation (EC) No 1774/2002 of the European parliament and the Council of 3 October 2002 laying down health rules concerning animal by-products not intended for human consumption (Official Journal of the European Communities 10/10/2002; L273:1-95), classifies animal by-products in three different categories depending on their relatively dangerousness, determining for each category the possible and allowed treatments and uses. Only materials compatible with the second and third category can be used in biogas production and some of them have to be pre-treated, through pasteurization, for one hour at 70 °C (Alfano and Gaeta, 2010).

residues or energy crops, can be added (DGS and Ecofys, 2005). The types of biomasses most commonly involved in farm-level AD are described hereafter.

- *Manures*: they are a plentiful source of organic material for use as feedstock in anaerobic digesters: in Italy alone approximately 150 million tons are collected annually (Piccinini, 2009). Even if their energetic potential is modest, they contribute to add micro-elements and a variety of important microorganisms with an inoculation function, limiting food shortages and micro-flora development difficulties. Manures also have a great buffering power, useful to maintain constant the pH level. Moreover manures treatment gives to the farmers several other benefits as described in chapter 2 (section 2.1.2 and section 2.2).
The main manures used in AD are: swine slurry, dairy slurry, dairy manure and chicken manure. Obviously they differ in several characteristics, due to the livestock species bred, breeding system, growth and stage of the animals, feed, recovery solution adopted, amount and type of bedding and also any degradation process which may take place during storage (Moller et al., 2004a,b). All of those must be taken into account during the project development, as they affect the operation and performance of anaerobic digestion systems (Brown et al., 2007).

- *Cultural residues* are agricultural production residues, especially from fodders, straws from wheat, rice and sorghum, silos, sugar beet tops, grape and olive pomaces, fruits and vegetables discarded, etc., which are in many cases byproducts of food production (Ward et al., 2008). Harvesting crop residues for energy use has the advantage that the direct costs of production of these materials are often low, and collecting them from the fields promotes nitrogen recycling and reduces eutrophication due to nitrogen leaching (Börjesson and Berglund, 2003).
Generally their dry solid content is relatively high, with a range of 15-35% (Ragazzoni et al., 2010).

- *Energy crops* are energy dedicated crops, cultivated especially for the purpose of AD. The use of energy crops assure an higher biogas yield (due to the higher level of total solids and volatile solids contents present in the crops), if compared with the biogas production from manure and sludge (Ragazzoni et al., 2010).
Certainly, in Mediterranean conditions, the most used are corn, sorghum, triticale, wheat, rye, *Lolium multiflorum*, barley and sunflower (C.R.P.A., 2008). In her study "Biogas production

from energy crops and crop residues", Lehtömaki (2006), argues that, in Boreal countries, energy crops are represented by many conventional forage crops, some perennial herbaceous grasses (e.g. timothy *Phleum pratense* and reed canary grass *Phalaris arundinacea*) and some leguminous crops (e.g. red clover *Trifolium pratense,* vetch *Vicia sativa* and lupine *Lupinus polyphyllus*). In addition, several less conventional agricultural species could have potential as energy crops: marrow kale (*Brassica olearacea* spp. *Acephala*), Jerusalem artichoke (*Helianthus tuberosus*) and rhubarb (*Rheum rhabarbarum).* In those difficult climatic condition, other species often identified as weeds (e.g. nettle *Urtica dioica* L. and giant knotweed *Reynoutria sachalinensis)* have emerged as interesting alternatives as energy crops thanks to their efficiency in photosynthesis, high competitiveness, ability to grow on soil of poor quality, wide distribution and fewer pests and diseases than with conventional forage crops. Furthermore, native weeds are invasive and resilient in nature, making them well suited for repeated harvesting (Lehtömaki, 2006).

Also for energy crops the dry solid content is high and it is necessary to have available suitable feeding and mixing devices (Ragazzoni et al., 2010).

Anyway, nowadays, the use of energy crops appears controversial, even if it assures a higher biogas yield: very often the use of energy crops raises concerns about competition between food versus energetic purposes (Paoletti and Gomiero, 2009) as well as doubts and uncertainties about their concrete contribution to climate change mitigation (FAO, 2008). The critics concentrate on the negative energetic balance of the energy crops (in the whole process, more energy is employed to cultivate crops than the amount of energy that the crops themselves can return) and on the fact that fertile arable lands should be exploited food rather than energy.

It is necessary to mention also the following categories, even if they are rarely used in farm-level AD plants:

- *Agro-industrial organic wastes* consist of rejects from the industrial processing of agricultural products. They can be either liquid (as milk serum) or solid substances, for example fruit juice rejects or slaughtering rejects (e.g. fats, blood, stomachal content, entrails, etc.). The latter category is very interesting as co-substrate, due to its high energetic potential

(Ragazzoni et al., 2010; Ward et al., 2008). But strict regulation has to be respected for the treatment and disposal of these materials[3].

- *Municipal solid waste* (MSW). Organic wastes from households and municipal authorities provide potential feedstock for anaerobic digestion (IEA Bioenergy, 2001). They are perhaps the most variable feedstock in term of methane production, depending not only on the sorting method, but also on the location from which the material was sourced and the time of year of collection (Ward et al., 2008).

Another form of municipal or industrial waste is slurry from the treatment of waste water. This is an easily-degraded material, so more of the organic matter is available for anaerobic decomposition. Therefore it has a higher ultimate methane yield (Ward et al., 2008). Also AD of industrial waste waters is becoming a standard technique (IEA Bioenergy, 2001).

[3] Regulation (EC) No 1774/2002 of the European parliament and the Council of 3 October 2002 laying down health rules concerning animal by-products not intended for human consumption (Official Journal of the European Communities 10/10/2002; L273:1-95).

Biomass	**Total Solids** (TS) (%)	**Volatile Solids** (VS) (% S.T.)	**Biogas** (m^3/t SV)	**Methane**	
				%	m^3/t t.q.
Dairy cattle slurry	10,5	83	325	65	18
Beef cattle slurry	12	80	280	65	17
Swine slurry	2,5	85	450	67	6
Fresh manure	23	78	290	63	33
Mature manure	45	60	240	62	40
Poultry bedding	60	68	350	65	93
Rumen contents	16	85	360	65	32
Molasses	81	90	850	60	372
Wheat residues	80	92	490	55	198
Whey	11	90	700	60	42
Fruit distillate residues	3	92	470	58	8
Potatoes distillate residues	7	90	580	60	22
Apple juice production residues	35	92	630	60	122
Fruit juice production residues	23	92	635	60	72
Fruit and vegetable rejects	13	92	450	55	30
Flotation fat	15	96	960	65	90
Bread rejects	73	96	790	56	310
Corn silage	35	95	640	52	111
Triticale silage	30	92	550	52	79
Wheat silage	30	92	520	52	75
Rye silage	30	92	535	54	80
Sorghum silage (*Sorghum vulgare* var saccaratum)	20	95	510	52	50

Table 2: Potential biogas and methane production from different biomass feedstock. All the data are direct measures on specific biomass samples. They have to be considered as indicative values, due to the considerable variability of biomass' characteristics (function of bedding typology, production processes, etc.) (Ragazzoni et al., 2010).

1.3.3.1 Co-digestion

Usually, to give a balanced and correct diet to the anaerobic microorganism's community, *co-digestion* is preferred. The term "co-digestion" means that more than one substrate are used in the anaerobic digester. This permits firstly to enhance methane production (Ward et al., 2008). Such practices have been widely adopted in Europe for years, especially co-digestion of manures with energy crops or agro-industrial organic wastes (Piccinini, 2006a).

A particularly strong reason for co-digestion of different feedstock is the adjustment of the carbon-to-nitrogen (C:N) ratio, that should reach the optimal ratio of 25–30:1, required for a regular microorganism community development (Ward et al, 2008). C:N ratios can often be considerably lower than this ideal; feedstock can vary widely in their C:N ratios, and some reactors are affected more than others by non-ideal ratios. Co-digestion of a low C:N ratio feedstock with a high C:N ratio feedstock such as biomass can adjust the ratio closer to ideality (Ward et al, 2008), assuring an acceptable methane production.

The interest in co-digestion is due not only to the higher methane yield (reflecting usually an higher income), but also to the possibility to receive a fee from "waste" producers, that would otherwise have to dispose of those materials to the landfills, usually at higher costs (Braun and Wellinger, undated).

The mixing of different products also permits to compensate the seasonal fluctuation in biomass availability and to avoid that the digester operates above or below its capacity, thereby maintaining stable and constant the process (Piccinini, 2006a).

Some studies demonstrate that "co-digestion of slurry should increase the supply of nitrogen to crop in the short term" (de Boer, 2008) when the digested rejects are used as fertilizer on the field.

However, some problems can derive from an incongruous addition of different substrates: for example a non controlled addiction of oils or fats could generate exaggerate froth generation; a disproportionate inclusion of materials with high inert matter content, like sands, stones and soils, could favour sediment formation in the digester and block valves and pipes: an excess in poultry manure can cause toxicity to the methanogenic flora, due to the excessive ammonia concentration.

The organic residues utilizable as co-substrate originate from assorted sources and have strong difference in chemical composition and biodegradability; some of them have to be pre-treated (for example with thermochemical process, additives addition, alkali treatment, metals addition (Ward et al., 2008)), chopped, mixed and require the installation of specific machinery and structures (Piccinini, 2006a). Therefore it is necessary consider and study carefully how their addition could influence the AD process and the profitability of the investment.

In this thesis, as farm-scale biogas plants are studied, only farm related feeds will be considered: animal defecation (dairy manure and sludge), energy crops and crop residues.

1.3.4 System description and components

In general, the principle of all anaerobic digestions is the same: manure and/or other possible biomass are homogenized and inserted into a large, sealed, airless container. In this oxygen-free environment bacteria community will produce biogas. In most digesters the contents will be heated to accelerate and optimize the process. Specific devices provide to collect, store and transform the biogas produced, and to remove the exhausted digested substrates (digestate). Generally, biogas could be transformed in electricity and heat, trough a CHP (*Combined Heat Power*) engine, and the digestate could be used as organic fertilizer on the farm fields. But there are several different ways to carry out all the process and the final utilization of biogas and digestate.

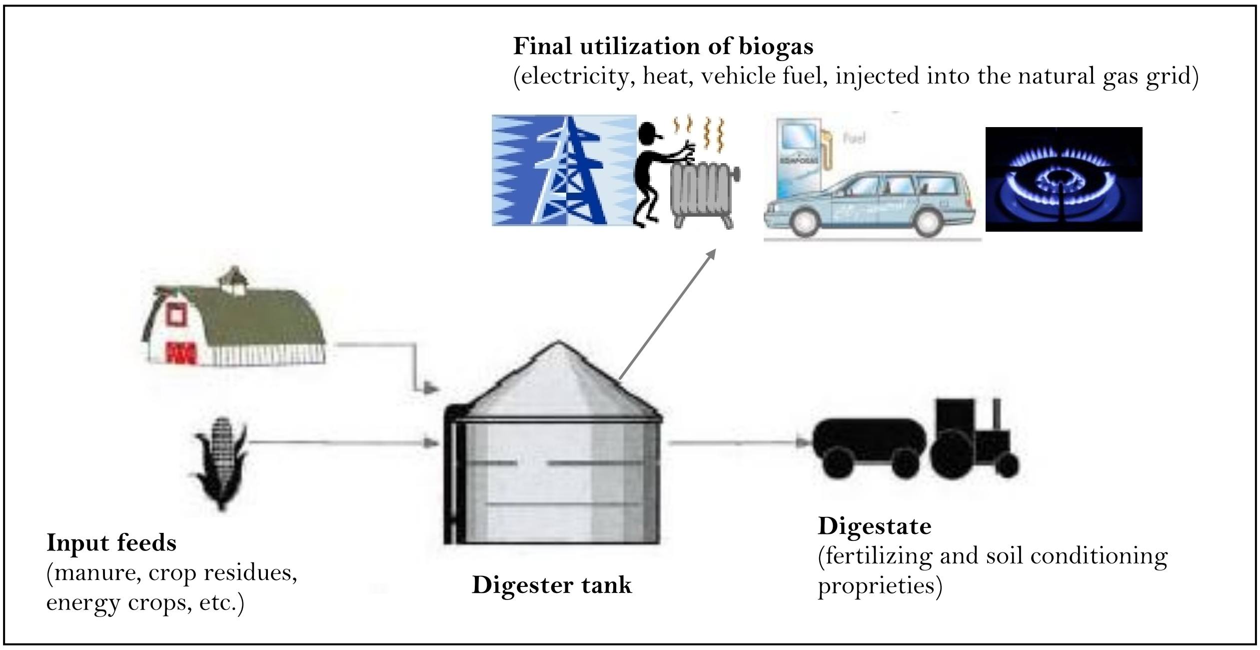


Figure 6: Simplified farm-scale AD process scheme (modified from Markus, 2009).

There are several options and types of AD systems, differing essentially for the following categories (DGS and Ecofys, 2005; Ragazzoni et al., 2010):

- Dimension;
- Temperature;
- Feedstock's total solid (TS) content;
- Process management.

AD can be applied in a range of scale, depending on the amount of biomass available. Systems can range from small (simple digesters for small quantity of substrates, with a capacity until 2000 m^3, until 100 kW_e), medium digesters (2000-5000 m^3 of digester capacity and 100-500 kW_e), to large centralized (or "industrialized") anaerobic digesters supplied with feedstock from several sources that exceed a capacity of 5000 m^3, and power from 500 to 1000 kW_e (Guercini, 2010).

Anaerobic digestion techniques differ from each other because the process temperature and the total solid content of digesting matters (Ragazzoni et al., 2010).

Concerning temperature differences, basically three temperature ranges are defined, in which specific strains of bacteria are most active (AA.VV., 2005). Low temperature ranges, below 30 °C, are referred to as *psycrophilic* AD; *mesophilic* plants work with temperatures within 30 °C and 45° C and the temperature range between 45 °C and 60 °C implies *thermophilic* systems (Cantrell et al., 2008).

Psycrophilic solution is a simple and low cost technology because no supplement energy is required to heat the plant, as it works at environmental temperature; in fact it is called also "cold plants" (Ragazzoni etal., 2010). Psycrophilic plants, suitable for biomass with low total solid content, spread during the 80's in Italy as swine sludge odour control solution (Ragazzoni et al., 2010) and they continue to be used by a great majority of swine producers in the United States (Miner et al., 2003). Miner et al. (2003) reported that "their popularity is based upon their relatively low construction cost to provide a complete system when employed in conjunction with land application and their operational flexibility". Moreover their contribution to odour reduction and other environmental benefits make these plants attractive even if their energy production is very low and not profitable in itself (Ragazzoni et al., 2010).

Nowadays most reactors operate in mesophilic and thermophilic condition (Ward et al., 2008), due to their higher biogas yields and to their capacity to treat different types of feedstock. It must be remembered that the increase in methane yield or production rate from thermophilic process has to be balanced against the increased requirement for maintaining the reactor at the higher temperature (Ward et al., 2008). This is not often an important consideration when the biogas produced is used for the generation of electricity or heat, as heating the reactor is accomplished by routing the waste heat, or the surplus heat, from the gas engines to heat exchangers within the reactor, and the engines usually produce more heat than the reactors requires (Ward et al., 2008).

Concerning the total solid content, there is a distinction between *dry* digestion and *wet* digestion. Wet reactors are those that treat biomass with a TS value of 10-16% or less. They are used mostly for treating many types of manure and sludge. Whilst dry reactors have between 20% and 40% TS; those that fall between wet and dry are considered *semi-dry*.

Dry technology is mainly used with municipal solid waste or vegetable wastes rather than with manures (Ward et al., 2008).

AD process can be manages as *continuous* or *discontinuous* process.

In a biogas plant running in continuous mode, there is always a continuous flow of materials through the plant. When input-feeds are added to the digester, a similar amount of digested will flow to a post-digestion tank via an overflow pipe (DGS and Ecofys, 2005). Therefore the feeding biomass level in the digester remains constant.

In turn, continuous options are subdivided in *mono-stage* or *multi-stage* systems. Mono-stage is represented by a single reactor, in which all the transformations occur. Multi-stage systems attempt to separate the hydrolysis/acidification process from the acetogenesis/methanogenesis process, as these do not share the same optimum environmental condition (Liu et al., 2006). Multi-stage reactors are usually only two stages and they improve the stability of the process compared to one-stage systems (Bouallagui et al., 2005).

In discontinuous plants, called also *batch systems*, different cells are filled, sealed and activated for a period of 30-40 days, then emptied and filled again with the next batches of fresh new substrate (Ragazzoni et al., 2010). Usually a little percentage of initial substrate (5-10%) is left in the cells to boost the starting of the digestion process (DGS and Ecofys, 2005).

This option is attracting some interest for its simplicity and for the possibility to treat dry biomasses without involvement of liquids (Ragazzoni et al., 2010).

Anyway, there are several plant engineering solutions and a variety of designs of AD system layouts, according to the type of substrates and their availability, the available investment resources, infrastructure (for example a silo to be retrofitted into a digester), and space, the sanitation requirements (particular organic matter categories must be undergone a sanitation or hygienic process[4]), the climate (cold climates require better insulation), the required storage time and also the preference for a supplier (DGS and Ecofys, 2005).

It is important to underline that each AD plant is planned to meet the individual needs of a particular farm and to fit the local reality; in this context it is difficult to generalize and standardize the exact components used in AD farm level systems.

However, the principal widespread components in typical farm-scale biogas plant are described below[5], even if often they are not present simultaneously in the same plant:

- *anaerobic digester*: it is the reactor tank where the anaerobic digestion occurs, the fundamental part of the system. The basic distinction is between horizontal and upright digesters, but several designs are available (DGS and Ecofys, 2005). To optimize the digester efficiency and to limit the heat losses, it is necessary dower the reactor tank with good insulation and heating systems, in mesophilic and thermophilic cases;
- *storage container*: the most commonly used manure storage systems are cellars, silos, basins and manure bags (DGS and Ecofys, 2005). When a digester is used it is advisable to store the manure for a time as short as possible before it is fed into the digester, because the digestion process starts during storage, and this leads to reduced biogas yields in the digester. The co-substrate storage container will depend largely on physical and chemical proprieties of the co-substrate itself. For example corn can be stored as silage, but fats are likely to require a specific storage tank;
- *co-substrate feeding system*: usually, in co-digestion, a volume reduction treatment is required before the insertion of the co-substrate in the digester; this requires a feeding system that will chop or grind the co-substrates. These could be inserted directly to the digester tank or pre-mixed. In order to ensure a good control of the amount of co-substrate supplied, a dose and weighing system is necessary (DGS and Ecofys, 2005);

---

[4] Regulation (EC) No 1774/2002 of the European parliament and the Council of 3 October 2002 laying down health rules concerning animal by-products not intended for human consumption. Official Journal of the European Communities 10/10/2002; L273:1-95.

[5] In this dissertation the principal components are only briefly listed. For a complete and deep description of all of them it is suggested to examine the book: AA.VV. 2005."Planning and installing bioenergy systems. A guide for installers, architects and engineers". German Solar Energy Society (DGS) and Ecofys. UK: James & James (Science publisher); pp.64-76.

- *mixing equipment*: the stirring devices provides for balancing of the substrate's temperature, homogenizing and mixing old substrate with new to ensure the presence of active bacteria in all the digesting mass and preventing the formation of agglomeration and layers (DGS and Ecofys, 2005);
- *post-digestion storage*: after the substrate has been sufficiently fermented it is transferred to the post-digestion tank to be stored until the digestate can be used or disposed of. Usually they are closed, in order to avoid nitrogen and methane losses and to collect the additional biogas that could be form during the storage phase. A floating covering system, placed on the separated digestate liquid phase's storage, is undergoing trials in Italy: the results show a daily increment of 3% of electricity production and a reduction of about 30% in CO_2 equivalent emissions per kWh_e produced (Balsari et al., 2010));
- *biogas storage*: biogas storage tanks can be distinguished by their operating pressure (low, intermediate or high pressure) and by their collocation (internal, positioned on the top of the digester tank, or external consisting of particular gas bags) (DGS and Ecofys, 2005). Usually they consist of flexible foils or polyester (or rubber) membranes in order to expand as biogas accumulates);
- *solid-liquid separator*: sometimes a liquid-solid separator is used to improve the substrate pumping characteristics, to prevent the possible pipes and storages' blockage, to divide the nutritive elements in two different phases and to improve the efficiency of the plant. It can be placed before or after the digester, depending on the different purposes (Guercini, 2008);
- *gas transformers*: there are several possible uses of the biogas produced by AD: direct combustion in heaters or gas burners to produce heat, direct combustion in boilers to provide hot water, transformation of biogas in electricity through power supply units, gas turbines, dual fuel engines or SI-engines and fuel cells (Persson et al., 2006), transformation in combined electricity and heat through CHP (combined heat and power). It is plain that biogas can be used for all applications designed for natural gas (IEA Bioenergy, 2005b)

  The most common electrical generator system used at farm biogas facilities today is a stationary internal combustion engine that has been modified to run on biogas, to drive a generator and to produce single or three phase electrical power. An induction generator is generally used since it can run off the signal from the utility and will allow parallel hook up with the grid (Lazarus, 2008).

In the process of electric production, since electricity production is only roughly 35% efficient, the remaining 65% could be characterized as “waste heat”, which is usually not exploited.

The CHP (combined heat and power) mode, is the most common and efficient system: CHP engines can make use of up to 90% of the fuel’s energy content, converting it to about 30% electric energy and 60% heat (DGS and Ecofys, 2005).

Biogas can be also refined and used as fuel for NGVs (natural gas vehicles) or vehicles equipped with dual fuel engines. Alternatively it can be injected and distributed through the natural gas grid;

- *upgrading system*: gas quality requirements depend strongly on its utilization. In general, cleaning and removing contaminants (such as hydrogen sulphide, water vapour and carbon dioxide) from the biogas is necessary. The upgrading phase is useful to fulfil the requirements of gas appliances (gas engines, boilers, fuel cells, vehicles, etc.), to increase the heating value of the gas and to standardize the gas. (Persson et al., 2006). Upgrading of biogas is an important cost factor in the production of fuel gas (IEA Bioenergy, 2005b);
- *pipes and pumps*: piping is usually necessary to transport the initial substrate, the digestate and the biogas; pumps are used to overcome a difference in height or to drive a hydraulic stirring system (DGS and Ecofys, 2005);
- *measurement , control and safety equipments*: there are several measurements devices like sensors, indicators and meters, that enable the operator of a biogas plant to run the system efficiently and thus ensure the plant’s economic success. They also facilitate the daily control of the performance of the various plants components and the detection of malfunctioning or misbehaviour of the system. In order to minimize the risk of accidents and to ensure safe operation, alarm systems and compliance with safety rules are also necessary (DGS and Ecofys, 2005).

It is useful to underline that this is an overview of farm-scale biogas plants only. Modern developments in agricultural waste digestion produced the notion of centralized anaerobic digestion (CAD), where many farms cooperate to feed a single larger digestion plant. Moreover there are different systems for industrial plants and for land-fill plants. But these technology lie outside the scope of this dissertation.

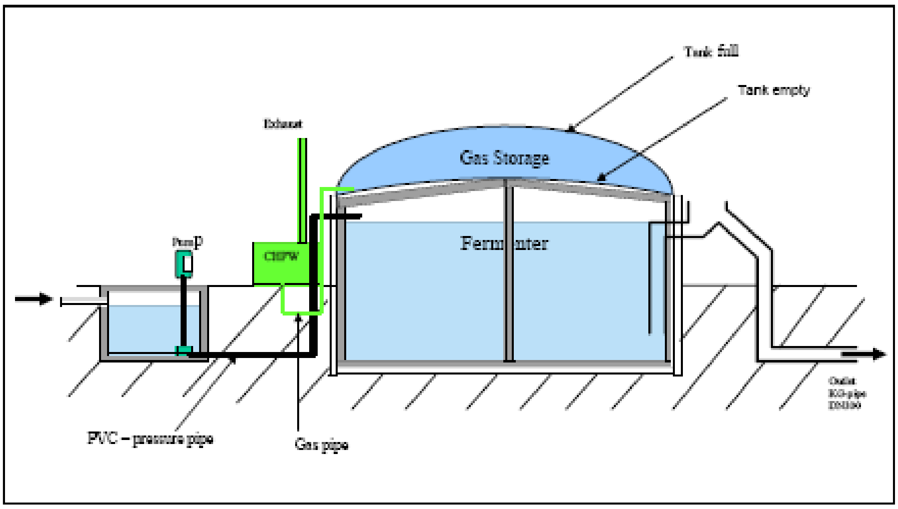


Figure7: Generic schematic AD plant (IEA, 2005b).

1.3.4.1 Developed anaerobic digester technologies

As already mentioned, digester designs vary remarkably from one farm to another and it is difficult to make generalizations and comparisons (Wilkie, 2005). Nevertheless, the most widespread anaerobic digester technologies are: covered lagoons, complete-mix, plug flow and fixed film (Lusk, 1998; Lazarus and Rudstrom, 2007; Cantrell et al., 2008).

Anaerobic lagoons are the most trouble-free and simple systems available for swine and dairy wastewater treatment, and this form of waste treatment is used in a large number of animal production systems to successfully store and process livestock manure, especially by swine producers in the United States (Miner et al., 2003). Anaerobic lagoons are usually chosen when the main goal is odour reduction (Lazarus and Rudstrom, 2007; Miner et al., 2003).
Covered lagoon systems (or covered lagoon digesters (CLD)) are typically earthen structures with the gas covers constructed out of geosynthetic materials – high-density polyethylene, polypropelyene, reinforced polyethylene, etc. The biogas is collected and moved through pipes to their intended use. Covered lagoon systems are generally not heated and the digestion temperature follows ambient, seasonal temperatures. Consequently, methane productivity

varies seasonally and is unlikely to reach high levels (from 0,1 to 1 m^3 of biogas per m^2 of plant's surface, always depending on the climatic conditions (Guercini, 2010). In addition to being a cheap solution for animal production facilities using hydraulic flushing systems, covered lagoons can handle a wide range of manure characteristics. The negative aspects of this technology are represented by the high HRT, the low OLR due to the watery-liquid sludge and solid settling issue. Moreover, repeated maintenance operation are required to remove the settling solid part of the non degraded matter.

Unfortunately, the large land area requirement, continual cover maintenance, and groundwater contamination potential have often prevented the establishment of covered lagoon systems as a widespread technology (Cantrell et al., 2008).

Complete mix digesters are engineered tanks, above or below ground, that treat slurry manure with total solids concentrations in the range of 3 to 10 percent. These structures require less land than lagoons and are heated (USEPA, undated). Complete mix digesters are compatible with combinations of scraped and flushed manure. While mixing the contents adds to the capital and operational costs of digesters, it helps to transfer heat and keep the solids in suspension. This in turn creates a more homogeneous manure/bacteria mixture (Karim et al., 2005).

From the case studies presented by Lusk (1998), mixing a digester's content can drastically decrease the HRT from months to between 10 and 20 days. This mixing also significantly improves biogas production to between 1 and 1,45 m^3 m^{-3} d^{-1}. In most instances, when compared to covered lagoon system's biogas production, the increase is over 10-fold (Figure 8) (Cantrell et al., 2008).

While mixing the contents of a digester improves biogas production, the co-digestion with energy crops and food waste can increase production even more (Cantrell et al., 2008).

Accounting for 50% of all installed AD designs in USA (AgSTAR, 2010a), mixed plug-flow digesters have the highest success rate. These plug-flow anaerobic digesters prevent GHG emissions by capturing biogas under an expandable top. The biogas is produced from belowground, rectangular digesters heated by hot water running through pipes inside the digester to maintain mesophilic temperatures. Plug-flow digesters are unmixed systems operating semi-continuously by regularly receiving a new, untreated ''plug" of manure while ejecting digested waste out the other digester end.

The digesters have a normal HRT between 20 and 30 days. In order to avoid mixing and separation of the manure, plug-flow designs are appropriate for manure with a range of total solid content between 11 to 13 percent total solids. Swine manure cannot be treated with a plug flow digester due to its lack of fibre (USDA, 2007).

The fixed-film digester uses a tank packed with an inert media on which the anaerobic microorganisms can attach and grow to form a biofilm. This biofilm remains in contact with the substrate as it flows past in either an upflow or downflow configuration. Due to the organisms immobilizing themselves on this media, potential washout is prevented, microbial biomass concentration increases, and consequently, biomass retention becomes independent of HRT. This gives the fixed-film digestion the advantages of higher conversion efficiency, shorter HRT, and smaller footprint (Wilkie, 2005).
This technology helps to offset the unfavourable economics prevalent when treating dilute and low strength animal waste streams (Cantrell et al., 2008). Like covered lagoon digesters fixed-film digesters are best suited for dilute waste streams typically associated with flush manure handling or pit recharge manure collection. Fixed-film digesters can be used for both dairy and swine wastes. However, separation of dairy manure is required to remove slowly degradable solids (USDA, 2007). It is important to say that this technology is going to be abandoned (Guercini, 2010).

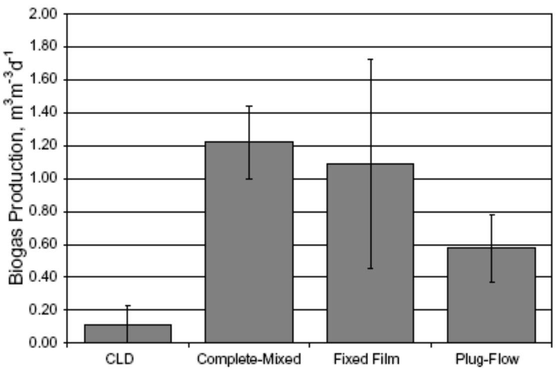


Figure 8: Biogas production from four different types of anaerobic digester designs. Errors bars represent range of reported values (Cantrell et al., 2008).

1.4 Final utilization of biogas

Once digestion is complete, the products that can be recovered are biogas and digestate.
Since biogas is only roughly 60-70% methane, it has a lower energy content that either natural gas or propane, but, thanks to equipment modifications or upgrading methods, biogas can be used in all energy-consuming applications designed for the previous ones.
In small-scale units of developing countries' rural communities, biogas can be used directly for cooking and lighting (IEA Bioenergy, 2005b). In more developed countries[6], biogas is used as a fuel for generating heat and electricity, or it could be upgraded and used as vehicle fuel or connected to the national gas grid. It also could be flared, but this is considered the last unlikely attractive option for biogas since it does not produce any energy revenues. However, flaring the biogas means transform methane in carbon dioxide: this represent an opportunity to reduce the GHG effect, as methane has a global warming potential (GWP) 23 times higher than carbon dioxide (FAO, 2006). Anyway, the biogas global warming mitigation role can not be recognized by the European Union's Emissions Trading Scheme (EU-ETS)[7], that excluded the agricultural sector from the accounting system (Pettenella, 2006; Brunori, 2010).
In general, flaring is limited to disposing of excess biogas which cannot be used by the engine-generator as a result of downtime or overproduction.
Biogas can also be exploited as raw material for the production of chemicals (Persson et al., 2006).

1.4.1 Heat generation

Even if burning biogas in a boiler is an established and reliable technology, and usually boilers and heaters represent a cheaper expenditure respect to other biogas transforming devices, in industrialized countries the exclusive heat energy production is not attractive and boilers without additional CHP are present only in a small number of plants (Persson et al., 2006). The secondary role of heat energy could be due also by a lack of supporting forms concerning heat energy production from renewable energy, as it is happening in Italy.

[6] In this thesis work only developed countries' biogas reality is taken into account. Especially European and Italian conditions.

[7] Directive 2003/87/EC of the European Parliament and of the Council of 13 October 2003 establishing a scheme for greenhouse gas emission allowance trading within the Community and amending Council Directive 96/61/EC.

In Northern Europe's Countries, however, demand for heat is very high, especially in the winter, due to the cold climate conditions, and biogas is mainly used to generate heat energy . For example, in 2007, in Finland, more than 60% of produced biogas was converted in heat (Rintala, 2009). This is far more relevant then electricity production, that reached scarcely 9% of total production (Rintala, 2009). Most farm-scale biogas plants are equipped with boilers or burners that transform the gas in heat, which is used to warm up the digester tank itself, the stables and the farm's buildings in the immediate vicinity and maybe conveyed to the nearest district heating system (Uusi-Penttilä, 2005; Rintala, 2008; Rintala, 2009). This allows the farmer to reduce the heating costs and also, in some cases, to improve the profitability of the farm.

Low demands are set on the biogas quality for heat generation application. Pressure usually as to be around 8 to 25 mbar. Furthermore it is recommended to reduce the level of hydrogen sulphide to below 1000 ppm, this allows to maintain the dew point around 150 °C (Persson et al., 2006).

1.4.2 Electrical generation and CHP

Most farm-based digesters use the biogas output to generate electricity (IEA Bioenergy, 2005b; EurObserv'ER, 2008; Lazarus, 2008). To a large extent, this reflect generous subsidies granted by the governments.

This is for example the case in Italy: high financial support levels (refer to section 1.7) are earmarked for boosting electricity production from biogas. This gives to the farmers the opportunity to increase their incomes selling the surplus electricity and the possibility to be energy self-sufficient. An analysis carried out by Ragazzoni et al. (2010) shows that the net annual profit derived from the electricity sale from an AD plant fed with 60% of manure and 40% of corn silage, working for 7800 hours per year, and supported with a feed in tariff of 0,28 € per kWh, could ranges from 555 € to 840 € per kW installed, depending on the power install (respectively 250 kW and 750 kW) (Ragazzoni et al., 2010).

Usually, when a CHP unit is used, the electricity generated by the gas engine can be either supplied to the electric national grid or used for own consumption, and the heat is used for warming the digester. The surplus heat can be used for heating stables or for residential heating. In some cases only the electricity generated is exploited, with consequent waste of heat energy.

1.4.3 Vehicle fuel generation

Biogas can be upgraded to natural gas quality and used in the same vehicles that use natural gas, or it can be used in vehicles equipped with a dual fuel engine. In addition to all the environmental benefits due to AD and to using biogas as fuel (see chapter 2, section 2.2), at farm level this could offer avoiding costs in fuel consumption and furthers earnings, if there is the concrete possibility to sell it.

At the end of 2005 there were 5 million natural gas vehicles in the world (Persson et al., 2006) and public transportation vehicles (such as busses and waste trucks) running on gas are increasing considerably. Moreover, several large carmakers, as Citröen, Fiat, Mercedes, Opel and Volkswagen , have already developed “biogas vehicles” for passengers and commercial purposes, which are available in the market (Svensen and Rydehell, 2009). Research is continuing in this area, which could represent a significant stimulus for biogas plant installation.

Anyway at the farm level, the installation of an upgrading system could increase significantly the investment costs: depending on the typology of the upgrading system and on the size of the plant, the costs could range from 0,25 € per kWh to 0,12€ per kWh (Petersson and Wellinger, 2009). Also the distribution costs (e.g. expenditures for the connection to the filling station grid, or for the creation of a on-farm biogas filling station) should be taken into account.

Maybe this option is more attractive for large scale plants, where the higher biogas production makes up for the high costs of installation and of operation and maintenance.

1.4.4 Injection into the grid

Biogas can be injected and distributed through the natural gas grid since biogas like natural gas mainly consists of methane.

One important advantage of this solution is that the grid connects the production site with demand in more densely populated areas. It is also possible to increase the production at a remote site and still use 100% of the gas.

Another benefit of injection of biogas into the natural gas grid is the consequently improving of the local security of supply. This is an important factor since most of the European countries consume more gas they produce (Persson et al., 2006). Even if usually farmers are not very much interested on this option, it could represent a valid alternative for earning new income, if a biogas grid market will be created.

Also in this case, as in the previous one, high investment costs is required for the upgrading operation.

1.5 Final utilization of the digestate

Beside producing biogas, AD technology also produces digestate, the residue part of the process, that contains all the nutrients present in the initial raw material and some residual carbon (Paavola et al., 2009b) (Table 3).

The anaerobic digestion process results in a mineralization of organically bounded nutrients, in particular nitrogen and carbon in a lowering of the C/N ratio. Both effects increase the short-term N fertilization effect, allowing to the digestate fertilizing or soil conditioning properties (Weiland, 2010).

The nutrient properties depend on the raw material fed into the digester, so the feedstock choice influence all the process.

The digestate has obvious uses as organic fertilizers and soil conditioners, but it can be processed in various digestate sub-products with specific characteristics (Al Seadi, undated). Some processing technology are for example the mechanical separation of it with centrifuges or belt presses, the stripping of liquid fraction or drying of solid fraction (Paavola et al., 2009b).

Using digestate instead of pure manure could offer several advantages to the farm. First of all a significant odour reduction: usually the presence of unpleasant odours causes conflicts with the neighbours, that can lead to the closing of the farming activity or the moving of it if other odour reduction solution are not found (USEPA, undated a; Wilkie 2000; Lazarus, 2008; Yiridoe et al., 2009). The better quality of the digestate fertilizer permits higher yields, reduction in pathogens (Wilkie 2000; Martin and Ross, 2004; Côte et al., 2006); and weed seeds germination (with the consequent reduction in herbicides and pesticides costs), the reduction in chemical fertilizers needs and more flexibility in the field-application (Ørtenblad, undated; Lazarus and Rudstrom, 2007; Yiridoe et al, 2009). Moreover improvement and stabilization of soil fertility and surface and groundwater pollution prevention and protection are attributable to digestate field spreading (Klingler, undated; Paavola et al., 2009a; Paavola et al., 2009b). All of these benefits are described in detail in chapter 2, section 2.2.

Digestate can also undergo a solid-liquid separation. In this case the liquid phase could be use as high value fertilizer to the field or treated in different ways, until obtain nearly water. The latter could be used in the farm activity, (for example to clean the milking area, or for domestic purposes), or used in ferti-irrigation or irrigation, when water resources are insufficient. The solid part can be used as organic fertilizer (as it is), or it can be composted to reach a higher level of stabilization, maybe packaged and sold as potting compost, or even used as livestock's bedding.

However it is necessary to analyze and monitor both the AD reject's composition and the area where spreading the digestate. In fact some compounds present in the digestate could transform their nutritional and fertilizer values in pollutants if they are in excessive concentrations, or spread on unfit fields.

For example, in farm-scale AD plants, nitrogen is one of the most important nutrients to keep under control, as imposed by the "Nitrate directive" (see section 1.7). If there is a too high level of ammonium or nitrates in the digestate, there is the possibility of leaching and percolation of those elements into the water bearing layer and volatilization of ammonia in the atmosphere after the spreading, increasing in this way the risk of pollution. Therefore, it is essential to measure and control the amount of nutrients in the digestate and estimate in advance the proportion that can be used as fertilizer on the fields. In fact, the remaining digestate exceeding field requirements will represent a waste and it will imply a cost for treatment and disposal.

Heavy metals in digestate usually come from anthropogenic sources. Domestic wastewater effluent contains metals from metabolic wastes, corrosion of water pipes, and consumer products. Industrial effluents and waste sludge may substantially contribute to metal loading. Agricultural wastes can contain persistent organic contaminants as pesticide residues, antibiotics and other medicaments. Industrial organic waste, slurry and household waste can contain aromatic, aliphatic and halogenated hydrocarbons, organo-chlorine pesticides, PCBs, PAHs etc (Al Seadi, undated).

In much the same way as with chemical fertilizers, when recycling these elements back to the soil by applying digestate as fertilizer, the content and accessibility for the plants of macro-elements must be precisely defined, in order to prevent pollution from nutrient turn off.

"Recycling of AD-residues, by utilisation as fertiliser in agriculture, is by far considered the only sustainable utilisation of digestate. Recycling requires a corresponding quality of digestate, to ensure application on farm land without hazard for humans, animals or the environment" (Al Seadi, undated).

Even if digestate has a considerable market potential, nevertheless, it is not still take off and applicable standards for these products do not exist. The recycling of AD-residues is generally poorly regulated in most countries (Al Seadi, undated). In the EU Regulation 1774/2002 concerning disposal procedures and use of animal origin by-products, as well as the subsequent temporary and implementation norms, gives some indications about the possible treatment and use of AD reject. Nevertheless for manures mixed with other biomass, the regulatory regime is still unclear and contradictory (Mantovi and Bonazzi, 2010). In Italy some regions adopted regulation that subjects digestates to the same rules as zootechnical effluents (Mantovi and Bonazzi, 2010).

Legislation seems to be still complicated and unclear, maybe due to the involvement and interlacement of several factors: energetic, agronomic, environmental and waste management aspects.

Total Solids[a] (g/kg)	**Volatile Solids**[b] (% TS)	**pH**	**NTK**[c] (g/kg)	**N-NH_4**[d] (% NTK)	**C/N**[e]	**Phosphorus (P_2O_5)** (g/kg)	**Potassium (K_2O)** (g/Kg)
30÷90	50÷70	7.5÷8.2	3÷6	50÷80	3÷8	0.8÷1.6	4÷7

[a]dry matter; [b]organic matter; [c]Kjeldahl total nitrogen; [d]ammonium proportion on total nitrogen; [e]carbon-nitrogen ratio.

Table 3: Digestate indicative composition (Ragazzoni et al., 2010)

1.6 State of the art of biogas

In the last decades, perhaps the most common use of AD-technology in the World, has been on farm manure facilities (Persson et al., 2006). In China, in 2005, there were 17million rural household-scale biogas digesters to provide biogas for cooking and lighting, whit a production of 6,5 billion m^3 of biogas (Yu et al., 2008), and in India, a census carried out in 1991-1992 counted around 39 million of family biogas plants (Rubab and Kandpal, 1995).

Before the year 2000, there were over 800 farm-based digesters operating in Europe and North America. Thousands of digesters help to anaerobically stabilize and thicken slurry before it is either used on agricultural land, dried and incinerated or landfilled. More than 1 000 high-rate anaerobic digesters were operated world-wide to treat organic polluted industrial waste water from processors of beverages, food, meat, pulp and paper, milk and other industries (Persson et al., 2006). There were more than 120 AD plants operating or under construction that use the organic fraction of source separated municipal solid waste to produce a high quality compost or mechanically separated MSW to stabilize the organic fraction before disposing it in landfills. Their combined total installed capacity was close to five million tons (Persson et al., 2006).

1.6.1 In Europe

In the EU-15, biogas is the most widespread fuel obtained from biomass and may derive from the natural process of methanization supply of organic waste present in landfills or from anaerobic digestion of slurry, crops and agro-industrial by-products and animal waste (Tricase and Lombardi, 2009).

In 2007, the most recent year for which data are available, the "Biogas Barometer" (EurObsrev'ER, 2008) estimates that the primary energy biogas production in Europe reached 5,9 Mtoe, representing an increase of 1 Mtoe compared to the previous year (Table 4).

Certainly the major increase in the price of fossil fuels that has taken place over the past few years and the intensive use of economic incentives to promote the use of renewable energy (Tricase and Lombardi, 2009) have made biogas more attractive. The applications of biogas – which were once limited to recycling and/or recovering energy from waste – have widened with the use of energy crops; this has stimulated European primary production from biogas which has increased of 20,5% in one year, from 2006 to 2007 (EurObsrev'ER, 2008).

The statistics produced by EurObsrev'ER (2008) only take into account biogas that is to be exploited, and not biogas that is burned in flares. The flared biogas is not a big percentage, but these losses should be restricted in a more environmentally friendly and energy-efficient point of view.

In 2007, landfill biogas was still the main source (49,2% of biogas energy) with a primary energy production of 3 Mtoe circa. Biogas from decentralized agricultural plants, centralized codigestion plants and municipal solid waste methanisation plants contribute to the total primary energy production for the 35,7%, and this mainly come from agricultural biogas units (EurObsrev'ER, 2008). This type of biogas is currently the real driving force of the growth of European biogas production within the European Union. It has the specific feature of being increasingly based on the development of dedicated energy crops (maize, wheat, sunflower, etc.). Urban and industrial slurry sector represented the starting point of biogas production in Europe (Piccinini, 2004), but in 2007, the amount of slurry treated with anaerobic digestion process produced around 887,2 ktoe of primary energy.

The increase in biogas production has been mainly to the benefit of electricity produced by cogeneration (76,1% of the increase in electricity production between 2006 and 2007) (Table 5). Electricity produced by cogeneration in 2007 represented 58,4% of electricity production from biogas, compared with 55,3% in 2006.

The total value of electricity registered in 2005 was approximately 14000GWh, that is, only 0,5% of total consumption of electricity in EU (2700TWh). The leading producers are Germany and Great Britain (Tricase and Lombardi, 2009). In 2006 the electricity production increased to approximately 17000 GWh, and in 2007 the production was estimated to reach about 20000 GWh (EurObsrev'ER, 2008).

Heat recovery from biogas is more difficult to determine because a certain number of countries do not always take into account the exploitation of all biogas sources. According to this survey, heat production increased in 2007 by 2,5%, to 356,9 ktoe in the European Union, as estimated in the "Biogas Barometer" journal (Table 6). Half of this production comes from cogeneration units. Heat recovery, whether or not by cogeneration, is aided by the presence of local outlets (heating of buildings, industrial processes, etc.) supplied by district heating systems.

Pays/ Countries	2006 Décharges/ *Landfill gas*	Stations d'épuration/ *Sewage sludge gas*[1]	Autres biogaz/ *Other biogases*[2]	Total/ *Total*	2007* Décharges/ *Landfill gas*	Stations d'épuration/ *Sewage sludge gas*[1]	Autres biogaz/ *Other biogases*[2]	Total/ *Total*
Allemagne/*Germany*	383,2	270,2	1 011,7	1 665,3	416,4	270,2	1 696,5	2 383,1
Royaume-Uni/*UK*	1 318,5	180,0	–	1 498,5	1 433,1	191,1	–	1 624,2
Italie/*Italy*	337,4	1,0	44,8	383,2	357,7	1,0	47,5	406,2
Espagne/*Spain*	251,3	48,6	19,8	319,7	259,6	49,1	21,3	329,9
France/*France*	150,5	144,0	3,6	298,1	161,3	144,2	3,7	309,2
Pays-Bas/*The Netherlands*	46,0	48,0	47,1	141,1	43,2	48,0	82,8	174,0
Autriche/*Austria*	11,2	3,5	103,4	118,1	10,7	2,0	126,4	139,1
Danemark/*Denmark*	14,3	21,0	57,6	92,9	14,3	21,0	62,6	97,9
Belgique/*Belgium*	51,0	17,6	9,1	77,6	48,1	18,0	12,5	78,6
Rép. tchèque/*Czech Rep.*	24,5	31,1	7,8	63,4	29,4	32,1	17,0	78,5
Pologne/*Poland*	18,9	43,1	0,5	62,4	19,1	43,0	0,5	62,6
Grèce/*Greece*	21,2	8,6	–	29,8	38,0	9,8	–	47,8
Finlande/*Finland*	26,1	10,4	–	36,4	26,4	10,3	–	36,7
Irlande/*Ireland*	25,4	5,1	1,8	32,3	23,9	7,9	1,7	33,5
Suède/*Sweden*	9,2	17,1	0,8	27,2	9,2	17,1	0,8	27,2
Hongrie/*Hungary*	1,1	8,0	3,1	12,2	2,1	12,4	5,7	20,2
Portugal/*Portugal*	–	–	9,2	9,2	–	–	15,4	15,4
Slovénie/*Slovenia*	6,9	1,1	0,4	8,4	7,6	0,6	3,8	11,9
Luxembourg/*Luxembourg*	–	–	9,2	9,2	–	–	10,0	10,0
Slovaquie/*Slovakia*	0,4	6,9	0,4	7,6	0,5	7,6	0,5	8,6
Estonie/*Estonia*	3,1	1,1	–	4,2	3,1	1,1	–	4,2
Lituanie/*Lithuania*	–	1,5	0,5	2,0	1,6	0,8	_	2,5
Chypre/*Cyprus*	–	–	0,0	0,0	–	–	0,2	0,2
UE/EU	**2 007,3**	**867,8**	**1 330,8**	**4 898,9**	**2 905,2**	**887,2**	**2 108,0**	**5 901,2**

1 Urbaines et industrielles/ *Urban and industrial*. 2 Unités décentralisées de biogaz agricole, unités de méthanisation des déchets municipaux solides, unités centralisées de codigestion/ *Decentralised agricultural plants, municipal solid waste methanisation plants, centralised codigestion plants.*

* Estimation/*Estimate.*

Source : EurObserv'ER 2008

Table 4: Primary energy production of biogas in the European Union in 2006 and estimation of it in 2007, expressed in ktoe (EurObserv'ER, 2008)

Pays/ Countries	2006 Centrales électriques seules/*Electricity plants only*	Centrales fonctionnant en cogénération/ *CHP plants*	Électricité totale/ *Total electricity*	2007* Centrales électriques seules/*Electricity plants only*	Centrales fonctionnant en cogénération/ *CHP plants*	Électricité totale/ *Total electricity*
Allemagne/*Germany*	–	7 446,0	7 446,0	–	9 520,0	9 520,0
Royaume-Uni/*UK*	4 424,0	463,0	4 887,0	4 795,6	503,4	5 299,0
Italie/*Italy*	1 061,9	241,8	1 303,7	1 125,6	256,3	1 381,9
Espagne/*Spain*	610,3	56,0	666,3	631,1	56,0	687,1
France/*France*	487,3	35,4	522,7	505,3	35,7	541,0
Pays-Bas/*The Netherlands*	146,1	215,2	361,3	274,2	223,2	497,4
Autriche/*Austria*	424,1	23,0	447,1	469,8	22,8	492,6
Danemark/*Denmark*	1,6	278,4	280,1	1,6	293,3	295,0
Belgique/*Belgium*	158,3	120,6	278,9	152,0	127,4	279,4
Rép. tchèque/*Czech Rep.*	63,1	112,8	175,8	80,3	142,6	222,9
Grèce/*Greece*	69,3	38,5	107,9	91,3	84,0	175,3
Pologne/*Poland*	0,0	160,1	160,1	0,0	160,1	160,1
Irlande/*Ireland*	108,4	13,6	122,0	101,9	16,9	118,8
Portugal/*Portugal*	25,2	7,4	32,6	58,0	7,3	65,4
Slovénie/*Slovenia*	8,6	26,1	34,7	8,9	39,2	48,2
Suède/*Sweden*	–	46,3	46,3	–	46,3	46,3
Luxembourg/*Luxembourg*	–	32,6	32,6	–	36,6	36,6
Finlande/*Finland*	0,9	21,4	22,3	0,9	21,4	22,3
Hongrie/*Hungary*	–	22,1	22,1	–	22,1	22,1
Estonie/*Estonia*	1,1	13,0	14,1	1,1	13,0	14,1
Lituanie/*Lithuania*	–	5,4	5,4	–	6,3	6,3
Slovaquie/*Slovakia*	–	4,0	4,0	–	4,0	4,0
Chypre/*Cyprus*	0,0	0,2	0,2	–	1,4	1,4
UE/EU	**7 590,3**	**9 382,9**	**16 973,2**	**8 297,7**	**11 639,5**	**19 937,2**

* Estimation/*Estimate.*

Source : EurObserv'ER 2008

Table 5: Gross electricity production of biogas in the European Union in 2006 and estimation of it in 2007, expressed in GWh (EurObserv'ER, 2008).

Pays/ *Countries*	2006 Unités de chaleur seules/*Heat plants only*	2006 Unités fonctionnant en cogénération/ *CHP plants*	2006 Chaleur totale/ *Total heat*	2007* Unités de chaleur seules/*Heat plants only*	2007* Unités fonctionnant en cogénération/ *CHP plants*	2007* Chaleur totale/ *Total heat*
Royaume-Uni/*UK*	61,9	–	61,9	61,9	–	61,9
France/*France*	44,4	5,8	50,2	47,4	5,8	53,2
Italie/*Italy*	–	38,6	38,6	–	40,9	40,9
Pologne/*Poland*	6,0	28,1	34,2	6,0	28,1	34,2
Rép. tchèque/*Czech Rep.*	10,0	13,9	23,9	9,6	14,3	23,9
Danemark/*Denmark*	3,7	17,1	20,9	4,7	18,8	23,6
Allemagne/*Germany*	8,7	14,5	23,2	8,7	14,5	23,2
Finlande/*Finland*	2,5	19,7	22,1	2,5	19,7	22,1
Suède/*Sweden*	4,7	11,7	16,4	4,7	11,7	16,4
Espagne/*Spain*	14,7	–	14,7	14,7	–	14,7
Belgique/*Belgium*	1,0	12,9	13,9	1,6	12,6	14,2
Autriche/*Austria*	4,7	4,2	8,9	4,3	4,2	8,5
Luxembourg/*Luxembourg*	–	4,4	4,4	–	5,0	5,0
Grèce/*Greece*	–	2,9	2,9	–	3,5	3,5
Irlande/*Ireland*	1,5	2,6	4,0	1,5	1,9	3,4
Slovaquie/*Slovakia*	2,3	0,9	3,2	2,3	0,9	3,2
Hongrie/*Hungary*	–	2,6	2,6	–	2,6	2,6
Estonie/*Estonia*	0,1	0,9	1,0	0,1	0,9	1,0
Pays-Bas/*The Netherlands*	–	1,0	1,0	–	1,0	1,0
Lituanie/*Lithuania*	–	0,3	0,3	–	0,3	0,3
Chypre/*Cyprus*	–	0,02	0,0	–	0,0	0,0
UE/*EU*	**166,2**	**182,1**	**348,3**	**170,1**	**186,8**	**356,9**

* Estimation/*Estimate.*

Source : EurObserv'ER 2008

Table 6: Gross heat production of biogas in the European Union in 2006 and estimation of it in 2007, expressed in ktoe (EurObserv'ER, 2008).

European regulations limiting the dumping of waste have encouraged the development of methanisation units as a means of treating and reusing waste. These regulations have made it possible to develop large household waste methanisation units. However, the methanisation market is moving more and more towards agricultural methanisation units, whether centralized or decentralized (which is the most frequent case). These installations have the specific feature of being increasingly based on energy crops produced within farms. In this new market, the rationale of biogas production for waste treatment is gradually being replaced by the rationale of the production of energy, and particularly electricity (EurObsrev'ER, 2008).

Agricultural biogas is currently the most vibrant area, because it is not limited to waste treatment. Its development prospects are related to the use of energy crops that act as a basis for production and that optimizes the productivity of installations. Therefore the growth potential is very high, particularly in Europe's large agricultural countries (notably France and Poland) (EurObsrev'ER, 2008). However, the large-scale use of energy crops poses the same environmental questions as for biofuels production. It remains fundamentally necessary to strike a balance between the need to produce large quantities of renewable energy and the consideration of environmental constraints such as the management of water resources, the use of pesticides, and the percentage of CO_2 reduction in comparison with to the use of fossil fuels. If the high prices of agricultural raw materials continue, this could also limit the prospects for growth in this area.

Beside the production of electricity and heat, there are also new outlets for the methanisation sector. Due also to the increase in the price of natural gas, a growing number of countries are now interested in producing biomethane in order to inject it into their natural gas networks or to use it as fuel for gas-powered vehicles (EurObsrev'ER, 2008).

Even if still a limited sector, this use is generating growing interest thanks to its vast potential economic strengths and environmental spin-offs (Tricase and Lombardi, 2009), such as reduction up to 95% in carbon dioxide (CO_2) emissions, drastic reduction in emissions of particles, soot, nitrogen oxides (NO_x) and non methane hydrocarbons (NMHC) (Persson et al., 2006).

Even if the number of biogas filling stations has multiplied over the last few years, it is still insufficient in Europe and elsewhere in the world: at the end of 2005, only 1600 biogas filling stations existed on European territory, especially in Sweden (that is the leader nation with 779 public busses and more than 4500 cars fuelled by biogas), Germany, Austria and Switzerland (Persson et al., 2006).

In just a few years, Germany has become the country which produces the most biogas (2,4 Mtoe in 2007, representing the 40% of the total primary energy produced from biogas in Europe in the same year) through the major development of its small farm methanization units, that represent the 71,2% of the total plants. It is also the leading country in terms of production per capita, with 29 toe produced for every 1000 people. It is followed by the United Kingdom, that in the same year produced 26,7 toe for 1000 people: the most part of this biogas is produced in landfill sites (88.2% of primary energy production from biogas) that have benefited from a specific incentive scheme, based on so-called Renewables Obligation Certificates (ROCs).

Denmark, Austria, the Netherlands and Sweden are also countries where significant biogas production and technology developments are taking place (EurObsrev'ER, 2008).

The current rate of is not sustained enough to reach the target of the European Commission's White Paper, i.e., 15 Mtoe in 2010 (Figure 9). The major increase in prices of agricultural raw materials should limit the growth of agricultural biogas production, which is the driving force of biogas growth in Europe. Considering this situation, the "Biogas Barometer" (2008) estimates that production will reach 7,8 Mtoe by 2010 (i.e., 10% annual growth). This production would represent 5,2% of the target of the European Commission's "Biomass Action Plan", which aims to produce 150 Mtoe in 2010. This plan takes into account all components of biomass, that is, biofuels, biogas, renewable household waste and solid biomass (including wood, wood waste, crop residues, etc.). This last sector is by far the largest, with 62,4 Mtoe of primary energy produced from solid biomass in 2006 (EurObserv'ER, 2008).

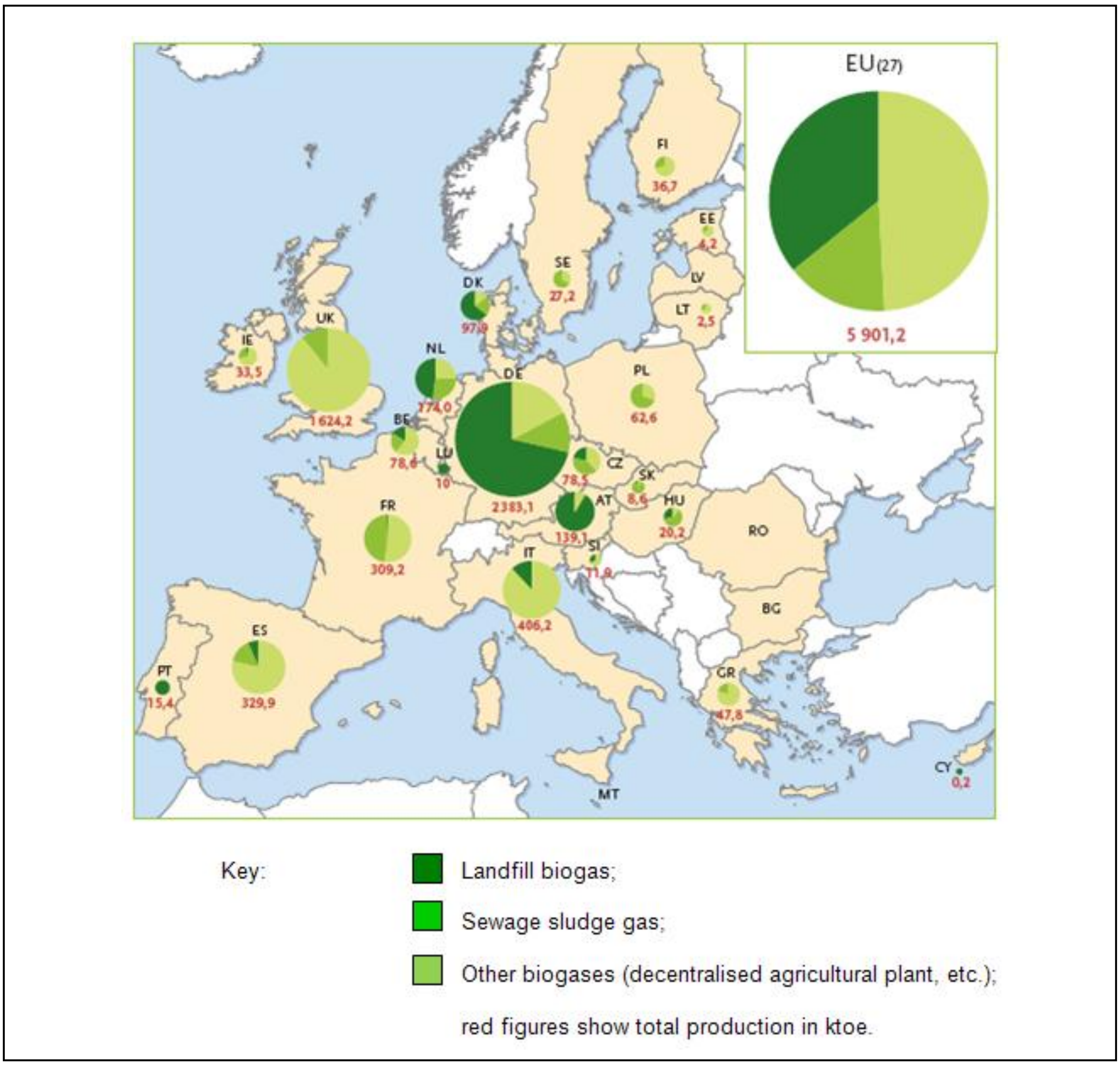


Figure 9: Estimation of primary energy production of biogas in Europe in 2007 (EurObserv'ER, 2008).

1.6.2 In Italy

In Italy, EurObserv'ER estimates that biogas production in 2008 stood at 410 ktoe (about 4,7 TWh) (Fabbri et al., 2010). This is very far from the national electrical requirement, that amounts of 340 TWh (Piccinini, 2009). About 80% of the biogas power energy comes from the recovery of biogas from municipal solid waste landfills (Fabbri et al., 2010).

The situation in Italy fundamentally reflects that of the EU, with biogas being mainly used to produce electricity and heat (Tricase and Lombardi, 2009). In 2005, gross energy production was almost 1.200 GWh, corresponding only to the 2,4% of total supplied by renewable energy sources. In 2007, the amount of gross electricity produced increased until 1382 GWh and the gross heat produced was 40,9 ktoe (EurObsrev'ER, 2008). In the same year Italy reached the 7% of the primary energy production of biogas, gaining the third place in Europe (EurObsrev'ER, 2008), as showed in table 4. A further increase was registered in 2008, where the electricity production reached 1.600 GWh (Fabbri et al., 2010)

CRPA (Research Centre of Animal Production, situated in Reggio Emilia, Italy) has carried out a survey of all operational anaerobic digestion plants in Italy in the livestock and agro-industrial sector in order to create an archive capable of providing a complete picture of the dimensions of the sector in Italy and of the main plant characteristics (Piccinini, 2008a).

As of March 2010, 273 biogas plants were identified operating on livestock effluent, energy crops, organic residues and discharges from the agro-industrial sector (Fabbri et al., 2010). This number includes plants which are awaiting authorization and under construction. The majority of the farm-scale plants surveyed, that were 139, operates with livestock slurry, agricultural waste, agro-industrial residues and energy crops (Table 7). In 2007 there were only 58 examples of active co-digesting plants: the increase occurred in few years has been of about the 139% (Fabbri et al, 2010). This confirms the strong expansion of the anaerobic digestion sector in Italy.

The recovery of gas from urban landfills is also significant. Here there are about 232 operating plants and about 306 MWe installed (data Aper as at September 2009) representing another important source of biogas from biomass (Piccinini, 2008a).

Relating to the farm-scale plants, the most part of them (139 plants) are operating in co-digestion using mainly pig and/or cattle slurry and/or chicken manure adding energy crops and/or organic waste. 91 plants are using only animal effluents, mostly cattle or swine manure and sewage (Table 7). A non negligible number of plants are operating exclusively with vegetable biomasses: 22 plants produce biogas from dedicated energy crops (Fabbri et al., 2010).

The most part of the agricultural-zootechnical biogas plants are operating in mesophilic conditions with a digester volume between 1000 and 5000 m^3 (Piccinini. 2008a). Only 10 plants produce exclusively heat energy burning the biogas in boilers; all the others AD plants have installed devices for electrical generation: the majority have a power less than 500 KW_e, 100 plants between 500 KW_e and 1 MW_e, and only 19 more than 1MWe (Fabbri ei al., 2010).

Sector and typology of substrate	**Number of plants**	
	2007[a]	**2010[b]**
Agricultural-zootechnical	154	273
livestock manure and/or sewage	87	91
co-digestion	58	139
energy crops	9	21
data not available	/	22
Solid municipal waste and sewage sludge from urban and industrial water treatment	130	135
Agro-industrial rejects	22	32
Total	306	440

([a] data from Piccinini, 2008a; [b] data from Fabbri et al., 2010)

Table 7: Number of biogas plants per type of involved activity sector and typology of substrates.

The areas where most Ad plants are located are those with the highest concentration of livestock farms such as Lombardy, Emilia-Romagna and Veneto (Figure 10). Some plants are being constructed in areas where significant quantities of waste and organic by-products are produced by the agro-industrial sector to be used in co-digestion including as a management solution to the recovery of this waste.

Plant numbers are significantly smaller in the Centre and South of Italy. On the other hand, the number of plants present in the province of Bolzano is influenced by its proximity to Austria and Germany in addition to the extensive policy of incentives adopted by the provincial administration (Piccinini, 2008a).

As European and national policy are turning to renewable energy exploitation, environmental preservation and conservation, and are supporting the agricultural sector's development, anaerobic digestion seems to have some possibility to grow and develop. Some prospects studies shows as the estimated potential production of biogas from animal slurry in Italy could reach 2,2 billion m^3 of biogas per year (Tricase and Lombardi, 2009), whereas methane production could be as high as 8 billion of methane m^3/year, taking into account not only animal slurry but also residues and energy crops, agro-industrial waste, waste water slurry, MSW and slaughtering waste (Piccinini, 2009).

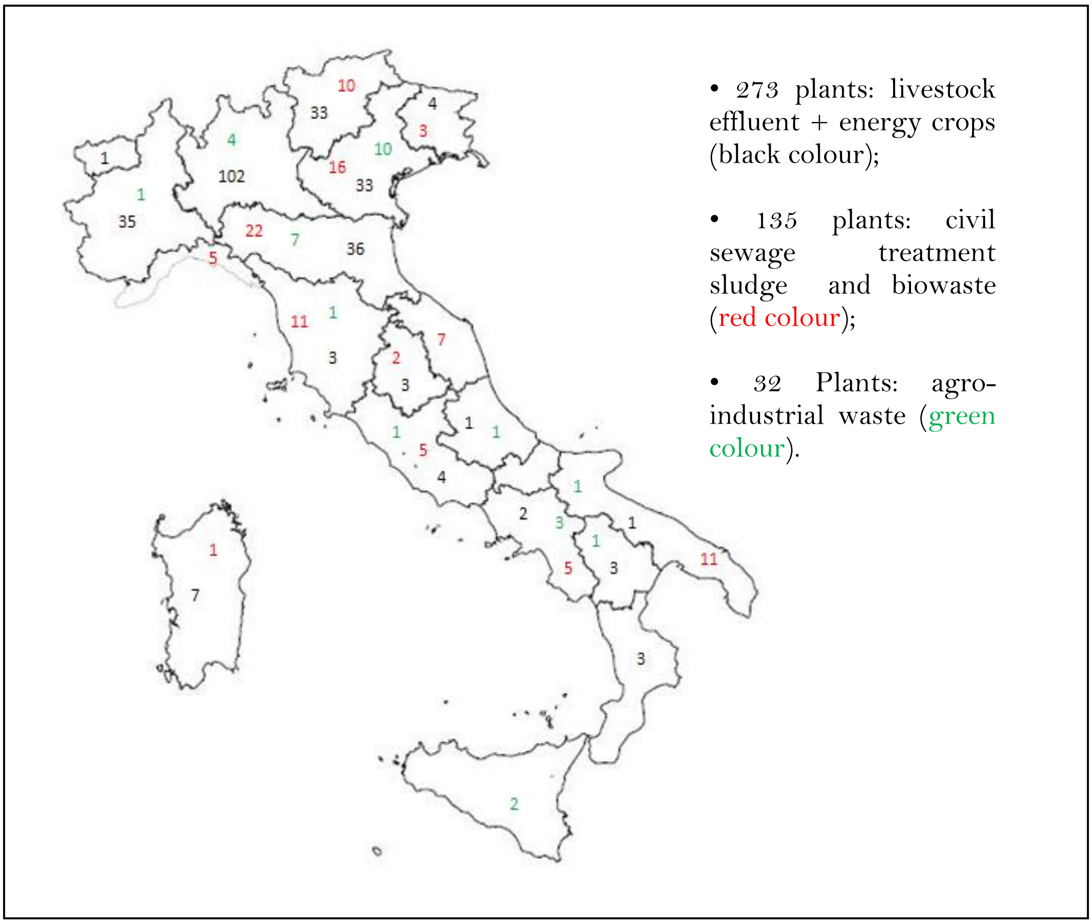


Figure 10: Regional distribution of biogas plants in operation and/or under construction in Italy (440), excluding plants for the recovery of biogas from landfill (personal elaboration from Piccinini, 2008a and Fabbri et al., 2010).

1.7 Overview of European and Italian legislation concerning biogas production

The production and the utilization of biogas are promoted by several provisions that regulate different interlaced aspects:

a) the promotion of renewable energies,

b) the disposal of organic waste, and

c) the control of surface- and ground-water pollution risk.

Starting from the Kyoto Protocol, in which industrialized countries and transition economies have undertaken to reduce the anthropic emissions of key greenhouse gasses by 5,2% to the levels of 1990 in the commitment period 2008-2012, several community action plans have been adopted with the intent to decrease the use of fossil fuels, improve energy efficiency, promote sustainable agricultural forms, research, promote, develop and increase the utilization of renewable energy sources, of new technologies for carbon sequestration and for environment protection, and, furthermore, for the limitation or decrement of methane emissions tanks to its recovery and utilization in waste and energy sectors (Zezza et al., 2008).

a) Concerning the promotion of renewables, Directive 2001/77/CE[8] confirmed the requirement that by 2010 member states obtain 12% of their energy consumption from renewable sources, prescribing a target of 22,1% of electricity generated within the same period to come from renewable energy sources in the EU.

In 2005 the European Commission published the Biomass Action Plant, a first coordinating approach to biomass. The plant sets out measures to increase the development of biomass energy from wood, wastes and agricultural crops by creating market-based incentives to its use and removing barriers to the development of the market.

Again in early 2007, the Commission elaborated a “energy-climate package”, called the “20-20-20” package, that included the goals for 2020 of reducing greenhouse gasses emissions by 20%, improving energy efficiency by 20% and achieving a 20% share of renewable energy (Zezza et al., 2008). Nevertheless more attention is address also to support biofuels in the transport sector, heat energy from renewable sources and the letting of gas from renewable sources into the national grid (Ministero dello sviluppo economic, 2010); the Commission

[8] Directive 2001/77/EC of the European Parliament and of the Council of 27 September 2001 on the promotion of electricity produced from renewable energy sources in the internal electricity market.

chose to impose a minimum target of 10% renewable fuels in the transport sector, which was expected to be composed mainly of biofuels[9], and some member states (such as Germany, Sweden, Italy, and other) decided to support heat energy with some incentive instruments and to replace part of the natural gas consumption with biogas (EurOvserv'ER, 2008; Ministero dello sviluppo economico, 2010).

Italy, not later than 2020, has to cover the 17% of the final national energy consumption with renewable energy forms, and has to run a quantity of biofuels into the national grid equal to the 3.5% of the total energetic rate of biofuels introduced in 2009, as described in the new National Action Plan for Renewable Energy (Ministero dello sviluppo economico, 2010).

Each member state implements EU legislation at the national level and has some flexibility in choosing the appropriate policy instrument to reach the targets settled in advance and to regulate the specific sectors.

In Italy, for example, agricultural biogas energy production is supported by two incentive instruments: the so called "green certificates" ("*certificati verdi*", CVs) and a feed in tariff (Berton, 2008).

The Legislative Decree 79/99[10], known as "*Decreto Bersani*", revised and implemented in the following years, stated and introduced "green certificates", negotiable titles annually recognized to energy producers that use renewable sources, with three-year validity (GSE, 2009). The number of CVs recognized to the producer, corresponds exactly to the renewable energy produced multiplied for a coefficient, that varies according to the different renewable energy sources used (GSE, 2009). The coefficient for biogas production is 1,80, if it derived from the digestion of agricultural or zootechnical products obtained from the farm or within a 70 Km radius. For all other biomass feedstock, the coefficient changes to 1,30. The CVs holder can choose to sell them either to the market price, or to the GSE (*Gestore Servizi Elettrici*, the electricity service national company) at a fixed price, that corresponds to an average of the prices in the previous year[11].

[9] Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of renewable sources and amending and subsequently repealing directives 2001/77/EC and 2003/30/EC.

[10] Decreto Legislativo 16 marzo 1999, n. 79, "Attuazione della direttiva 96/92/CE recante norme comuni per il mercato interno dell'energia elettrica", pubblicato nella *Gazzetta Ufficiale* n. 75 del 31 marzo 1999.

[11] This procedures and coefficient values refer to the Law 29/11/2007 n. 222.

As an alternatives to CVs, biogas plants with installed power lower than 1 MW, can choose to sell the biogas electricity energy produced at a fixed feed in tariff ("*tariffa onnicomprensiva*")[12] of 0,28 €/kWh (GSE, 2009).

For biogas plants that began operations from 2008 on this incentive scheme will protract for 15 years.

There are also other forms of support, such as public refunds for a maximum of 40% of biogas plant investment costs (Berton, 2008) and a tax allowance of 55% for expenditures of heating devices installation is under approval (Ministero dello Sviluppo Economico, 2010). Moreover "white certificates" system is under development to incentive the heat energy production from AD plants and other technologies that use renewable sources.

There are also specific incentive schemes at national, regional and EU level, usually accessible after calls for competitions.

The Italian feed in tariff for electricity production from biogas is one of the highest in the Europe Union. Germany has a basic price of 0,1167 €/kWh for biomass plant under 150 kW_e, and it has established premium prices for those AD plants that use: agricultural biomasses (the premium will be raised from 0,6 €/kWh to 0,7 €/kWh); more than 30% of liquid manure (an extra premium of 0,4 €/kWh); cogeneration units (0,2-0,3 €/kWh for plants below 20 MW_e) and high technologic plants (0,2 €/kWh for plants below 5 MW_e). Austria supports the biogas plants with a feed in tariff of 0,17 €/kWh, the Netherland and France have maximum feed in tariffs of 0,12€/kWh, and Denmark of 0,1 €/kWh (EurObserv'ER, 2008).

b) One of the first European Directive that promoted implicitly the biogas technology was the Directive 99/31/CE[13] concerning the reduction of biodegradable municipal waste to landfill, as landfilling of municipal solid waste (MSW) leads to negative environmental impact of leach and percolation of pollutant compounds and emission of gasses, most of them GHG (Nordberg, undated). This regulation impose to find some alternatives in disposing organic waste, and biogas resulted a possible solution.

[12] Legge 24 dicembre 2007, n. 244 "Disposizioni per la formazione del bilancio annuale e pluriennale dello Stato (legge finanziaria 2008)" pubblicata nella *Gazzetta Ufficiale* n. 300 del 28 dicembre 2007 - Supplemento ordinario n. 285

[13] Council Directive 1999/31/EC of 26 April 1999 on the landfill of waste. Official Journal of the European Communities 16/07/1999; L182.1-19.

Anyway, in the following year, specific regulations have been developed to define what materials can be used in anaerobic digestion plants (such as the Regulation 1774/2002[14] concerning disposal procedures and use of animal origin by-products as well as the subsequent temporary and implementation norms): the raw materials have been subdivided in three categories, depending on the typology of the material and on the human health risk, and for each category possible treatment or use limitation were defined[15]. Moreover other regulations defined guidelines and standards for biogas and composting plants working with manures.

c) One of the most important pieces of legislation connected with agronomic utilization of waste from livestock operation - and thus also with farm-scale biogas production - is Directive 91/676/EEC[16], so-called "Nitrates Directive", the regarding the protection and preservation of surface- and underground- water, that are threatened with excessive agricultural soil exploitation and consequent nitrates accumulation (Pettenella et al., 2010). In the Annex III of this directive three action programs are indicates regarding prohibition period of soil fertilizer application, adjustment of manures storage capacity and limitation in fertilizer use based on the equilibrium between the expected crop needs and the nitrogen supply from soil and fertilization. The Nitrates directive imposed also a cap on the amount of nitrogen (N) that can be applied to the soil: the limit is 170 Kg of N per hectare per year in zones classified as vulnerable (VZ) and 340 Kg of N per hectare per year in areas classified as non-vulnerable zones (NVZ).

Even if the anaerobic digestion technology offers farmers the opportunity to solve some problems associated with the application of the aforementioned directive (such as the storage of the manures for long time), usually it cannot be an efficient solution for reducing N content: in fact the total nitrogen content in the digestate is the same of the raw material input

[14] Regulation (EC) No 1774/2002 of the European parliament and the council of 3 October 2002 laying down health rules concerning animal by-products not intended for human consumption. Official Journal of the European Communities 10/10/2002; L273:1-95.

[15] Referring to : Commission Regulation (EC) No 810/2003 of 12 May 2003 on transitional measures under regulation (EC) No 1774/2002 of the European parliament and of the council as regards processing standards for category 3 material and manure used in biogas plants. Official Journal of the European Union 13/05/2003;L117:12–3. And Commission Regulation (EC) No 92/2005 of 19 January 2005 implementing regulation (EC) No 1774/2002 of the European parliament and of the council as regards means of disposal or uses of animal by-products and amending its Annex VI as regards biogas transformation and processing of rendered fats. Official Journal of the European Union 21/01/2005;L19:27–33.

[16] Council Directive 91/676/EEC of 12 December 1991 concerning the protection of waters against pollution caused nitrates from agricultural sources. Official Journal of the European Communities 31/12/1991;L375.

in the digester. Furthermore, in co-digestion cases, where usually extra-farm feedstock are used, a further quantity of nitrogen is added to the manures or crops, increasing the amount of total nitrogen. Thus, where there is nitrogen in excess with respect to the quantity applicable to the soil, it is essential to adopt further treatments, or other solutions have to be considered.

Moreover digestate management and its final use seem to be the most complicated and unclear aspects of Italian regulation concerning biogas. Even if the EU Regulation 1774/2002 concerning disposal procedures and use of animal origin by-products, as well as the subsequent temporary and implementation norms, has been assimilated to the national legislation, the classification of the digestate is still unclear, especially when co-digestion is applied (Mantovi and Bonazzi, 2010). When manures are mixed with other biomass (the most widespread technique in Italy), the resulting digestate could be classified as fertilizer for agronomic uses, or a reject that have to be treated or disposed in landfills. It is clear that in the first case digestate could benefit the farm, but in the latter case it constitutes a considerable cost. Some regions issued regulation that considers digestates as zootechnical effluents (Mantovani and Bonazzi, 2010), but national regulation that establishes a common digestate classification and a national way of managing is needed.

Chapter 2: Costs and benefits of farm-scale biogas plant

In order to assess the potential advantages or disadvantages of the technology applied in specific case and to adequately inform farmers' decisions, cost benefit analysis of an anaerobic digestion project should evaluate not only its feasibility and profitability from a financial point of view, but also its indirect social and environmental consequences. As reported by Yiridoe et al. (2009) "Growing interest in energy from renewable sources is prompting governments, power utility companies, and private individuals to more carefully evaluate technologies for generating ''green'' energy, which previously were considered technologically infeasible and/or economically not viable".

Nowadays biogas is quite popular with farmers, as it can very often offers a direct improvement of agricultural income, due to the possibility to commercialize energy forms, and to benefit from a variety of governmental supporting systems, such as incentives, financing, feed in tariff and gate fees. While biogas production certainly generates monetary returns for farmers, it also has potentially significant positive environmental externalities. In fact, as asserted by Yiridoe et al. (2009), "On-farm biogas energy production is not only a potential source of income for farmers, but can also generate environmental benefits to society as a whole".

The most part of the assessment of biogas production have focused on financial feasibility and market costs and benefits of electricity production; however also the "non-energy" and the external benefits generated by the on-farm AD plant should be taken into account when evaluating the technology from society's point of view: savings in costs and environmental benefits can crucially influence the overall process (Highman, 1998; Yiridoe et al., 2009).

The financial profitability of anaerobic digestion plants has been widely studied and several financial analysis of different biogas plants have been carried out (Rubab and Kandpal 1996; Highman, 1998; Lien, 2001; Metha, 2002; Murphy et al., 2004; Lazarus and Rudstrom, 2007; Wulf et al., 2006; Brown et al., 2007; Gebrezgabher et al, 2009; Madlener et al., 2009; Tricase and Lombardi, 2009; Yiridoe et al., 2009; Binkley, 2010; Karellas, 2010; Ragazzoni et al., 2010).

Some Authors developed different models to give a preliminary technical and financial assessment of project's feasibility. For example de Vries et al. (2006) create a Microsoft

Excel spreadsheet[17] that evaluates the financial feasibility of investment in anaerobic manure digesters on Florida (USA) dairy farms that use hydraulic flushing systems for manure management; yet Gloy (2008) planned a Microsoft Excel spreadsheet[18] to give a pro-forma financial statements for biogas projects and conduct a discounted cash flow analysis of the projects; also Lazarus (2009) constructed another model[19] in Microsoft Excel which helps users to make initial screening of profitability or financial feasibility of installing a plug flow or mixed anaerobic manure digester on a Minnesota (USA) dairy farm; while Ragazzoni et al. (2010) published a book in which they propose some guide lines to the farmers interested in investing in the biogas chain, giving introductory information about the bioenergy chain and the relative Italian legislation, supplying data concerning the costs and the revenues implied in the investment, explaining in detail all the steps to fulfil the financial model, named "GasWerde", and presenting some cases of study.

Actually some software have been developed to provide guidance for farmers, livestock producers, developers, investors, and others in the agricultural and energy industry that may consider biogas technology as a livestock manure management option. For instance: the American "FarmWare 3.1"[20], developed by the United States Environmental Protection Agency (U.S. EPA) inside the AgSTAR program, provides guidance on screening for project opportunities, selecting a gas use option and conducting site-assessments to identify technically appropriate, suggests cost-effective biogas recovery option(s) and assists farmers in securing an energy contract, selecting a developer, obtaining project financing and complying with permitting requirements (U.S.EPA, undated a); and the Italian ADEcoTecDSS[21] realized by C.R.P.A. s.p.a. (Animal Production Research Centre) that elaborates different technical solutions depending on the farm conditions, and permits to analyze different business scenarios to determine the real economic opportunities of the AD investment through the classical financial analysis (C.R.P.A. s.p.a., 2008).

It should be underlined that the benefits considered in those models refer strictly to the revenues derived from the selling of energy (or gas) generated by the biogas, and few of them evaluate the "non-energy" benefits. For example Ragazzoni et al. (2010) include in the assessment the potential avoided transport costs, and de Vries et al. (2006), Gloy (2008) and

[17] Available at: http://dairy.ifas.ufl.edu/tools/#digesters. Last access: 16th September 2010.
[18] Available at: http://agfinance.aem.cornell.edu/Publications/AD%20Systems/Digester%20Economics.xls. Last access: 16th September 2010.
[19] Available at: http://tinyurl.com/digester-xls. Last access: 16th September 2010.
[20] Available at: http://www.epa.gov/agstar/resources/handbook.html. Last access: 16th September 2010.
[21] A consultive version is freely downloaded at: http://www.crpa.it/nqcontent.cfm?a_id=4782&sp=adecotec. Last access: 16th September 2010.

Lazarus (2009) consider the benefit derived by the avoided methane emissions in term of carbon credits, always in a private financial point of view.

Moreover no one of the aforementioned models carry out an economic analysis, valuating and apprising the external costs and benefits that could be generated by the installation of the AD plant.

Only few studies concerning the economic analysis of dairy and swine farm-scale biogas plants have been found in literature. For example: Gebrezabher et al. (2009) analyzed the economic performance of a AD plant in The Netherlands using shadow prices of inputs and capacity, which highlights the social value of using the digestate as organic fertilizer or soil conditioner, and Yiridoe et al. (2009) carried out an analysis of the economic feasibility of biogas plants, assessing also the "nonmarket cobenefit" (Yiridoe et al., 2009) (to be further discuss in Section 2.2).

Since the scope of this thesis is to assess the feasibility of a farm-scale AD plant, taking into consideration also the "non-energy" benefits and the externalities induced by the biogas chain, basing on the aforementioned models, a simple model has been developed in order to carry out a financial and an economic analysis with the Costs-Benefits analysis approach. It will be explained in detail in Chapter 3.

The remainder of this chapter presents an overview of the main costs and benefits generated by on-farm AD and biogas production, with a focus on Europe and, more specifically, Italy.

It has been decided to distinguish those costs and benefits in two main categories in accordance with the different level of beneficiaries involved:

- costs and benefits to the farmer: the costs and benefits that pertain to the individual farmer (private level), and
- external costs and benefits: the costs and benefits that influence the whole community (public level).

Table 8 presents a schematic summary of the main costs and benefits that can arise from the installation of a farm scale biogas plant.

Potential costs and benefits to the farmer:	Potential external costs and benefits:
Costs: • investment costs; • operation and maintenance costs; • transport; • acquisition of feedstock; • disposal of digestate; • opportunity cost of feedstock.	Costs: •increase of NH_3 losses; • H_2S and NO_x emissions ; • potential stress to the ecosystem if large scale energy crops plantation are exploited.
Benefits: • electricity selling; • heat energy selling; • biogas or biomethane selling; • digestate selling; • supporting systems (incentives, feed in tariff, financing); • oil derived fuels savings; • gate fees; • potential savings in chemical fertilizers, herbicides and pesticides; • water savings if combined with water treatment technologies; • easier management and handling of the farm animals effluents; • hypothetical market for carbon credits ; • reduction in costs of negotiation and management of the possible legal disputes with the residents caused by the farm activities; • potential bedding savings.	Benefits: • energy self-sufficiency; • social welfare derived from the production of renewable energy; • provision of employment and industry development; • potential reduction in farm products price due to the reduction in management and disposal costs of the farm animal effluents; • odour control; • GHG emissions reduction and consequent climate change mitigation; • lower air pollution; • replacement of chemical fertilizers; • use of rejects materials and recycle and recirculation of the matters; • potential surface- and ground-water conservation and protection; • potential recycling water use; • potential reduction in pesticides use.

Table 8: main costs and benefits accruing from a farm scale biogas plant at private and social level.

2.1 Costs and benefits to the farmer

The installation of an anaerobic digestion plant imply sure expenditures (costs) and potential incomes (benefits) for the farmer concerned.

Usually the various costs components for an operational farm-scale AD plant are essentially the investment costs and the operation and maintenance costs (O&M) (DGS and Ecofys, 2005). There are also some variable factors that influence enormously the entire profitability of the plant (as explained in section 2.1.1): the acquisition of the raw material, transport, the end disposal of the digestate could represent significant costs in some cases (Gebrezgabher et al., 2009; Ragazzoni et al., 2010).

The main sources of benefits for the individual farmer are constitute by the selling of energy derived from biogas and by the acquisition of the incentives. In Italy feed in tariff for electricity production is the main sure source of income for the farm with an operating AD plant. Moreover an AD plant can offer also some indirect benefits, such as savings in costs. For example using the self-produced renewable energy could generate savings in the electricity bill, or using the end digestate as organic fertilizer could avoid part of the chemical fertilizer cost (as explained in the following sections). “A comprehensive economic analysis should include any avoided costs”, as affirmed by Highman (1998).

Even if those benefits could represent only a little percentage of income in comparison with the total revenue guaranteed by the national supporting scheme, they could influence positively the farmers’ decision about the installation of the AD plant and its profitability.

Those potential savings have not been studied carefully yet, and many existing studies and financial analysis have not given those benefits appropriate consideration (Yiridoe et al., 2009).

2.1.1 Costs to the farmer

Usually the investment costs category groups together the main plant engineering components (such as excavation, digester, storage tanks, mixing equipment, pumps, pipes, biogas transformation unit, upgrading system, etc), the civil works and personnel, the engineering and construction and the development of the project. Investment costs are consider fixed costs (Brown et al., 2007; Karellas et al, 2010).

Since AD plants are often engineered to fit the individual needs of a particular farm, due to the wide range of possible designs and operating conditions, capital cost figures are not easily obtained and it is difficult to standardize the exact components included in each system (Metha, 2002; DGS and Ecofys, 2005; Karellas et al., 2010). The task is further complicated by the fact that itemized budgets with each component (e.g. pumps, valves, mixers) separated out by cost are generally not publicly available. For example, the listed cost of a digester tank will generally aggregate the cost of the tank, roof, insulation, heating and related components together.

The variability of the total investment costs is wide: for example, depending on the typology of digester installed and on the size of the plant, the cost of a digester may vary between 250 € and 700 € for each cubic meter of digester (DGS and Ecofys, 2005; Tricase and Lombardi, 2009). The costs of the installation of AD plant, taking into account civil works, electromechanical works and a cogeneration unit, could range from a minimum of 2.500 € per kW of installed power for plant with a power higher than 500 kW, to a maximum of 7.500 € per kW for plants with a power lower than 250 kW, depending also by the typology of the digester and of the CHP units (Tricase and Lombardi, 2009; Ragazzoni et al. 2010). This range is wide, but it is confirmed by a survey of recently installed AD plants conducted in Italy (Ragazzoni et al., 2010).

However, Ragazzoni et al. (2010) suggest a unitary investment cost for small-medium farm scale plant between 4.000 € and 5.000 € per kW installed. Obviously the cost per unit of kW is higher for small plants (power ≤ 250 kW) than for bigger plants (power ≥ 500 kW) (Figure 11).

Several factors could influence the initial investment expenditure, such as the diet type: for example, the amount of total solids and the relative organic matter increase with the addition of energy crops or crop residues to the digester, requiring in this way more complex management of the not homogeneous matrix (especially concerning transporting, loading, mixing and downloading actions). Obviously, the installation of additional devices (such as pre-heater, sanitization systems, upgrading systems, nitrogen removal systems, etc.) increases remarkably the final costs.

It is also important to indicate the increase of the investment costs related to the increase of the power installed (Figure 12). The installation of an AD plant with a power equal or higher than 500 kW imply considerable costs; therefore it is suggested to analyze carefully the financing opportunities, the feedstock supply chain and consider how to use (or dispose) the digestate (Ragazzoni et al., 2010) when such plant size are provide for.

Anyway, Ragazzoni et al. (2010) estimate a total investment costs between 500.000 € and 1.500.000 €, for Italian small and medium farm-scale AD plant.

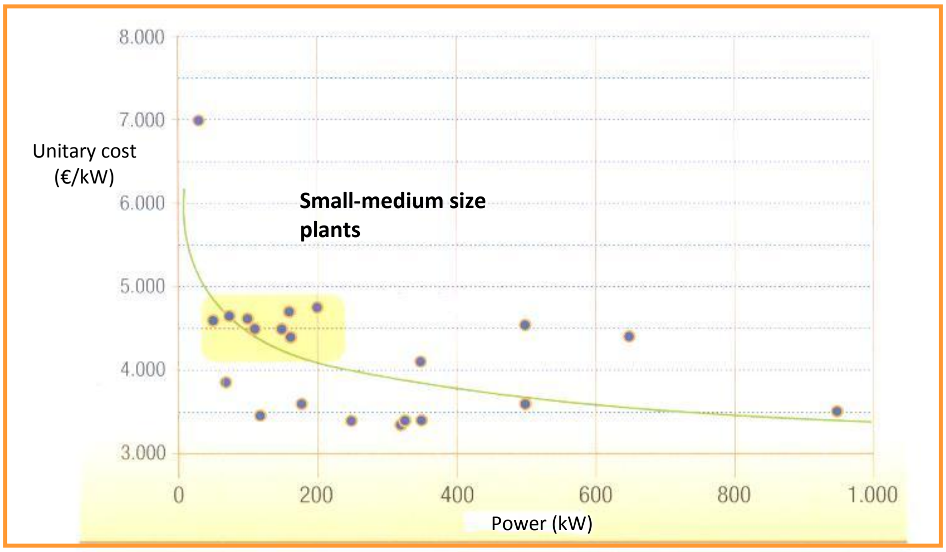


Figure 11: Dynamic of the costs of AD plants related to power installed (Ragazzoni et al., 2010).

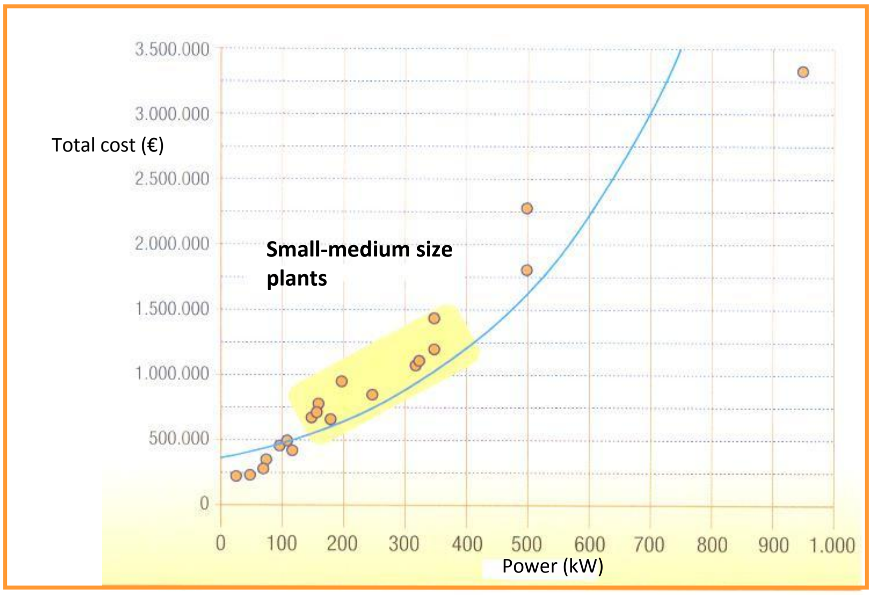


Figure 12: Dynamics of the total investment costs related to power installed (Ragazzoni et al., 2010).

The other source of cost is represented by the operation and maintenance (O&M) costs, that refer to all the operations needed annually by the plant to run in a optimal way (such as engine oil change, plant overhaul, etc.) (DGS and Ecofys, 2005; Brown et al., 2007). They are classified as variable costs.

Ragazzoni et al. (2010) estimate the costs of the ordinary management of the plant, the routine maintenance, the full service of co-generator, physical-chemical analyses and other general expenditures, to be in the range 0,047-0,074 €/kWh of electricity produced. Considering the average of these value and supposing to have an AD plant with an installed power of 200 kW, working annually for 7.800 hours (this is a precautionary value because generally a good functioning AD plant has to work annually about 8.200-8.300 hours (Guercini, 2010)), the O&M costs reach approximately the average value of 94.400 € per year.

Karellas et al. (2010) assumed that the total annual O&M costs correspond to the 3-5% of the total plant costs (the total plant costs in this study includes “the costs of the basic equipment plus costs for erection, piping, instrumentation, electrical works, civil works, buildings, engineering, management, commissioning, contingency and interest during construction” (Karellas et al, 2010)).

It could be possible that also extraordinary costs occurs during the investment lifetime. An analysis carried out by C.R.P.A s.p.a. (2008) considers an extraordinary maintenance cost of the cogenerator of 0,072€ per electric kWh produced that should be paid every 8 years after the installation, and an extraordinary maintenance cost of the entire plant of about 0,11 €/kWh_e paid every 10 years. Whereas Ragazzoni et al. (2010) suggest to use an annual risk coefficient to evaluate the extraordinary costs, which can reach an average value of 0,007 € per kWh_e produced: 0,005 €/kWh_e for the plant and 0,002 €/kWh_e for the cogenerator.

Then there are some variable factors that affect considerably the total costs of the AD plant, such as: costs for the acquisition of extra-farm raw materials and related transport costs, cost for the digestate disposal, costs for the distribution of the biogas (such as the connection to the electricity or gas supply), costs related to the possible water use for mixing the material fed into the digester (especially when materials with a high dry matter content are used) and the energy to run the digester, etc. (Brown et al., 2007, Gebrezgabher et al, 2009; Ragazzoni et al, 2010).

Usually a farm-scale biogas plant is built where zootechnical or agricultural productions are already present. In this case it could be possible to neglect the costs of feedstock’s production, because it is assume that it is already present and counted in the farm production-chain. Nevertheless it could be taken into account the production cost of the energy crops, if they are not already cultivated in the farm. The cost of production of the corn silage could vary from 30 €/t and 35 €/t, whereas the cost of production of the sorghum silage could range from 23€/t to 26 €/t (Corradini, 2010).

Anyway the use of those materials as AD dedicated feedstock implies an opportunity cost, especially regarding to energy crops. In fact directing the crops to the digester means to lose the opportunity to sell them in the market, also for other purposes (for example for human or animal feeding). So the opportunity cost could be considered as the market price of crops (table 9). In some cases some products are not traded in a national market, as happens in Italy regarding the silage. Usually the silages are produced in the farm, to supply the farm needs, and rarely it is possible to witness the trade of those products (Rossetto, 2010; Corradini, 2010). In those cases the opportunity costs could be matched to the crops' production costs (Corradini, 2010) (table 9).

Concerning manure and animal sludge generally there is not an opportunity cost because usually they are used in the farm as organic fertilizers (function replaced by the digestate) or even farmers pay to get rid of them.

If the farmer is interested to increase the final production of biogas, the acquisition of external matters is necessary: this implies further expenditures to buy the materials needed.

As reported by Gebrezgabeher et al. (2009), "Cost of feedstock is the next most important economic factor" after the amount and the type of the feedstock. This is clearly proved by what happened in Germany: between the year 2006 and 2007 the rate of installation of AD plants decreased by 69%. This decrease was firstly due to the major increase in the price of agricultural raw materials, since 98% of these production units methanize energy crops. The cereal most used in German co-digestion AD plants is maize, whose price increased by 83% between October 2006 and 2007 (from 18€ to 33 € per ton, excluding transport and silage costs) (EurObserv'ER 2008).

To estimate the cost for extra-farm feedstock it is necessary to know the current price of the matter (table 9, figure 13).

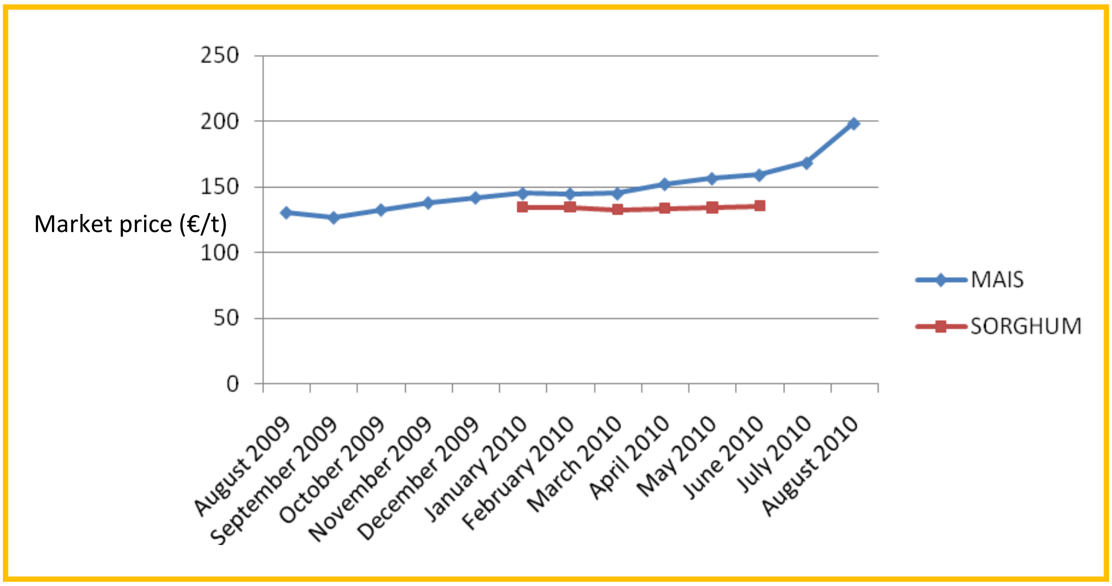


Figure 13: Dynamics of the market price of corn and sorghum grains[22].

Crop	Grain price[a] (€/t)	Silage price[b] (€/t)
Corn	148	>30
Sorghum	134	>24
Wheat	171	≥ 18
Barley	138,8	≥ 18
Triticale	191	≥ 18

a= the prices of Sorghum and Triticale grains are calculated as the average value of the annual prices revealed by "L'Informatore Agrario"; the price of the other grains is the average value of the annual prices reported by ISMEA.

b= in Italy a national market for silage is not developed yet; the selling prices could vary considerably, but they are always not lower than the crops' production cost. Data supplied by CALV (*Consorzio Agrario Lombardo Veneto*) and Venetoagricoltura offices.

Table 9: Average price for corn and sorghum energy crops used for biogas production in Italy.

[22] Corn's data refers to the period August 2009-August 2010, they are collected from ISMEA website, available at: http://www.ismea.it/flex/cm/pages/ServeBLOB.php/L/IT/IDPagina/126#IsmeaAnchPMO6, last access: 15th September 2010. Sorghum's data refers to the period January 2010-June 2010, collected from the weekly newspaper "L'informatore agrario").

Also the digestate could represent a source of further costs. If it is not used as soil fertilizer for some reasons (such as it exceed the amount reachable by the soil or it contains pollutants and it can't be applied on the soil), it has to be disposed in landfill or subjected to specific treatments or more fields have to be leased or bought. Those actions usually represent further costs. Therefore, it is important to quantify the amount of digestate in order to estimate the eventual costs of disposal (if the digestate is classified as waste) or spreading (if the digestate is classified as fertilizer). A possible method to evaluate the final amount of digestate is proposed by Ragazzoni et al. (2010): the reduction quota of the input biomass is calculated through the amount of biogas generated from the dry organic matter. It could be defined by the following formula:

$$R\ (kg/t) = DOM\ (kg/t) * BY\ (\%)$$

Where R represents the reduction coefficient of the input biomass; DOM is the amount of dry organic matter and BY represents the biogas yield of dry organic matter.

In the following table are reported the value of DOM, BY and R for some feedstock that could be direct to anaerobic digestion.

Feedstock	**DOM** (dry organic matter)	**BY** (biogas yield)	**R** (reduction coefficient of the input biomass)	
	(kg/t)	(%)	(kg/t)	(%)
Energy crops:				
Corn	304,00	60	182,40	18,24
Sorghum	270,00	60	162,00	16,20
Slurry:				
Swine slurry	45,00	45	20,25	2,03
Cow slurry	63,75	40	25,50	2,55
By-products:				
fruit and vegetables	114,00	40	45,60	4,56
potato pulp	121,50	55	66,83	6,68
olive press rejects	855,00	80	684,00	68,40
vinasses	387,00	60	232,20	23,22
whey	43,00	70	30,10	3,01
slaughtering rejects	126,00	80	100,80	10,08
intestines	127,50	75	95,63	9,56
blood flour	720,00	80	576,00	57,60

Table 10: estimation of the reduction coefficient of input biomass (Ragazzoni et al., 2010).

Transport is another variable that weigh heavily on the final costs (Ørtenblad, undated; Ragazzoni et al, 2010). Carrying and volumetric capacity, weight, dimension and kind of vehicle, time needed to move the biomass, covering distance and type of biomass are the main factors that affect the transport costs (Ragazzoni et al., 2010).

Ragazzoni et al. (2010) estimated the transport costs for a subcontracting vehicle with a biomass carrying capacity of 20 tons: the transport unitary costs could vary from 3,05 € per ton of biomass for a distance of 1 kilometre, to 5,5 €/t for a distance of 50 kilometres. For example the total transport cost to cover a distance of 10 km comes to about 70 €, reaching 110 € to cover a distance of 50 km (table 11).

Buratti et al. (2009) calculate the transport cost considering only the fuel consumption of the tanker vehicle, with a carrying capacity of 35 m^3, corresponding to 34,9 tons of animal slurry. They calculate a consumption (average between full load on the going way, and empty load on the return trip) of 41,4 litres of fuel to cover a distance of 100 km. In 2009 the average price of the light diesel was 1,37 €/l, thus, the transport cost was estimated to be 0,57 €/km.

It is evident that transport costs could be decrease by limiting the distance of supply feedstock and by spreading of the digestate on fields situated near the biogas plant.

It should also be reminded that if the distance of supplying feedstock exceeds 70 km far from the farm with the AD plant, the incentives are not granted in the Italian support scheme.

Distance (Km)	Total cost[(a)] (€)	Unitary tariff[(b)] (€/km)	Unitary cost[(c)] (€/t)
1	61,00	61,00	3,05
5	65,00	13,00	3,25
10	70,00	7,00	3,50
15	75,00	5,00	3,75
20	80,00	4,00	4,00
25	85,00	3,40	4,25
30	90,00	3,00	4,50
35	95,00	2,71	4,75
40	100,00	2,50	5,00
45	105,00	2,33	5,25
50	110,00	2,20	5,50

[(a)] = the total cost is the sum of a fixed tariff (60€) and a tariff related to the distance;
[(b)]= the unitary tariff represent the total cost divided by the distance;
[(c)]= the unitary cost is the total cost related to the carrying capacity (20t of biomass per carrier): it is the unitary tariff multiplied for the distance and divided by the carrying capacity.

Table 11: Transport costs (Ragazzoni et al., 2010).

Obviously, electricity pricing and interconnection requirements for connecting small electricity production sites to utility grids are complicated issues which can "make or break" a project financially (Lazarus and Rudstrom, 2007).
Moreover some bureaucratic problems could be generated: cases where the production of electricity is active and the biogas plant is in full swing, but it cannot be exploited because utility grid connection is in preliminary stage, or licence or permissions are late, are not rare in Italy (Zoppelletto, 2008; Energia Rinnovabile, 2010).

Taxes should also be taken into account in a detailed and true financial analysis. Anyway, in Italian agricultural reality, under certain fairly general condition (such as the "prevalence principle" ("*principio della prevalenza*")) you don't have to pay any income taxes on energy production if the latter is considered as a farm activity. Usually farm-scale biogas plant are subjected to this principle. Other cases are outside the scope of this dissertation.

2.1.2 Benefits to the farmer

The production and sale of energy (electricity, heat, or untransformed bio-methane) derived from biogas transformation constitute the main reason why a farmer would consider installing a biogas system (U.S. EPA, undated a). In fact, by recovering biogas and producing on-farm energy, farmers can reduce monthly energy purchases from electricity or gas suppliers, enlarging the farm energy self-sufficiency (U.S. EPA, undated a and b), and obtain further profits, if there is the possibility to sell the surplus energy.
Electricity sale constitutes the main source of extra-income for farmers who installed a biogas plant in most European countries, such as Germany, Denmark, Austria and Italy. This is due especially to the favourable electricity price maintained by the government, to support the renewable energy production.
In some European countries and in the USA, independently of the incentive systems, there is the concrete possibility to draw up a real energy contract with the national electricity company or private companies. The main typology of energy contracts are: "sell all-buy all" where all the electricity produced is sold to the company and all the electricity required by the farm is bought back; "surplus sale", in which only the surplus electricity is sold; "net metering" where the utility allows a costumer to offset only their electrical requirements and

receive credits for any energy produced which exceed that need (Lazarus and Rudstrom, 2007).

In Italy, the sale of electricity is completely bound with the incentive system.

Several investment analyses of AD plants assert that supporting instruments are fundamental to make the investment feasible, especially for small farm-scale plants (Brown et al, 2007; Lazarus and Rudstrom, 2007; Gebrezgabher et al, 2009). Brown et al. (2007) affirm distinctly that "Without incentive schemes, on-farm biogas energy production was not economically feasible".

As already mentioned (see previous section and chapter 1, section 1.7), there are two main possible alternatives:

- a feed in tariff incentive system ("*tariffa onnicomprensiva*") which is a sort of "sell all-buy all" contract where all the electricity produced by the AD plant is sold to the utility for a fixed price (0,28 €/kWh) and the electricity needed for running the plant and the whole farm is bought back. Indeed the retail price of electricity is typically lower than the subsidized price they receive, in fact the current market price of electricity comes to about 0,07 €/kWh (D'Imporzano et al, 2010). It is important to notice that this option is only available to plants with a power lower than 1MW;
- under the "Green Certificate" (CV) scheme CVs are assigned based on the total amount of electricity produced by the AD plant, irrespective of whether it is sold or consumed. Usually, with the "green certificate" system, the farm sell only the surplus electricity to the utility company at the market price.

Heat energy from biogas is fundamental in cold climate countries. In Finland for example farm-scale AD plants are built mainly to fulfil the heat demand: nowadays no farm-scale plants are converting biogas in electricity (BIONOVA Engineering, 2009). Most farms in Finland are warmed using light oil, due to their position far from the urban areas and far from centralized heat district units. Replacing light oil with on-farm produced biogas represents a significant saving in costs. For example, the Koivikko experimental hi-technology dairy farm located in northern Ostrobotnia region (Finland) is interested to built an anaerobic digestion plant to supply energy for the stable operations. Currently the farm uses about 20.760 litres of light oil annually to warm the dairy stable (120 cows) and to dry cereals, at cost of 0,43€ per litre[23]. The expenditure for heating reaches 8.927€ per year. If the digester will be fed only

[23] The price of light oil is referred to the minimum level recorded during the winter of 2010 (Kaisto, 2010).

with the manure produced by the animals present in the stable, and if a co-generator will be installed, the heat energy that could be generated in one year is about 185.382 kWh, that could replace about 12.977 litres of light oil (see table 12). In this case the guarantee annual saving in heat energy costs come to 5.580 €, the 62,5% of the current heating expenditures.

Considering that the price of oil derived fuels is increasing considerably, an AD plant could help farmers to avoid heating expenditures.

In Italy the major part of the plants are built to produce electricity or they are CHP plants, but heat constitute only a secondary form of energy. Waste heat from anaerobic digestion usually is used to warm water for space heating digester, stables, and other outbuildings, for milking and weaning processes, or for dry animal fodders, thereby offsetting heating costs on the farm (Brown et al, 2007). There are only few isolated cases of selling or exchanging the heat energy produced by biogas plant with neighbouring buildings. Usually these selling contracts are the result of private negotiations, and involve large scale or industrial biogas plants rather than farm-scale plants (Malagoli, 2009). Anyway incentive system of “white certificate” is under development (Energia Rinnovabile, 2010).

Some authors assert that the possibility to exploit the heat energy derived from an AD plant could influence positively the whole profitability of the plant (Metha, 2002; Brown et al., 2007; Balsari et al., 2009a; Balsari et al., 2009b; Guercini, 2010; Ragazzoni et al., 2010). Thus AD heat energy production will be taken into account during the economic analysis: trough the higher heating value (or gross calorific value) of the different fuels, it has been calculated the amount of fuels that could be replace with one cubic meter of biogas (table 12). Multiplying the total amount of fuel replaced with biogas to generate heat energy with its price (table 13), it is possible to calculate the heating savings.

Fuel	Higher heating value(a,b)			To obtain 1 kWh		One m³ of biogas could replace	
	kcal/Nm³	MJ/Nm³	kWh/Nm³	Nm³		Nm³	
biogas	4500	18,83	5,23	0,19		1	
methane	8400	35,15	9,77	0,10		0,54	
LPG	27000	112,97	31,41	0,03		0,17	
natural gas	8250	34,52	9,60	0,10		0,55	
	kcal/kg	MJ/kg	kWh/kg	kg	l	kg	l
diesel	10210	42,72	11,88	0,08	0,07	0,44	0,37
gasoline	10986	45,97	12,78	0,08	0,06	0,41	0,31

(a): the higher heating value of biogas was calculated as the average value reported in: Cassini, S.T. 2003. "*Digestão de resíduos sólidos orgânicos e aproveitamento do Biogás".* Vitória – ES: PROSAB – Programa de Pesquisa em Saneamento Básico, 2003. Cap. 5, p. 121-130.
(b): the higher heating value of the other fuels were found in the webpage: http://it.wikipedia.org/wiki/Potere_calorifico, (last access: 14th September 2010). Some of them refer to the UNI10389-1:2009 regulation.

Table 12: Comparative table of different fuels.

Fuel	kWh	Ponderal price (€)	Energy price (€/kWh)	VAT
1 m³ of methane from the grid	10	0,7	0,070	20%
1 kg of agricultural diesel	11,67	0,901	0,077	10%
1 kg of heating diesel	11,67	1,22	0,105	20%
1 l of LPG	6,82	1,116	0,164	20%

Table 13: Market prices of different fuels used in agricultural sector referred to September 2008 (personal elaboration from Antonini and Francescato (2009)).

Use bio-methane (the upgraded biogas) as a vehicle fuel or injecting it into the gas utility are actual challenges. A new market is developing and extra-earnings for farmers are presumed, especially in those country that are leaders in biogas production and biogas innovation, such as Germany and Sweden (EurObserv'ER, 2008). Unfortunately, in Italy these option of using biogas are only in a development phase, as reported in the National Action Plan for Renewable Energy[24]. It is important to underline that the investment cost of upgrading is very high: it could vary from 0,5 to 1,7 million of Euro, for upgrading system with a capacity between 100 to 1.000 m^3/h (Piccinini, 2007b). Conventional wisdom suggests that only plant with a power equal or higher than 1MWe can justify such high investment and maintenance costs (Veneto Agricoltura, 2009). In this dissertation the use of bio-methane is not analysed because only small farm-scale plants are considered, with a power upper-limit of 250 kW.
Anyway assuming that the upgraded biogas could be injected into the national grid and paid to the farmer as the Italian household consumers pay for the natural gas, there could be an income of 0,2-0,3 € per standard cubic meter (Sm^3) [25] of bio-methane.

It is clear that biogas fuel generated by the AD plant could substitute totally or partly the fossil fuel used in the farm, avoiding the farmer energy costs and generating also several externalities, that relapse on the whole society.

Another income could be represent by gate fees. Generally a gate fee (or tipping fee) is the charge levied upon a given quantity of waste received at a waste processing facility. Nowadays the costs to dispose in landfills some categories of products, such as residues from agro-industries, rejects from slaughters or biomass in general, are high. So it is possible to reach an agreement (the gate fee) between the producer of the "bio-wastes" and the owner of the AD plant. Both of them will take advantage of this gate fee because the waste producers will save part of the money for the disposal (usually the gate fees paid to dispose bio-waste in AD plants are cheaper than the gate fees paid for the disposal in landfills), and the AD owners will earn extra money from the waste producer and also he will increase the biogas production feeding the plant with additional substrate.

[24] Ministero dello Sviluppo Economico, Piano di Azione Nazionale per le Energie Rinnovabili (Direttiva 2009/28/CE), June 11th, 201. Available at: http://www.sviluppoeconomico.gov.it/pdf_upload/documenti/Piano.pdf. Accesed: July 29th, 2010.

[25] This is only an indicative and estimated value derived from the average of the gas bill's price pay by the households of Veneto region (Italy). Available at http://www.autorita.energia.it/it/dati/condec_gas.htm; last access: August, 31st, 2010.

Usually selling contracts and gate fee's price are the result of private negotiations.
Anyway care must be taken when particular categories of co-substrates are used (e.g. animal slaughtering and butchering rejects, organic fraction of solid municipal waste, slurry from urban and industrial water treatment, etc.). In fact the rejects of the AD could be classify as refuse if those materials are added in the digester; the costs of disposal are high and, in most cases, would completely offset the gains from AD digestion.

Chemical fertilizer savings could be a significant benefit for the farmer that use the digestate as fertilizer. In fact the digestate products have obvious value as organic fertilizers and soil conditioners (Paavola et al., 2009b; Yiridoe et al., 2009): most of the macro-nutrients (nitrogen (N), phosphorous (P) and potassium (K)) present in the original raw feedstock are retained in the digestate, and some molecules are modified during AD process, resulting more readily available as crop nutrients (Yiridoe et al., 2009).
During anaerobic digestion about 25 to 40% of the organic dry matter is transformed and converted to methane and carbon dioxide, while the nitrogen content remain essentially unchanged: this results in a decrease of the carbon/nitrogen ratio and improvement of the quality of digested substrates (Klingler, undated).
The most part of organic nitrogen mineralizes, converting in ammonium ($NH4^+$) or nitrate (NO_3^-) ions, which are easily available and absorbable for plants roots (Nelson and Lamb, 2002; Börjesson et al., 2007; de Boer, 2008; Ragazzoni et al., 2010). Therefore anaerobic digestion should increase the supply of nitrogen to crops in the short term (de Boer, 2008).
Experiments conducted in Finland suggested that the biogas process enhances the fertilizer value of the digestate as compared to using raw manure by increasing its ammonium content by 20-30% on average. Its phosphorous content remains approximately the same. This could imply that the need for inorganic N-fertilizers is reduced by 20-30%, with consequent savings in inorganic fertilizers costs and decrease in energy consumption in the fertilizer industry (Paavola et al., 2009a).
An Italian farmer (working in a dairy farm near Brescia city) confirmed that the most interesting aspect of using separate digestate as fertilizer is that it permit to reduce the resort to chemical fertilizers, whit a considerable economic saving and a remarkable diminution of the environmental impact (Mossini, 2010).
As Klingler (undated) reported, in southern Germany a study revealed that 75% of the farmers interviewed agreed that digestate is similar to mineral fertilizers and 50% of them were able to reduce the amount of mineral fertilizers.

In Denmark, a dairy farm, noticed that, from 1991 to 1993, since the installation of an AD plant, and the spread of the digestate on the fields, the purchase of nitrogen mineral fertilizer has decreased from 130 to 58 Kg per hectare (45%), corresponding to a saving in costs of 36% (Ørtenblad, undated).

Moreover, with the help of a simple solid-liquid separator, the farmers has an array of different organic fertilizers for different needs on the fields: the insoluble phosphorous ends up in the solid fraction making it an effective P-fertilizer, whereas nitrogen ends mostly in the liquid fraction, making it a efficient N-fertilizer, while more slowly available nitrogen is retained in the solid fraction (Paavola et al., 2009a; Ragazzoni et al., 2010).

Even if the benefits are clearly described, it is not possible to affirm with certainty the amount of savings in nitrogen chemical fertilizers: the literature presents only few studies about this topic and more samples and analysis are necessary.

The management and the operations of storage and transport of the digestate are facilitated respect to the untreated farm animal effluents. The benefits bearer by the biogas chains affect the effluents management most of all. Surveys concerning the management of the animal slurry and manure demonstrate that anaerobic digestion could influence positively the economic balance of the farm (Bonazzi, 2003). The disposal of the swine slurry has a cost – which is affected especially by the transport cost of the slurry and it increases with the distance from the stable to the spreading fields – that can weigh heavily upon the final costs of the swine meat, as indicated in table 14. It is clear as the lower cost in swine effluents management entails both private and a social benefits.

Treatment	**Treated manure (€/m^3)**	**Meat produced (€/kg)**
Nitrogen biologic removal with Sequencing Batch Reactor	6	0,18
Nitrogen biologic removal with Sequencing Batch Reactor combined with anaerobic digestion treatment of the dense fraction	2,4	0,07

Table 14: The incidence of the disposal cost of swine slurry per kilogram of meet produced (Bonazzi, 2003).

Replacing the manure with the digestate can also allows easier handling and management of the fertilization operations, as timing of the plant uptake of ammonium and nitrate nitrogen, similar to that used in commercial fertilizers, is more predictable than the plant uptake of organic nitrogen from raw manure (Nelson and Lamb, 2002). Since the dry matter content decrease during AD, the fluidity of the treated manure increases and this allows an easier handling and increase the infiltration after spreading (Klingler, undated).

Moreover through anaerobic digestion phytotoxic acids are degraded. Phytotoxic substances in the immature manure (such as a too high concentration of NH_4^+, a too high levels of heavy metals, or organic acids, depending on the typology of manure (Salminen et al., 2001)) can cause necroses and scleroses when applied to growing plants. This is the main reason why overhead fertilizing of a growing field is not done with organic fertilizer, but mineral fertilizer.

Results from phytotoxicity tests on cattle and poultry digestates showed no toxic effect on the germination of garden cress (*L. sativum*) seeds combined with a stimulating effect on the growth of roots (Sánchez et al., 2008). The level of phytotoxicity could be reduced further on by aerobic post-treatment of the digestate (Salminen et al., 2001).

Therefore digested manure can be applied to a growing field (e.g. maize) which usually has a high demand for nutrients and farmers are able to reduce their amount of mineral fertilizer (Köttner, 1994). In this way, anaerobically treated manure increases the range application possibilities in terms of time, crops and housing (Klingler, undated).

This propriety can be consider as a further benefit: in this way the reject can be used and spread on the crops in different period of the crop biologic cycle, according to the nutrients requirement.

In confirmation of the above, Klingler (undated) reported that 100% of the farmers interviewed found digested manure easier to handle compared to untreated manure, as they were able to use the digestate more on crop demand, and 81% of the farmers stated a higher crop yield through better and easily demand driving handling. In fact, measurements showed a yield increase of 2 to 3% compared to untreated manure, even if the type of crops are not specified (Klingler, undated), and the first results of current experimental and demonstrative tests, carried out in Emilia-Romagna (Italy) on corn, sorghum, triticale and other energy crops, prove that the crop production obtained with the use of digestate is substantially equivalent to the one obtained with mineral fertilizer (Ragazzoni et al., 2010).

Organic fertilizer generally contains weed seeds (Klingler, undated), but some authors state that the anaerobic digestion process lowers the ability of seeds to germinate, probably due to the high temperature and to the microorganisms attacks (Engler et al., 1999; Klingler, undated; Nelson and Lamb, 2002; Yiridoe et al., 2009). Anyway further study is needed as results from different proof show contrasting. For example in a study carried out in the fall of 2001 and 2002 in Minnesota (USA), the ability to reduce weed seeds germination was not verified (Katovich and Beker, undated), but, on the contrary, it was confirmed in the findings from a study carried out in Germany: 40% of the farmers agreed on weed seeds germination reduction after using digested manure on farmfields (Klingler, undated).

Also because the AD process lowers weed seed germination, replacing manure with digestate could allow farmers to reduce herbicides use: this could represent savings in the farm economic balance (Engler et al., 1999; Nelson and Lamb, 2002; Yiridoe et al., 2009) and this positive effect could also constitute a reason for organic farmers to integrate a biogas plant in their farming system, since they are not allowed to use chemical herbicides and pesticides in general.

Lazarus and Rudstrom (2003) interviewed the owner of a dairy farm in Minnesota (USA) that adopted an AD plant. The farmer's perception was to have saved in herbicide use an average of US$30 per acre (58,9 €[26] per hectare) (Lazarus, 2010). Unfortunately no estimation of herbicide costs savings are reported in the literature about European or Italian conditions. The value estimated for the Minnesota dairy farm is not transferable to Italian reality: the average costs of herbicide operation (average herbicides cost and distribution cost) is around 70 €/ha for corn crops, and 50 €/ha for wheat crops (Berti, 2010); it is difficult to believe that almost all the costs are knocked down by AD, considering also the complicated and variable cycles of weeds seeds germination.

Additional scientific measurements are needed to quantify the effect and whether biogas technology is able to reduce the use of pesticides (Klingler, undated).

For those reasons, in this study, savings in herbicide use will not considered.

Usually animal manure and slurry, human sewage and organic wastes may contain a wide variety of pathogenic bacteria, parasites and viruses (Colleran, undated).

The use of manure, slurry and sewage as fertilizer, could introduce pathogens that may enter

[26] Changing currency value: 0,7865 on the 9th September, 2010 Available at: http://it.finance.yahoo.com/valute/convertitore/#from=USD;to=EUR;amt=1, accessed the September, 9th, 2010.

in animal and human food chains and water systems, originating potential health hazards (Côte et al., 2006).

Even though only few studies have been carried out to assess the efficiency of anaerobic digestion to remove pathogens from organic wastes (Côte et al., 2006), the results are encouraging.

Keanry et al. (1993) and Kumar et al. (1999), demonstrated that at low temperatures (respectively 28 °C and 20 °C-35 °C in the two experiments) AD technologies partially removed *Escherichia coli*, *Salmonella* and other pathogenic bacteria. Recently, Côte et al. (2006) showed that within the psychrophilic temperature range of 10-21 °C, the anaerobic treatment of swine manure helps successfully to remove the indigenous populations of *Salmonella*, *Cryptosporidium* and *Giardia*, and natural populations of indicator microorganisms (*E. coli* and coliforms) were reduced by 97-100%.

Duarte et al. (1992), Benedixen (1994), Martin and Ross (2004), Song et al. (2004) have been successful in using anaerobic digestion in mesophilic and thermophilic temperatures to remove *Salmonella*, *Streptococci* and other fecal coliform groups.

Concerning the pathogen *Mycobacterium avium paratuberculosis*, responsible for paratuberculosis (Johne´s disease) in cattle and other ruminants and suspected causative agent in Crohn´s disease (chronic enteritis) in humans, the reduction slightly exceeded 99% in Martin and Ross (2004) study.

Given that this pathogen is a major problem in the USA's dairy industry with transmission by fecal-oral contact and the possibility that it is also responsible for the development of Crohn´s disease in humans, the effective 99% reduction in the density of this pathogen is highly significant (Martin and Ross, 2004).

The AgStar Handbook (undated a) declared that pathogen reduction is one of the principal reasons that make a farmer or producer interested in consider installing a biogas system.

In fact, the digestate can be applied to the field with less contamination risks, and a larger number of crops can be fertilized with it, even vegetables and fruits for human consumption. Reduction in pathogens could mean also improvement of animal health with potential savings in cure and antibiotic costs.

Nowadays, the increasing exploitation of anaerobic digestion as co-digestion, treating animal manures and slurries from a large number of farms, food-processing waste, slaughtering processing waste, fish-processing waste, sewage and the organic fraction of municipal solid waste, potentially increases the diversity of pathogens that may be landspread and may enter the animal and human food-chains. This has raised the need for more effective hygiene and sanitation procedures during the operations of anaerobic digestion plants. Usually, in fact, a feedstock pre-sanitation or post-sanitation is required if the plant utilize certain waste categories, in accordance with the EU Regulation number 1774/2002 of the European Parliament and of the Council of 3rd October 2002, laying down health rules concerning animal by-products not intended for human consumption.

Definitely, further studies are necessary and unavoidable to understand and estimate the appropriate benefits due to the whole anaerobic digestion process.

The adoption of solid-liquid separation devices and water purification systems combined with the anaerobic digestion technology could permit to use recyclable water and reduce the farm water consumption, purifying the liquid part of the digestate, until obtaining water, that can be recycled in the stable operations (for example to clean the stable). Recycling water could represent a benefit especially for barn flushing stables, where the amount of water used is significantly high (Wilkie, 2000) or for those farms located in water shortage areas.

Even if the costs of water purification are considerably high, the possibility to provide recyclable water is valuable, as water is becoming an increasingly precious and limited resources.

In this dissertation it has been decided to not factored the water savings into the economic analysis, pending additional documentation.

The solid-liquid separation of the digestate could also offer the possibility to save money in bedding. The solid separated part of manure, called “separated”, could replace the traditional bedding materials (such as straw, wood shaving, sawdust, or synthetic beddings) (Ferrari et al., 2008), as well as the solid separated part of the digestate (Lazarus and Rudstrom, 2007).

The annual cost of those traditional kind of bedding could vary from 56 to 149€/cow. It has been estimated that using the “separated” could generate a saving of 43,6€ per cow per year (Ferrari et al., 2008).

Anyway the use of the “separated” could cause more hygienic-sanitary problems influencing the health of the animal and the quality of the milk (Ferrari et al., 2008).

In Italy the use of the solid part of the digestate is rare and the traditional beddings are favourite. In USA the use of “separated” is more widespread than in Italian farms, but the “separated” is usually composted or dry up before its used or some additives are added to limit the development of pathogens. Those further operations require additional investment, for example for the manure post-separator or the composting site. Moreover additional operating expenses would be also involved (Lazarus and Rudstrom, 2007).

The additional investments and the uncertainty about the health-hygienic-sanitary effects that could come up using the "separate" could affect enormously the final savings in changing the traditional beddings (Ferrari et al., 2008). More studies and proofs are necessary to quantify better the real savings and costs given by the "separated". In this dissertation it has been decided to not count this potential benefit.

Further profits could be obtained by selling the digestate. Usually the digestate is used as fertilizer on-farm fields, but it could be also used as soil conditioner in several sectors: nursery gardens, public green areas, private gardens, environmental and landscape restoring, etc.

In fact the digestate could be eventually transformed (for example pelletized), packaged and sold as potting compost, especially when the digestate undergoes a liquid-solid separation operation and an aerobic post-treatment in order to reach optimal levels of maturity and quality. Currently there is no market in Italy for the digestate. Realistically it is possible to image that digestate could trade for price similar to those of compost or manure, 8-16 €/m^3 [27] and 0,5 €/q[28] respectively.

AD technology could give also the benefit of reducing transport costs. As already explained in the previous section (section 2.1.1) during anaerobic digestion a reduction of the volume of the matter occurs. Even if the reduction of volume is small for some materials (2% for swine slurry and 2,5% for cow slurry (Ragazzoni et al., 2010)) it could favour the reduction in transport costs if compared with the transport needed for the raw material, not undergone to anaerobic digestion process.

For example a dairy farm with 400 heads, produce annually about 8.400 tons of manure[29]. Supposing that the fields distance from the farm is 5 km, and taking into account the value estimated by Ragazzoni et al. (2010) (see table 11) the cost of transport is about 27.300 €. After anaerobic digestion the amount of manure and the transport costs diminish of 2,55% (see table 10): the amount of digested manure that now should be spread is about 8.185 t/y

---

[27] The prices referred to the current price of compost in Italian compost market.

[28] The price refer to the manure available at the farm, without any transport addiction price, and it refers to the year 2006. Available at: http://www.informatoreagrario.it/ita/riviste/vitincam/home_consigli/pdf/letame-corretto-impiego.pdf. Last access: September, 1st, 2010.

[29] The annual amount of manure is calculated starting from the values reported in exhibit of the "*Testo coordinato delle disposizioni regionali vigenti in materia di disciplina dell'utilizzazione agronomica degli effluenti di allevamento e di talune acque aziendali*", section III, attachments from B to H in application of the Regional Decree of the 7th of April 2006. Available at: http://www.regione.veneto.it/NR/rdonlyres/CA04BEA6-39B6-4B11-AEB8-9D437925043E/0/DGR_2495_Coordinato_SEZ_3_4_LDSFDRVersione11.pdf. Last access: September, 3rd, 2010.

and the cost of transporting is decreased at 26.604 €, by 696 €. In the same case, the transport cost calculated as Buratti et al. (2009) suggested amounts to 1.368 €. After AD there should be a savings of 35 €.

In this example the saving is a limited sum respect the total transport cost but if other feedstock are added into the digester, such as energy crops or agro-industrial residues, the savings in transport cost increase, sometimes more than 50%, depending on the raw material and on the amount used (table 10).

2.2 External costs and benefits

Externalities are defined as "... those project inputs or outputs which affect the level of the economic (material) welfare but which do not have market prices" (Campbell and Brown, 2003). Both positive and negative externalities, called also respectively "non-marketed" benefits and "non-marketed" costs, could affect the realization and the feasibility of the AD plant and should be taken into account in an economic analysis.

An AD plant could generate both negative externalities such as an increase of ammonia volatilization, sulphur and nitrogen oxide emissions and potential health risk associated with the exposure to the biogas (Brown et al, 2007) and several positive externalities (see the following sub-sections).

Since these benefits and costs do not have monetary values, externalities are quite difficult to estimate and monetize; usually standard analysis of the financial profitability of biogas production abstracts from the associated non-marketed costs and benefits (Yiridoe et al., 2009).

Srinivasan (2008) affirms that "Such positive externalities imply that the total benefits accruing from the installation of biogas plants exceed the benefits to the individual who receive the service. Society is perhaps, likely benefit more than the individual recipient does.". So, a cost-benefit analysis that omits the consideration of those values is incomplete and misleading (Menegaki, 2008).

An analysis that takes into account both financial and external components could be an instrument useful to evaluate the correctness of the incentives. For example, the quantification of the externalities generated by AD, even though approximate and indicative, could permit to verify if the externalities are accounted for properly in the feed in tariff or in the other incentives.

Moreover, although small scale renewable energy is not competitive when compared to bulk power generation, it could become economically attractive from society's standpoint if the external benefit derived from the AD plant and the external costs of producing energy from fossil fuels are also taken into account (Menegaki, 2008)

Last, considering externalities and emphasizing the environmental and social benefits it would be possible to influence the farmers' decision about installing an AD plant. In this way, it is possible that some of them would act not only in response to monetary profit point of view, but also in accordance with an ethical code.

The main positive externalities that should be taken into account when a farmer is considering to install an AD plant are the following:

- odour reduction;
- GHG emission reduction, contribution to global change mitigation and improving air quality;
- others (such as the reduction of the exploitation of fossil reservoirs, the improvement of energy sources variability and energy self-sufficiency, the provision of employment, environmental benefits, and the social welfare derived from the production of renewable energy).

An AD plant could generate some negative externalities:

- increase of ammonia volatilization especially during digestate storage and handling;
- sulphur and nitrogen oxide emissions from the digester tank due to the microbial metabolism; and
- potential degradation of land, consumption of water, harm to water quality, stress on the ecosystem if large scale energy crops plantations are exploited to produce biogas (Abbasi and Abbasi, 2000).

The main externalities are discussed below.

2.2.1 Odour reduction

As reported by Noone (1990), anaerobic digestion was developed originally because of its ability to control and eliminate the malodour associated with domestic sludge.

In ordinary uncontrolled conditions, when wastes, manure or sludge are stored or spread on the fields, an imbalance is created between the acidification and the methanogenesis steps in the microbial degradation of organic matter, and the accumulation of volatile malodorous intermediates is inevitable. Obviously, in AD systems, the two phases of acidification and methanogenesis are kept in balance: the compounds which generate foul odours, such as volatile fatty acids, ammonia (NH_3), hydrogen sulphide (H_2S), phenols and indols are converted into more stable forms, mainly methane (CH_4) and carbon dioxide (CO_2) (Lusk, 1998), resulting in lower concentration in the digestate effluent and consequently lowering offensive odour than the raw materials (Welsh et al., 1977).

Anaerobic digestion has been shown to reduce the offensiveness of foul odour: deodorization and the correlated benefit are supported and confirmed in several studies that describe AD as a manure management strategy. For example Pain et al. (1990) measured a reduction of malodours of 70-80%, with a potential reduction of up to 97% (Lusk, 1998). Welsh et al. (1997), Pain et al. (1990), Powers et al. (1997), Martin and Ross (2004), Klingler (2005), Brown et al. (2007), Yiridoe et al. (2009), the AgSTAR handbook (U.S.EPA, undated a), and others authors, agree on the effective and unquestionable reduction of odour of manure and sludge when treated with AD, also after the spreading on the fields.

Depending on the typology of the digester and the management of the digestate storage, the effectiveness of odour reduction change, but all the AD technology reach, at least, a "good" or "excellent" level of odour reduction, as reported in a study carried out by the AgSTAR Program (U.S.EPA, 2002).

Some authors attribute to the capability of biogas to reduce noxious manure odours an important role in the investment decision. Klingler (undated) affirms that odour reduction is the major reason to install a biogas plant for many farmers, in particular for those who are working near housing areas and have to face problems with the local population due to odour complaints. In the AgStar Handbook (U.S. EPA, undated a) is declared that, in the USA, the second principal reasons a farmer or producer would consider installing a biogas system is the reduced odours (after on-site farm energy).

In fact, offensive odours from overloaded or improperly managed manure storage facilities or from its spreading on the fields have emerged as one of the primary public relations problems facing animal husbandry farms due to the threat of nuisance complaints and potentially damaging litigation (Wilkie, 2000). This is confirmed also by the Canadian Agricultural End Energy Use Data and Analysis Centre (CAEEDAC, 1999), where it is declared that offensive odours and surface and ground water pollution resulting from farming are two of the most heightened legal issues linked to agriculture.

Already in the ´70s Barth et al. (1974) affirmed that livestock manure odour control was a major consideration in livestock operation, especially for swine production near urban settlements (Barth et al, 1974).

Urbanization of formerly rural areas and concentration and intensification of livestock production facilities have increased the threat of nuisance complaints from neighbours that might result in litigation. This threat has placed intense pressure on producers to control odour emissions: some farmers risk to close their activity or move in other areas unless they find a solution to the problem. In the literature there are several lawsuits against farmer because of odour complaints (CAEEDAC, 1999; Kramer, 2004).

As odorants volatilize most conspicuously when manure is land-applied (Wilkie A.C., 2000), anaerobically treated manure allows farmers to spread manure also close to villages and thus increase the application possibilities, also in term of time, crops and housing (Klingler B., undated). Moreover, on-farm anaerobic digestion could substantially reduce the legal costs and potential huge legal fees, barriers to, and reason to dislike, larger dairy farm, or farms settled near urban centres (Metha A., 2002).

Concluding, for new farms, some means of odour control is often either implicitly or explicitly required for the facility to be sited and built.

Currently, only aerobic treatment offers similar benefits. However, the operational costs and complexity of aerobic treatment systems are greater than for anaerobic systems. Compared to conventional aerobic methods, which consume energy and produce large amounts of sludge requiring disposal, anaerobic treatment processes are net energy producers and produce significantly less sludge (Wilkie A.C., 2000).

Although the benefits derived from the reduction of foul odours by anaerobic treatment are evidently illustrated, the value of odour reduction is notoriously difficult to gauge (Mehta A.,2002).

A master thesis by Sanders (2009) at Ohio State University examines consumers attitudes towards anaerobic digestion, reasons for supporting renewable energy premiums, and willingness to pay for digester outputs, such as odour elimination and greenhouse gas reduction. More than the half of the interviewees answered that they are willing to pay a per-month premium, paid as additions to their monthly utility bill for either electricity or natural

gas, depending on the type of energy produced from the anaerobic digester. The mean pre-month premium is estimated to be 4,31 US$, corresponding to 3,39 €[30].
Since the location of livestock farms near residential settlements can affect the real estate values and property rights linked to nuisance law, hedonic techniques are also used to evaluate the odour impact, measuring the change in value of the surroundings properties. Hedonic scale (0-10) rating of smell, with 0 denoting no odour and 10 indicating very strong odour is commonly used to assess the odour of digested manure (Engen, 1974). Welsh et al. (1977) reported manure odour reduction of two units on a hedonic scale: from 6,5 (for undigested manure) to 4,6 (for digested manure), while Powers et al. (1995) reported that odour from digested manure was half as offensive as undigested manure.
Palmquist et al. (1997) showed that the value of a house located 0,5 mile far from a 2.400 head finishing facility was reduced by as much as 5%, while the same house located two mile away could experience a reduction of nearly 0,6%. Recently, Ready and Abdalla (2003) estimated that a building cluster located 500 meters from the farm decrease its price by 6,4%, at 800 meters the impact on the house price is 4,1% and at 1.200 meters the impact decrease at 1,6%. The impact is assumed to be zero past 1.600 meters far from the odour source.

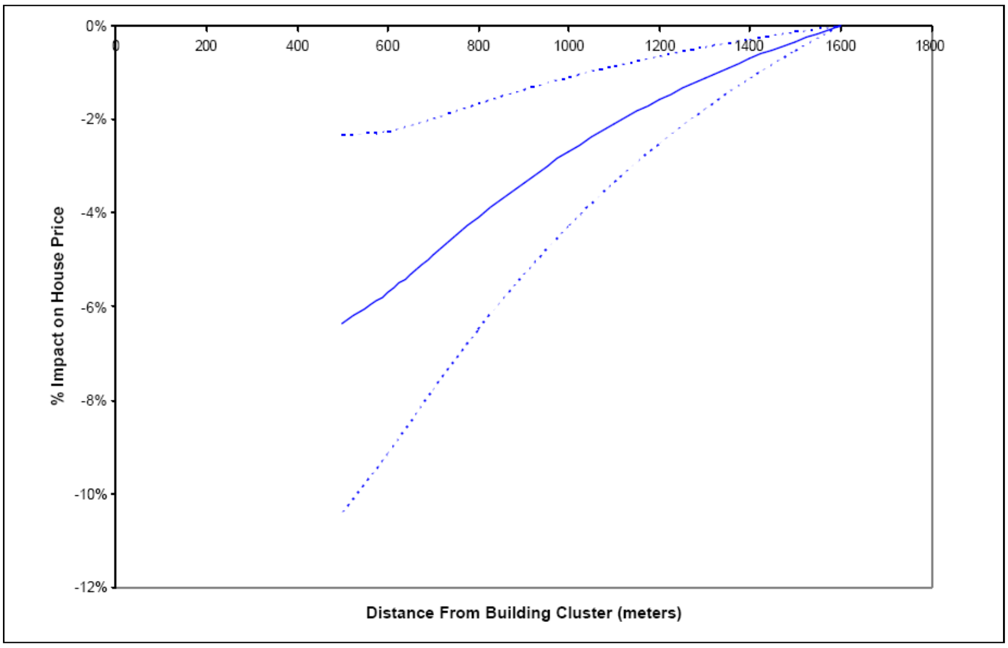


Figure 14: Impact on house price from a single farm building cluster (Ready and Abdalla, 2003).

[30] The changing currency values for all the following transformation are: 0,7865 for US dollar, value on the 9th September, 2010. Available at: http://it.finance.yahoo.com/valute/convertitore/#from=USD;to=EUR;amt=1; accessed the September, 9th, 2010.

No similar studies were found in literature for European or Italian realities. Because of the absence of local hedonic estimations, it is necessary to base the further estimation on those data.

Even if the reduction of houses' value depends on the distance from the odour source, it has been decided to use an average value to give an hypothetical monetary measure. Assuming that, in a typical common Italian rural-urban area, distances between houses and farms could range from 400 meters to 1.600 meters, the reduction of the houses price could reach a reasonable and precautionary average value of 2%. Assuming that the selling price of houses in rural areas of Veneto region is around 600 €/m^2, the reduction of value caused by odour nuisance could be around 12 €/m^3. Moving away from the odour source of a radius of 1.600 m, the area that should be analyzed reaches about 804 hectares. It is plausible to think that one house is present every four hectares of land, and its extension could be about 150 m^2. In this case the total area covered by houses is about 3 hectares. The total house built area's value is about 18.090.000 €. So, the presence of unpleasant odour could make the value of the house-built area decrease by 361.800€.

It is important to underline that this is only a back of the envelope calculation of the possible benefit that an AD plant could generate diminishing unpleasant odours: the difficulties met with to find information related to the value of odour reduction, the value of the rural houses and the rural population density, forced to make assumptions and approximations.

2.2.2 GHG emission reduction, contribution to global change mitigation and improvement of air quality

Livestock activities contribute significantly to climate change through considerable emission of green house gasses (GHGs) (FAO, 2006).

Recent studies such as *Livestock's Long Shadows*, by the United Nation Food and Agriculture Organization (FAO, 2006), have attributed about 18% of total anthropogenic GHG emissions to the livestock sector, taking into account the entire livestock commodity chain – from land use and feed production, to livestock farming and waste management, to product processing and transportation (FAO, 2006).

Livestock sector is responsible for the emission of the principal greenhouse gasses involved in climate change process, that include mainly methane (CH_4), carbon dioxide (CO_2), nitrous

oxide (N_2O) and also ammonia (NH3). It has to be underlined that ammonia is not considered a greenhouse gas but it could be a dangerous compound for the environment if present in excessive concentration and could have indirect greenhouse gas effects: it is one of the main responsible for acid rain and the main precursor for nitrogen oxides in the atmosphere (NO_x).
On-farm anaerobic digestion of feedstock can help to reduce these GHGs (Engler et al, 1999), by a change in the management, storage and final utilization of zootechnical effluents, by a potential change on fields management and by the substitution of fossil energy sources due to the production and use of a renewable energy, the biogas.
Methane is by far the largest contributor to total GHG emissions from the livestock sector: globally, the methane released from enteric fermentation and animal manure represent some 80% of agricultural methane emissions and about 35-40% of the total anthropogenic methane emission (FAO, 2006).
Anaerobic digestion of manure to produce biogas is a proven technique that has a significant potential in decreasing methane emission from manure storage (FAO, 2010): it is assumed that biogas can achieve a 50% reduction emission in cool climates for manures which would otherwise be stored as slurry (and hence have relatively high methane emission); for warmer climates, where methane emissions from slurry storage systems are estimated to be over three times higher, a reduction potential of 75% is possible (FAO, 2006).
The anaerobic digestion process itself does not decrease the amount of carbon dioxide emitted in atmosphere compared with conventional manure management or other production process of renewable energy (such as rape methyl ester or bioethanol) (Fredriksson et al., 2006); actually, sometimes CO_2 emissions increase if compared with other renewable energy due to the production of electricity or heat and to other operations, such as the upgrading to biomethane (Börjesson and Berglund, 2007). For example, using lay crop-based biogas to replace methanol from willow is calculated to increase the GHG emission by 30-50%, mainly due to the need for additional petrol or diesel in the biogas system to compensate for the lower energy output per hectare (Börjesson and Berglund, 2007).
But biogas use as fuel for heat, electricity or CHP purposes or as vehicle fuel have a significant role in decreasing the CO_2 emissions level. A life cycle perspective study carried out by Börjesson and Berglund (2007), has shown that CO_2 emissions and the related global warming potential are significantly smaller in large and small scale AD plants for heat, CHP and vehicle fuel production, than in other reference systems based on oil, diesel and natural gas. In this study, the contribution to the global warming potential (GWP) is normally reduced by between 50% and 80% when biogas replaces petrol and diesel as a transportation fuel in

light- and heavy-duty vehicles (Börjesson and Berglund, 2007).

Livestock activities contribute 65% of global anthropogenic emissions of nitrous oxide, the most potent of the three major greenhouse gasses (with a GWP 296 times higher than CO_2 (FAO, 2006)), and defined as the "killer" gas because contribute to the atmospheric ozone layer's thinning. A technical option to mitigate N_2O emission from livestock seems to be anaerobic digestion (Börjesson and Berglund, 2007; FAO, 2006; Möller and Stinner, 2009).

It can be inferred that during anaerobic digestion readily available C (that otherwise fuel denitrification and increase gaseous nitrogen loss) is incorporated into microbial biomass or lost as CO_2 or CH_4. Hence there is less available C in the slurry to fuel the denitrification process. Moreover the lower viscosity and the higher amount of NH_4 present in the digestate, permit respectively a faster penetration of the digestate into the soil and a faster assimilation of N by the crops, reducing the potential formation of N_2O.

It follows that anaerobic digestion can substantially mitigate nitrous oxide emission during both the storage of the manure, and the spreading of the digestate on the fields (FAO, 2006).

In her report Kingler (undated)

It is important to stress that the results of some experiments and studies about the positive action of AD on nitrous oxide emission reduction are in contrast with this conclusion: even if some of them demonstrate as the emissions of N_2O could be effectively reduced - for example Kingler (undated) in her report asserts that it could be assumed a N_2O reduction of 10% - someone else obtained completely opposite results (Möller and Stinner, 2009).

On the contrary, AD shows a negative impact concerning ammonia losses. In fact it is demonstrated that the risk of ammonia volatilization is very high from digestate, both during its storage and during its soil applications. Actually, measurements show that the evaporation of ammonia from the storage tanks containing digested slurry is greater than from storage tanks containing swine or cattle slurry (Ørtenblad, undated). This is because the increased inorganic nitrogen content and the higher pH, developed during AD, stimulate the formation of NH_3 (Möller and Stinner, 2009). Anyway, covering the storage tanks with plastic material or making a simple floating layer by straw reduces the volatilization by 96% (Ørtenblad, undated).

Therefore, the reliable and wise installation of anaerobic digestion plant to produce biogas may seriously mitigate the global warming potential of livestock manure, reducing significantly greenhouse gasses emission.

In the literature few studies estimated the value of CO_2 emission reduction and of global warming mitigation. Balsari et al. (2009) conducted an analysis about the costs to limit the

CO_2 emission in atmosphere trough AD plants. Even if the amount of CO_2 emitted from this technology – that reach 0,4 kg of CO_2eq. per electric kWh generated - is significantly less that the amount of CO_2 emitted by fossil fuel use, the costs to limit the emissions amount to over 500 € per ton of CO_2eq., value that seems to be too high respect the willingness to pay of the society (50 -100 € per ton of CO2eq). The policy maker should consider this aspect and get around this discrepancy with appropriate incentive schemes.

Buratti et al. (2009) studied the environmental impact of an anaerobic digestion plant in term of CO_2 equivalent. The anaerobic digestion plant should collect swine sludge coming from five farms and maize silage cultivated in 37 hectares of fields. They estimated that the installation of the AD plant could generate an annual reduction of CO_2eq. emission of 91,5% respect the emissions generated in the current situation, without the AD plant.

The current official price of the CO_2 emission quota is 14,39 €/tCO_2eq., even if it is always in fluctuation (i.e. the 1st march 2008 reached 20,6 €/tCO_2eq. and the 31st of the same month of the same year increased at 22,23 €/tCO_2eq, decreasing two years later to 13,01 €/tCO_2eq) (Brunori, 2010).

Unfortunately agriculture is still outside of the compulsory mechanisms of the European GHG emission reduction (Coderoni and Bonati, 2010), such as the market for carbon credits, but, when agriculture will be made part of the system, anaerobic digestion would constitute an important instrument to reach the level of emission and it would offer a serious alternative to diversify and improve the agricultural incomes.

Hypothetically speaking, the farms studied by Buratti et al. (2009) could earn annually about 17.670€ from selling their carbon credit quotas, if agriculture sector would be insert in the carbon credit system.

Anyway there is the possibility to commercialize the avoided CO_2 emissions in a “voluntary market”: the carbon dioxide neutralization is not imposed by normative obligation or by hefty penalties, but it arise from an environmental and image sensibility of privates and of those States which did not adhere to the Kyoto Protocol or to the European Emission Trading Scheme (i.e. United States of America). In this market usually the price for CO_2 quota is lower and it could vary from 2,35 $/t$CO_2$eq to 15 $/t$CO_2$eq (respectively 1,85 €/tCO_2eq and 11,8 €/tCO_2eq[31]). Also in Italy there are some few societies that work in this voluntary market, but however they act more in the forest sector than in agricultural sector (Brunori, 2010).

[31] The changing currency values for all the following transformation are: 0,7865 for US dollar, value on the 9th September, 2010. Available at: http://it.finance.yahoo.com/valute/convertitore/#from=USD;to=EUR;amt=1; accessed the September, 9th, 2010.

Even if agricultural sector is still not included in the market for carbon credits, it has been decided to estimate the quantity of CO_2 that can be avoided in a farm-scale AD plant and evaluate the externality derived, appraising it at 14,39 €/tCO_2eq, the current price of a CO_2 quota, since the potential contribution of AD technology in knocking down methane emissions.

Some authors (Börjesson and Berglund 2006; Börjesson and Berglund 2007; Klingler, undated) asserts that using biogas could also contribute to improve air quality. Some studies in fact demonstrate that biogas has a lower air pollution impact after its burning respect other fuels (Klingler, undated).

Börjesson and Berglund (2006) carried out a life-cycle analysis for different biogas systems based on different raw materials. They found that manure and tops and leaves of sugar beet are the raw materials in farm-scale biogas production and applications (boilers, turbines and vehicle fuel) that cause the lowest emissions, in terms of CO_2, CO, NO_x, SO_2, hydrocarbons and particles. Developing this study Börjesson and Berglund (2007) found that biogas systems normally lead to environmental improvement, as reduced emissions of air pollutants, when biogas systems are introduced and replace various reference systems (based on oil, diesel or natural gas) for energy generation, waste management and agricultural production.

2.2.3 Other externalities

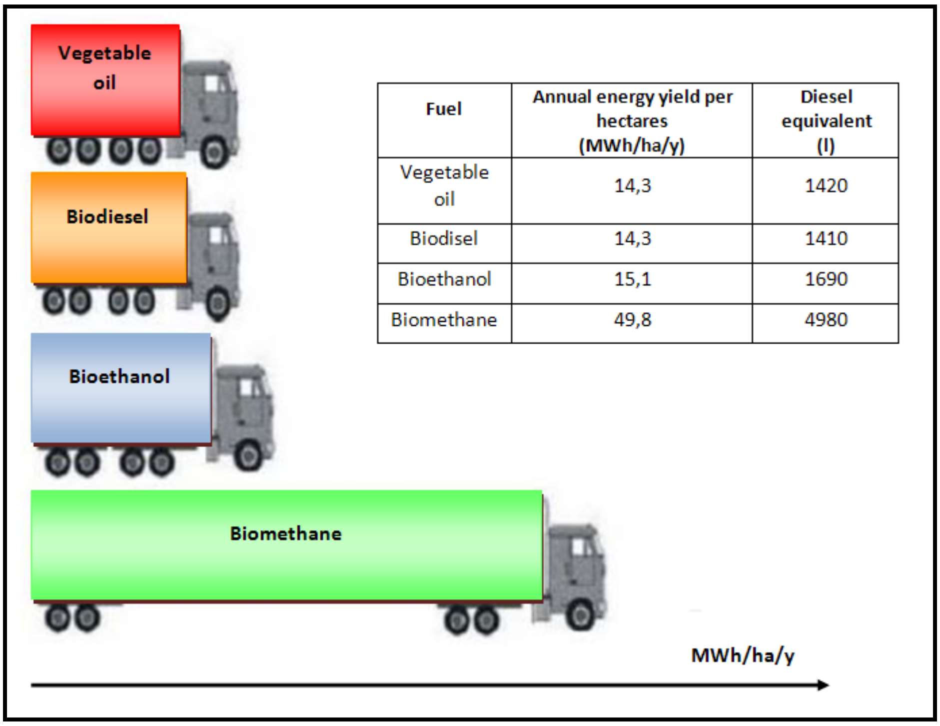
One of the most important sources of value of biogas, and of all other renewable energies, is that they allow to keep our reserves of fossil fuel essentially intact (IEA, 2007c; Menegaki, 2008).

Nevertheless it is important to asses carefully and critically the whole life cycle of renewable. For example, the energy spent for cultivating crops for energy purposes, which involves energy intensive operations such as fertilization, irrigation, herbicide and pesticide treatments, very often is not counterbalance by the energy contained by the crops; if so, the energy balance is negative and the social and environmental benefits are not guaranteed.

The production of biogas from manure or from substances considered as rejects or waste could really reduce drastically the exploitation of fossil resources, as the energy generated from the plant is used to satisfy the big part of the energy needs of the farm or of urban buildings or industries.

Biogas could also be evaluated for its low energy requirements compared with other fossil and renewable fuels. Fredriksson et al. (2006) tested that the total energy efficiency (calculated as the energy in the fuel produced divided by the total allocated energy use) for biogas is 4,6, better than bio-ethanol that reach a total energy efficiency of 2,8. Tuomisto and Helenius (2008) studied the energy requirements of field-based biogas and compared it with different alternatives (barley-based ethanol, rape methyl ester and biowaste-based biogas) using a life cycle perspective. The results of this study clearly showed that biogas requires lower energy input per unit energy output than bioethanol and biodiesel.

The following figure (figure 15), proposed by Fachagentur Nachwachsende Rohstoffe (FNR), the German Agency for Renewable Sources that is interested in renewable raw materials, shows that the methane obtained by the upgrading of biogas is the vehicle biofuel with the best energy yield, which is more than three time superior to the other biofuels.



Fuel	Annual energy yield per hectares (MWh/ha/y)	Diesel equivalent (l)
Vegetable oil	14,3	1420
Biodisel	14,3	1410
Bioethanol	15,1	1690
Biomethane	49,8	4980

Figure 15: Annual energy yield per hectare of different biofuels (personal elaboration from Piccinini, 2007a).

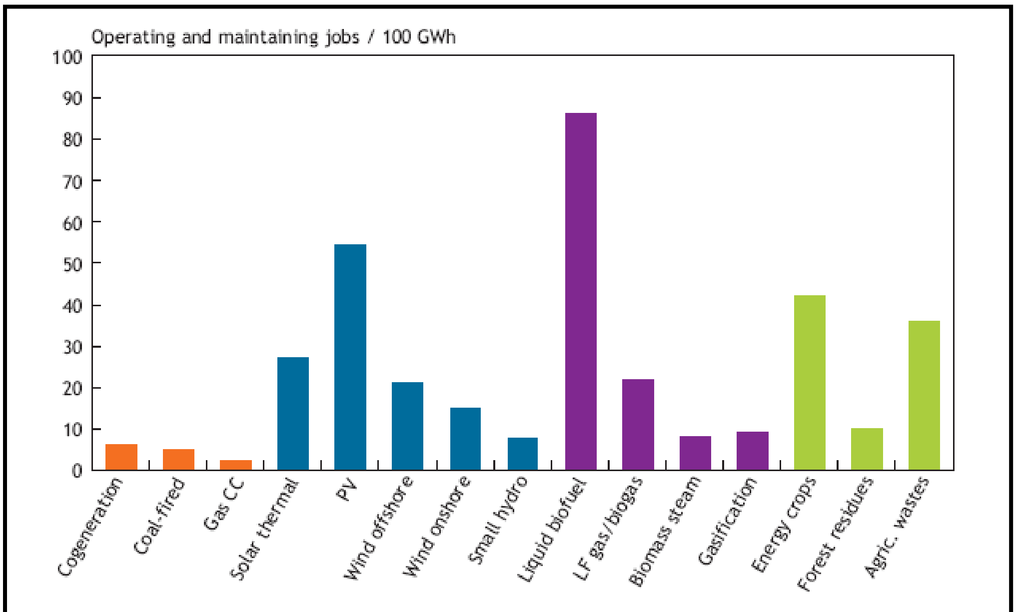
Moreover, anaerobic digestion technology and biogas production could contribute to guarantee the fuel diversity, increase the security of energy supply, reduce the energy price volatility effects on the economy, improving the national economic security (fossil energy is vulnerable to political instabilities, trade disputes, embargoes and other disruptions) and increase the gross domestic product (GDP) through more efficient production process and creation of new jobs (IEA, 2007c; Menegaki, 2008).

The recent expansion of the biogas chains in Italy do not allow to have precise and consolidated information about the spinoffs on employment (Pettenella and Gallo, 2008). However it is reasonable to expect an employment increase in the agricultural and zootechnical sectors and in the factories linked with those activities, as happened in other European countries that boast a longer experience in biogas. In Germany, in the year 2007, it has been calculated that 10.000 workers were employed in the biogas sector, corresponding to 7,8 employees per MW installed, as the power installed generated by 3.700 plants reached 1.270 MW (Piccinini, 2008c).

Within a research finalized to examine in detail the bioenergy projects, the International Energy Agency (IEA) has estimated the occupational requirement of different renewable energies. From figure 16, it is possible to deduce that the biogas chain generate 20 jobs per 100 GWh of energy produced (IEA, 2007c). The employment typology takes into consideration all the process necessary for the realization and the working of the plants: from the planning and projecting, to the building, and to the ordinary operational and management actions.

Beyond the results of the estimation that could be done basing on those information sources, it has to be underlined that biogas chain can provide useful employment opportunities in rural areas, possibly in the off-season when some harvesting or processing of energy crops can be carried out (IEA, 2007c), allowing a no seasonal employment in the agricultural sector, that is finding a progressive ageing and a fall in the number of employees (Pettenella and Gallo, 2008).

It is reasonable to think also that biogas chain can influence positively the industry development. In fact "... manufacturing industry will need to be expanded in order to design and build more appliances as increased deployment occurs. In addition more ancillary handling and processing equipment will be needed. Together this will provide local employment and possibly export opportunities for some manufacturing companies" (IEA, 2007c).



Labour is required for operating and maintaining various renewable energy projects after their construction, with bioenergy projects also requiring additional labour to produce and deliver the biomass to the plant.

Figure 16: Employment requirements for renewable energy projects (IEA, 2007).

Biogas production at farm level could constitute a support for nitrate knocking down.

It is important to notice that AD technology does not decrease the amount of nitrogen compounds present in the raw feedstock; actually, through co-digestion with energy crops, crop residues or municipal solid waste, the amount of total nitrogen increases considerably in the digestate compared with the untreated manures. In zones vulnerable to nitrogen pollution from manure and sludge management (for example the drainage basin of Venice lagoon, or the resurgence areas in Veneto region), AD alone may not represent a right and efficient solution to solve nitrogen pollution problems, since the content of the total nitrogen doesn't change during anaerobic digestion. Anyway several treatments exist to remove the nitrogen content (e.g. stripping of liquid fraction, inverse osmosis, nitrification/denitrification cycle, etc) and, alternatively, there is the possibility to find lands fit for digestate disposal and enlarge the farm landed propriety, in order to have an adequate spreading surface with reference to the law nitrogen limits. But both of those alternatives will weigh considerably upon farm manures management costs (Guercini, 2008; Brambilla and Navarotto, 2010).

Therefore care must be taken to manage and handle the digestate in such a way as to improve the nutritive potential and minimize the nitrogen losses from leaching and volatilization (especially of ammonia, recognized as a pollutant in the atmosphere, and nitrous oxides, that contribute to the thinning of ozone layer). It is suggested to mulch immediately the digestate, or inject it into the soil, always within the legislative restrictions concerning the spreading prohibition period and the upper limit of N applicable[32] (Nelson and Lamb, 2002; Paavola et al, 2009a; Ragazzoni et al, 2010).

Even if AD technology do not decrease directly the nitrogen content of the feedstock, it could offer an economic support to invest in some nitrogen knocking down treatments, which are very expensive and represent a onerous investment for the farmers. The selling of the electricity energy produced by the AD plant could generate an extra-earning that could be invested in those specific technologies, that otherwise would be difficult to exploit because too expensive (Ragazzoni et al.2010).

Moreover, using digestate as fertilizer could contribute to the protection and preservation of surface- and ground-water. In fact some samples reveal that digestate can reduce the risk of nitrate leaching phenomena (Börjesson and Berglund, 2007; Möller and Stinner, 2009; Ørtenblad, undated), thus prevent or reduce the risk of contamination and eutrophication of groundwater sources (Klingler, undated; Nelson and Lamb, 2002).

Berglund and Börjesson (2006) affirm that applying digestated in place of undigested pig manure on arable land can reduce the nitrogen leakage. The reduction is estimated to correspond approximately 7,5 kg of nitrogen per hectare per year.

During the anaerobic digestion, also the level of Total Oxygen Demand (TOD)[33] decreases significantly, and the hazards of a potential catastrophic pollution spill could be avoided (Nelson and Lamb, 2002). Similarly Chemical Oxygen Demand (COD) can be reduced by 60-90%, and Biochemical Oxygen Demand (BOD) by up to 80% (Yiridoe et al., 2009).

Anyway, it is important to underline that each biogas plant and the relating digestate use, should be designed, located and managed wisely, in accordance to the environmental local characteristic and legislative rules (Börjesson and Berglund, 2007).

---

[32] The "Nitrate Directive": Council Directive 91/676/EEC of 12 December 1991 concerning the protection of waters against pollution caused nitrates from agricultural sources. Official Journal of the European Communities 31/12/1991;L375.

[33] Total Oxygen Demand (TOD) is a measure of how much oxygen could potentially be consumed by breaking down organic matter, such as that found in manure. This is an issue if there is a catastrophic spill of manure that enters surface water. If too much oxygen in the water is used to break down manure that spills into a stream, natural stream life will suffer or be killed (Nelson and Lamb, 2002). Usually it is split in Chemical Oxygen Demand (COD) and Biochemical Oxygen demand (BOD). COD refers to the amount of chemical oxydizable compounds present in the water, and BOD refers to the amount of dissolved oxygen needed by aerobic biological organisms in a body of water to break down organic material present in a given water sample at certain temperature over a specific time period.

As stable carbon is the main constituent of humus, biogas reject might have a potential for increasing soil organic matter levels, thus improve and preserve soil fertility, but no scientific evidence of this effect was found (Terhoven-Urselmans et al., 2009).

Using digestate produced on-farm as fertilizer or soil conditioner involves also the recirculation of nutrients. Recirculation facilitates the replacements of inorganic and non-renewable phosphorus resources as well as energy intensive nitrogen fertilizers. The recirculation of nutrients is important as phosphorus resources are expected to be exhausted even before the oil reserves (Paavola et al., 2009a), and about 1% of the world's energy is used for the production of nitrogen fertilizers with the Haber-Bosh process (FAO, 2006).

Another externality is represented by the possible reduction of pesticides and herbicides use, thanks to the weed seeds germination disadvantage and pathogen reduction created by anaerobic digestion, with a consequent benefit for the whole society.

Anyway, to quantify the effect and whether biogas technology is able to reduce the use of herbicides and pesticides, additional scientifically measurements are needed (Klingler, undated).

Chapter 3: The model and its application

The research tool developed in this study has three main purposes:

- to assess the value of the externalities that should occur to make the investment of a farm-scale AD plant profitable, that is the primary focus of this dissertation;
- to conduct, compare and study the financial and the economic assessments of a farm-scale AD plant; and
- its utilization as a supporting decision tool to evaluate and to make consideration on the financing politic interventions.

The model, created with the support of Microsoft Excel spreadsheet program, is developed in different worksheets in accordance to the subjects analyzed (see figure 17):

1- Input biomasses;
2- Energy production;
3- Transport;
4- CO_2eq. emissions calculation;
5- Costs;
6- Benefits and externalities;
7- Financial analysis;
8- Economic analysis;
9- Summary results.

The user can introduce data related to the quality and quantity of biomass that should be fed into the digester; automatically the model provide to estimate annual costs and benefits, in accordance with the Costs-Benefits approach. A cash flow analysis is conduct to set both the financial and the economic analysis worksheets. In the end a summary worksheet shows the results of the assessment and a sensitivity analysis can be carried out.

The flexibility of the model, due to the option to utilize either default values or directly entered investment data based upon user's own information, and its easily change, provide an initial support decision in the absence of specific data, and allow the user to adjust the model for different solutions and to study different scenarios.

The data given as default value are based upon values from the published literature, from existing working systems, or from personal communications with expert in the AD sector.

The model has been developed observing some assumptions. The main are:
- only farms with cattle and/or swine livestock are considered, as they represent the ordinary farm categories in which AD plants have been installed in Italy;
- the electric power installed has to be equal or lower than 250 kW_e, to respect the default cost values used. Moreover usually, in Italy, farm-scale AD plants do not exceed this power both for the limited amount of feedstock available and for bureaucratic reasons: plants with a power upper than 250 kW_e requires particular permits and licences, which are not necessary for the smaller power plants (Guercini, 2010);
- the investment period investigated is of 15 years, corresponding to the duration of the national incentive;
- the interest rate used is 5%, as suggested by the European Commission for the programming period 2007-2013 (European Commission, 2008).

Further assumptions are mentioned while describing the model in the following sections.

Although reliable sources have been consulted for the development of the model, it is important to underline that this is an investigative tool above all, that offers raw and initial profitability statement, since a variety of assumptions and superficial estimations (such as the appraisal of the odour reduction benefit, estimated in Chapter 2, section 2.2.1) have been formulated. If the model is used as a supporting decision tool, the users should carefully consider the validity of the assumption proposed and of the results obtained before giving opinions or making investment decisions.

The remain of this chapter explains the details of the model and how it works, illustrating the worksheets one by one, and applying it to five different farms.

The five example farms investigated – called AD1, AD2, AD3, AD4 and AD5 from now on - represent the ordinary farms in Veneto region in which an anaerobic biogas plant has been installed, according to the results emerged from the project “PROBIO-BIOGAS”, under the Biofuels National Program, coordinated by Veneto Agricoltura, concerning the mapping and the monitoring of the biogas plants operating in Veneto region. The survey shows that the ordinary feedstock used in farm-scale anaerobic digestion plants could be classified in three main categories (Zoppelletto, 2008):

- only animal defecations (especially bovine manure and slurry, and swine slurry);
- animal defecation combined with energy crops;
- only energy crops (the most used appears to be the corn silage).

It has been decide to parameterized the AD plants installing a general electric power of 130 kW for all the different farms, in order to obtain comparable results. This assumption obliges to consider livestock herds not always correspondent to ordinary situation in Vento region: this is the case of the swine farm (AD3), where are bred for butcher's shops 16.300 swine to get to the established electrical power. This number of animal deviates significantly from the ordinary average herd swine size that amount to about 5.000 pigs (Guercini, 2010).

The example-farms considered are outlined in Table 15.

By way of example the model in its comprehensiveness will be presented for only one farm (AD2), and the results of all the farms will be reported and discussed in the following chapter (Chapter 4).

AD plants	Livestock typology	N° of livestock heads	Typology of defecation	Total defecations (t/y)	Crops typology	Crop production (t/y)
AD1 (dairy farm)	dairy cattle dry cattle heifers Total	380 100 305 785	cow manure	13205	/	/
AD2 (dairy and cereals farm)	dairy cattle dry cattle heifers Total	260 60 150 470	cow manure	8297	corn silage on-farm produced	1825
AD3 (swine farm)	swine for butcher's shop	16300	swine slurry	83293	/	/
AD4 (swine and cereals farm)	swine for butcher's shop	6000	swine slurry	40880	corn silage on-farm produced	2450
AD5 (energy crops dedicated farm)	/	/	/	/	corn and wheat silage on-farm produced	5720

Table 15: Typologies of feedstock considered and typologies of farms studied.

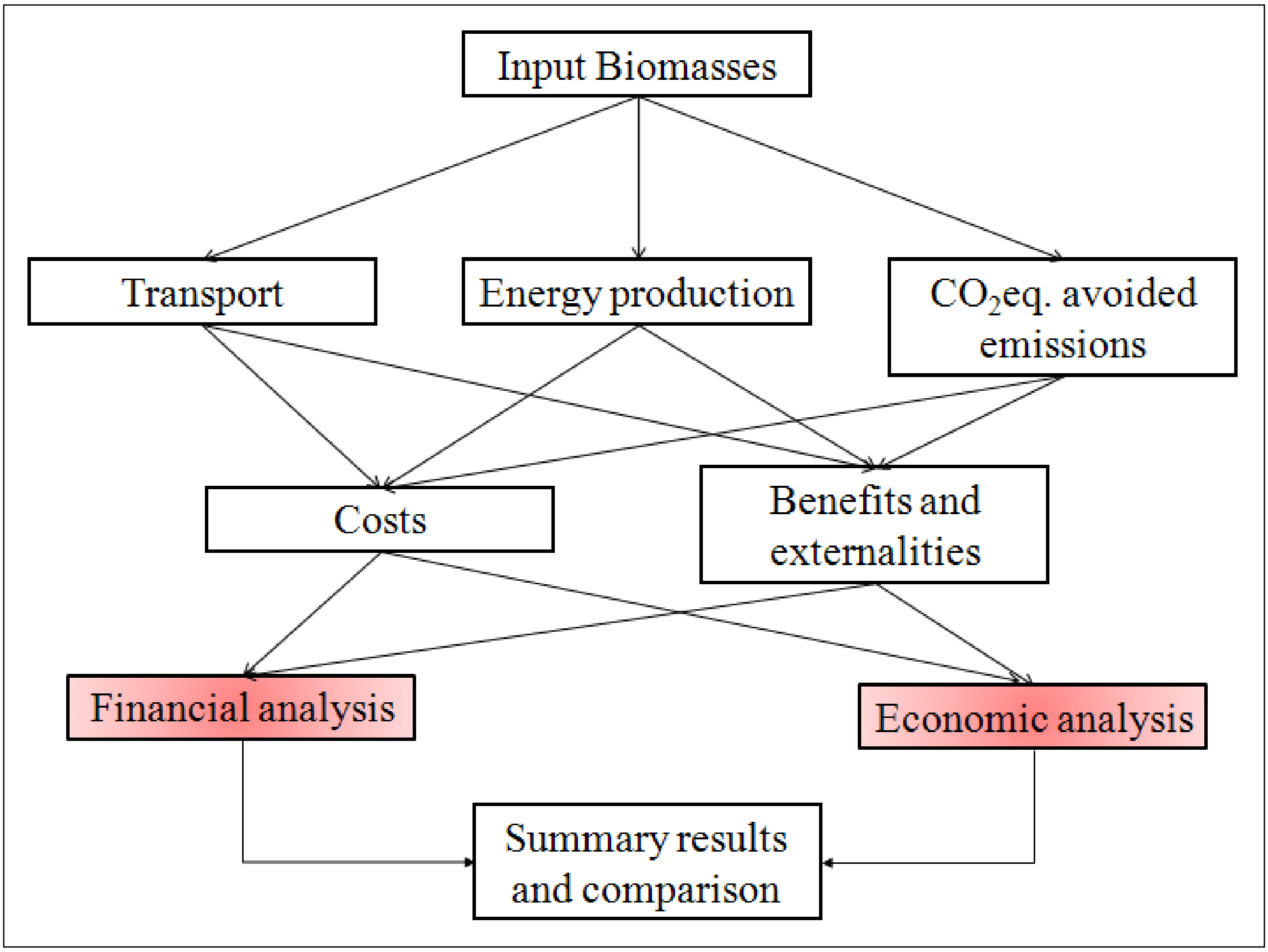


Figure 17: Functional diagram of the main worksheets of the model.

3.1 Input biomasses worksheet

In the first worksheet users enter the number of livestock present in the farm, depending on the type of livestock and the type of bedding adopted. Cells coloured in blue are reserved for users input data. In the dairy farm acting as example, there are 470 livestock heads, divided in 260 milky cows, 60 dry cows and 150 heifers: those number are entered in the specific blue cells (see Figure 18).

Bovine and swine livestock are divided in different categories (Table 16), according to their live weight and their activity in the farm.

Livestock activities:	Live Weight (LW) (kg)
BOVINAE:	
Dairy activities:	
Dairy cattle	600
with straw bedding	
without bedding	
Dry / Wet-nurse cattle	600
with straw bedding	
without bedding	
Until first delivery	300
with straw bedding	
without bedding	
Weaning calf (0-6 months)	100
with straw bedding	
without bedding	
For meat:	
Bullock for fattening (>6 months)	350
with straw bedding	
without bedding	
White meat calf	130
with straw bedding	
without bedding	
SWINE	
Sow in preparation	180
Sow in delivery zone	180
Sow until first delivery	70
Sulking pigs without sows (7-30kg)	18
Boar	250
For butcher's shops (31-110kg)	70
For salami factory (31-160kg)	90

Table 16: Categories of livestock considered in the model. The live weight data refer to Ministerial tables (Ministerial Decree of 7^{th} April 2006, Official Gazette n.109 of 12^{th} May 2006, Ordinary Supplement n.120).

This subdivision permits to obtain a more accurate estimation of the amount of animal rejects, therefore of the final reachable biogas production.

Regarding the bovines it has been decided to distinguish the presence or not of straw bedding as it influence significantly the effluent characteristics (especially the volatile solids content) and the final biogas yield. So for bovines different effluent will be considered: fresh manure, straw and slurry.
On the contrary, it has been assumed that all the swine categories are breed without straw bedding addition, as this is the common system in Veneto region (Guercini, 2010); so only slurry fraction is estimated for swine livestock.

To obtain a more accurate estimation of the amount of animal effluents produced, necessary for planning the volume of the digester and the volume of storages, it should have been considered also the typology of housing, the stable cleaning systems with the relative amount of water use, and the annual precipitation. Anyway the technical and engineering planning of the AD plant is outside the topic of this work.

Once that the farmer define the herd size, the model calculate the amount of manure, slurry and straw produced annually per each animal category, through the following equations:

$$\text{Total slurry (t/y)} = LW\ (t) * S_{LW}\ (t/t_{LW}/y) \qquad \text{(Equation 1)}$$

$$\text{Total manure (t/y)} = LW\ (t) * M_{LW}\ (t/t_{LW}/y) \qquad \text{(Equation 2)}$$

$$\text{Total straw (t/y)} = LW\ (t) * St_{LW}\ (t/t_{LW}/y) \qquad \text{(Equation 3)}$$

Where: LW = live weight (t);
S_{LW} = ton of slurry per live weight per year ($t/t_{LW}/y$);
M_{LW} = ton of manure per live weight per year ($t/t_{LW}/y$);
St_{LW} = ton of straw per live weight per year ($t/t_{LW}/y$).

For example in AD2 farm, where the animals are bred in freestall housing system with straw bedding, the total amount of manure correspond to be 8.297 t/y (composed by 5.874 t of pure manure, 1.908 t of slurry and 515 t of straw).

The data related to the live weight of the animals and the annual amount of effluents produced refer to the tables published by the Minister of Agriculture and Forestry (Ministerial Decree of 7th April 2006, Official Gazette n.109 of 12th May 2006, Ordinary Supplement n.120).

In the same worksheet there is the possibility to enter also the annual quantity of crops that farmers are planning to fed into the digester. Only corn silage, sorghum silage and wheat silage are included in this model, as they are the most used additional feedstock in AD in Veneto region. It is required to the user to specify if the crops are produced in the farm or if they are extra-farm crops. This distinction is useful in order to estimate the crop supply cost, the crop opportunity cost and the crop transport cost, as explained in section 3.3 and 3.5.
In AD2 case farm 1.825 t of corn silage on-farm produced are added annually to the manure to fed the anaerobic digester: this figure have to be entered in the specific blue cells, as showed in Figure 18.

Livestock activities:	Heads	Live Weight (LW)[a] (kg)	Total Live Weight (t)	Slurry (t/t_{LW}/year)[a]	Total Slurry (t/year)	Manure (t/t_{LW}/year)[a]	Total Manure (t/year)	Straw (Kg/t_{LW}/day)[a]	Total Straw (t/year)
BOVINAE:									
Dairy activities:									
Dairy cattle		600							
with straw bedding	260		156	9	1404	26	4056	5	284,7
without bedding	0		0	33	0				
Dry / Wet-nurse cattle		600							
with straw bedding	60		36	9	324	18	648	5	65,7
without bedding	0		0	26	0				
Heifers		300							
with straw bedding	150		45	4	180	26	1170	10	164,25
without bedding	0		0	26	0				
Weaning calf (0-6 months)		100							
with straw bedding	0		0	4	0	22	0	10	0
without bedding	0		0	22	0				
TOTAL	**470**				**1908**		**5874**		**514,65**
For meat:									
Bullock for fattening (>6 months)		350							
with straw bedding	0		0	4	0	26	0	10	0
without bedding	0		0	26	0				
White meat calf		130			0				
with straw bedding	0		0	40	0	26	0	5	0
without bedding	0		0	27	0				
TOTAL	**0**				**0**		**0**		**0**
SWINE									
Sow in preparation	0	180	0	37	0				
Sow in delivery zone	0	180	0	55	0				
Sow until first delivery	0	70	0	37	0				
Sulking pigs without sows (7-30kg)	0	18	0	44	0				
Boar	0	250	0	37	0				
For butcher's shops (31-110kg)	0	70	0	73	0				
For salami factory (31-160kg)	0	90	0	37	0				
TOTAL	**0**				**0**				

It is possible to modify ONLY the blue cells

a = Ministerial Decree of 7th April 2006, Official Gazette n.109 of 12th May 2006, Ordinary Supplement n.120

CROPS:	Quantity (t/year)	Daily quantity (t/day)
Corn (silage)	**1825**	**5,00**
produced on farm	1825	5,00
bought	0	0
Sorghum (silage)	**0**	**0**
produced on farm	0	0
bought	0	0
Wheat (silage)	**0**	**0**
produced on farm	0	0
bought	0	0

Figure 18: Graphic representation and structure of the “Input biomasses” worksheet.

3.2 Energy production worksheet

Basing on the data entered in the "Input biomasses" worksheet, calculations concerning the energy production are carried out.
To calculate the biogas yield from either manure, slurry or additional feedstock, equation 4 is used:

$$\text{Total Biogas } (m^3/y) = \sum \text{TVS } (t/y) * B_{(VS)} \ (m^3/t \text{ of VS}) \qquad \text{(Equation 4)}$$

where: TVS = total volatile solids content (t/y)
$B_{(VS)}$= biogas produced per ton of volatile solids (VS) (m^3/t of VS)

The total biogas produced with the mixed effluents and corn silage available in AD2 farm results to be about 933.606 m^3 per year.

The TVS is calculated multiplying the total solids (TS) of the substrate by the volatile solids (VS) proportion (both of them are expressed as percentage value) and the amount of substrate (M) expressed as ton per year (t/y):

$$\text{TVS } (t/y) = \text{TS } (\%) * \text{VS } (\%) * \text{M } (t/y) \qquad \text{(Equation 5)}$$

The proportion of TS and VS of the different feedstock are given by Ragazzoni et al. (2010) (see Table 2, Chapter 1).

The methane yield, that for AD2 reaches 531.685 m^3, it could be calculated multiplying the biogas yield by the methane concentration (CH_{4C}) contained in it:

$$\text{Total Methane } (m^3/y) = \text{Total biogas } (t/y) * CH_{4C} \ (\%) \qquad \text{(Equation 6)}$$

Also the data referred to the methane concentration are obtained by Ragazzoni et al. (2010) (Table 2, Chapter 1).

It is possible to estimate also the electricity yield (E) and the heat yield (H) multiplying the total methane by specific conversion factors: for electricity the conversion factor is included between 1,8 kWh_e and 2,2 kWh_e (Piccinini, 2007a; Ragazzoni et al., 2010), whereas the heat conversion factor could vary from 2 kWh_h to 3 kWh_h (Piccinini, 2007a). In this study the lowest values are considered, to respect a prudential approach and to avoid overestimation of the production.

$$E\ (kWh_e) = \text{Total Methane } (mc/y) * 1{,}8\ kWh_e \qquad \text{(Equation 7)}$$

$$H\ (kWh_h) = \text{Total Methane } (mc/y) * 2\ kWh_h \qquad \text{(Equation 8)}$$

When biogas, methane, electricity and heat yields are calculated for each category of livestock and eventually also for additional energy crops, and each contribute is summed together, it is possible to quantify the total energy producible (see Figure 19).

In the example of AD2 farm the annual electricity production is more than 1.063 MWh/y and the production of heat energy reaches about 1.600 MWh/y.

Livestock activities:	Total substrate (t/year)	Total Solid (proportion of total substrate)[b]	Volatile Solid (proportion of total solid)[b]	Total Volatile Solid (t/year)	Biogas per unit of VS (m^3/t VS)[b]	Total Biogas (m^3/year)	Methane (proportion of total biogas)[b]	Total Methane (m^3/year)	Total Electricity (kWh/year)[c]	Total Heat (kWh/year)[c]
BOVINAE:										
Dairy activities										
total manure (t/year)	5.874	0,23	0,78	1.053,80	290	305.600,72	0,63	192.528,46	385.056,91	577.585,37
total slurry (t/year)	1.908	0,105	0,83	166,28	325	54.041,72	0,65	35.127,11	70.254,23	105.381,34
total straw (t/year)	515	0,8	0,92	378,78	490	185.603,38	0,55	102.081,86	204.163,71	306.245,57
For meat										
total manure (t/year)	0	0,23	0,78	0,00	290	0,00	0,63	0,00	0,00	0,00
total slurry (t/year)	0	0,12	0,8	0,00	280	0,00	0,65	0,00	0,00	0,00
SWINE:										
total slurry (t/year)	0	0,025	0,85	0,00	450	0,00	0,67	0,00	0,00	0,00
Total	**8.296,65**					**545.245,82**		**329.737,43**	**659.474,86**	**989.212,28**
Crops:	**Quantity (t/year)**	**Total Solid (proportion of total substrate)[b]**	**Volatile Solid (proportion of total solid)[b]**	**Total Volatile Solid (t/year)**	**Biogas per unit of VS (m^3/t VS)[b]**	**Total Biogas (m^3/year)**	**Methane (proportion of total biogas)[b]**	**Total Methane (m^3/year)**	**Total Electricity (kWh/year)[c]**	**Total Heat (kWh/year)[c]**
Corn (silage)	1.825	0,35	0,95	606,81	640	388.360,00	0,52	201.947,20	403.894,40	605.841,60
Sorghum (silage)	0	0,2	0,95	0,00	510	0,00	0,52	0,00	0,00	0,00
Wheat (silage)	0	0,3	0,92	0,00	520	0,00	0,52	0,00	0,00	0,00
Total	**1.825,00**					**388.360,00**		**201.947,20**	**403.894,40**	**605.841,60**
TOTAL ENERGY PRODUCTION:		**Daily energy production:**								
Biogas (m^3/year)	**933.605,82**	2.557,82								
Methane (m^3/year)	**531.684,63**	1.456,67				b = Ragazzoni et al. (2010)				
Electricity (kWh/year)	**1.063.369,26**	2.913,34				c = Piccinini (2007a)				
Heat (kwh/year)	**1.595.053,88**	4.370,01								

Figure 19: Graphic representation and structure of the "Energy production" worksheet.

3.3 Transport worksheet

A worksheet dedicated to the transport calculation is necessary since it could influence the cost or benefit items.

This worksheet calculate the transport costs of both the untreated matter and the digestate. Moreover also the transport cost of extra-farm material is estimated (Figure 20).

Basing on data collected by Ragazzoni et al. (2010) (see Table 11, Chapter 2), and assuming that distances between the farm and the spreading fields, or between the farm and the supply point, are lower than 20 kilometres (common situation in Veneto region), it has been decided to give an average value of 3,5€ per ton of substrate transported.

Thus the transport cost ($C_{transport}$) is calculated multiplying the unitary cost by the amount of matter (M) considered:

$$C_{transport} = 3{,}5\ €/t * M\ (t/y) \qquad \text{(Equation 9)}$$

Anyway the unitary transport cost value could be changed and users can insert freely the value that they think to be more correct.

The transport cost is calculated for each form of animal effluent and for each crop. The latter are subdivided in crops produced in the farm fields or extra-farm crops, thus bought crop.

It has been assumed that before the installation of the AD plant a livestock activity is already present in the farm and presumably also crops are already cultivated on-farm fields: thus the transport cost of animal effluents and of eventual crops are already considered in the economy of the farm, and their utilization as digester feedstock do not imply further costs in transport. On the contrary, usually, in this case, the transport cost is reduced as the volume of the substrate diminishes after anaerobic digestion (see Table 10, Chapter 2).

The amount of matter rejects by the digester is calculated multiplying the initial amount of matter by the reduction percentage (Ragazzoni et al., 2010).

The avoided transport costs are calculated subtracting the transport cost of the whole substrate after anaerobic digestion ($C_{transport}A_{AD}$) from the transport cost of the raw animal effluents without anaerobic digestion ($C_{transport}W_{AD}$) as shown below:

$$\text{Avoided Transport Cost} = C_{transport}W_{AD} - C_{transport}A_{AD} \qquad \text{(Equation 10)}$$

This saving is entered automatically in the worksheet concerning the description and the calculation of the benefit (to be further discuss in section 3.6).

When farmers are interested in adding extra-farm feedstock to the digester further transport costs are implied if compared to the on-farm production situation. The transport cost of extra-farm crops are simply calculated as in equation 9, and it is automatically reported in the costs table (section 3.5).

Moreover it is important to notice that when extra-farm feedstock are used, usually the positive effects derived from the reduction of substrate volume is eliminate since the amount of extra-feedstock exceeds the reduced quantity. This happens in AD2, where the corn silage added makes the transport costs increase of 4.482 € per year.

The additional cost will be entered the same in the benefits table but with a negative sign.

Kind of matter	Unitary transport cost[b] (€/t)	amount before AD (t)	% reduced[b]	amount reduced after AD (t)
cow slurry		1.908,00	2,55%	1.859,35
cow manure	3,5	6.388,65	2,55%	6.225,74
swine slurry		0,00	2,03%	0,00
Total matter		8.296,65		8.085,09
Total transport costs		**29038,275**		**28297,79899**
corn silage produced		1.825,00	18,24%	1.492,12
sorghum silage produced	3,5	0,00	16,20%	0,00
wheat silage produced		0,00	16,56%	0,00
Total matter produced		1.825,00		1.492,12
Total transport costs (produced)				**5222,42**
corn silage bought		0	18,24%	0
sorghum silage bought	3,5	0,00	16,20%	0,00
whaet silge bought		0	16,56%	0,00
Total matter bought		0,00		0,00
Total transport costs (bought)		**0**		**0**
TOTAL transport costs (€)				**33.520,22**
Saved (€)		**-4.481,94**		
			b= Ragazzoni et al. (2010)	

Figure 20: Graphic representation and structure of the “Transport” worksheet.

3.4 CO_2eq. avoided emission worksheet

The Italian Greenhouse Gas Inventory Report (Romano et al., 2010) provides update information on the estimation of greenhouse gas emissions from the Agriculture sector. Regarding the livestock activity, emissions from enteric fermentation and manure management are estimated through the utilization of emission factors (EF).

Since anaerobic digestion systems affect primarily the methane emissions of manure management, it has been decided to excluding the other greenhouse gasses in this study.

Referring to the dairy cattle bred in AD2 farm, the adoption of an AD could reduce the methane emissions by the 13%, equal to 880 kg per year.

The methane emissions avoided ($CH_{4\ avoided}$) by the installation of an AD plant, expressed as ton of CH_4 per year, are calculated as follow:

$$CH_{4avoided}\ (t\ CH_4/y) = \frac{(n^\circ\ \text{of livestock head} * EF_{CH4}) - (n^\circ\ \text{of livestock head} * IEF_{CH4})}{1000}$$

(Equation 11)

Where:

EF_{CH4} = emission factor with ordinary manure management (expressed in kg of CH_4 per head per year); and

IEF_{CH4} = emission factor with biogas recovery management (expressed in kg of CH_4 per head per year).

This calculation is made for all the typology of livestock present in the farm; each contribution is sum to the other and in this way the total avoided emissions ($totCH_{4\ avoided}$) are estimated.

As the global warming potential of methane is counted as 23 (FAO, 2006), the avoided CO_2 equivalent emissions ($CO_2eq._{avoided}$) are calculated multiplying the total avoided CH_4 emissions by 23.

$$CO_2eq._{avoided}\ (t/y) = 23 * totCH_{4\ avoided}\ (t/y)$$

(Equation 12)

The amount of CO_2eq saved by the anaerobic digestion plant in AD2 example farm reaches about 20 t/y.

Once that methane is converted in CO_2eq. it is possible to apprise the externality (E_{CO2eq}) derived by the AD plant considered, as carbon credits are assume to be traded at 14.39€ per t of CO_2eq., the current market price of one ton of CO_2 (Brunori, 2010).

AD2 farm could earn more than 290 € per year if the Emission Trading Scheme will be applied also for the agriculture sector. Anyway, in spite of that, the avoided GHG emissions benefits all the society and are accounted in this model as an externality item.

The value obtained is charge automatically to the externalities worksheet (section 3.6).

Type of livestock:	Number of head of livestock population	EF_{CH4} (kg CH_4 head^{-1}year^{-1})[d]	CH_4 emission (kg CH_4 year^{-1})	IEF_{CH4} (kg CH_4 head^{-1}year^{-1})[d]	CH_4 emission with biogas recovery (kg CH_4 year^{-1})	Avoided CH_4 emissions (tCH_4 year^{-1})
Dairy cattle	470	15,04	7068,8	13,17	6189,9	0,8789
Non-dairy cattle	0	7,7	0	6,74	0	0
Swine	0	8,32	0	6,94	0	0
Total avoided CH_4 emissions (tCH_4 year^{-1})						**0,88**
GWP of CH_4[e]						**23,00**
Total avoided CO_2 emissions (tCH_4 year^{-1})						**20,21**
€/t CO_2eq.[f]	14,39					
CO_2eq. emission reduction	290,89				d= Romano et al. (2010)	
					e= (FAO, 2006)	
					f = Brunori (2010)	

Figure 21: Graphic representation and structure of the "CO_2eq. avoided emission" worksheet.

3.5 Costs worksheet

The aim of this worksheet is to estimate and collect together the costs implied by the installation of the AD plant, describing them in three different categories: investment costs, financial costs and other costs.

The investment costs are calculated as the sum of the installation costs, the ordinary operation and maintenance costs (O&M) and the extraordinary operation and maintenance costs.

Basing on the data collected and reported by Ragazzoni et al. (2010) about the installation costs, a default average value of 5.000 € per kW of electric power installed is given, subdivided as follow:

- 2.150 €/kW for civil work;
- 1.750 €/kW electromechanical work; and
- 1.100 €/kW for the cogenerator.

The comprehensive plant installation costs (PIC) is simply calculated multiplying the default average value by the electric power installed ($power_e$).

$$PIC = 5.000\ (€/kW) * power_e\ (kW) \qquad \text{(Equation 13)}$$

In AD2 case of study, as in all the other farms that have the same power installed (130 kW) the total installation plant costs reaches about 650.000 €.

Also the default average costs concerning the O&M costs are elaborate from Ragazzoni et al. (2010): the O&M cost was estimated to be 0,065 €/kWh. It is possible to consult the single O&M items and their relative average costs in figure 22.

In this case to obtain the O&M cost, it is necessary to multiply the unitary average O&M cost value by the annual electricity produced (E).

$$O\&M = 0{,}065\ (€/kWh) * E\ (kWh) \qquad \text{(Equation 14)}$$

Both installation costs and O&M costs can be changed by the user, who can enter in the specific blue cells the figures more reliable.

In order to maintain a prudential approach to the evaluation of the costs, it has been decide to include into the analysis also the extraordinary costs (EC) that could occur during the investment lifetime period. Basing on the suggestion of Ragazzoni et al. (2010) the extraordinary costs are estimated with annual risk factors: for the cogenerator a risk factor of 0,002 €/kWh$_e$ and for the entire plant a risk factor of 0,005 €/kWh$_e$. The following equations explain how to calculate the annual extraordinary quotas:

$$EC_{cogenerator} = 0{,}002\ (€/kWh_e) * E\ (kWh_e) \qquad \text{(Equation 15)}$$

$$EC_{plant} = 0{,}005\ (€/kWh_e) * E\ (kWh_e) \qquad \text{(Equation 16)}$$

Those are only precautionary expenditures that it has been decided to count in the model, considering that a cogenerator fullservice contract is assumed and usually the plant do no needs special maintenance and a complete cleaning and overhaul of the digester is done only after 20 or more years of working (Guercini, 2010).

Anyway the user could decide to enter or not those data, and can change the default given value.

The AD2 farms should account in the financial balance an annual expenditure of 64.334 € for ordinary operation and maintenance costs and 7.443 € for extraordinary operation and maintenance costs.

To determine the electric power (power$_e$) that should be installed, default values of the working hours per year and the electric efficiency are given (they always can be changed by the users).

The realistic default value used in the model for the number of working hours suggested by specialists in AD plants is 8.200 h and it has been assumed a theoretic power efficiency conversion of 100%.

The power of the cogenerator is estimated dividing the amount of electricity produced annually by the annual working hours (W_{hours}), and then dividing it by the electric efficiency (E_{eff}), as shown in the equation below:

$$power_e = \frac{E\ (kWh)}{W_{hours}\ (h)} \Big/ E_{eff}\ (\%) \qquad \text{(Equation 17)}$$

In this way the output figures of the installation costs are always linked with the power of the plant.
It is important to remember also that those figures refers to AD plants with an installed electric power lower than 250 kW.

To determine the financial costs, the user can decide the down payment of the loan, the interest rate (*i*) and the duration of the investment (n). Automatically the model calculate the capital that should be paid at the beginning of the investment (through equation 18), the consequent borrowed capital (equation 19) and the annual instalment (equation 20).

$$\text{Paid capital} = \text{plant installation cost} * \text{down payment} \qquad \text{(Equation 18)}$$

$$\text{Borrowed capital} = \text{plant installation cost} * (1 - \text{down payment}) \qquad \text{(Equation 19)}$$

$$\text{Annual instalment} = \text{borrowed capital} * \frac{i}{1-(1+i)^{-n}} \qquad \text{(Equation 20)}$$

Following those indication the AD2 farmer should pay immediately a sum of about 130.000 € and an annual instalment of about 50.000 € per 15 years of investment duration.

The other costs considered are related to the acquisition of extra farm material, especially energy crops, the transport costs of extra-farm material and the opportunity cost of crops, which is equal to the crop production cost, as shown in figure 22.
The transport cost of the eventual extra-farm material has been already calculated in the “transport” worksheet. The other two items are calculated respectively multiplying the amount of extra-farm crops and the amount of on-farm produced crops by their unitary market price. The worksheet offers default value relative to Veneto reality, estimated by CALV (*Consorzio Agrario Lombardo Veneto*), but users can enter personal data.
AD2 uses also corn silage and it should count in the balance the annual costs of crop production, that comes to about 55.000 €. Since the crops are produced in the farm fields, no further costs are required.

Electricity production (kWh)	**1.063.369,26**	
Working hours per year	**8.200**	
Power efficiency	**100%**	
Electric power installed (kWe)	**130**	
INVESTMENT COSTS:		
Plant installation costs (€)[b]:	**648.395,89**	
civil work (€/kW)	2.150	€ 278.810,23
electromechanical work (€/kW)	1.750	€ 226.938,56
co-generator (€/kW)	1.100	€ 142.647,10
Total (€/kW)	5.000	
Operation & Maintenace costs (O&M)[b] (€) :	**64.333,84**	
ordinary operations (€/kWh)	0,0095	€ 10.102,01
ordinary maintenance (€/kWh)	0,0075	€ 7.975,27
cogenerator fullservice (€/kWh)	0,03	€ 31.901,08
chemical-physical analysis (€/kWh)	0,0025	€ 2.658,42
general expenditures (€/kWh)	0,011	€ 11.697,06
Total (€/kWh)	0,0605	
Extarordinary plant maintenance (€)[b]	**5.316,85**	
plant (€/kWh)	0,005	
Extraordinary cogenerator maintenance (€)[b]	**2.126,74**	
cogenerator (€/kWh)	0,002	
FINANCIAL COSTS:		
Down payment	**20%**	
Paid capital	**129.679**	
Borrowed capital	**518.716,71**	
Interest rate	**5,0%**	
Period (years)	**15**	
Coefficient	**0,10**	
Annual instalment (€)	**49.974,35**	
OTHER COSTS:		
Acquisition of extra-farm material (€)	**0,00**	price (€/t)[g]
Corn (silage)	0	30
Sorghum (silage)	0	24
Wheat (silage)	0	18
Opportunity costs of crops (€)	**54.750,00**	price (€/t)[g]
Corn (silage)	54750	30
Sorghum (silage)	0	24
Wheat (silage)	0	18
Transport costs of the extra-farm material (€)[b]	**0,00**	
b= Rgazzoni et al. (2010)		
g = CALV (Consorzio Agrario Lombardo Veneto) and Veneto Agricoltura (2010)		

Figure 22: Graphic representation and structure of the “Costs” worksheet.

3.6 Benefits and externalities worksheet

The benefits to the farmer investigated are:

- electricity revenues;
- potential heat revenues; and
- transport costs avoided.

Unfortunately the uncertainty or the deficiency of the information about the potential heating costs avoided, the potential selling of the digestate, the chemical fertilizer savings, herbicides savings and water use savings, has no permitted their inclusion in the balance. Anyway the model give the possibility to users who are in possession of reliable data to enter any figures in the specific cells.

Electricity revenues ($E_{revenues}$) are calculated multiplying the all-inclusive tariff incentive ("*tariffa onnicomprensiva*") by the amount of electricity produced annually (equation 21). Anyway there is the possibility to change the price of the electricity in order to have the possibility to investigate different scenarios.

$$E_{revenues}\ (€/y) = 0{,}28\ (€/kWh) * E\ (kWh) \qquad \text{(Equation 21)}$$

The same operation is made to calculate the heat revenues, multiplying the heat energy produced by the tariff for the heat energy.

Since in Italy the incentive for the heating is only under debate, a national market of heat energy do not exist and only few isolated cases of AD plants are trading the selling of heat energy through private agreement, it has been decided to put 0 €/kWh as default value. Anyway it has been decide to not exclude totally the possibility of selling the heat energy produced by the AD plant; the user can enter a unitary price for heat energy and evaluate how it can influence the whole financial balance.

Moreover the electricity and heat revenues are calculated also with the relative market prices, necessary to run the economic analysis: the Italian market price of the electricity is estimated to be 0,07 €/kWh (Brunori, 2010), whereas the heat energy is computed in the model as 0 €/kWh, for the reason explained above.

The revenue derived from the selling of the electricity produced in AD2 plants comes to about 298.000 € with the feed-in-tariff incentive, and only to 74.436 € considering the electricity market price.

The transport avoided costs derive from the estimation made in the transport worksheet is negative due to the inclusion of the energy crops, as explained in Section 3.3.

Concerning the evaluation of the externalities, it has been decided to include in the economic analysis only those that have already been apprized in literature (see Chapter 2, section 2.2):

- the CO_2eq. emissions reduction; and
- the reduction of unpleasant odours.

The CO_2eq. emissions reduction are calculated in the specific worksheet (see Section 3.4), and it has been estimated to correspond to 14,39 €/t of CO_2eq. (Brunori, 2010).
As already discuss in Chapter 2 (section 2.2.1) the odour reduction externality (E_{OR}) in an ordinary rural area of Veneto region has been evaluated approximately to reach on the whole 361.800 €, assuming that it is possible to count 200 houses within a 1,6 km radius from the farm for a total value of 18 million of euro.
It has been assumed that the benefit is constant during the investment period and that it is the same for all the farm investigated.
In order to have an annual value of the odour reduction benefit, its annuity has been calculated using the following formula:

$$a = C_o \frac{i * q^n}{q^n - 1}$$

(Equation 22)

where:

- a is the annuity;
- C_0 is the capital at the beginning (year 0);
- *i* is the interest rate;
- n is the period of the investment; and
- q is equal to $(1+i)^n$.

For example, if the interest rate is 5%, the period of the investment is consider to be 15 years and the odour reduction benefits value on the whole is 361.800 €, the resultant annuity is 34.856,64 €/y, which will be counted in the economic cash flow.

r	a
1%	3.618
2%	7.236
3%	10.854
4%	14.472
5%	18.090
6%	21.708
7%	25.326
8%	28.944
9%	32.562
10%	36.180
11%	39.798
12%	43.416
13%	47.034
14%	50.652
15%	54.270
16%	57.888
17%	61.506
18%	65.124
19%	68.742
20%	72.360

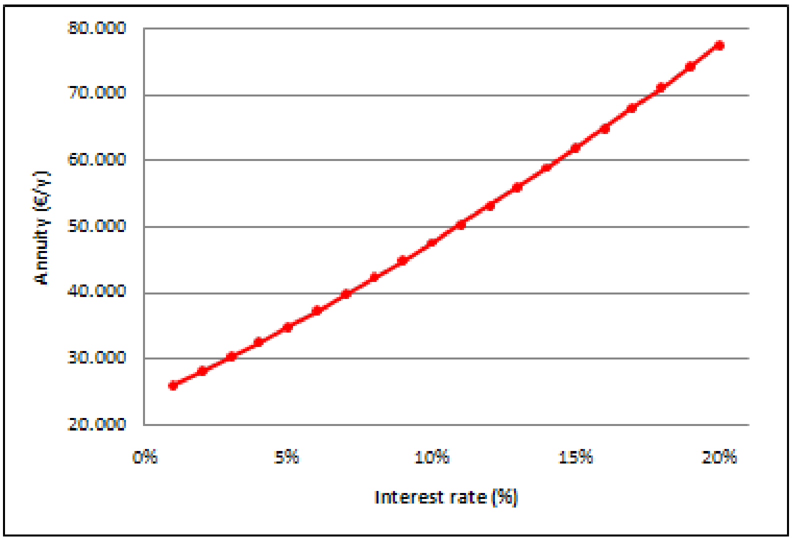


Figure 23: Annuity of odour reduction benefit with a period of investment of 15 years under different interest rate values.

BENEFITS TO THE FARMER:			
Incentive energy prices			
Electricity (kWh/year)	1.063.369,26		
Unit price (EUR/kwh)	0,28		
Total daily electricity revenues (EUR/day)	815,74		
Total electricity revenues (EUR/year)	**297.743,39**		
Heat (kwh/year)	1.595.053,88		
Heat used (kwh/year)			
Unit price (EUR/kwh)	0,00		
Total daily heat revenues (EUR/day)	0,00		
Total heat revenues (EUR/year)	**0,00**		
Market energy prices			
Electricity (kWh/year)	1.063.369,26		
Unit market price (EUR/kwh)	0,07		
Total daily electricity revenues (EUR/day)	203,93		
Total electricity revenues (EUR/year)	**74.435,85**		
Heat (kwh/year)	1.595.053,88		
Unit market price (EUR/kwh)	0,00		
Total daily heat revenues (EUR/day)	0,00		
Total heat revenues (EUR/year)	**0,00**		
Transport cost avoided	**-4.481,94**		
Other benefits	0,00	quantity	unitary price
Heating cost avoided	*0,00*	0	0
Digestate selling	*0,00*	0	0
Chemical N-Fertilizer savings	*0,00*	0	0
Herbicide savings	*0,00*	0	0
Water savings	*0,00*	0	0
EXTERNALITIES:			
CO_2eq. emission reduction	**290,89**		
Odour reduction	**361.800**		

Figure 24: Graphic representation and structure of the “Benefits and externalities” worksheet.

3.7 Financial analysis and economic analysis worksheets

In the financial analysis cash flow the following items are counted:

- cost items:
  - paid capital;
  - annual instalment;
  - ordinary O&M;
  - extraordinary plant O&M;
  - extraordinary cogenerator O&M;
  - acquisition of extra-farm material;
  - opportunity cost of crops;
  - transport cost of extra-farm crops;
- revenue items:
  - total electricity revenues;
  - total heat revenues;
  - avoided transport costs;
  - other benefits.

Per each year of the investment period (15 years) the cost items are subtracted from the revenues, to obtain the net cash flow (NCF) (see figure 25).
Obviously, in the year 0, in which the investment starts, the only balance item present in the cash flow is the proportion of the capital that the farmer have to pay at the beginning. Instead in the following years also the other cost and benefit items are include in the cash flow. Out of precaution, in order to not overestimate the benefits' contributions, it has been decide to lower the energy production in the first year of running of the AD plant of the 30%, because usually the anaerobic digester is started up during spring or summer seasons and some operating problems could occur during the beginning phases of the plant's start.

Then the main economic factors, such as Net Present Value (NPV), Internal Rate of Return (IRR) and the payback period (PP) are calculated to evaluate the profitability of the investment.
The NPV is defined as "... the sum that results when the expected investment and operating costs of the project (suitably discounted) are deducted from the discounted value of the

expected revenues" and it is a measurement of the capacity of operating revenues to sustain the investment costs (European Commission, 2008). To obtain the NPV the following formula should be used:

$$NPV = \sum_{t=0}^{n} a_t * S_t$$

(Equation 23)

where S_t is the balance of the cash flow at time t and a_t is the financial discount factor chosen for discounting at time t.

The IRR, that measure the capacity of the net revenues to remunerate the investment costs (European Commission, 2008), is defined as the discount rate that produces a zero NPV:

$$NPV = \sum_{t=0}^{n} \frac{S_t}{(1 + IRR)^t} = 0$$

(Equation 24)

In this model both NPV and IRR are calculate with the formulas suggested by Microsoft Excel.

The PP is another financial and economic decision parameter that could be useful to define the number of years required for a projects to recover its costs. To determine the PP it is necessary to calculate first the net cumulated discounted cash flow (NCDCF) and consider the number of years in which there is a negative NCDCF (NCDCF <0). Then The PP is calculate with the following Italian Microsoft Excel formula:

PP= NCDCF <0 + ASS(INDICE(NCDCF cells set;1; NCDCF <0))/INDICE(NCDCF cells set;1; NCDCF <0)

where: "ASS" is the absolute value option and "INDICE" refers to the option that gives back the value or the value reference of a table or of a values interval.

The same actions and calculations are made also in the economic analysis worksheet (Figure 26), but this time also the externalities, such as the reduction of CO_2 emissions and odour reduction, are accounted in the cash flow.

Usually in the economic analysis the observed distorted market price of the cost and benefit items are converted in the accounting shadow price through the conversion factors since the main objective of the economic analysis is to apprize the social value of the investment (European Commission, 2008).

In spite of that, in order to proceed with a simplified approach, it has been decide to consider the market prices of the inputs and outputs corrected and net of direct and indirect taxes, subsidies, loans and all the other transfer payments.

FINANCIAL ANALISYS																
	YEARS															
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Cost items																
Paid capital	129.679,18	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Annual instalment	0,00	49.974,35	49.974,35	49.974,35	49.974,35	49.974,35	49.974,35	49.974,35	49.974,35	49.974,35	49.974,35	49.974,35	49.974,35	49.974,35	49.974,35	49.974,35
Ordinary O&M	0,00	64.333,84	64.333,84	64.333,84	64.333,84	64.333,84	64.333,84	64.333,84	64.333,84	64.333,84	64.333,84	64.333,84	64.333,84	64.333,84	64.333,84	64.333,84
Extraordinary plant O&M	0,00	5.316,85	5.316,85	5.316,85	5.316,85	5.316,85	5.316,85	5.316,85	5.316,85	5.316,85	5.316,85	5.316,85	5.316,85	5.316,85	5.316,85	5.316,85
Extraordinary cogenerator O&M	0,00	2.126,74	2.126,74	2.126,74	2.126,74	2.126,74	2.126,74	2.126,74	2.126,74	2.126,74	2.126,74	2.126,74	2.126,74	2.126,74	2.126,74	2.126,74
Acquisition of extra-farm material	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Opportunity cost of crops	0,00	54.750,00	54.750,00	54.750,00	54.750,00	54.750,00	54.750,00	54.750,00	54.750,00	54.750,00	54.750,00	54.750,00	54.750,00	54.750,00	54.750,00	54.750,00
Transport cost of extra-farm m.	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
TOTAL COST ITEMS	**129.679,18**	**176.501,78**	**176.501,78**	**176.501,78**	**176.501,78**	**176.501,78**	**176.501,78**	**176.501,78**	**176.501,78**	**176.501,78**	**176.501,78**	**176.501,78**	**176.501,78**	**176.501,78**	**176.501,78**	**176.501,78**
Revenue items																
Total electricity revenues	0,00	208.420,37	297.743,39	297.743,39	297.743,39	297.743,39	297.743,39	297.743,39	297.743,39	297.743,39	297.743,39	297.743,39	297.743,39	297.743,39	297.743,39	297.743,39
Total heat revenues	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Avoided transport costs	0,00	-4.481,94	-4.481,94	-4.481,94	-4.481,94	-4.481,94	-4.481,94	-4.481,94	-4.481,94	-4.481,94	-4.481,94	-4.481,94	-4.481,94	-4.481,94	-4.481,94	-4.481,94
Other benefits	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
TOTAL REVENUE ITEMS	**0,00**	**203.938,43**	**293.261,45**	**293.261,45**	**293.261,45**	**293.261,45**	**293.261,45**	**293.261,45**	**293.261,45**	**293.261,45**	**293.261,45**	**293.261,45**	**293.261,45**	**293.261,45**	**293.261,45**	**293.261,45**
NET CASH FLOW	-129.679,18	27.436,65	116.759,67	116.759,67	116.759,67	116.759,67	116.759,67	116.759,67	116.759,67	116.759,67	116.759,67	116.759,67	116.759,67	116.759,67	116.759,67	116.759,67
NET CUMULATED DISCOUNTED CASH FLOW	-129.679,18	-103.549,03	2.355,43	103.216,82	199.275,29	290.759,54	377.887,40	460.866,32	539.893,86	615.158,18	686.838,49	755.105,45	820.121,60	882.041,75	941.013,32	997.176,71
NDCF <0 to the end of the year	1															
Investment decision criteria (15 years)																
interest rate	5,0%															
NPV	**€ 997.176,71**															
IRR	**63%**															
PP	**0,2**															

Figure 25: Graphic representation and structure of the “Financial analysis” worksheet.

ECONOMIC ANALISYS																
	YEARS															
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Cost items																
Paid capital	129.679,18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Annual instalment	0	49.974,35	49.974,35	49.974,35	49.974,35	49.974,35	49.974,35	49.974,35	49.974,35	49.974,35	49.974,35	49.974,35	49.974,35	49.974,35	49.974,35	49.974,35
Ordinary O&M	0	64.333,84	64.333,84	64.333,84	64.333,84	64.333,84	64.333,84	64.333,84	64.333,84	64.333,84	64.333,84	64.333,84	64.333,84	64.333,84	64.333,84	64.333,84
Extraordinary plant O&M	0	5.316,85	5.316,85	5.316,85	5.316,85	5.316,85	5.316,85	5.316,85	5.316,85	5.316,85	5.316,85	5.316,85	5.316,85	5.316,85	5.316,85	5.316,85
Extraordinary cogenerator O&M	0	2.126,74	2.126,74	2.126,74	2.126,74	2.126,74	2.126,74	2.126,74	2.126,74	2.126,74	2.126,74	2.126,74	2.126,74	2.126,74	2.126,74	2.126,74
Acquisition of extra-farm material	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Opportunity cost of crops	0	54.750,00	54.750,00	54.750,00	54.750,00	54.750,00	54.750,00	54.750,00	54.750,00	54.750,00	54.750,00	54.750,00	54.750,00	54.750,00	54.750,00	54.750,00
Transport cost of extra-farm m.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL COST ITEMS	**129.679,18**	**121.751,78**	**121.751,78**	**121.751,78**	**121.751,78**	**121.751,78**	**121.751,78**	**121.751,78**	**121.751,78**	**121.751,78**	**121.751,78**	**121.751,78**	**121.751,78**	**121.751,78**	**121.751,78**	**121.751,78**
Revenue items																
Total electricity revenues	0	52.105,09	74.435,85	74.435,85	74.435,85	74.435,85	74.435,85	74.435,85	74.435,85	74.435,85	74.435,85	74.435,85	74.435,85	74.435,85	74.435,85	74.435,85
Total heat revenues	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Avoided transport costs	0	-4481,94399	-4481,94399	-4481,94399	-4481,94399	-4481,94399	-4481,94399	-4481,94399	-4481,94399	-4481,94399	-4481,94399	-4481,94399	-4481,94399	-4481,943988	-4481,943988	-4481,943988
Other benefits	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CO_2eq. emission reduction	0	290,89	290,89	290,89	290,89	290,89	290,89	290,89	290,89	290,89	290,89	290,89	290,89	290,89	290,89	290,89
Odour reduction	0	34.856,64	34.856,64	34.856,64	34.856,64	34.856,64	34.856,64	34.856,64	34.856,64	34.856,64	34.856,64	34.856,64	34.856,64	34.856,64	34.856,64	34.856,64
TOTAL REVENUE ITEMS	**0**	**82.770,68**	**105.101,43**	**105.101,43**	**105.101,43**	**105.101,43**	**105.101,43**	**105.101,43**	**105.101,43**	**105.101,43**	**105.101,43**	**105.101,43**	**105.101,43**	**105.101,43**	**105.101,43**	**105.101,43**
NET CASH FLOW	-129.679,18	-38.981,10	-16.650,35	-16.650,35	-16.650,35	-16.650,35	-16.650,35	-16.650,35	-16.650,35	-16.650,35	-16.650,35	-16.650,35	-16.650,35	-16.650,35	-16.650,35	-16.650,35
NET DISCOUNTED CASH FLOW	-129.679,18	-166.804,04	-181.906,39	-196.289,58	-209.987,87	-223.033,85	-235.458,59	-247.291,68	-258.561,29	-269.294,25	-279.516,12	-289.251,23	-298.522,77	-307.352,80	-315.762,36	-323.771,46
NDCF <0 to the end of the year	15															
Investment decision criteria (15 years)																
social interest rate	5,0%															
NPV	-€ 323.771,46															
IRR	<0															
PP	>15															

Figure 26: Graphic representation and structure of the “Economic analysis” worksheet.

3.8 Results worksheet

In the results worksheet are summarized the financial and economic cash flows and the main financial and economic indicators of the investment, in order to compare the different results. AD2 farm, which is acting as practical example of the model, present a positive financial NPV equal to 997.176,7 €, a IRR of 63% and a PP less than one year. On the contrary the economic NPV is negative, the IRR is less than zero and the PP greater than 15 years, indicating the economic unfeasibility of the project.

Results:

	NPV	IRR	PP
Financial analysis	€ 997.176,71	63%	0,2
Economic analysis	-€ 323.771,46	<0	>15

Cash flow

	YEARS															
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Financial analysis																
TOTAL COST ITEMS	129.679,18	176.501,78	176.501,78	176.501,78	176.501,78	176.501,78	176.501,78	176.501,78	176.501,78	176.501,78	176.501,78	176.501,78	176.501,78	176.501,78	176.501,78	176.501,78
TOTAL REVENUE ITEMS	0	203.938,43	293.261,45	293.261,45	293.261,45	293.261,45	293.261,45	293.261,45	293.261,45	293.261,45	293.261,45	293.261,45	293.261,45	293.261,45	293.261,45	293.261,45
NET CASH FLOW	-129.679,18	27.436,65	116.759,67	116.759,67	116.759,67	116.759,67	116.759,67	116.759,67	116.759,67	116.759,67	116.759,67	116.759,67	116.759,67	116.759,67	116.759,67	116.759,67
NET CUMULATED DISCOUNTED CASH FLOW	-129.679,18	-103.549,03	2.355,43	103.216,82	199.275,29	290.759,54	377.887,40	460.866,32	539.893,86	615.158,18	686.838,49	755.105,45	820.121,60	882.041,75	941.013,32	997.176,71
Economic analysis																
TOTAL COST ITEMS	129.679,18	121.751,78	121.751,78	121.751,78	121.751,78	121.751,78	121.751,78	121.751,78	121.751,78	121.751,78	121.751,78	121.751,78	121.751,78	121.751,78	121.751,78	121.751,78
TOTAL REVENUE ITEMS	0	82.770,68	105.101,43	105.101,43	105.101,43	105.101,43	105.101,43	105.101,43	105.101,43	105.101,43	105.101,43	105.101,43	105.101,43	105.101,43	105.101,43	105.101,43
NET CASH FLOW	-129.679,18	-38.981,10	-16.650,35	-16.650,35	-16.650,35	-16.650,35	-16.650,35	-16.650,35	-16.650,35	-16.650,35	-16.650,35	-16.650,35	-16.650,35	-16.650,35	-16.650,35	-16.650,35
NET CUMULATED DISCOUNTED CASH FLOW	-129.679,18	-166.804,04	-181.906,39	-196.289,58	-209.987,87	-223.033,85	-235.458,59	-247.291,68	-258.561,29	-269.294,25	-279.516,12	-289.251,23	-298.522,77	-307.352,80	-315.762,36	-323.771,46

Figure 27: Graphic representation and structure of the “Results” worksheet.

Chapter 4: Results and discussion

This chapter is separated into three main sections. The first one consist of reporting the results of the financial and economic analyses that have been carried out on the five different farms considered as cases of study, listing and summarizing also the cost and benefit items considered in the cash flows. Since the economic analysis presents negative results for the most part of the farms analyzed, the second section is focused on the valuation and appraisal of the externalities that should be present to make the AD projects economically feasible. In the final section a sensitivity analysis is carried out to examine the national incentive of the electricity production from biogas.

4.1 Results concerning the financial and economic analysis

In this study a cash flow has been carried out for each farm considered to set the financial and the economic analysis.

In table 17 are reported the unit price of the cost, benefit and externality items that have been accounted in the cash flow.

The installation costs and the ordinary and extraordinary O&M costs are the same for all the cases analyzed, since fix and common figures found in literature have been adopted as default values (especially from Ragazzoni et al., 2010), as explained in the previous chapter.

The costs regarding the opportunity cost of crops, the acquisition of extra-farm crops (or other material) and the transport of the latter, refers to the different kind of matter (corn, sorghum and wheat silage) and the relative used quantity.

The CO_2 emission reduction externality (E_{CO2eq}) is influenced by the typology of the livestock present in the farm and the farm size, that is the number of the animals. In fact in AD2 the E_{CO2eq} has been estimated to reach only 290 €/y (0,0003 €/kWh), due to the small number of animals present in the farm, whereas in AD3 the E_{CO2eq} reaches 7.745 €/y (0,007 €/kWh) because of the high number of pigs. The unit value of the benefit derived from the reduction of unpleasant odour (E_{OR}) is influenced by the amount of electricity produced from the biogas plant; as a fix annual value of 34.856,6 €/y has been established, it is obvious that the smaller the installed power, the higher the unit value of the externality becomes.

	AD1 (cow manure)	**AD2 (cow manure, corn silage)**	**AD3 (swine slurry)**	**AD4 (swine slurry, corn silage)**	**AD5 (corn and wheat silage)**
Cost items (€/kWh)					
Installation cost [a]	0,610	0,610	0,610	0,610	0,610
Ordinary O&M [a]	0,061	0,061	0,060	0,060	0,061
Extraordinary plant O&M [a]	0,005	0,005	0,005	0,005	0,005
Extraordinary cogenerator O&M [a]	0,002	0,002	0,002	0,002	0,002
Acquisition of extra-farm material [b]	0	0	0	0	0
Opportunity cost of crops [b]	⁄	0,051	⁄	0,069	0,130
Transport cost of extra-farm material [a]	0	0	0	0	0
TOTAL COSTS	0,68	0,73	0,68	0,75	0,81
Revenues items (€/kWh)					
Total electricity revenues	0,28	0,28	0,28	0,28	0,28
Total heat revenues	0	0	0	0	0
Avoided transport costs [a]	0,001	-0,004	0,006	-0,004	-0,016
Other benefits	0	0	0	0	0
TOTAL BENEFITS	0,281	0,276	0,286	0,276	0,264
CO_2eq. emission reduction [c]	0,0005	0,0003	0,0070	0,0034	0
Odour reduction [d]	0,033	0,033	0,033	0,033	0
TOTAL EXTERNALITIES	0,033	0,033	0,040	0,036	0

([a] Ragazzoni et al., 2010; [b] CALV and Veneto Agricoltura, 2010; [c] Brunori, 2010; [d] personal estimation from Raedy and Abdalla, 2003)

Table 17: Unit prices for cost, benefit and externality items considered in the analyses.

The biogas energy production is financially feasible for the dairy, swine and dedicated energy crops farms studied when the incentive of 0,28 €/kWh is applied per 15 years, in accordance with the national supporting scheme. In fact the financial analysis proves that all the cases of study investigated present a positive NPV, a IRR greater than the assumed discount rate of 5%, and the payback periods are lower than 6 years, as showed in Table 18 .

AD1 and AD3 farms records the highest values of NPV, reaching 1.627.078 € and 1.679.363 € respectively. Also the IRR are the highest (102% for AD1 and 105% in AD3) and the PP is lower than one year.

In those farms only the costs related to the installation and operation and maintenance costs are counted in the cash flow, since they do not include any crops in the diet of the digester and they do not have to incur in further expenditures. Moreover the reduction in volume of the digestate produce a reduction of the transport costs that increase the benefits.

It is important to notice the difference in biogas production between caw and swine: AD1 farm need only 785 cows to reach a electric production able to satisfy the power of 130 kW, whereas AD3 swine farm needs more than 16.000 animals to reach the same energy production. This is due to the different TS concentration in the effluents. The swine slurry in fact has a lower TS content respect the caw slurry (see Chapter 1, Table 2) . The presence of straw as stable bedding increase significantly the TS content, accentuating the energy production difference.

Obviously the addiction of energy crops to the animal effluents guarantees higher incomes in term of energy trading, but further costs should be accounted for the cultivation of the corn. This is reflected in AD2 and AD4 farm, where the NPV (997.176,71 € and 810.505,58 € respectively) and the IRR (63% and 52% respectively) are lower respect the two farms that use only manure or slurry.

It should be noticed that more energy crops are used, higher are the expenditures related to the cultivation and transport of the crops, influencing the final project feasibility. In fact, farm AD4, that add more energy crops than in farm AD2, shows a lower NPV which comes to about 810.506 € (as reported in Table 18).

When only energy crops are used to fed the digester high biogas yields are assured, due to the high content of both total solids and volatile solids. Anyway the opportunity costs of the crops weighs in the balance and, for the same power installed (130 kW), the NPV and the IRR of the energy crop dedicated farm are lower than the once of the AD2 and AD4 farm, which adds only a little percentage of crops in the animal effluents.

AD5 in fact register the lowest NPV (about 9.200 €), the lowest IRR (5,7%) and 14 years will occur to cover the investment and the expenditures (as reported in Table 18).

On the contrary, the economic analyses establish that the biogas energy production result to be unfeasible, as showed in the table below.

The farm that use only swine slurry to fed the digester (AD3) show the less dramatic values of NPV, IRR and PP. This is due to the CO_2 emission reduction externality which reaches about 7.445 € per year (see Table 18). The CO_2 emission reduction occurring in the swine farm is significantly higher respect the one occurring in the dairy farms analyzed, due to the higher number of animals bred and the higher effluent production.

When the energy crops are added to the swine slurry and to the cow manure the NPV values decrease significantly, by the 50%. Since the investment costs and O&M costs are the same for all the farms, this discrepancy is due only to costs related to the energy crops production and management.

The AD5 case of study present the worst economic NPV, -814.155 €, since odour reduction and CO_2 reduction generated by animal defecation management are not counted in the cash flow. The cultivation and utilization of dedicated energy crops for biogas production do not generate those kind of externalities. Moreover the crop production cost is high and influences significantly the balance, turning it to the unprofitability (Table 18).

		AD1 (cow manure)	**AD2 (cow manure, corn silage)**	**AD3 (swine slurry)**	**AD4 (swine slurry, corn silage)**	**AD5 (corn and wheat silage)**
Livestock typology		dairy	dairy	swine	swine	/
Total N° of livestock heads		785	470	16300	6000	/
Defecation typology		manure	manure	slurry	slurry	/
Annual defecation	(t/y)	13205	8297	83293	40880	/
Crops typology		/	corn silage	/	corn silage	corn and wheat silage
Crop production	(t/y)	/	1825	/	2450	5720
Energy production						
from animal defecation						
biogas	(m^3/y)	882.146,84	545.245,82	796.489,31	390.915,00	/
methane	(m^3/y)	532.628,37	329737,4277	533.647,84	261913,05	/
electricity	(kWh)	1.065.256,75	659474,8553	1.067.295,68	523826,1	/
heat	(kWh)	1.597.885,12	989212,283	1.600.943,52	785739,15	/
from crops						
biogas	(m^3/y)	/	388.360,00	/	521.360,00	1.023.232,00
methane	(m^3/y)	/	201.947,20	/	271.107,20	532.080,64
electricity	(kWh)	/	403.894,40	/	542.214,40	1.064.161,28
heat	(kWh)	/	605.841,60	/	813.321,60	1.596.241,92
Total energy production						
biogas	(m^3/y)	882.146,84	933.605,82	796.489,31	912.275,00	1.023.232,00
methane	(m^3/y)	532.628,37	531.684,63	533.647,84	533.020,25	532.080,64
electricity	(kWh)	1.065.256,75	1.063.369,26	1.067.295,68	1.066.040,50	1.064.161,28
heat	(kWh)	1.597.885,12	1.595.053,88	1.600.943,52	1.599.060,75	1.596.241,92
Power installed	(kW)	130	130	130	130	130
Total investment	(€)	649.546,80	648.395,89	650.790,05	650.024,70	648.878,83
Ordinary O&M costs	(€)	64.448,03	64.333,84	64.571,39	64.495,45	64.381,76
Extraordinary O&M costs	(€)	7.456,80	7.443,58	7.471,07	7.462,28	7.449,13
Opportunity cost of crops	(€)	/	54.750,00	/	73.500,00	138.000,00
Elecricity revenues	(€)	298.271,89	297.743,39	298.842,79	298.491,34	297.965,16
Transport cost avoided	(€)	1.178,51	-4.481,94	5.917,97	-4.106,40	-16.532,99
CO_2eq. emission reduction (E_{CO2})	(€/y)	485,85	290,89	7.444,84	3.653,91	0
Odour reduction (E_{OR})	(€/y)	34.856,64	34.856,64	34.856,64	34.856,64	0
Financial analysis						
NPV	(€)	1.627.077,84	997.176,71	1.679.362,66	810.505,58	9.185,07
IRR	(%)	101,9%	63,3%	105,0%	52,2%	5,7%
PP	(years)	1	1	1	2	14
Economic analysis						
NPV	(€)	-264.133,99	-323.771,46	-143.939,19	-286.579,33	-814.154,78
IRR	(%)	<0	<0	<0	<0	<0
PP	(years)	>15	>15	>15	>15	>15

Table 18: Summary results of the application of the model.

4.2 Evaluation and appraisal of the externalities

The negative results of the economic analysis could be due to the fact that only CO_2 emission reduction and odour reduction benefits are estimated and counted in the balance.

It has been decide to quantify the amount of externalities necessary to make economic feasible the investments (Table 18).

It is known that the investment is feasible when NPV is equal or higher than 0. Only CO_2 emission reduction and odour reduction benefits are included in the economic analysis, so it has been calculated the amount of further externality (E_n), or rather an externality delta, necessary to cover the costs and reach a null NPV solving the following equation:

$$\sum_{t=0}^{n} \frac{B_n + E_n - C_n}{(1+i)^n} = 0$$

(Equation 25)

where:

- B_n is the sum of the benefit and externalities known, such as the selling of electricity, the avoided transport costs, the CO_2 emission reduction and the odour reduction (the heat energy selling is not included since it is not trade yet in Italy);
- E_n are the further externalities needed to make the NPV equal to 0;
- C_n are the costs;
- i is the interest rate (5% in this case); and
- n is the investment period (15 years)

Supposing that E_n are constant during the 15 years of the investment, the equation is solved as follow:

$$E = -\sum_{t=0}^{n} \frac{B_n - C_n}{(1+i)^n} * (1+i)^{-n}$$

(Equation 26)

Farm AD1 requires about 23.200 € of further externalities per year to make the investment profitable also from the economic point of view, the 66% of the apprised externalities (odour reduction (E_{OR}) and CO_2 emission reduction (E_{CO2eq})). The total externalities should reach a monetary value of 58.533,55 € per year.

Farm AD2 needs on the whole more than 63.599 € per year of total externalities to assure an economic profitable AD project. The amount of further externalities needed comes to 28.452 €, the 81% of the already apprized E_{OR} and E_{CO2eq}. This means that only the 55% of the whole externalities have been already monetized and internalized. It is probable that the set of further externalities (such as the potential replacement of chemical fertilizer, the potential conservation and protection of surface and ground-water, the social benefits of energy self-sufficiency and the social welfare derived from the production of renewable energy, etc.) could cover this gap, but, unfortunately, it should be noted that the lack of information about the appraisal of the other externalities determines high uncertainty about the interpretation of the results.

The same thing happens to AD4 case, where the total amount of externalities should reach 63.694 € per year, and only the 60,5% have been already internalized.

To make null the economic NPV of the swine AD3 farm, only 12.650 € of extra externalities are required; the E_{OR} and E_{CO2eq} already internalized cover the 77% of the need.

In the energy crop dedicated farm (AD5) there was not the possibility to account any externality in the economic cash flow, because usually odour reduction problems do not exist in the farm without livestock and the reduction of CO_2 emission considered in the assessment refers only to the animal defecation management. So, 71.544 € is the monetary value that the further externalities share should cover alone, as showed in Table 19.

It is plausible to think that the economic feasibility of this project, where only energy crops are used, could really be negative, since the benefits and the positive externalities could not balance the costs. Moreover it should be underlined that, usually, the installation costs and O&M costs for AD plants that treats only energy crops or other vegetable biomasses are higher than the default value used in the model – which was settled at 5.000 €/kWh_e – due to the necessity of further ancillary equipments and further operation and maintenance activities (Guercini, 2010). Therefore, this could imply that the amount of externalities needed to cover the costs could results higher than the once calculated even more.

		AD1 (cow manure)	AD2 (cow manure, corn silage)	AD3 (swine slurry)	AD4 (swine slurry, corn silage)	AD5 (corn and wheat silage)
Economic analysis:						
NPV	(€)	-264.133,99	-323.771,46	-143.939,19	-286.579,33	-814.154,78
IRR	(%)	<0	<0	<0	<0	<0
PP	(years)	>15	>15	>15	>15	>15
CO_2eq. emission reduction (E_{CO2})	(€/y)	485,85	290,89	7.444,84	3.653,91	0
Odour reduction (E_{OR})	(€/y)	34.856,64	34.856,64	34.856,64	34.856,64	0
$E_{CO2} + E_{OR}$	(€/y)	35.342,49	35.147,53	42.301,48	38.510,55	0
E (further externalities to make NPV≥ 0)	(€/y)	23.211,07	28.451,77	12.648,81	25.183,47	71.544,75
Total externalities ($E_{CO2} + E_{OR} + E$)	(€/y)	58.553,55	63.599,30	54.950,29	63.694,02	71.544,75
E proportion of $E_{CO2} + E_{OR}$	(%)	65,7%	80,9%	29,9%	65,4%	n.a.*
E proportion of total externalities	(%)	39,6%	44,7%	23,0%	39,5%	100%
$E_{CO2} + E_{OR}$ proportion of total externalities	(%)	60,4%	55,3%	77%	60,5%	0%

(*: not applicable)

Table 19: Calculation of the monetary value of the externalities that make economically feasible the investment.

Once that the externalities have been apprised as a whole, it has been calculated their unit price, relating to the electricity production (€/kWh), as reported in Table 20.
The unit price of the CO_2 emissions reduction ranges from the lowest value of 0,0003 €/kWh for the AD2 farm, to the highest value of 0,007 €/kWh of farm AD3. As already noticed the unit value of this externality is linked both to the typology and the number of animals.
Whereas the unit price of odour reduction, which is 0,003 €/kWh, is the same for all the farms, since it has been decide to fix a general figure for this externality and the production of electricity is nearly the same in all the plants.

It important to underline that this is only a raw approximation of the odour reduction externality, since its value could change dramatically depending on the specific farm' situations (as explained in Chapter 2, section 2.2.1).
In this study the whole monetary value of the externalities which are needed to guarantee the economic feasibility of the AD plants in the farms considered, ranges from 0,05 €/kWh to 0,07 €/kWh.
Since the "*tariffa onnicomprensiva*" of 0,28 €/kWh, the national incentive relative to the electricity production from biogas, is a feed in tariff, it is necessary to sum the market price of the electricity to the unit value of the externalities internalized in order to obtain a theoretic lower limit price of the whole economic benefits. Summing the market electricity price of 0,07 €/kWh to the calculated externalities' unit values, the all-inclusive theoretic tariff ranges between 0,12 to 0,14 €/kWh.
Therefore there is a discrepancy that varies from 0,14-0,16 €/kWh between the externalities values calculated in this study and that incorporated into the national incentive tariff.
From those results seems that the "*tariffa onnicomprensiva*" is overestimated from the 51% to the 57%, as highlight in the table below.

		AD1 (cow manure)	AD2 (cow manure, corn silage)	AD3 (swine slurry)	AD4 (swine slurry, corn silage)	AD5 (corn and wheat silage)
E_{CO2}	(€/kWh)	0,0005	0,0003	0,007	0,0034	0
E_{OR}	(€/kWh)	0,03	0,03	0,03	0,03	0
$E_{CO2} + E_{OR}$	(€/kWh)	0,03	0,03	0,04	0,033	0
E	(€/kWh)	0,02	0,027	0,012	0,024	0,07
Total externalities TE ($E_{CO2} + E_{OR} + E$)	(€/kWh)	0,05	0,06	0,05	0,06	0,07
Electricity market price (0,07 €/kWh) + TE	(€/kWh)	0,12	0,13	0,12	0,13	0,14
Electricity Incentive (EI)	(€/kWh)	0,28	0,28	0,28	0,28	0,28
Discrepancy with the incentive tariff (0,28 €/kWh)	(€/kWh)	0,16	0,15	0,16	0,15	0,14
	(%)	55,4%	53,6%	56,6%	53,7%	51,0%

Table 20: Unit prices (€/kWh) of economic benefits and positive externalities.

4.3 Sensitivity analysis of the incentive for electricity production

The national feed in tariff of 0,28 €/kWh does not seem to be completely justified by the results of the economic analyses carried out for the five different farms. In fact the calculations suggest the total economic benefits comes to about an average value of 0,13 €/kWh. Therefore a sensitivity analysis of the incentive value has been carried out to capture the effects of decreasing the incentive prices up to the calculated minimum tariff of 0,12 €/kWh and at the electricity market price of 0,07 €/kWh. The results are showed in Table 21.

As expected the biogas electricity production is not profitable without any incentive scheme: if the electricity is trade with its market price all the investments analyzed register negative financial NPVs. Similarly, biogas electricity production is not profitable when the value of the incentive is lower or equal to 0,12 €/kWh.

However, when the incentive reachs the 0,13 €/kWh the farms that treat only animal effluents, become feasible: AD1 reaches a NPV of 14.182 € and a IRR of 6%, whereas AD3 reaches a NPV of 63.379 € and a IRR of 10%. This reflect the results obtained from the calculation above (section 4.2) where the economic feasibility of the AD plants was tested for an average electricity offset value higher than 0,12 €/kWh.

The farm that use a mixed diet to fed the anaerobic digester reach the financial profitability when the electricity tariff exceeds the 0,19 €/kWh for dairy farm (AD2), and 0,21 €/kWh for swine farm (AD4). This difference is due to the amount of crops used: AD2 adds in the digester 5 tons of corn silage per day (the 20% of the total manure used), that contributes to the whole energy production for about 38%, whereas AD4 uses 7 tons of corn silage per day (only the 5% of the total amount of swine sludge) but which generates the 51% of the electricity yield. Those two cases demonstrate that the crops production costs influence enormously the electricity minimum offset price.

This is highlights also by AD5 case of study which results unprofitable already when the tariff decreases at 0,27 €/kWh. The greater the amount of energy crops used, the higher production costs becomes and the higher electricity tariff is needed to make the investment feasible.

The situation is more evident when the crops are bought and not produced into the farm fields: the acquisition of the crops and their transport could affect dramatically the project feasibility as clearly shown in table 22, where the same AD2, AD4 and AD5 farms were investigated changing only the origin of the crops, from on-farm produced to extra-farm bought. The costs for the acquisition of the extra-farm material combined with the costs of transport decrease the NPV and turn the feasibility of the dedicated energy crop farm to the unfeasibility.

With a price of electricity of 0,21 €/kWh only the investment of the energy crop dedicated farm (AD5) is unfeasible, as clearly visible in figure 28. This is essentially due to the higher costs that the farm should pay: the opportunity cost of the on-farm crops and the acquisition and transport costs of extra-farm crops affect significantly the feasibility of the projects.
Anaerobic digestion is profitable for all the farm when the value of the incentive reaches the current 0,28 €/kWh.

Incentive tariff (€/kWh)		AD1 (cow manure)	AD2 (cow manure, corn silage)	AD3 (swine slurry)	AD4 (swine slurry, corn silage)	AD5 (corn and wheat silage)
0,28	NPV (€)	1.627.077,84	997.176,71	1.679.362,66	810.505,58	9.185,07
	IRR (%)	102%	63%	105%	52%	6%
	PP (years)	1	1	1	2	14
0,27	NPV (€)	1.519.551,42	889.840,82	1.571.630,44	702.900,05	-98.230,77
	IRR (%)	96%	57%	99%	47%	<0
	PP (years)	1	3	1	3	>15
0,21	NPV (€)	874.392,92	245.825,45	925.237,09	57.266,88	-742.725,82
	IRR (%)	60%	22%	63%	9%	<0
	PP (years)	2	5	0,3	10	>15
0,20	NPV (€)	766.866,50	138.489,56	817.504,86	-50.338,65	-850.141,66
	IRR (%)	54%	15%	57%	<0	<0
	PP (years)	3	7	2	>15	>15
0,19	NPV (€)	€ 659.340,09	31.153,66	709.772,64	-157.944,18	-957.557,50
	IRR (%)	48%	7%	51%	<0	<0
	PP (years)	4	12	3	>15	>15
0,18	NPV (€)	551.813,67	-76.182,23	602040,41	-265.549,70	-1.064.973,34
	IRR (%)	41%	<0	44%	<0	<0
	PP (years)	6	>15	4	>15	>15
0,13	NPV (€)	14.181,58	-612.861,71	63.379,28	-803.577,35	-1.602.052,55
	IRR (%)	6%	<0	10%	<0	<0
	PP (years)	13	>15	9	>15	>15
0,12	NPV (€)	-93.344,83	-720.197,60	-44.352,94	-911.182,88	-1.709.468,39
	IRR (%)	<0	<0	<0	<0	<0
	PP (years)	>15	>15	>15	>15	>15
0,07	NPV (€)	-630.976,92	-1.256.877,07	-583.014,07	-1.449.210,52	-2.246.547,59
	IRR (%)	<0	<0	<0	<0	<0
	PP (years)	>15	>15	>15	>15	>15

Table 21: Sensitivity analysis of alternative incentive electricity offset rates for the five farms analyzed.

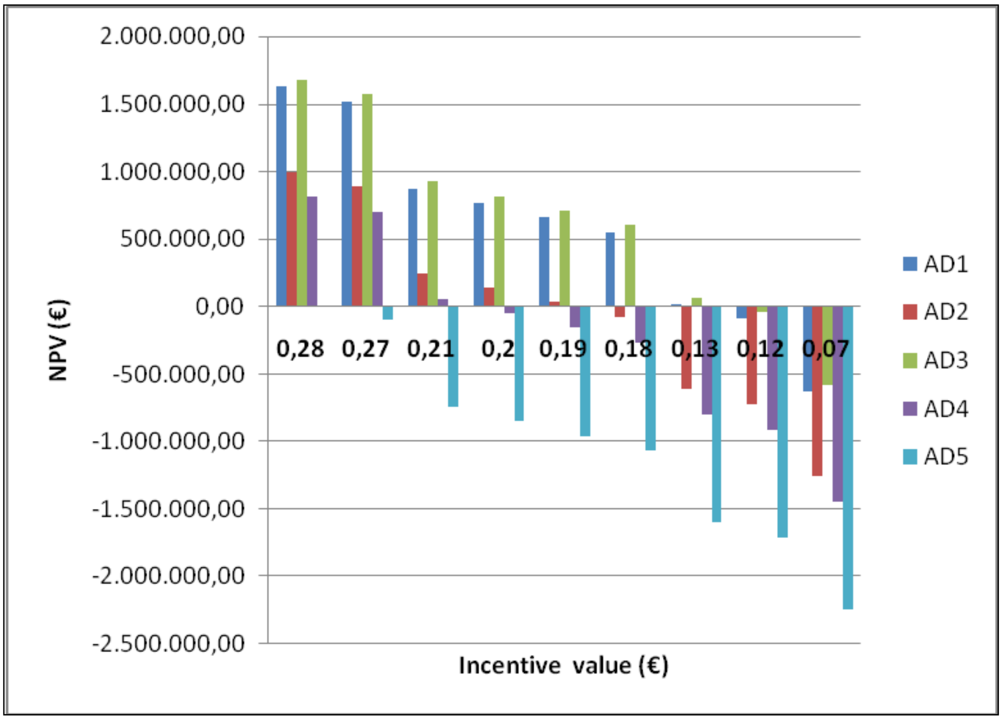


Figure 28: Profitability of the biogas plants under different incentive values.

		AD2 (cow manure, corn silage)	AD4 (swine slurry, corn silage)	AD5 (corn and wheat silage)
On-farm crops	NPV (€)	997.176,71	810.505,58	9.185,07
	IRR (%)	63%	52%	6%
	PP (years)	0,2	2	14
Extra-farm crops	NPV (€)	930.876,65	721.500,01	-198.615,68
	IRR (%)	59%	47%	<0
	PP (years)	2	3	>15

Table 22: Influence of the origin of the crops (on-farm or extra-farm crops) in the financial analysis of AD plants fed with mixed diet or energy crops options.

Chapter 5: Conclusions

The analysis of the results obtained from this study highlights the importance of the national incentive scheme to support the biogas electricity production from farm-scale anaerobic digestion plants. In fact the projects of the five different farms analyzed with the support of the model developed and discussed in Chapter 3, results financially unfeasible if the electricity produce is sold at the current market price. Whereas with the "*tariffa onnicomprensiva*" the farmer has financial advantages to start up a biogas chain due to the increase of the business income, the differentiation of the agricultural activity and the possibility to dispose zootechnical and agricultural rejects.

However when the assessment is extended to incorporate the potential externalities, through the economic analysis, some important aspects emerge about biogas energy feasibility.

First of all it should be underlined the difficulty of including those common benefits in the analysis due to the scarcity of data in literature and to the difficulty of monetization of the externalities themselves. It was possible to count only the reduction in methane emissions (calculated as reduction of carbon dioxide equivalents) and the benefit derived by the reduction of unpleasant odours, even if it should be recognized that there is considerable uncertainty in their appraisal, especially for the latter.

It is interesting to note that the internalization of those two externalities does not bring forward the economic feasibility of the projects anyhow.

It has been decide to proceed with the assessment of the hypothetical externalities needed to reach a null NPV, to determine a basic price of electricity selling above which the project results profitable.

The AD plants that use exclusively zootechnical effluents need more than 0,05 €/kWh of externalities on the whole; the AD plants that use a mixed diet (animal defecations and energy crops) reach the feasibility with whole externalities valuated upper than 0,06 €/kWh and the AD plants that use only energy crops results to be profitable only with a externality's set apprised at 0,07 €/kWh.

The last case appears improbable in the real situation considering that the dedicated crops energy biogas plants do not accomplish the reduction of CO_2 emission from manure management and of odours, which represents the 55-77% of the known and apprised externalities in the other plants, on the contrary.

So it is difficult to image that the totality of the externalities needed by the energy crops plants could lie outside the CO_2 emission reduction and to the odour reduction benefits.

Moreover the study underline that the national feed is tariff is overestimated by the 50% respect the tariff that make the projects economically feasible: the average of the economic minimum prices for the electricity trade is 0,13 €/kWh versus the 0,28 €/kWh of the incentive. This is demonstrated also by the sensitivity analysis: the AD plants fed with animal manure and slurry maintain the profitability even with a electricity setoff price of 0,13 €/kWh and the AD plants with a mixed diet are profitable with a electricity price that vary from 0,19 €/kWh to 0,21 €/kWh, depending on the amount of energy crops added to the animal effluents.

The AD plants fed exclusively with energy crops are unprofitable already at 0,27 €/kWh, reflecting the fact that there are much more costs which could not be covered by the benefits and the externalities.

The national feed in tariff supports those three different typology of farm-scale AD plants without distinction. But this is not justify from the economic and social point of view, since it is evident that the biogas plant based exclusively on energy crops do not offer the same externalities than the once that use only zootechnical effluents. It could be appropriate to decrease the "*tariffa onnicomprensiva*" of few euro cents, for example at 0,22 €/kWh, to make the business not profitable for the energy crops based AD plants or it could be useful to adopt a differentiated tariff in order to support more the AD plants typology that have a real social value. This happens in Germany, for example, where a basic electricity tariff of 0,1167 €/kWh is assured to the biogas plants that use biomasses, but a premium of 0,06 €/kWh is assigned to the "agricultural biogas" and a further premium of 0,04 €/kWh is destined to those plants that use more than 30% of liquid manure (EurObserv'ER, 2008).

In a period of decreasing price of cereals it could be useful to adopt an higher feed in tariff to favour the use of energy crops in biogas production in order to maintain the cereals sector active in the national trade market, but in the current situation, where the prices of cereals for livestock and human feeding seem to increase, this is not socially justified.

Concluding the biogas production could represent a modern multifunctional rural activity, that offers benefits to the farmers and to the whole community, increasing the value of the zootechnical and agricultural reject products transforming them to energy and organic fertilizer. Anyway further studies are needed to verify the environmental and social benefits derived by the farm-scale biogas chain, especially those about the exploitation of the digested rejects as organic fertilizers, that could limit the chemical fertilizer and pesticides uses, increase the organic fraction in the soil and protect and conserve the surface- and underground-water sources. Research should be addressed also to the appraisal of those externalities necessary to obtain a complete economic assessment and to design an appropriate national incentive system.

References

Abbasi, S.A. and N. Abbasi. 2000. “The likely adverse environmental impacts of renewable energy resources”. *Applied Energy* 65: 121-144.

Abbasi, S.A. and N. Abbasi. 2009. “Biomass energy and the environmental impacts associated with its production and utilization”. *Renewable and Sustainable Energy Reviews* 14:919-937.

Albuzio, A. and P. Paparelli. 2008. “Note di uso e riciclo delle biomasse”. Padova: CLEUP sc, Second edition.

Alfano, V. and M. Gaeta, 2010. “ Rifiuti organici e scarti di macellazione per il biogas”. *Energia Rinnovabile,* supplement to L’informatore Agrario (17): 17-21.

Al Seadi, T. Undated. “Good practice in quality management of AD residues from biogas production”. IEA Bioenergy, Task 24. Available at: http://www.iea-biogas.net/Dokumente/managementpaw3.PDF. Verified: August 4, 2010.

Amon, T., H. Mayr, M. Eder, P. Hobbs, S. Rao Ravella, U. Roth, A. Niebaum, H. Doehler, P. Weiland, E. Abdoun, A. Moser, M. Lyson, M. Heiermann, M. Plöchl, J. Budde, A. Schattauer, T. Suarez, H. Möller, A. Ward, F. Hillen, P. Sulima, A. Oniszk-Polplawska, P. Krampe, Z. Pastorek, J. Kara, J. Mazancova, H. Jan van Dooren, C.` Wim, F. Gioelli and P. Balsari. 2007. “Eu Agro Biogas Project”. Available at: www.eu-agrobiogas.net. Verified: April 10, 2010

Antonini, E. and V. Francescato. 2009. “Aspetti e valutazioni economiche. Impianti termici a cippato”. Associazione Italiana Energie Agroforestali (AIEL). Available at: http://www.crpa.it/media/documents/crpa_www/Progetti/Seq-Cure/19-20_3_09_Corso/Antonini_19_3_09.pdf. Verified: August 8, 2010

Balsari, P.. 2009. “Energy recovery and reduction of GHG emission by the coverage of a digestate storage tank”. In: *EU-Agrobiogas Symposium*, Wels, Austria, 26th November 2009. Available at: http://www.eu-agrobiogas.net/images/14.pdf . Verified: June 28, 2010

Balsari, P., E. Dinuccio and F. Gioielli. 2009.“Valutazione energetica e ambientale di impianti di digestione anaerobica: primi risultati emersi dal programma EU AGRO BIOGAS”. In: *IX convegno Nazionale dell’Associazione Italiana di Ingegneria Agraria*. Ischia Porto, 12-16 settembre 2009.

Balsari, P., E. Dinuccio and F. Gioielli. 2010. “Il sistema che recupera biogas e riduce le emissioni di CO_2. Impianto galleggiante di copertura delle vasche del digestato”. *Energia Rinnovabile*, supplement to L’informatore Agrario (6): 21-24.

Barth, C.L., D.T. Hill and L.B. Polokowski. 1974. “Correlated odor intensity index and odorous compounds in stored dairy manure”. Transactions of the ASAE 17(4): 742-747. (Mentioned by Yiridoe, E.K., R. Gordon e B.B. Brown. 2009. “Nonmarket cobenefits and economic feasibility of on-farm biogas energy production”. *Energy Policy* 37: 1170-1179).

Bauer, A., H. Mayr, k. Hopfner- Sixt and T. Amon. 2009. “Detail monitoring of two biogas plants and mechanical solid-liquid separation of fermentation residues”. *Journal of Biotechnology* 142: 56-63.

Bazen, E.F. and R.A. Fleming. 2004. “An economic evaluation of livestock odor regulation distances”. *Journal of Environmental Quality,* 33: 1997-2006.

Benedixen, H.J. 1994. “Safeguards against pathogens in danish biogas plants”. *Water Science Technology*. 30 (12): 171-180. (Mentioned by: Côte, C., D.I. Massé e S. Quessy. 2006. “Reduction of indicator and pathogenic microorganisms by psychrophilic anaerobic digestion in swine slurries”. *Bioresource Technology* 97: 686-691).

Berglund. M. and P. Briossen. “Assessment of energy performance in the life-cycle of biogas production”. *Biomass & Bioenergy* 30: 254-266.

Berti A. 2010. Personal statement. Facoltà di Agraria, Università degli Studi, Padova.

Berton, M. 2008. “La riforma dei certificati verdi premia l’agricoltura”. *Energia Rinnovabile,* supplement to L’informatore Agrario (3): 10-13.

Binkley, D.F. 2010. “The economics of anaerobic digestion under different electricity purchase agreements”. Master Degree Thesis, Agricultural Economics, Michigan State University, USA.

BIONOVA Engineering. 2009. “Best Available Techniques. Biogas production in Finnish operational environment”. Proceedings of *Bioenergy 2009, Sustainable Bioenergy Businnes Conference*, 1st September 2009, Jyväskylä, Finland.

Bonazzi G. 2003. “Come ridurre le emissioni azotate negli allevamenti suini”. *L’Informatore Agrario* (50): 59-61.

Börjesson, P. and Berglund, M. 2003. “Environmental analysis of biogas systems”. p.80, Report No. 45, Environmental and Energy Systems Studies, Lund University, Lund. (Mentioned by: Lehtomäki, A. 2006. “Biogas production from energy crops and crop residues”. Academic dissertation, Department of Biological and Environmental Science, University of Jyväskylä, Finland).

Börjesson, P. and M. Berglund. 2006. “Environmental system analysis of biogas system – Part I: Fuel cycle emission”. *Biomass & Bioenergy* 30: 469-485.

Börjesson, P. and M. Berglund. 2007. “Environmental system analysis of biogas system – Part II: The environmental impact of replacing various reference systems”. *Biomass & Bioenergy* 31: 326-344.

Bouallagui, H., Y. Tuohami, R.B. Cheikh and M. Hamadi. 2005. “Bioreactor performance in anaerobic digestion of fruit and vegetables wastes”. *Process Biochemistry* 40: 989-995. (Mentioned by: Ward, A.J., P.J. Hobbs, P.J. Holliman and D.L. Jones. 2008. “Optimization of the anaerobic digestion of agricultural resources”. *Bioresource Technology* 99: 7928-7940.)

Brambilla, M. and P. Navarotto. 2010. “Consigli per massimizzare la resa di biogas in azienda”. *Energia Rinnovabile*, supplement to L’informatore Agrario (4):44-46.

Braun, R. and A. Wellinger. Undated. “Potential of co-digestion”. IEA Bioenergy, Task 37 - Energy from Biogas and Landfill Gas. Available at: http://www.iea-biogas.net/Dokumente/Potential%20of%20Codigestion%20short%20Brosch221203.pdf. Verified: March 7, 2010.

Braun, R., P. Weiland and A. Wellinger. Undated. “Biogas from energy crops digestion” IEA Bioenergy, Task 37- Energy from Biogas and Landfill Gas. Available at: http://www.iea-biogas.net/Dokumente/energycrop_def_Low_Res.pdf . Verified: August 8, 2010.

Brown, B.B, E.K. Yiridoe and R. Gordon. 2007. “Impact of single versus multiple policy option of the economic feasibility of biogas energy production: swine and diary operation in Nova Scotia”. *Energy Policy* 35: 4597-4610.

Brunori, A. 2010. “Crediti di carbonio, mancata occasione di fare reddito. La normative non ha dato concretezza al settore”. *Energia Rinnovabile,* supplement to L’Informatore Agrario (32):13-15.

Buratti, C., M. Barbanera and F. Fantozzi. 2009. “Studio di fattibilità di un impianto di digestione anaerobica nel Comune di Castiglione del Lago”. 64° Congresso Nazionale ATI, L’Aquila, 8th-12th September 2009.
Available at: http://www.crbnet.it/File/Pubblicazioni/pdf/1459.pdf.
Verified: September 8, 2010.

Buswell, A.M. and W.D. Hatfield. 1936. “Anaerobic fermentation”. Bulletin 32. Urbana, K. Dep. of Registration and Education (Mentioned by: Wellinger, A. 1999. “Process design of agricultural digesters”. Available at: http://www.adnett.org/. Verified:April 5, 2010).

CAEEDAC (Canadian Agricultural Energy End Use Data and Analysis Centre). 1999. “The economics of biogas in the hog industry”. University of Saskatchewan, Saskatoon, Saskatchewan, Canada. (Mentioned by: Yiridoe, E.K., R. Gordon e B.B. Brown. 2009. “Nonmarket cobenefits and economic feasibility of on-farm biogas energy production”. *Energy Policy* 37: 1170-1179.)

Campbell, H. and R. Brown. 2003. “Benefit-cost analysis. Financial and economic appraisal using spreadsheet”. New York: Cambridge University Press.

Cantrell, K.B., T. Ducey, K.S. Ro and P.G. Hunt. 2008. “Livestock waste-to-bioenergy generation opportunities”. *Bioresources Technology* 99: 7941-7953.

Cecchi, F., P. Traverso, P. Pavan, D. Bolzonella and L. Innocenti. 2003. “Operational parameters for the management of an anaerobic digester”. In: Biomethanization of the organic fraction of the municipal solid waste, by Mata-Alvarez, J., 151-161. Padstow, Corwall (UK): IWA Publishing.

Chen, C.C., C.Y. Lin and M.C. Lin. 2002. “Acid-base enrichment enhances anaerobic hydrogen production process”. *Applied Microbiological Biotechnology* 58:224-228. (Mentioned by: Cantrell, K.B., T. Ducey, K.S. Ro e P.G. Hunt. 2008. “Livestock waste-to-bioenergy generation opportunities”. *Bioresources Technology* 99: 7941-7953.)

Coderoni, S. and G. Bonati. 2010. “Le emissioni di gas serra della zootecnia: potenzialità di mitigazione e recupero di biogas”. *Agriregionieuropa*, 6 (21): 27-31.

Colleran E.. Undated. “Hygienic and Sanitation Requirements in Biogas Plants Treating Animal Manures or Mixtures of Manures and Other Organic Wastes”. Environmental Research Unit, Dept. of Microbiology,National University of Ireland. Available at: http://www.adnett.org/. Verified April 5, 2010

Commission of the European Communities. 2009 a. “Towards a comprehensive climate change agreement in Copenhagen- Extensive background information and analysis-Part I”. Brussels, 28- 1- 2009.

Commission of the European Communities. 2009 b. “Towards a comprehensive climate change agreement in Copenhagen- Extensive background information and analysis-Part II”. Brussels, 28- 1- 2009.

Commission of the European Communities. 2009 c. “Towards a comprehensive climate change agreement in Copenhagen- Additional background information”. Brussels, 28- 1- 2009.

Corradini, E. 2010. Personal statement. Centro Ricerche Produzioni Animali (C.R.P.A. S.p.a)

Côte, C., D.I. Massé and S. Quessy. 2006. “Reduction of indicator and pathogenic microorganisms by psychrophilic anaerobic digestion in swine slurries”. *Bioresource Technology* 97: 686-691.

C.R.P.A. (Centro Ricerche produzioni Animali) s.p.a. 2008. “Biogas: l’analisi di fattibilità tecnico-economica”. Prospectus C.R.P.A. 6.20, N°4/2008. Availble at http://www.crpa.it/media/documents/crpa_www/Pubblicazi/Opuscoli-C/Archivio_2008/CRPA_4_2008_ultima_versione.pdf . Verified: September 1, 2010.

de Boer, H.C.. 2008. “Co-digestion of animal slurry can increase short-term nitrogen recovery by crops”. *J. Environ. Qual.* 37: 1968–1973.

de Vries, A., R.G. Geesy, A.C. Wilkie and R.A. Nordstedt. 2006. ”Spreadsheet to calculate the economic feasibility of anaerobic manure digesters on Florida dairy farms”. Available at: http://dairy.ifas.ufl.edu/tools/digester1.1.xls. Verified: June 18, 2010.

Duarte, E.A., B. Mendes and J.S. Oliveira. 1992. “Removal of Salmonella streptococci and coliforms in pig breeding effluent by anaerobic mesophilic digestion”. *Water Science Technology*, 26 (9-11), 2169-2172. (Mentioned by: Côte, C., D.I. Massé e S. Quessy. 2006. “Reduction of indicator and pathogenic microorganisms by psychrophilic anaerobic digestion in swine slurries”. *Bioresource Technology* 97: 686-691).

EEA (European Environment Agency). 2008. “Energy and environment report 2008”. Copenhagen: EEA report No: 6/2008.

EEA (European Environment Agency). 2010. “Annual European Union greenhouse gas inventory 1990-2008 and inventory report 2010”. Submission to the UNFCCC Secretariat. EEA technical Report No6/2010. Available at:
http://www.eea.europa.eu/publications/european-union-greenhouse-gas-inventory-2010.
Verified: 24 July, 2010.

ENEA (Comitato per la Ricerca e per lo Sviluppo dell’Energia Nucleare e delle Energie Alternative). 1983. “Biogas domani: incontro fra industria e ricerca”. Proceedings of “Biogas domani: incontro fra industria e ricerca” congress, organized by ENEA. Bologna, 11st November 1983.

Engen, T. 1974. “Method and theory in the study of odour preference”. In: “Human response to biological odours, by Turk, A., J. Johnston, D. Moulton. Academic press, New York, NY, USA. (Mentioned by: Yiridoe, E.K., R. Gordon and B.B. Brown. 2009. “Nonmarket cobenefits and economic feasibility of on-farm biogas energy production”. *Energy Policy* 37: 1170-1179.)

Engler. C.L., E.R. Jordan, M.J. McFarland and R.D. Lacewell. 1999. “Economics and environmental impacts of biogas production as a manure management strategy. In : proceedings of the 1999 Texas Animal Manure Management Conference. Texas A & M università. Collage station, TX, USA (Mentioned by: Yiridoe, E.K., R. Gordon e B.B. Brown. 2009. “Nonmarket cobenefits and economic feasibility of on-farm biogas energy production”. *Energy Policy* 37: 1170-1179.)

Ericsson, K., S. Huttunen, L.J. Nilsson and P. Svenningsson. 2004. “Bioenergy policy and market development in Finland and Sweden”. *Energy Policy* 32: 1707-1721.

EurObsrev’ER. 2008. “Le Baromètre du biogaz. Biogas barometre”. Systèmes solaire le jurnal des énergie renouvelables, 186: 45-59. Available at: http://www.eurobserv-er.org/pdf/baro186_a.pdf. Verified: February 15, 2010.

European Commission, Florio M. (Scientific director). 2008. "Guide to costs-benefits analysis. Structural funds, cohesion funds and instrument for pre-associacion. Final report", 30-57. Bruxelles. Available at: http://ec.europa.eu/regional_policy/sources/docgener/guides/cost/guide2008_en.pdf. Verified: August 5, 2010.

European Commission. 2010. "Europa's energy position - market and supply". Market Observatory for Energy. Report 2009. Luxemburg: Publication Office of the European Union. SEC(2009) 1734 of 21 December 2009.

EEA (European Environment Agency). 2006. "How much bioenergy can Europe produce without harming the environment?". EEA Report 7/2006. Copenhagen. Available at: http://www.eea.europa.eu/publications/eea_report_2006_7. Verified : June 20, 2010.

EUROSTAT. 2009a. "Energy, transport and environments indicators". EUROSTAT Poketbooks. Luxembourg: Publication Office of the European Uninion.

EUROSTAT. 2009b. "Panorama of energy. Energy statistics to support EU policies and solution". EUROSTAT Statistics. Luxembourg: Publication Office of the European Uninion.

FAO (Food and Agriculture Organization of the United Nations). 2004. "Unified Bioenergy Terminology (UBET)". FAO Forestry department, Wood Energy Programme. Available at: ftp://ftp.fao.org/docrep/fao/007/j4504e/j4504e00.pdf. Verified: January 25, 2010.

FAO (Food and Agriculture Organization of the United Nations). 2006. "Livestock's long shadows, environmental issue and options". FAO, Rome. Available at: http://www.fao.org/docrep/010/a0701e/a0701e00.HTM. Verified: May 7, 2010.

FAO (Food and Agriculture Organization of the United Nations). 2008. "The state of food and agriculture. Biofuels: prospects, risk and opportunities". Electronic Publishing policy and Support Branch Communication Division FAO, Rome. Available at: ftp://ftp.fao.org/docrep/fao/011/i0100e/i0100e.pdf. Verified: January 25, 2010.

FAO (Food and Agriculture Organization of the United Nations). 2010. "Greenhouse gas emission from the dairy sector. A life-cycle assessment". Food and Agriculture Organization of the United Nations, Animal Production and Health Division, Rome. Available at: http://www.fao.org/docrep/012/k7930e/k7930e00.pdf. Verified: April 13, 2010.

Ferrari, P., Barbari M. and Rossi P.. 2008. "Il risparmio del separato in cuccetta". *Benessere Animale*, supplement to L'Informatore Agrario, (38): 47-50.

Fredriksson, H., A. Baky, S. Bernesson, Å. Nordberg, O. Norén and P.-A. Hansson. 2006. "Use of on-farm produced biofuel in organic farm – Evaluation of energy balances and environmental loads for three possible fuels". *Agricultural System* 89: 184-203.

Gebrezgaber, S.A., Meuwissen M.P.M., Prins B.A.M. and Oude Lansink A.G.J.M.. 2009. "Economic analysis of anaerobic digestion - A case of green power of biogas plant in The Netherlands". *NJAS, Wageningen Journal of Life Science* (3): 1-7.

Gerardi, M.H. 2003. "The microbiology of anaerobic digesters". Wiley-Intrescience, First ed. (Mentioned by: Ward, A.J., P.J. Hobbs e D.L. Jones. 2008. "Optimization of the anaerobic digestion of agricultural resources". *Bioresources Technology* 99: 7928-7940.)

German Solar Energy Society (DGS) and Ecofys. 2005."Planning and installing bioenergy systems. A guide for installers, architects and engineers". German Solar Energy Society (DGS) and ecofys. UK: James & James (Science publisher).

Gloy, B. and U. Cornell. 2008. "Inputs for biogas economic assessment". Available at: http://agifinance.aem.cornell.edu/Publications/AD%20Systems/Digester%20Economics.xls. Accessed June 18, 2010.

Grover, V.I., V.K. Grover e W. Hogland. 2002."Recovering energy from waste. Various aspects". Enfield, New Hampshire, USA: Science Publisher Inc.

GSE (Gestore Servizi Energetici), 2009. " Incentivazione delle fonti rinnovabili. Bollettino aggiornato al 30 giugno 2009". Available at: http://www.gse.it/attivita/Incentivazioni%20Fonti%20Rinnovabili/Pubblicazioni%20informative/Bollettinoal30giugno2009.pdf. Verified: June 27, 2010.

Guercini, S.. 2008. "Monitoraggio e gestione degli effluenti zootecnici". Lesson's notes, Facoltà di Agraria, Università degli Studi, Padova.

Guercini, S.. 2009. "Digestore nell'allevamento: utili superiori a 77 mila euro". *Dossier Biogas*, supplement to L'Informatore Zootecnico, (10): 30-36.

Guercini, S. 2010. Personal statement. Facoltà di Agraria, Università degli Studi, Padova.

IEA (International Energy Agency). 2007a. "Biomass for power and CHP generation". Available at: http://www.iea.org/publications/free_new_Desc.asp?PUBS_ID=1939 . Verified: June 18, 2010.

IEA (International Energy Agency). 2007b. "Renewable for heating and cooling. Untapped potential". OECD/IEA.
Available at: http://www.iea.org/publications/free_new_Desc.asp?PUBS_ID=1975.
Verified: June 18, 2010.

IEA (International Energy Agency) 2007c. "Bioenergy project development and biomass supply. Good Practice Guideline". IEA publications.
Available at: http://www.iea.org/textbase/nppdf/free/2007/biomass.pdf. Verified: September 23, 2010.

IEA (International Energy Agency). 2008. “Key world energy statistic”. Available at: http://www.iea.org/textbase/nppdf/free/2009/key_stats_2009.pdf. Verified: February 20, 2010.

IEA Bioenergy. 2001. “Biogas and more! Systems and markets overview of anaerobic digestion”. IEA Bioenergy, Task 24. Oxfordshire (UK): AEA Technology Environment.

IEA Bioenergy. 2005a. “Benefits of bioenergy”. ExCo 2005:01. Available at: http://www.ieabioenergy.com/media/52_BenefitsofBioenergy.pdf . Verified: June 2, 2010.

IEA Bioenergy. 2005b. “Biogas production and utilization” . IEA bioenergy, Task 37 – Energy from Biogas and Landfill Gas.

Available at: www.novaenergie/iea-bioenergy-task37/index.htm . Verified: June 2, 2010.

IEA Bioenergy. 2008. “Biofuels for transport- Part of a sustainable future?” Summary and conclusions for the IEA Bioenergy Summit ExCo61 Workshop. Executive Committee of IEA Bioenergy in Oslo, Norway, on 14th May 2008.

D’Imporzano, G., A. Schievano, F. Tambone, F. Adani, T. Maggiore and M. Negri. 2010. “Valutazione tecnico-economica delle colture energetiche”. *Energia Rinnovabile*, supplement to L’informatore Agrario, (32):17-19.

Kaisto A. 2010. Personal statement. Headmaster of the Koivikko unit school farm, Oulu, Finland.

Karellas, S., I. Boukis and G. Kontopoulos. 2010. “Development of investment decision tool for biogas production from agricultural waste”. *Renewable and Sustainable Energy Reviews* 14: 1273-1282.

Karim, K., R. Hoffmann, T. Klasson and M.H. Al-Dahhan. 2005. “Anaerobic digestion of animal waste: Waste strength versus impact of mixing”. *Bioresource Technology* 96:1771–1781. (Mentioned by: Cantrell, K.B., T. Ducey, K.S. Ro e P.G. Hunt. 2008. “Livestock waste-to-bioenergy generation opportunities”. *Bioresource Technology* 99:7941-7953).

Katovich, E.J. and R.L. Beker. Undated. “Weed seeds survival in anaerobic digestion”. Environmental Impacts and Economic Comparison of Alternative Dairy System. Publication of Minnesota Project.

Available at: http://www.mnproject.org/pdf/weed%20seed%20short%20-%20web%20cx.pdf.

Verified: July 9, 2010.

Keanry, E.T., M.J. Larkin, J.P. Frost and P.N. Levett. 1993. “Survival of pathogenic bacteria during mesophilic anaerobic digestion of animal waste”. *Journal of Applied Bacteriology*, 75: 215-219. (Mentioned by: Côte, C., D.I. Massé e S. Quessy. 2006. “Reduction of indicator and pathogenic microorganisms by psychrophilic anaerobic digestion in swine slurries”. *Bioresource Technology* 97: 686-691).

Klaus, W. 2009. "Safe havens from methane eaters" Environment & Climate_ Methane Eaters, *Max Plank Research* 2: 72-79. Available at:

http://www.mpg.de/english/illustrationsDocumentation/multimedia/mpResearch/2009/heft02/034/pdf36.pdf. Verified: May 7,2010.

Klingler B. Undated. "Environmental Aspects of Biogas Technology". German Biogas Association. (12 pages). Available at: http://www.adnett.org/. Verified: April 5, 2010.

Köttner M. 1994. "Ökologische düngerwirtschaft mit biogasgülle". *Biogas für Österreich*. Hrsg. Österreischische Hochschülerschft, Wien. (Mentioned by: Klingler B.. Undated. "Environmental Aspects of Biogas Technology". German Biogas Association. Available at: http://www.adnett.org/. Verified: April 5, 2010).

Kramer, J. 2004. "Agricultural biogas casebook: 2004 update". Madison, WI: Resource Madison, WI resource Startegies, Inc. (Mentioned by Binkley, D.F. 2010. "The economics of anaerobic digestion under different electricity purchase agreements". Master Degree Thesis, Agricultural Economics, Michigan State University, USA).

Kumar, R., M.K. Gupta and S.S. Kanwar. 1999. "Fate of bacterial pathogens in cattle dung slurry subjected to anaerobic digestion ". *World Journal of Microbiology & Biotechnology*, 15: 335-338. (Mentioned by: Côte, C., D.I. Massé e S. Quessy. 2006. "Reduction of indicator and pathogenic microorganisms by psychrophilic anaerobic digestion in swine slurries". *Bioresource Technology* 97: 686-691).

Lazarus, W.F. e M. Rudstrom. 2007. "The economics of anaerobic digester operation on a Minnesota dairy farm". *Review of Agricultural Economies* 29 (2): 349-364.

Lazarus, W.F. 2008. "Farm-based anaerobic digesters as an energy and odor control technology: background and policy issues". United States Department of Agriculture. *Agricultural Economic Report*, n.843.Washington, DC, USDA Office of Energy Policy and New Uses.
Available at: http://www.usda.gov/oce/reports/energy/AnerobicDiegesters0308.pdf.
Verified: March 23, 2010.

Lazarus, W.F. 2009. "Tools to calculate digester economics". In *Renewable Energy from Organics Recycling Conference*, Minneapolis, Minnesota, USA, 19th October 2009. Availble at: http://tinyurl.com/digester-xls. Verified: June 18, 2010.

Lazarus, W.F. 2010. "Anaerobic digester economics - spreadsheet". University of Minnesota (UM). Available at: https://tinyurl.com/digester-xls. Verified: June 5, 2010.

Lehtomäki, A. 2006. "Biogas production from energy crops and crop residues". Academic dissertation, Department of Biological and Environmental Science, University of Jyväskylä, Finland.

Lien, G. 2003. “Assisting whole-farm decision making trough stochastic bugeting”. *Agricultural System* 76: 399-413.

Energia Rinnovabile. 2010. “Le rinnovabili chiedono certezza alla politica”. *Energia Rinnovabile*, supplement to L’Informatore Agrario (11).

Lusk, P. 1998. “Methane recovery from animal manure: the current opportunities casebook”. Report prepared for National Renewable Energy Laboratory, Golden, Colorado, USA. (Mentioned by: Binkley, D.F. 2010. “The economics of anaerobic digestion under different electricity purchase agreements”. Master Degree Thesis, Agricultural Economics, Michigan State University, USA.)

Madlener, R., C.H. Hantunes and L.C. Dias. 2009. “Assessing the performance of biogas plants with multi-criteria and data envelopment analysis”. *EuropenJjournal of Operational Research* 197: 1084-1094.

Malagoli, M. 2009. “Uso e riciclo delle biomasse”. Lesson’s notes. Facoltà di Agraria, Università degli Studi, Padova.

Mantovi, P. and G. Bonazzi. 2010. “Quali opportunità per l’uso dei residui organici nei terreni”. *L’Informatore Agraio* (14): 42-45.

Markus, L. 2009. “*Paras käytettävissä oleva tekniikka (BAT). Biokaasun biotantu suomalaisessa toimintaympäristössä*”. Suomen Impäristö 24/2009. Helsinky: Edita Prima Oy.

Martin, J.H. and K. Ross. 2004. “A comparison of dairy cattle manure management with and without anaerobic digestion and biogas utilization”. AgSTAR Program. Eastern Research Group Inc., Boston, MA (USEPA Contract No.68-W7-0068 Work assignment/Task Order No.400). Available at: http://www.epa.gov/agstar/pdf/nydairy2003.pdf .
Verified : February 7, 2010.

Mata-Alvarez, J.. 2003. “Biomethanization of the organic fraction of the municipal solid waste”. Padstow, Corwall (UK): IWA Publishing.

Menegaki, A. 2008. “Valuation for renewable energy: a comparative review”. *Renewable and Sustainable Energy Reviews* 12: 2422-2437.

Metha, A. 2002. “Economics and feasibility of electricity generation using manure digesters on small and medium-size dairy farms”. Energy Analysis and Policy Program, Department of Agricultural Economics, University of Wisconsin, Madison, WI.

Miner, R.J., F.J. Humenic, J.M. Rice and D. Rashash. 2003. “Anaerobic lagoon with permeable cover for reduction of odor and ammonia volatilization”. In: *Anaerobic Digester Technology Application in Animal Agriculture – A National Summit*, Water Environment Federation, Alexandria, Virginia, USA, 2nd-4th June 2003.

Moller, H.B, S.G Sommer and B.K. Ahring. 2004 “Biological degradation and greenhouse gas emission during pre-storage of liquid animal manure”. *Journal of Environment Quality* 33: 27-36. (Mentioned by: Ward, A.J., P.J. Hobbs, P.J. Holliman and D.L. Jones. 2008. “Optimization of the anaerobic digestion of agricultural resources”. *Bioresource Technology* 99: 7928-7940.)

Möller, K. e W. Stinner. 2009. “Effects of different manuring systems with and without biogas digestion on soil mineral nitrogen content and on gaseous nitrogen losses (ammonia, nitrous oxide)”. *European Journal of Agronomy* 30: 1-16.

Mosey, F.E. and X.A. Fernandes. 1989. “Patterns of hydrogen in biogas from the anaerobic digestion of milk-sugars”. *Water Science and Technology* 21: 187-196. (Mentioned by: Ward, A.J., P.J. Hobbs, P.J. Holliman and D.L. Jones. 2008. “Optimization of the anaerobic digestion of agricultural resources”. *Bioresource Technology* 99: 7928-7940.)

Mossini A.. 2010. “Quando da una stalla nasce 1MW di Potenza installata”. *Energia Rinnovabile*, supplement to L’ Informatore Agrario, (11): 22-23.

Murphy, D.J., E. Mckeogh e Kiely G.. 2004. “Technical/economic/environmental analysis of biogas utilization”. *Applied Energy* 77: 407-427.

Nelson, C. and J. Lamb. 2002. “Final report: Haubenschild farms anaerobic digester”. The Minnesota Project. St. Paul, MN, USA.
Available at: http://www.mnproject.org/pdf/Haubyrptupdated.pdf. Verified: July 9, 2010.

Noone, G.P. 1990. “The treatment of domestic wastes”. In: Wheatly, A. (ed), anaerobic digestion: a waste treatment technology. Elsevier Applied science, London, pp139-170. (Mantioned by: Wilkie, A.C. 2000. “Anaerobic digestion: holistic bioprocessing of animal manures”. In: *Proceedings of the Animal Residuals Management Conference*, 1-12. Water Environment Federation, Alexandria, Virginia).

Ørtenblad H.Undated. The use of digested slurry within agriculture. Hering Municipal Utilities, Denmark. Available at: http://www.adnett.org/ . Verified: April 5, 2010.

Paavola, T., S. Luostarinen, P. Kaparaju e J. Rintala. 2009a. “Increasing overall energy impact of biogas concepts through processing digestate to valuable products”. In: Editor Mia Savalainen. Bioenergy 2009: Sustainable bioenergy business : 4th International Bioenergy conference 31.8.- 4.9.2009, Book of Proceedings, part II. FINBIO Publication 45: 985-989.

Paavola, T., S. Luostarinen, J. Rintala. 2009b. “Processing biogas plant digestates into value-added products – BIOVIRTA”. In: Tuula Mäkinen & Eija Alakangas (eds.). BioRefine Programme 2007-2012 : Yearbook 2009. Tekes Review 264/2009: 221-225. Available at: http://akseli.tekes.fi/opencms/opencms/OhjelmaPortaali/ohjelmat/BioRefine/fi/Dokumenttiarkisto/Viestinta_ja_aktivointi/Julkaisut/BioRefine_Yearbook_2009_www.pdf .
Verified: March 30, 2010.

Pain, B.F., T.H. Misselbrook, C.R. Clarkson and Y.J. Rees. 1990. “Odour and ammonia emssions following the spreading of anaerobically-digested pig slurry on grassland”. *Biological Wastes* 34:259-267. (Mentioned by: Yridoe, E.K., R. Gordon e B.B. Brown. 2009. “Nonmarket cobenefits and economic feasibility of on-farm biogas energy production”. *Energy Policy* 37: 1170-1179).

Palmquist R.B., F. M. Roka and T. Vukina. 1997. “Hog operation, environmental effects and residential property values”. *Land Economics* 73 (1): 114-124.

Paoletti, M.G. and T. Gomiero, (edited by), 2009. “Opportunità e limiti delle agroenergie. La necessità di un approccio multicriteriale alla sostenibilità dell’”energia verde””. Roma: Aracne editore.

Persson, M., O. Jönsson and A. Wellinger. 2006. “Biogas upgrading to vehicle fuel standard and grid injection”. IEA Bioenergy, Task 37. Available at: http://www.iea-biogas.net/Dokumente/upgrading_report_final.pdf. Verified: January 3, 2010.

Petersson, A. e A. Wellinger. 2009. “Biogas upgrading technologies – developments and innovations”. IEA Bioenergy. Task 37. Available at: http://www.iea-biogas.net/Dokumente/upgrading_rz_low_final.pdf . Verified: February 17, 2010.

Pettenella, D., 2006. “Agroenergie e Protocollo di Kyoto: quali possibilità di remunerazione degli investimenti?”. Proceeding of the Congress: *Agroenergie per lo sviluppo rurale. Scenari a confronto*, Veneto Agricoltura and Università degli Studi di Padova, Legnaro (Padova, Italy) September 18th, 2006.

Pettenella D., M. Cai, D. Maso and M. Zoppelletto. 2010. “Riduzione del carico inquinante generato dai reflui zootecnici nell’area del bacino scolante della laguna veneta”. RiduCaReflui project, in press.

Pettenella, D. and D. Gallo. 2008. “Analisi economico-ambientale degli impianti a biogas”. Programma Nazionale Biocarburanti “PROBIO”. Progetto “BIOGAS”. Available at: http://probiogas.venetoagricoltura.org/relazioni/Analisi%20economico-ambientale%20degli%20impianti%20a%20biomassa.pdf. Verified: November 25, 2009.

Piccinini, S.. 2004. “Biogas: produzione e prospettive in Italia”. In Proceeding of the *Convegno Nazionale sulla Bioenergia*, Roma, 12th May 2004.

Piccinini, S.. 2006a. “L’integrazione tra la digestione anaerobica e il compostaggio”. Comitato Tecnico-GDL Digestione Anerobica, Gruppo di lavoro CIC sulla Digestione Anaerobica. C.R.P.A.

Piccinini, S.. 2006b. “Il biogas: una possibile integrazione al reddito agricolo”. In Proceeding seminar on *Biogas-Biomasse: energia dall’agricoltura, un’opportunità da valorizzare* .Leno (BS) , Italia, November 2006. Available at: http://www.ambienteingegnere.it/wp-content/uploads/2008/03/impianti-biogas.pdf . Verified May 13. Verified: May 7, 2010.

Piccinini, S.. 2007a. “Le tecnologie di produzione del biogas”. In Proceedings seminar on *Il biogas: modello di calcolo a supporto della fattibilità tecnico-economica. C.R.P.A.*, Reggio Emilia, 30th May 2007.

Piccinini, S.. 2007b. “Biometano: prospettive in Italia”. In Proceeding seminar on *Spaghetti e biocarburanti: le opportunità di sviluppo e impatti dei biocombustibili sul settore agroalimentare*, Ecomondo and KeyEnergy, Rimini Fiera 7-10 November 2007, Rimini, 9 November 2007. Available at: http://www.fattoriedelsole.org/servizi/Documents/Coldiretti%20-%20Piccinini%20-%20KeyEnergy%20Ecomondo%202007.pdf. Verified: September 8, 2010.

Piccinini, S.. 2008a. “State of the art of biogas in Italy”. In *Workshop: Biogas – a promising renewable energy source for Europe*, European Parliament, Brussels, Belgium, 11th December 2008.

Piccinini, S.. 2008b. “Biogas in Italia: lo stato dell’atre”. In Proccedings seminar on *Digestione anaerobica: opportunità per l’agricoltura e per l’ambiente* Milano, Italy, 25th January 2008.

Piccinini, S.. 2008c. “Materia o energia? Compostaggio e digestione anaerobica”. In Proceedings of *La Decima Conferenza Nazionale sul Compostaggio*. ECOMONDO, Rimini, 6th November 2008. Available at: http://www.crpa.it/media/documents/crpa_www/Convegni/20081105_ecomondo2008/Piccinini-Ecomondo-6-11-08.pdf. Verified: 21st September 2010.

Piccinini, S. 2009. “Biogas e biometano. Il ruolo del settore agricolo e agro-alimentare italiano nella produzione del biogas-biometano”. In Proceedings seminar of *Solarexpo: delivering a sustainable future*. Verona, Italy, 8th May 2009.

Powers, W.J., A.C. Wilkie and H.H. Van Horn. 1995. “Effects of anaerobic digestions and commercial additives on odors from liquid dairy manure”. In: *Proceeding of the International Livestock Odor Conference*. Ames, IA, USA. (Mentioned by: Yridoe, E.K., R. Gordon e B.B. Brown. 2009. “Nonmarket cobenefits and economic feasibility of on-farm biogas energy production”. *Energy Policy* 37: 1170-1179).

Powers, W.J., A.C. Wilkie, H.H. Van Horn and R.A. Nordstedt . 1997. “Effects of hydraulic retention time on performance and effluent odour of conventional and fixed film anaerobic digesters fed dairy manure wastewaters”. *Trans.* ASAE 40:1449-1455. (Mentioned by: Yridoe, E.K., R. Gordon e B.B. Brown. 2009. “Nonmarket cobenefits and economic feasibility of on-farm biogas energy production”. *Energy Policy* 37: 1170-1179).

Ragazzoni, A., P. Navarrotto, A. Castellini, L. devenuto, L. Barbanti, S. Capponi and D. Banzato. 2010. “Biogas. Come ottenere reddito per l’agricoltura”. Verona: Edizioni L’Informatore Agrario S.p.A.

Ready, R. and C. Abdalla. 2003. "GIS analysis of land use on the rural-urban fringe: the impact of land use and potential local disamenities on residential property values and on the location of residential development in Berks Country, Pennsylvania". Staff Paper 364. Department of Agricultural Economics and Rural Sociology, The Pennsylvania State University. University Park, PA. (Mentioned by: Yiridoe, E.K., R. Gordon e B.B. Brown. 2009. "Nonmarket cobenefits and economic feasibility of on-farm biogas energy production". *Energy Policy* 37: 1170-1179).

Rintala, J. 2008. "Energy from biogas and landfill gas – Country report Finland". IEA Task 37. University of Jyväskylä, Finland. Available at: http://www.iea-biogas.net/Dokumente/countryreports/08/ludlow/finland_report4-08.pdf . Verified: February 8, 2010.

Rintala, J. 2009. "Country report Finland". University of Jyväskylä, Finland. Available at: http://www.iea-biogas.net/Dokumente/countryreports/09/finland_report4-09.pdf. Verified: February 5, 2010.

Rossetto R. 2010. Personal statement. Veneto Agricoltura.

Rubab, S. e T.C. Kandpal. 1996. "A methodology for financial evaluation of biogas technology in India using cost functions". *Biomass & Bioenergy* 10 (1): 11-23.

Sanders D.J.. 2009. "Ohio's consumers profiles, willingness to pay, and attitudes regarding anaerobic digestion on dairy farms". Master Degree Thesis, Agricultural, Environmental and Development Economics, The Ohio State University, USA.

Salminen, E., J. Rintala, J. HärKönen, M. Kuitonen, H. Högmander and A. Oikari. 2001. "Anaerobically digested poultry slaughterhouse waste as fertilizer in agriculture". *Bioresource Technology* 78: 81-88.

Sánchez M., X. Gomez, G. Barriocanal, M.J. Cuetos e A. Morán. 2008. "Assessment of the stability of livestock farm wastes treated by anaerobic digestion". *International Biodeterioration and Biodegradation* 62: 421-426.

Song, Y.-C., S.-J. Know e J.-H. Woo. 2004. "Mesophilic and termophilic temperature co-phase anaerobic digestion compared to single stage mesophilic- and termophilic digestion of sewage sludge". *Water Research* 38: 1653-1662.

Srinivasan, S. 2008. "Positive externalities of domestic biogas initiatives: implication for financing". *Renewable and Sustainable Energy Review* 12: 1476-1484.

Svensen, B. and M. Rydehell. 2009. "Market opportunities for introduction of large scale biogas for vehicle use, based on regional fleet assessments, resource potentials and upgrading possibilities". BIOGASMAX a driving force. Project supported by the European Commission under RDT contract: 019795. Available at: http://www.biogasmax.eu/media/r7_market_opportunities_for_biogas__059544700_1411_21072009.pdf . Verified: June 15, 2010.

Terhoeven-Urselmans T., E. Sheller, M. Raubuch, B. Ludwig e R.G. Jeorgensen. 2009. "CO_2 evolution and n mineralization after biogas slurry application in the field and its yield effects on spring barley". *Applied Soil Ecology* 42: 297-302.

Titjen, C. 1975. ”From biodung to biogas – Historical review of European experience”. In: (W.J. Jewell ed.) ”Energy, agriculture and waste management”. Ann Arbor Science: 347-359 (Mentioned by: Wellinger, A. 1999. "Process design of agricultural digesters")

Tricase, C. e M. Lombardi. 2009. "State of the art and prospect of Italian biogas production from animal-sewage: technical-economic considerations". *Renewable Energy* 34: 477-485.

Tuomisto, A. e J. Helenius. 2008. "Comparison of Energy and greenhouse gasses balances of biogas with other transport biofuels options based on domestic agricultural biomass in Finland". *Agricultural and Food Science* 17: 240–251.

U.S. EPA. Undated a. "AgSTAR Handbook". AgSTAR Program and ERG, Inc. under contract # GS-10F-0036K. second edition.
Available at: http://www.epa.gov/agstar/resources/handbook.html. Verified: July 15, 2010.

U.S. EPA. Undated b."Market opportunities for biogas recovery systems. A guide to identify candidates for on-farm and centralized systems".
Available at: http://www.epa.gov/agstar/pdf/biogas%20recovery%20systems_screenres.pdf.
Verified: March 3, 2010.

U.S. EPA. Undated c. "FarmWare 3.1". AgSTAR Program. Washington, D.C.. Available at: http://www.epa.gov/agstar/resources/handbook.html. Verified: March 3, 2010.

U.S. EPA. 2002. "Managing manure with biogas recovery systems. Improved performance at competitive costs". The AgSTAR Program.
Available at: http://www.epa.gov/agstar/pdf/manage.pdf . Verified: March 3, 2010.

U.S. EPA. 2009. "Anaerobic decision capital costs for dairy farms". AgSTAR.
Available at: http://www.epa.gov/agstar/pdf/digester_cost_fs.pdf . Verified: March 3, 2010.

Uusi- Penttilä, P. 2005. "Biogas in Finland – production and utilization". In Proceedings of *Bioenergy 2005, Nordic Bioenergy Conference*, Trondheim, 25 -27 October 2005.

Van Brakel, J. 1980. "The ignis fatuus of biogas" Delft University Press. p.141. (mentioned by: Wellinger, A. 1999. "Process design of agricultural digesters").

Veneto Agricoltura. 2009. "Il biometano" Proceedings of the Congress: *Politiche e innovazioni per le imprese bioenergetiche: esperienze in Europa e Stati Uniti*. Caorle (VE), September 23rd 2009.

Ward, A.J., P.J. Hobbs, P.J. Holliman and D.L. Jones. 2008. "Optimization of the anaerobic digestion of agricultural resources". *Bioresource Technology* 99: 7928-7940.

Weiland, P. 2010. "Biogas production: current state and perspective". *Appied Microbiology and Technol*ogy 85: 849-860.

Wellinger, A. 1999. "Process design of agricultural digesters". Available at: http://www.adnett.org/. Verified: April 7, 2010.

Wellinger, A. Undated. "Energy from biogas and landfill gas. European outlook". Available at: http://akseli.tekes.fi/opencms/opencms/OhjelmaPortaali/ohjelmat/Streams/fi/Dokumenttiarkisto/Viestinta_ja_aktivointi/Seminaarit/2004/9-9-2004/1-Energiaa_biokaasusta.pdf. Verified: February 14, 2010.

Welsh, F.W., D.D. Schulte, E.J. Kroeker and H.M. Lapp, 1997. "The effect of anaerobic digestion upon swine manures odours. *Can. Agric. Eng*. 19:122-126. (Mentioned by: Wilkie, A.C. 2000. "Anaerobic digestion: holistic bioprocessing of animal manures". In: *Proceedings of the Animal Residuals Management Conference*, 1-12. Water Environment Federation, Alexandria, Virginia.)

Wilkie, A.C. 2000. "Anaerobic digestion: holistic bioprocessing of animal manures". In: *Proceedings of the Animal Residuals Management Conference*, 1-12. Water Environment Federation, Alexandria, Virginia.

Wilkie, A.C. 2005 . "Anaerobic digestion of dairy manure: design and process considerations". In dairy Manure management: Treatment, Handling and Community relations. Natural resources, Agriculture and Engineering Service, Cornell University, Ithaca, NY, USA.

Willrich, T.L. and J.R. Miner. 1977. "Litigation experience of five livestock and poultry producer. In: The Livestock Waste Management and Poultry Abatement. ASAE. St. Joseph, MI, USA. (Mentioned by: Yiridoe, E.K., R. Gordon e B.B. Brown. 2009. "Nonmarket cobenefits and economic feasibility of on-farm biogas energy production". *Energy Policy* 37: 1170-1179.)

Wulf, S., P. Jäger e H. Döhler. 2006. "Balancing of greenhouse gas emission and economic efficiency for biogas production through anaerobic co-fermentation of slurry with organic waste". *Agriculture, Ecosystems and Environment* 112: 178-185.

Yiridoe, E.K., R. Gordon e B.B. Brown. 2009. "Nonmarket cobenefits and economic feasibility of on-farm biogas energy production". *Energy Policy* 37: 1170-1179.

Yu, L., K. Yaoqiu, H. Ningsheng, W. Zifheng e X. Lianzhong. 2008. "Popularizing household-scale biogas digesters for rural sustainable energy development and greenhouse gas mitigation". *Renewable Energy* 33: 2027-2035.

Zezza, A., V. Costantini, R. Sardone, G. Dizonno, G. Bardi, A. Rossi and S. Giuca. 2008. "*Bioenergie: quali opportunità per l'agricoltura italiana*", Studi & Ricerche INEA, Napoli: Edizioni Scientifiche Italiane s.p.a.

Zoppelletto, M. 2008. "Monitoraggi impianti biogas in Regione veneto". Programma Nazionale Biocarburanti PROBIO, Progetto BIOGAS (Biofuels National Program PROBIO, Project BIOGAS). Available at:

http://probiogas.venetoagricoltura.org/relazioni/Mappatura%20e%20monitoraggio%20impianti.pdf. Verified: November 25, 2009.

Websites looked up

http://www.adnett.org/: The European Anaerobic Digestion Network

http://www.arbi.ch/lca.htm: LCA Agriculture

www.attra.ncat.org: ATTRA - National Sustainable Agriculture Information Service

http://www.biogasmax.eu: Biogas European projects for biogas production and biogas fabrication for transport and sustainable development

http://www.crbnet.it: Centro di Ricerca sulle Biomasse – Università di Perugia

http://www.crpa.it : Centro Ricerche Produzioni Animali

http://dairy.ifas.ufl.edu: IFAS – University of Florida IFA Extension

http://ec.europa.eu : European Commission

http://www.eea.europa.eu : European Environment Agency

http://www.epa.gov : EPA – United States Environmental Protection Agency

http://www.eu-agrobiogas.net: EU-AGRO-BIOGAS: European Biogas Initiative to improve the yield of agricultural biogas plants

http://www.fao.org: Food and Agriculture Organization of the United Nations

http://www.iea.org: International Energy Agency

http://www.ieabioenergy.com: International Energy Agency – IEA Bioenergy

http://www.iea-biogas.net: International Energy Agency - Biogas

www.ifeu.de: IFEU - Institute for Energy and Environmental Research Heidelberg

http://www.isprambiente.it: Istituto Superiore per la Protezione e la Ricerca Ambientale http://www.gse.it: Gestore Servizi Energetici

http://www.mpg.de: Max Planck Society

http://www.metla.fi: Finnish Forest Research Institute (Metla)

http://www.mnproject.org: The Minnesota Project

http://www.ouka.fi: City of Oulu, Finland

http://probiogas.venetoagricoltura.org: Programma Nazionale Biocombustibili: PROBIO-BIOGAS

http://www.senternovem.nl: Agentschap NL – Ministerie van Economische Zachen

http://www.usda.gov : United State Department of Agriculture

http://venetoagricoltura.regione.veneto.it : Osservatorio Innovazione – Veneto Agricoltura

www.wupperinst.org: Wuppertal Institute for Climate, Environment and Energy