Potential for Biogas at Wineries in Moldova - A case study based techno-economic analysis

Master's Thesis within the Sustainable Energy Systems programme

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CHALMERS UNIVERSITY OF TECHNOLOGY
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MASTER'S THESIS

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Cover:
Vineyard outside Chisinau, Moldova. Photo: Valeriu Istrati

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ABSTRACT

Biogas produced by anaerobic digestion is a proven and renewable energy technology that has a role to play reaching towards a sustainable development. It is a process where microorganisms feed on organic matter. Moldova is wine producing country where the energy-rich waste from the wine production, pomace, is mostly landfilled today. It is therefore both free and readily available for biogas production.

The aim of this thesis is to investigate if biogas produced at wineries in Moldova can be economic, it also evaluates its environmental and social benefits. The technical aspects investigated include plant scale, preferred technology, substrate and gas offset.

The thesis was carried out in three steps. First a pre study, then field work during a three months stay in Moldova and finally plant calculations and dimensioning. Five wineries were included in the case study. The waste streams at the wineries and their properties and potential for biogas production were identified. The data was analyzed to get understanding of how biogas from wine production residues can be implemented in Moldova. The amount of grapes harvested at the studied wineries determined the size of the biogas plants, at each winery. Flows of energy, substrate, fertilizer and money were calculated which served as a basis for investment proposals and recommendations for the wineries.

The proposed biogas plant is a tank reactor, fed with stored pomace from the local winery. It produces combined heat and power and organic fertilizer. A Moldovan winery that processes 3800 tons of grapes annually can with this technology produce over 500 GWh of electricity and 260 GWh of useful heat. The reduction in climate impact is 1100 ton of CO_2-equivalents per year. The annual income of such a plant is 60 000 euro. On top of this comes the economic benefit from the organic fertilizer. This plant has an investment cost of 260 000 euro which gives a payback time of less than five years. The export potential for biogas companies to deliver these solutions is 6.4 million euro for the 20 largest wineries in Moldova. Moldovan wineries are interested but need assistance with planning and implementation.

The conclusion is that a biogas plant at a Moldovan winery is profitable and also reduces climate impact and contributes to energy independency and security. Investment is therefore recommended. It can also be an interesting possibility for other wine producing countries.

Key words: Biogas, Anaerobic Digestion, Moldova, Winery, CSTR, CHP

Contents

Preface

This Master's thesis covers a wide range of topics, from biogas and renewable energy to wine and agriculture. It has been made in a Swedish-Moldovan multicultural context and includes aspects of Moldovan society and politics and how these aspects relate to the engineering perspective of biogas. An experience in itself is often greater than the report of it, however I will try to make clear the understanding I got during my stay in Moldova on how a biogas project can be realized.

I first got the idea of producing biogas from wine production residues during my initial meeting with Borlänge Energi and Sida, the Swedish development cooperation agency, at BNG communications in Stockholm, February 2011. There was a presentation of a country called Moldova, of which I knew very little. In the presentation it was mentioned that Moldova is a wine producing country that uses Russian natural gas. I therefore came up with the idea of producing biogas from the wine production residues and feeding it to the gas grid. I thought that would increase the income for the Moldovan people and at the same time decrease the environmental impact. At this point all I had was questions; I knew nothing of anaerobic digestion, wine production or its residues. As they often do, answers came with time; and as usual, they were not the expected ones.

Before beginning the report I want to stress an important matter. There are five biogas plants in Moldova today. None of them work. Four of them were operational, but not anymore. In all cases the reason for the failure was not in the biogas plants; technically they all worked fine. So why did they fail? The answer of that question will be given in the report and is a key for successfully implementing biogas at wineries in Moldova. Implementing biogas in Moldova will not be huge technical challenge. The problem lies instead in adapting the technology to the situation and context in which it will be used in. It does not matter if one finds the perfect technical solution for a problem if that solution does not work in its context.

The prestudy was made during the spring and summer in Sweden. A way of transport with low environmental impact was chosen to get to Moldova, the bicycle. The trip was 2000 km and was made in three weeks through Sweden, Poland, Ukraine and Moldova. The autumn was spent in Chisinau, Moldova, at the Department for Foreign Relations in the Chisinau City Hall. The finishing work took place at the Division of Energy Technology at Chalmers.

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Apart from that I would like to send my thanks to:

The inspiration and contacts of my supervisor Ronny Arnberg at Borlänge Energi gave me what I needed to carry out this thesis and broadened its boundaries beyond the academic world.

My examiner and supervisor at Chalmers, Erik Ahlgren, provided useful assistance and guiding throughout the project.

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Helen Butacova – interpretation

Nelu Proca – practical assistance

Nicolae Chiosa – wine making knowledge and winery guiding

Finally I would like to thank the friendly and helpful people of Moldova for making this thesis possible and for making my stay in the country both interesting and pleasant.

Notations

AD – Anaerobic Digestion

ANRE – National Agency for Energy Regulation

CHP – Combined Heat and Power

CH_4 – Methane

CO_2 – Carbon Dioxide

CSTR - Continuously Stirred Tank Reactor

DH – District Heating

EBRD – European Bank of Reconstruction and Development

GDP – Gross Domestic Product

HRT – Hydraulic Retention Time

NGO – Non Governmental Organization

NPV – Net Present Value

OLR – Organic Loading Rate

SRT – Solids Retention Time

TSO – Transmission System Operator

UASB – Upstream Anaerobic Sludge Blanket

UNDP – United Nations Development Program

1 Introduction

Finding strategies to implement renewable energy is a growing issue; further development of the fossil energy system is not sustainable. To mitigate climate change, feasible renewable alternatives have to be developed. Biogas is such an alternative and has a part to play in a sustainable development, since it has low climate impact and a small environmental footprint. This thesis is an energy systems analysis about biogas in Moldova that focuses on grape residues and their conversion to biogas.

1.1 The Republic of Moldova

Moldova is situated between Ukraine and Romania in the southeast of Europe, see Figure 1.1. It has a population of 3.6 million and is about the size of Dalarna. The capital is Chisinau which officially has around 700 000 inhabitants. (1) The spoken languages are Moldovan, or Romanian, which is the official language, and Russian. Next to the Ukrainian border there is a region, Transnistria, which formally belongs to Moldova but in reality is independent.

Figure 1.1. Eastern Europe. (2)

The collapse of the Soviet Union in 1991 left Moldova, which is a farming country, with cut off exports of agricultural products and cut off imports of energy. This led to a deep economic crisis that lasted throughout the nineties and from which the county still recovers. There is now an economic growth in Moldova; however it is still the poorest country in Europe in terms of GDP per capita. (3) Moldova is a large wine producer and still exports most of its products to Russia, however a turn towards the EU has begun and is supported by Prime Minister Filat, EU and Sida.

A major problem in the country is the energy issue. Moldova imports 96% of its energy needs from Russia and Ukraine (4), mainly natural gas, for which there is a wide-span distribution grid throughout the country. The dependence on Russian natural gas has brought large depts. Moldova has an aim to increase its energy independence.

Moldova has almost no natural resources, such as fossil fuels, raw materials or further possibilities for hydro power. However they do have a fertile soil and due to that a large agricultural sector that generates large streams of waste that in general are not used. There is therefore a large potential for bio-energy in the country. The driving forces behind energy projects in Moldova are economic, rather than environmental.

Much of the development work that is done in Moldova aims at improving energy security by the use of national energy resources and improving energy efficiency. Today the country is held back because of the energy issue, both politically and economically. To mitigate climate change Moldova has set up an aim to have 20% of their energy consumption coming from renewable sources by 2020, but no binding agreement is signed. Moldova is a receiving country according to the Kyoto protocol.

1.2 The Cooperation between Sweden and Moldova

The aim of the development cooperation between Sweden and Moldova is improved democracy and sustainable development through membership in the EU. The following extract is from the Swedish Ministry of Foreign Affairs' strategy for development cooperation with the Republic of Moldova in following years and puts this thesis in a broader context. (5)

"Support to increase the country's own capability to secure its energy supply through the development of alternative energy sources and energy-efficiency measures is considered to be of key importance to both reduced dependence on energy imports and to the development of domestic goods production. Swedish companies that are active in energy efficiency and municipal environmental infrastructure are considered to have experience and knowledge that could beused in implementing the strategy."

1.3 The Cooperation between Borlänge and Chisinau

In 2009 cooperation started with the signing of a twinning agreement between Borlänge Energi and Chisinau City Hall. Before that Borlänge Energi had cooperation with APA Canal, the energy-, water- and sewage-service company in Chisinau. The cooperation between Borlänge Energi and Chisinau is still ongoing and aims at exchanging knowledge and experience. So far the cooperation has focused on waste management and energy issues, but since October 2011 it also includes landscape design and city planning. Peace&Love foundation is involved in the cooperation, as well as Avfall Sverige and Borlänge municipality.

The NGO Hai Moldova is made up of young and inspired people who work with waste management in Moldova. They organize huge clean-up actions and educate people in Moldova in waste management. They are a main partner of Borlänge Energi in this area.

1.4 Aim

The aim of this thesis is to investigate if biogas produced from wineries in Moldova can be economic, it also evaluates its environmental and social benefits. A brief description of these issues is provided below.

Since the economic drivers are stronger than the environmental in Moldova, the plant has to be profitable to be realized and achieve environmental benefit. The technical aspects investigated include plant scale, preferred technology, substrate and gas offset. The thesis brings up requirements for a biogas plant in general and describes how this technology can be implemented in Moldova. A biogas plant design is proposed and adapted to the situation and requirements of the country in terms of ownership, laws, economics and operating mode. Connected to this design are ownership and financing issues as well as environmental and social aspects. These aspects include reduced climate impact, energy independence and security, economic growth and reduced unemployment.

1.5 Method

The thesis was carried out in three steps. First a literature study, then the field work during a three months stay in Moldova and finally plant calculations and dimensioning. For the proposed design, the payback time and reduction in climate impact were calculated.

The literature study covered the following questions:

- How does the process and technology of producing biogas from anaerobic digestion work?
- Which technologies and processes exist today and which of them would be beneficial with respect to the Moldovan situation?
- What are the costs associated with the production of biogas?
- What kind of rest product is obtained and how can it be handled and used?
- What is Moldova like as a country and what are the possibilities in general for renewable energy and biogas?
- What does the social situation look like in Moldova, how does people think and what are the key social issues connected to a biogas project?
- How is wine produced, what are the residues and how much energy do they contain?

To successfully implement a biogas plant at a Moldovan winery, the aspects in Figure 1.2 need to be considered. The thesis covers these aspects of biogas to find a way in which it can be implemented.

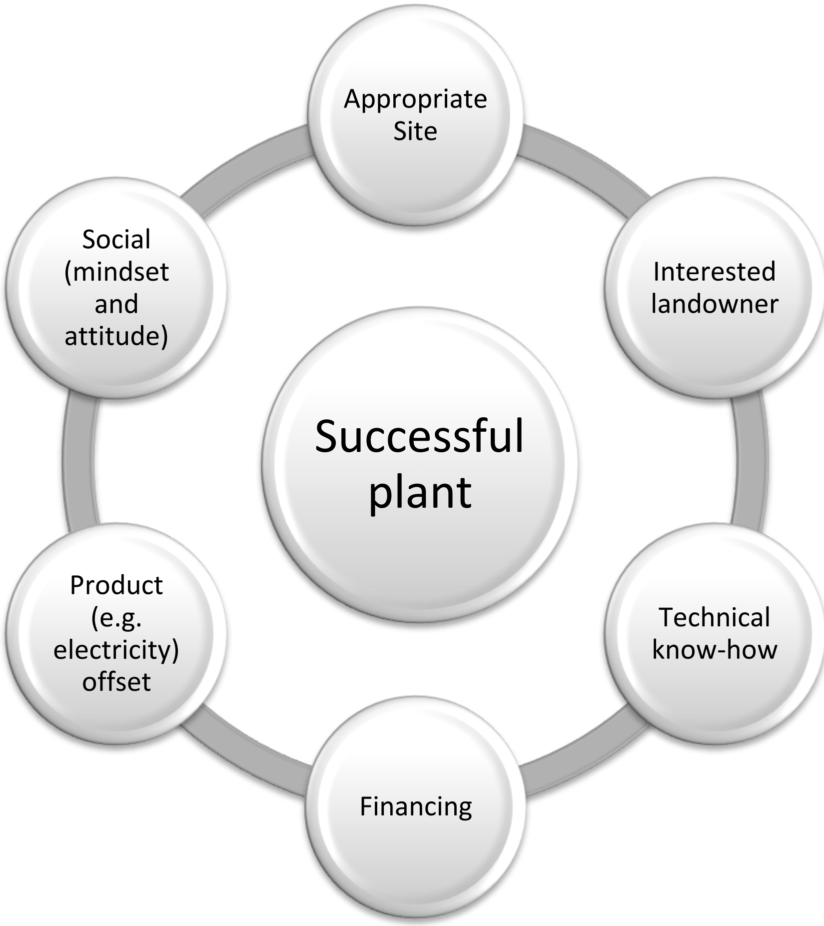


Figure 1.2. Aspects to take into consideration for a biogas plant.

Five wineries were included in the case study. The wineries were chosen to represent different aspects of winemaking in Moldova; a mix or old, modern, large, cheap, and exclusive wineries were chosen. At these wineries data which served as a basis for the calculations were collected. General conditions, waste streams and energy consumption was looked into. The waste streams and their properties and potential for biogas production were identified, as well as the current waste treatment. An important part of the work was to study existing biogas projects in Moldova and why they failed to avoid making the same mistakes again.

Apart from the wine industry, meetings were made with development cooperation agencies and donors, e.g. UN, Sida, European Bank for Reconstruction and Development and USAID to learn about their projects and how they work. Meetings with government officials and politicians were made to get their perspective and thoughts.

Cooperation was made with Moldova State University, whose vice-director has been working on a biogas from wine project in Moldova, to take part of their understanding and knowledge on the topic. The results were presented to Agriculture and Winemaking students at the Moldova State Agrarian University, whom will be the future managers at Moldovan wineries.

The data and interviews was analyzed and used to get understanding of how biogas from wine production residues can be implemented in Moldova. The following questions were answered during the analysis.

- What type of process design is preferred?
- What is the required size of the plant?
- How can the biogas be used?
- Is there need for upgrading or cleaning of the raw biogas?

The preferred process design was determined by studying different plant types and choosing the most appropriate, with respect to the conditions in Moldova. The amount of grapes harvested at the studied wineries determined the size of the biogas plants at each winery. The profit from each plant was examined in the economic analysis. To investigate how the biogas can be used, the potential for electricity and heat production were studied as well as the possibility to deliver the biogas to the natural gas grid. The most feasible option with respect to economics, grid access and laws were chosen. The gas offset determined the need for cleaning or upgrading.

Flows of energy, grapes, substrate, fertilizer and money were calculated. Investment proposals and recommendations for the wineries were made, based on the calculations and experience gained.

The knowledge and experience of the Swedish energy companies Göteborg Energi and Sweco was used in the thesis, to design the biogas plant.

Since the fresh pomace contains a large share of moisture, biogas production by anaerobic digestion is a suitable process for energy recovery of pomace. Focus was therefore put on anaerobic digestion, rather than other ways of recovering energy from the waste. The scope of the thesis is to design a process solution for a winery in Moldova without being consumed by technical detail. The aim is not to optimize the process parameters at every level with respect to the specific site, but rather to find a process that with small modifications would work at most wineries.

1.6 Limitations

There is an abundance of agricultural by-products and other waste available for energy recovery in Moldova. This thesis will focus on waste from wine production, which is interesting since it is a relatively unexplored area that has a large potential. Also the wineries in Moldova have a relatively good economical situation compared to the rest of the country. If there is a need or a belief that the winery will benefit from an investment, the wineries will in general carry it out. (6) Because of economics of scale, it will be more feasible to have a biogas plant at a large winery than a small. Also it is easier to get donor funding for large projects. The thesis will therefore concentrate on the large wineries in Moldova. However it should be noted that these are still small with international measures. Even through a small biogas plant can have social and environmental benefits, it is usually less efficient in terms of biogas production and for a single plant it will have limited effects on the environment and energy situation in Moldova. It is also less attractive in economic terms. Since most development cooperation in Moldova today works as loans with interest rates, even small investments have to pay off. This is to make sure that only the most feasible projects gets funding. Since small plants are less likely to pay off (7) the opportunity for small scale biogas will not be further investigated

2 Background

The background begins with the energy system in Moldova and then covers biogas and biogas technology as well as grapes and winemaking, it also gives an introduction to the wineries where the case studies were carried out. Finally, it brings up the situation for biogas in Moldova today.

2.1 Energy System in Moldova

Since Moldova has little energy resources, the country is dependent on other countries for their energy supply. The power plants that are operational in Moldova covers 30% percent of the electricity demand, which was 3.2 TWh in 2009. (8) The Moldovan production mix consists of 87% NG CHP, the rest is hydro power. These plants are old and inefficient; the electrical efficiency is 22%, which make them expensive to operate. They are therefore turned off in the summer when there is no heat offset. The rest of the electricity is imported from Ukraine or Transnistria. There is also a connection with the Romanian power system, but no power is bought from Romania due to higher prices. The electricity production mix in Ukraine consists mainly of nuclear (48%), coal (32%), natural gas (13%) and hydro power (5%). (9) The electricity production in Transnistria is dominated by a 2520MW thermal power plant. This is from the beginning a coal power plant but has been rebuilt and currently fires NG. This power plant is also old and inefficient, but has a lower generating cost then the Moldovan plants since the gas price is lower in Transnistria. During the last years, electricity has been imported from Ukraine due to conflicts between Moldova and Transnistria, but since October 2011 all electricity imports once again come from Transnistria. (8) Balancing power is supplied by Ukraine. The marginal electricity is likely to come from NG, either from the Moldovan CHPs, when they are operating, or from the NG plant in Transnistria. If electricity once again will be imported from Ukraine, coal is likely to be on the margin. The discussion about transfers and tariffs is not transparent but rather a political matter connected to other issues like laws and border conflicts between the parts involved.

The electricity grid is owned by the Spanish company Union Fenosa, who has a complete monopoly. The grid losses are high, 11-14% in 2009. (8) There is a wide distribution grid for both electricity and gas in Moldova. Natural gas is imported from Russia. The gas grid in Moldova is owned by Russian Gazprom to 50 %, who may have limited interest of biogas delivered to the gas grid in Moldova since this will reduce their gas sales and increase energy independence. The gas and electricity market is regulated by the TSO ANRE, who sets the tariffs and sets up rules.

Moldova has a heating demand during six months of the year (10). The country has long, warm summers and quite cold winters. The thermal insulation of buildings is poor and a lot of energy and money is spent on heating. In the cold moths, it is common that the gas bill for an apartment reaches the level of the rent. There is district heating in Chisinau and Balti, the rest of the country uses local heating by gas, coal and firewood. (10). In Chisinau the DH network is owned and operated by Termocom. They are not very interested in energy efficiency, which limits the possibility for delivering heat to the DH network.

Since 2008 there is a law in Moldova that all renewable electricity produced in the country must be purchased and delivered to the grid before electricity can be imported from other regions, for example Transnistria or Ukraine. This is called the law of renewables and for such electricity law a special feed in tariff is applied. This tariff applies to plants built after the law is applied. Currently the ANRE-tariff is not applied for any operating plant.

The gas market is a closed monopoly. A contract with ANRE has to be made to get the permit of transporting gas through their grid. To be attractive, biogas has to be sold at a lower price than the import price for natural gas, subsidized or used to produce a more valuable product.

2.1.1 Implementation of Renewables in Moldova

The General Director of ANRE, Victor Parlicov (11), believes that a transition towards a sustainable Moldovan energy system has to be done in three steps. The first is reliable statistics on the current situation, which Moldova currently lacks. The second step is to define a set of goals to fulfill, based on the statistics. There is currently no binding document signed in Moldova on renewable energy. The last step is the support schemes or mechanisms that are needed to reach the goals, such as:

- Environmental legislation that puts a price on landfilling waste to provide opportunities to recover energy from the waste.
- A price of emitting fossil carbon or a CO_2 savings price
- Feed in tariffs

Factors that need to be considered when investigating possibilities for a new biogas plant are security of supply of resources and products. Substrate, fertilizer, electricity, gas and heat have to be delivered to and from the plant at the right times and in a reliable way. This can imply that recourses like substrate or fertilizer has to be stored near the plant during some time of the year. To achieve security of supply it is important to adapt and integrate the biogas process design to the conditions and culture in Moldova rather than of building a copy of a successful Swedish biogas plant.

2.2 European Bank for Reconstruction and Development

EBRD has different development programs for financing the implementation of renewable energy in Moldova, depending of project size. In general they tend to favor large projects, because of fixed cost that all projects come with. MoSEFF, Moldovan Sustainable Energy Financing Facility, covers investments in the size of 25 000 to 2 million euro. It aims at decreasing the energy intensity, which is currently three times higher than in the European Union (12), through energy efficiency measures.

For projects under MoSEFF, free consulting is offered by the German company Fichtner and gives a grant of 15% of the investment cost for biogas plants. A biogas plant at a winery can be eligible under MoSEFF, provided that the winery is owned by a Moldovan company and not by the state. MoSEFF operates the best technology principle and works through three Moldovan banks. The investor has to apply for a loan at one of these banks together with EBRD. The rate is for an average client 8.5-8.6 %, but depends on financial track record and is negotiated with the partner bank. (13) There are currently at least three large biogas projects in the planning stage in Moldova; from manure, at a sugar factory and one from corn. All three are on MW scale, two of them are under MoSEFF. (14)

2.3 Biogas

Biogas is a renewable fuel gas derived from biomass, for example agricultural products, sewage sludge, household waste and forest. In its pure form it consists of methane, CH_4, and is virtually the same gas as natural gas. The difference is that it is non-fossil and therefore in theory is climate neutral and renewable. Biogas can play an important role in reaching towards a fossil free energy system and a sustainable development.

There is a benefit of having a gaseous fuel compared to a liquid or solid fuel when it comes to transport, emissions and convenience. Biogas is therefore a more attractive fuel then for example firewood.

Biogas can be produced by thermal gasification or anaerobic digestion. In thermal gasification the biomass is heated to high temperature in a low oxygen environment. This leads to gasification of the fuel. The fuel gas can then be cleaned and upgraded to pure biogas. This process does not yet exist commercially, however there are small scale plants in operation.

Biogas is produced as a byproduct in anaerobic digestion, AD, which is the natural process where microorganisms feed on organic matter in the absence of oxygen. The biogas produced by these microorganisms typically has contents given in Table 2.1.

Table 2.1. The composition of biogas from digestion of organic substances. (15)

Biogas composition	**Volume-%**
Methane	55-80
Cabon Dioxide	20-45
Nitrogen	0-1
Oxygen	trace
Hydrogen	trace
Sulfur	50 - 2000 ppm

This process occurs by itself in nature when there is organic matter but no oxygen available. As all life, the microorganisms need a suitable environment to live. They need the right amount of nutrients, vitamins, minerals, the right temperature, pH and absence of toxics to strive and multiply. Efficient AD is a complex microbiological process where different kinds of microorganisms cooperate and depend on each other to break down the organic matter. If one of these processes is inhibited, the whole process can fail.

The idea of producing biogas-fuel from anaerobic digestion is to create a suitable environment for the microorganisms inside a closed vessel, feed them with organic matter and collect the biogas at the top of the vessel. The incoming material to the vessel, or reactor, is called the substrate. The outgoing residue can be used as fertilizer.

2.3.1 The Steps of Anaerobic Digestion

Anaerobic digestion takes place in four steps. These steps complete the process from substrate to biogas.

2.3.1.1 Hydrolysis

The fresh substrate consists of long molecule chains of carbohydrates, proteins and fats. The carbohydrates have different lengths, from sugar to starch and cellulose. The microorganisms exudate enzymes that cut and break the long molecules in the substrate into smaller pieces that the microorganisms can digest. The rate of this step depends of the length and reactivity of the molecules in the substrate. Proteins are broken down into amino acids. Sugars can be taken up by the microorganisms directly while cellulose takes long to hydrolyze. Because of its structure lignin are not hydrolyzed at all and passes unaffected through the AD process. It is therefore not beneficial to digest material that has high lignin content.

2.3.1.2 Fermentation

During the fermentation step, the products formed in the hydrolysis are digested further by microorganisms to different organic acids, alcohols, ammoniac, carbon dioxide and hydrogen. (16) The organic acids lower the pH in the reactor, and are typically present in their ion forms, e.g. acetate which is the anion of acetic acid.

2.3.1.3 Anaerobic Oxidation

The fatty acids and alcohols are oxidized by other types of microorganisms. This is a complex process in which the microorganisms are highly dependent on the microorganisms that produce the methane. In the anaerobic oxidation, hydrogen, acetate and carbon dioxide is formed. For this production to be thermodynamically favorable, the concentration of hydrogen has to be low. The methane producers consume hydrogen.

2.3.1.4 Methane Production

This is the most critical step in the process; the methane producers are sensitive and grow slow. This step is therefore often rate determining. Acetate, hydrogen and carbon dioxide are used by the methanogens to produce methane and carbon dioxide. The methanogens belong to a special group of microorganisms and are not as robust as the microorganisms involved in the other steps; they are inhibited by pH drops and presence of toxics, like heavy metals. They are also temperature sensitive and sensitive to sudden changes in process conditions. However they can cope with large changes and different environments, if they are given sufficient time to adapt. An inhabitation of the methanogens will also affect the anaerobic oxidation step.

A common problem when it comes to the AD process, especially for substrate with a large fraction of material easy to digest, like sugar, is the accumulation of organic acids inside the reactor. This is because the first steps in the biogas process can take place rapidly and the slow methanogens will then be unable to keep up and digest the organic acids. It leads to a pH drop which will inhibit the methanogens which eventually gives an even lower pH. The result is an odorous, acid slurry, which kills many remaining microorganisms. The slurry has to be discarded and the process restarted on fresh material. It is therefore important to monitor pH as well as other process parameters and choose a substrate which is not too easily digested.

2.3.2 The Substrate

Many types of substrates can be used to produce biogas through anaerobic digestion, common examples are manure, sewage sludge, household waste and agricultural residues. Chemical and physical properties determine if a substrate is suitable as food for microorganisms. The substrate is characterized by certain parameters.

2.3.2.1 Total Solids, TS

The amount of water the substrate contains, in weight %. Determined by heating a sample to 105°C during 24h and weighing before and after.

2.3.2.2 Volatile Substance, VS

The amount of organic substance available for biogas production nitrogen the substrate contains, in weight % of TS. Determined by heating a sample to 550°C and weighing before and after.

2.3.2.3 Chemical Oxygen Demand, COD

The amount of oxygen needed to completely oxidize the sample, in g O_2/l substrate. A measure of how much organic substance available for biogas production a substrate has. The efficiency of the AD process is measured in COD reduction. High COD reduction means that most of the organic matter has been broken down and therefore is an indication of an efficient digestion process.

2.3.2.4 Nitrogen, N

The amount of nitrogen the substrate contains, in weight % of TS

2.3.2.5 pH

The microorganisms are pH sensitive; they prefer pH 7.0 – 7.5 but can outside this range as well. (16)

2.3.2.6 Sugar

The share of sugar, or fast hydrocarbons, in the substrate is an important process parameter since too much sugar can lead to accumulation of organic acids.

2.3.2.7 Carbon / Nitrogen quota

The microorganisms need nutrients like carbon and nitrogen. The C/N quota is therefore an important process parameter. If the quota is too high, the microorganisms lack nitrogen, if it is too low, the process can suffer from ammoniac inhibition. A quota of 10-30 is considered adequate, 15-25 optimal. (16)

2.3.2.8 Alkalinity

The alkalinity or buffer capacity is important. A good buffer capacity makes the digestion process more stable as it prevents pH changes. The most important buffer in the biogas process is bicarbonate ions that are in equilibrium with carbon acid. If the alkalinity in the rector is not sufficient, bicarbonate can be added to the reactor.

2.3.3 Processes and Technologies

There are different ways to produce biogas through anaerobic digestion. Different options will be examined to find an appropriate process solution for biogas produced at wineries in Moldova. In most cases it is desirable to have an even biogas production from the plant, both for the microorganisms and the gas engine, if the plant has one.

2.3.3.1 Batch and Continuous Processes

In a batch process the substrate is placed in the reactor, usually a tank or container. The microorganisms are allowed to grow and digest the substrate for a certain period of time, from a couple of weeks up to a month, depending on how difficult the substrate is to digest. (17) The reactor is then emptied and the process can be repeated. This process is used for dry substrates. Biogas production is initially high and then drops as the food for the microorganisms is consumed. A batch biogas plant therefore typically has several units that are in different stages to even out the biogas production.

A continuous process operates at steady state, substrate flows in, residue and biogas flows out. A common example is the Continuously Stirred Tank Reactor, CSTR. The process can also be done in a tube reactor where material is transported through the rector by a screw.

2.3.3.2 Dry and Wet Digestion

Dry digestion is characterized by a TS-level of 20 – 35 % and that the substrate is too dry or viscous to be pumped. (16) It is common in Germany (17) and is often carried out in batch mode. For example it can be done in a container where material is added and removed with a front loader. Dry digestion is not common in Sweden and knowledge among companies about the process is limited.

The dominating biogas production technology today is wet digestion, which is characterized by a TS-level of 2 - 15 %. (16) The material is transported by pumping which simplifies the design of the biogas plant. Wet digestion can be carried out in continuous or semi-continuous mode, where fresh material is fed to the rector for example every hour. (16) It is a continuous process which is simple and economical. (18) Wet digestion of dry substrates can be done by adding water to the substrate and pumping it into the reactor or by feeding the dryer substrate to the reactor by a screw and adding water separately.

2.3.3.3 Reactor Design Parameters

The bioreactor has certain parameters, used when designing and describing the plant. These are temperature, retention time, TS-level, reactor volume and organic loading rate and will be described in the following sections.

2.3.3.3.1 Temperature

Anaerobic digestion can take place in different temperature windows, which are characterized by the type of microorganisms that are most active at that specific temperature. According to Figure 2.1 the thermophilic AD is the fastest and the mesophilic is the most stable since it has a wider temperature range. The microorganisms that operate at this temperature are also more robust then the thermophilic microorganisms which are more sensitive to changes in process conditions. (16) Because of this, mesophilic AD process are the most used today. The psychrophilic temperature window is too slow to be of interest in a biogas plant.

Both aerobic and anaerobic digestion reactions are exothermic, but the anaerobic digestion releases a lot less heat. When 1 kg of glucose is digested without oxygen, 0.4 MJ of heat is released. Most energy ends up bound in the methane, 14MJ. This can be compared with aerobic digestion of the same amount of glucose, which releases 9MJ of low grade heat. (18) This means the reactor has to be heated to the desired temperature, which can be done by a heat exchanger at the reactor inlet. The reactor itself can be insulated to reduce heat losses. The amount of heat needed depends on process solution, climate and if the reactor operates in mesophilic or thermophilic mode; the biogas plant can be heat integrated and insulated in a way that it uses less heat. However if electricity is the main product, heat is abundant. If no electricity is produced some of the produced biogas can be incinerated to heat the process, which makes energy efficiency more important. For CHP plants, it is a tradeoff between operating cost and investment cost.

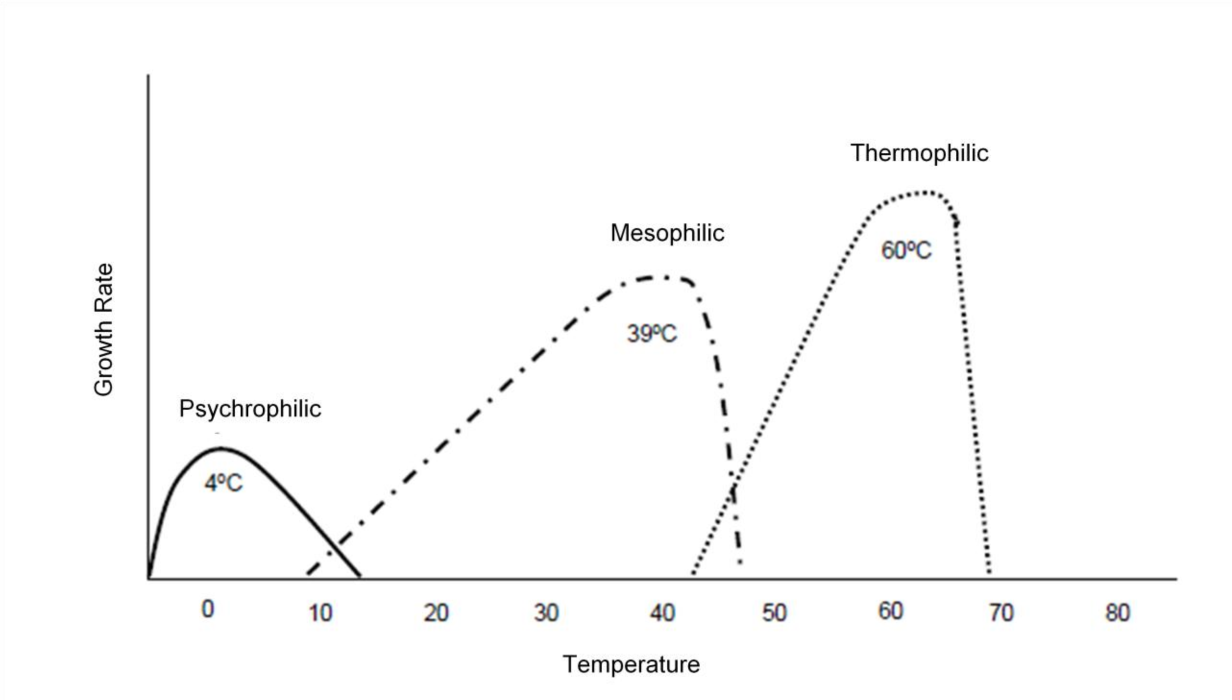


Figure 2.1. The temperature windows in which AD takes place. (16)

2.3.3.3.2 Retention Time

An important parameter for a continuous process is the hydraulic retention time, HRT, which is the average time an infinitely small element of fluid stays inside the reactor. It has to be longer that is takes for the microorganisms to multiply, which is up to 12 days, otherwise the microorganisms will be washed out of the reactor and the methane production will stop. (16) The shorter the HRT, the larger the flow through the reactor. The choice of HRT depends on how difficult the substrate is for the microorganisms to digest; material with a lot of cellulose can require over a month.

The Solids Retention Time, SRT, is the average time that a solid particle, i.e. a microorganism, stays inside the reactor. If no measure is taken to keep the microorganisms inside the rector the SRT equals the HRT. It is beneficial if the solid particles are kept for a longer time in the reactor then the fluid, which is water, since more biogas then can be produced, per m^3 reactor.

The HRT is chosen depending on the type of substrate. A long HRT means that the substrate will be completely digested when it leaves the reactor and it will therefore not be any problems with methane leakage. If the HRT is shorter, the biogas production per rector volume can be is higher, which can make the investment cost lower. But the total biogas in the reactor is lower, which means the substrate is not completely digested and therefore will lead methane to the atmosphere.

2.3.3.3.3 Reactor Volume

The volume of the reactor is calculated by dividing the flow rate with the retention time and will be described further in the Calculations section.

2.3.3.3.4 Organic Loading Rate

The organic loading rate, OLR, is the amount of digestible material that is being fed to the rector in kg TS per m^3 reactor and day. Higher load enables high microorganism growth and high biogas production per volume and is therefore desirable but also puts pressure on the microorganisms. Too high organic load means the microorganism are not able to keep up and material therefore passes undigested through the reactor and can also lead to process collapse. Suitable organic load can be 2-3 kg TS/m3reactor/day but values up to 20 kg TS/m3reactor/day has been reached in laboratory scale. (16) Higher TS gives higher OLR.

2.3.3.3.5 TS-level

A high TS-level allows a longer HRT in a reactor, which increases the methane yield. Put another way, it gives a smaller reactor and hence smaller investment cost at constant HRT. Higher TS makes the substrate more viscous, which increases the energy required for pumping and at a certain level makes the material impossible to pump. In many cases the viscosity of the slurry determines the maximum TS-level, rather than the organic loading rate. It is desirable to maximize TS but still have a pumpable slurry.

2.3.3.4 Reactor Types

2.3.3.4.1 The Continuously Stirred Tank Reactor

The CSTR is a mixed vessel through which the reacting substance flows, see Figure 2.2. The stirred tank solution can be carried out in steps, which will give the system more of a tube appearance, since many tanks in series in theory forms a tube reactor. To extract more methane from a substrate, two tanks in series can be used. The first is the main digester, which is heated to desired temperature and where most of the methane is produced. In the second reactor the substrate is allowed to cool while it gives off its last methane. This reduces the methane leakage compared to a situation where the residue is fed directly to the fertilizer storage.

If the substrate contains a lot of sugar, there is a risk of process failure due to pH-drop. This can be solved by having two tanks. In the first tank the hydrolysis and fermentation takes place in an acid environment. A controlled flow is fed from this tank to the tank where the methane production takes place and where the pH is higher.

Figure 2.2. The CSTR at Horshaga biogas plant, with the mixer in the middle. The biogas extraction pipe can be seen at the top, the yellow material is thermal insulation. Photo: Magnus Johansson

2.3.3.4.2 Filter Reactors

There are several ways to keep the microorganisms inside the reactor and prevent them from being washed out. By having an inert carrier material inside the reactor, the microorganisms can attach to this and SRT can be increased. Such reactors are called filter reactors. The inert material can for example be porous stones (19), plastics as in Figure 2.3 or nets (20). Carrier materials will make reactor more difficult to stir and is a common solution for substrates with low TS-levels, like sewage sludge.

Figure 2.3. Plastic carrier materials for microorganisms. (16)

2.3.3.4.3 UASB Reactor

The Upstream Anaerobic Sludge Blanket, which is outlined in Figure 2.4, is a filter reactor that is not stirred which allows the incoming solid material to sediment and form granules, to which where the microorganisms can attach. This allows a low HRT, maybe a couple of days, while still achieving long enough SRT. A low HRT and a long SRT makes it possible to reach high methane yields and COD reduction with a given rector volume. For this technology to work properly, the substrate has to be a liquid, or have very small particle size. (21)

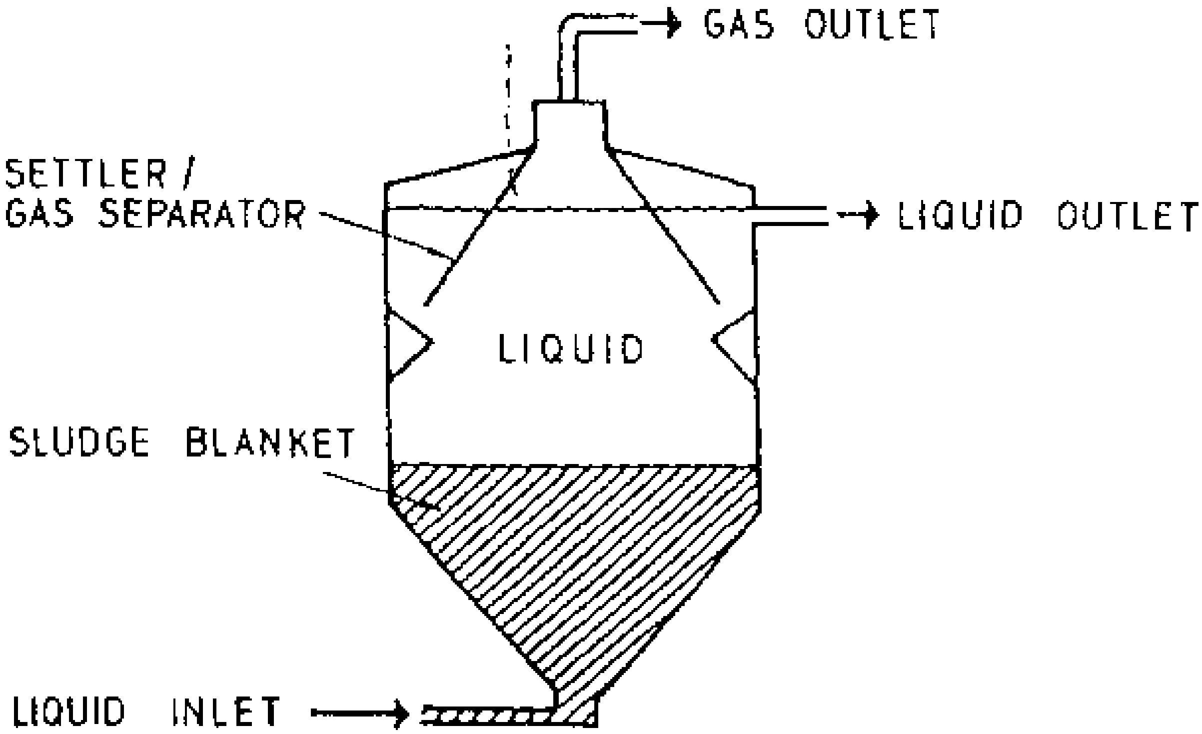


Figure 2.4. Schematic of UASB reactor. (22)

2.3.4 What can be done with the Biogas?

The biogas can be used for heating, cooking, to produce electricity or Combined Heat and Power, CHP, as vehicle fuel or it can be fed to a natural gas grid. A combination of producing electricity and delivering gas to the grid is possible and would increase security of sales as prices of electricity and gas vary. Depending of use, the biogas first has to be treated in different ways, for example cleaning and upgrading. To use it for cooking and heating, little treatment of the raw gas is needed. The gas is burned in a stove or a boiler. Hot water or process steam can be generated.

2.3.4.1 Electricity Production

For electricity production it is preferred to desulfurize the gas since the hydrogen sulfide it contains is highly corrosive and therefore damages the engine and turbine. It is also preferred to dry the raw gas to avoid accumulation of water in the pipes. For small scale plants, turbines are typically less efficient and less common than gas engines. (15) A gas engine can operate according to the Diesel- or Otto-principle. A Diesel engine compresses air and fuel to the degree at which it self ignites. Due to the high carbon dioxide content of the biogas the compression in the engine is not enough to make it self-ignite. Therefore a spark plug or an ignition fuel, typically diesel, is needed. Diesel engines have higher efficiency than Otto engines, the efficiency also increases with capacity. (15)

Since the biogas production can have slight variations throughout the day and the engine works best on steady load, a gas storage for a couple of hours of operation can be used to even out the biogas flow. Larger storages can also be used but is difficult to justify economically; it is more advantageous to store the energy in solid form, as substrate, than as a gas.

The produced electricity can be used on site or delivered to the electric grid. Since a farm biogas plants has limited electric capacity, typically less than one MW, grid investments are not likely to be needed if the plant is built at a place where electricity is used. The biogas plant will stabilize the grid and reduce grid losses for the electricity used locally. Biogas is not an intermittent energy source that need backup capacity.

2.3.4.2 Cogeneration

To produce CHP, a heat exchanger is connected to the cooling circuit of the engine and to the exhaust, for hot water production. Typical temperature of the heated water is 80-85 °C, it can reach maximum 90 °C. (23). This means that the heat can be used for space heating and hot water for process and personal use but not for process steam generation, if not some of the electricity is used to heat the water further which can be justified if the value of the heat is greater than the value of electricity.

2.3.4.3 Gas Grid

To feed the biogas to the natural gas grid, it has to be cleaned and upgraded to natural gas quality standards. Technically it is convenient to connect the biogas to the grid as it is a counter pressure system; every cubic meter of biogas that is pumped in to the grid would replace the same amount of natural gas. By feeding the biogas to the gas grid, investment cost for engine is saved. On the other hand, there is a cost for upgrading as well.

The biogas delivered to the grid may be used only for cooking and heating, depending on area. In that case there is no real need to upgrade the gas; it can be used with the same quality as the gas used to produce electricity, which would lower the production cost. To make this possible, the company who buys the gas has to accept lower methane content. Also there has to be away of charging the customer only for the methane. The biogas plant can also be built near a large energy consumer. The gas would thereby replace natural gas without using the national gas grid.

2.3.4.4 Vehicle Fuel

In Moldova there are vehicles, mostly old trucks and buses, which run on natural gas. Gas tubes are filled at stations connected to the natural gas grid and are mounted on the vehicles. The biogas can be used as vehicle fuel, by placing the biogas plant close to an existing filling station of by building a new filling station that uses biogas. This requires the biogas to be upgraded to natural gas standards. The price of the vehicle fuel has to be lower that the price of natural gas.

2.3.4.5 Flare

The biogas can be flared, which does not generate anything useful but is better than simply emitting the biogas into the atmosphere. Flaring can be used in CDM biogas projects, where the aim is to reduce climate impact. It is also common to have a flare by the plant as a safety measure. If there is a problem with the engine or during maintenance, the biogas can be flared instead.

2.3.5 The Rest Product

At the same rate as fresh substrate is fed to the reactor, rest product is taken out. Since it may still contain some undigested material, it is advantageous to cool it as fast as possible to stop the AD process. The rest product has a TS-level of about 5% (18) and can be used as liquid fertilizer or dried and used as solid fertilizer. Drying can be done by pressing or by sedimentation in an open lagoon. If excess heat is available from the process, this can be used to dry the fertilizer further. The preferred TS-level of the fertilizer depends on the method that is used to distribute it on the fields. Since the vine plants have a limited season during which they can take up nutrients, the fertilizer is preferably stored and spread on the fields during these seasons only.

2.4 Grape Residues as a Resource

Grapes have the following content, expressed as percent of total fresh weight. (24) The pulp contains juice for winemaking. Grape pomace consists of destemmed and pressed grapes, see Figure 2.6.

- Stalks 3-5 %
- Skin 6-10 %
- Pulp 82-90 %
- Seeds 2-4 %

As can be seen in Table 2.2 the content of the grape residues vary with type of grape and land upon which they are grown, as well as treatment of the grape.

Table 2.2. Content and methane potential of grape pomace from different sources.

Grape Origin	Proteins	Fat	Fibre	Sugar	C/N	Methane potential [Nm^3CH^4/tonTS]
	[% of TS]					
Spain (25)	7.5	2.5	75	5	79	
Iran (26)	17	3.7	60	14	34	
Greece (27)	7.5	0.68		0.22	44	280
Italy (28)			60		39	130
Chile (19)		0.24			65	200
Germany (29)					38	380
Moldova (14)						320
Chile (30)						470

The Spain data is an average of white and red pomace, with crushed seeds. The Iran data is from white pomace only, with crushed seeds. The data from Greece, Chile and Moldova is from vinasse (explained below) rather than pomace. The Italian data is for pomace, but neither crushed nor ground, which explains the low biogas potential. The German data is from digestion trials with pomace and is the data that will be used for calculations.

Figure 2.6. Fresh grape pomace from red grapes. The initial particle size is over a centimeter, and the seeds are intact. (24)

The pomace and stalks can be used in several ways to create useful product. The seeds are rich in fat and can therefore be used to make grape seed oil. The pomace can be used to produce pomace brandy, or grappa. To do this water is added to the pomace after which it is fermented. After the fermentation it is distilled to increase the ethanol content, to produce ethanol for technical uses or to be used as vehicle fuel. The rest material from this process is called vinasse and can also be used for biogas production. (30) (27) (14) However it has lower biogas potential since much of the energy in the pomace ends up bound in the ethanol.

After drying, which removes any residual alcohol, pomace can be used as animal fodder. (26) It can also be spread on the fields as fertilizer or it can first be composted and then spread. The digestion process that takes place during composting increases the quality of the pomace as fertilizer since it makes the nutrients easier to take up for the plants and reduces its volume.

The pomace can also be used to produce energy. It can be combusted in small ovens in villages, used to produce heat and power in larger units with steam cycles or used to produce fuel pellets. These possibilities will briefly be investigated in the next section.

Currently in Moldova, the residues are mostly landfilled but they are also used as fertilizer on the vineyards, as animal fodder and burned for heat. In other countries, for example in the USA, pomace is composted and then used as fertilizer. (24)

Finally, pomace can be used to produce biogas and fertilizer by AD, which is the focus for this thesis. For the pomace that is landfilled or used as fertilizer, there is no opportunity cost of using it for biogas production. If the pomace is used as animal fodder or for heating, there may be a social opportunity cost of producing biogas from it, for the people who would have used it.

2.4.1 Possibilities for Combustion of Pomace

Energy can be recovered from grape pomace by combustion, the twigs and branches from the vineyards can also be utilized. (31) It is difficult to digest this waste in a biogas plant, due to the cellulose it contains. In Moldova today, this waste is mostly burned by the fields without recovery of energy or nutrients. The amount of woody waste is small compared to the amount of pomace, 1 - 1.5 ton per hectare and year is generated. The HHV of pomace is 19.5 MJ/kg TS, which is about the same as for oak fire wood. (31) Converting all that energy to useful heat gives 5.4 kWh/kg TS, which can be compared to the amount of biogas energy from AD, 4.14 kWh/kg TS. However this comparison in somewhat unfair, since biogas is a more pure form of energy than pomace. Flue gas condensation will be beneficial because of the high moisture content in the pomace, without flue gas condensation the energy recovered will be significantly lower.

Pomace can be burned for heat, used to power a steam cycle or used to make bio-pellets. Used for local heating it can, at most, cover the full heat demand of the winery; since there are small possibilities to deliver heat to a DH network. Electricity can be produced in a Rankin cycle with a steam turbine. This process requires units of about 20 MW to be efficient. Pomace-pellets can be produced and sold. Today there exist no market for pellets in Moldova but this may change in the future. For example UNDP is currently working on a bio pellets project to make pellets from straw. (32) It might however be difficult to encourage local villagers to buy pomace pellets when they can get the pomace for free at the landfill.

2.4.2 Grape Pomace as a Biogas Substrate

According to Table 2.2, the dry part of the grape pomace mostly consists of fibers, to digest them the reactor must have a sufficient SRT. The high sugar content of the grape mostly goes into the juice, though some sugar is left in the pomace. The red grapes contain about 22% sugar before pressing, the white grapes contain somewhat less. (33) Accumulation of acids in the reactor is not likely since the sugar content in the pomace is low. The fibers are not too difficult for the microorganisms to digest, which is illustrated by the high COD conversion reported in (19) and (30), over 90%.

The proteins are the main source of nitrogen in the substrate. The nitrogen content is low, which gives a high C/N quota, as can be seen in Table 2.2. This lowers the biogas potential of the pomace. The skins and seeds are rich in tannins, aromatic compounds that inhibit the microorganisms at higher organic loading rates then 19 g COD/l $_{reactor}$/day. (19)

20-24% of total fresh grape weight is pomace. (34) (35) Stalks can also be used to produce biogas. The seeds in the pomace are not crushed in the winemaking process. The higher the surface area of the substrate in the reactor, the easier it is for the microorganisms to access and digest. The pomace can therefore be crushed and ground prior to fermentation to increase gas production. After crushing and grinding the substrate can have a particle size of a few millimeters, which means it is a slurry rather than a liquid. The water content of the substrate also has to be e adjusted to enable an efficient AD process. (28)

2.4.2.1 Storing of Substrate

Residues from wine production are available in Moldova from early September to late October, or some years early November. The vast majority of all grapes are harvested during a period of four weeks; the last two weeks of September and the first two weeks in October. From a substrate availability this point of view, biogas from wine production residues are less attractive then substrates available all year. There are three options for producing biogas from grape pomace; storing the pomace, producing biogas only in the fall and to codigest the pomace with other substrates. A description of the three possibilities is provided below.

1. **Storage**
   If the substrate is stored the reactor can be fed with an equal amount of material throughout the year. This means that the heat produced during summer will be lost since there is no heat demand in Moldova during that period. Storing pomace in the open leads to production of lactic acid which lowers the pH. If the pomace has access to oxygen it will be digested by aerobic microorganisms and no biogas will be produced. It therefore requires a gastight place of storing the substrate, for example plastic bales.

2. **No storage**
   Without substrate storage, all the biogas has to be produced directly in the fall. This increases the use of the produced heat and saves the effort and cost of storing the pomace but requires a larger reactor and hence a larger reactor investment cost. This option means that the reactor has to be started up every year. Starting up a biogas reactor is a complex process that requires close monitoring of the conditions inside the reactor. Since the pomace in itself does not contain enough of the microorganisms to start the process, a startup material, such as cow manure, is needed. It has to be transported to the site and placed in the reactor to start the process, it takes about a month before full organic load can be achieved. Biogas reactors tend to run all year, to avoid the startup procedure. When crops are used as substrate, these are commonly stored and the reactor is operated at the same capacity all year. (18) A compromise is possible; the reactor can be operated at lower load in the spring and summer and using that substrate in the winter instead to utilize more of the heat. This means that the reactor does not have to be started up from the beginning every fall, but will instead be fed a higher load.

3. **Codigestion**

Codigestion is the anaerobic digestion of two or more different substrates in the same reactor. Codigestion increases the methane production and makes the process more stable, since the different substrates provide a more mixed diet for the microorganisms. If pomace is codigested it may not have to be stored to last throughout the year. Pomace can be codigested with animal manure or agricultural by-products. Vineyards in Moldova mostly exist in the southern and central parts of the country. Cattle farms, on the other hand, are often situated in the northern part of the country. It is therefore not attractive to codigest wine residues with cow manure in Moldova if long transports of the substrate are to be avoided. However there are pig and chicken farms in the central and southern parts of the county. When it comes to codigestion with household waste and sewage sludge a biogas plant near Chisinau is preferred since that area concentrates about a third of the Moldovan population on a small area. Another possibility is to codigest pomace with beer production residues, which are available all year, however mostly during the warm period of the year.

2.5 Alternative Sources; Fruit, Spent Grain and Ethanol

An option to further prolong the season of available substrate is to use fruit juice residues. Fruit juice biogas potential and properties are similar to those of grape residues. The first fruit juice residues are cherries which are available from May in Moldova, during the summer many different kinds are available. This means that less grape pomace have to be stored. However it is difficult to adapt the biogas process to different substrates, since the microorganisms get used to a certain type of feeding. During the switch, which can take up to a month, process conditions have to be closely monitored and adjusted.

Biogas can also be produced from brewery residues. The spent grain is currently sold as animal fodder at the brewery that has 70% of the Moldovan market share, which means that there is an opportunity cost of using it for biogas production. (36) However there are other smaller waste streams from the brewery that can be used, for example spent yeast and process water.

There are about 15 ethanol factories in Moldova, the waste streams from these can also be used to produce biogas. (20)

2.6 Wine Production

After the grapes are harvested by hand they are destemmed in a machine and pressed to extract juice. The juice is then fermented into wine; the process takes about a week and is carried out in large steel tanks with close monitoring of temperature. A ton of grapes give maximum 700 liters of wine. The process from is outlined in Figure 2.7.

Figure 2.7. The wine making process. The harvested grapes are fed by a screw to the juice press. The fresh grape juice is collected under the juice press, in the top-right corner. The juice is then fermented into wine in steel tanks showed in the mid-left and after a second fermentation it is bottled. The bottom pictures show how the pomace is pressed to extract the last juice and then stored waiting for transportation to the landfill.

Red wine is produced from red grapes, with the pomace present during the whole fermentation process, which allows the colors and tannins in the skins to be absorbed by the juice. The fermentation process takes a week at 26-30 °C and takes place in stirred steel tanks. The pomace is separated from the wine by pressing after the fermentation.

White wine is made by fermenting the juice of white or red grapes without the pomace present during the fermentation. The grapes are pressed into juice and pomace directly after crushing, before the fermentation. It takes a week at 13-14 °C for the juice to ferment into wine in tanks that are not stirred. After the fermentation the lees, which is the sediment at the bottom of the fermentation tank consisting of yeast and solid byproducts, are removed. Both the lees, which can be seen in Figure 2.8, and the stems can be used to produce biogas. Since they make up a smaller fraction of the residues than the actual pomace, they are considered to be included in the term pomace for simplicity.

Figure 2.8. The lees, consisting of spent yeast and sedimentation products, can also be used for biogas production. (24)

The make rose wine the shells and seeds of the red grapes are taken out of the fermentation tank after some time; usually a couple of days.

Pure grape juice without any pomace is used to make brandy. This means that the first grape pomace, coming from white wine and brandy production, are available for biogas production at the start of the harvest. The red grape pomace are available a couple of weeks later.

The same amount of pomace is produced from red, white and rose wine as well as brandy production. However the red pomace has a higher quality as a fertilizer since the fermentation process makes the nutrients easier to access for the plants. (37)

After the fermentation the wine rests and undergoes a second fermentation until January. This process also gives a small amount of sediment waste. The wine is then stored on oak casks or bottled, depending of type of wine. Finally it is labeled and sold. These processes produce negligible organic waste streams.

2.6.1 Wine Production in Moldova

In Moldova there are in total 144 000 hectares of vineyards. Half of these are owned by individual farmers, owning about a couple of hectares each, rather than commercial wineries. (38) The size of the commercial vineyards ranges from 200 up to 600 or even 800 hectares in some cases. Many vineyards today are not taken care of, since Moldova produces less wine today than during USSR.

Currently many Moldovan wineries are in a difficult economic situation, due to the Russian wine embargo in 2006 and the low grape yields last years. In general there is a trust in new technology in Moldovan wineries. Even if the production methods are old, the equipment is usually modern. Profit is the main driver; social and environmental benefits of an investment are likely to have little impact on the decision.

A remark concerning wine industry waste in Moldova and probably waste in Moldova in general, is that waste is seen as waste rather than resource. The thinking is not in circles but in straight lines, from field to product. Then the production manager at Cricova is asked why the pomace is not spread on the fields as a fertilizer instead of buying synthetic fertilizer it seems that it is the first time that he is asked this question. He does not know why. It is a challenge in itself to change the way that people think about waste. To produce valuable products like electricity, heat and fertilizer from waste requires a different perspective on waste by the parts involved. Demonstrative examples can be a powerful tool to acquire this perspective and gain public acceptance and awareness.

Most wineries in Moldova uses gas for heating, this heat can be replaced to a large extent but gas heating can still be needed in the cold days of winter if the heat generated by the biogas plant is not enough. Some wineries have wine tourism complexes with hotels, villas, restaurants, and wine tasting. At such wineries the heat demand is considerably higher.

Below the wineries included in the case study are presented in brief.

2.6.1.1 Purcari

Purcari is a large wine producer in Moldova; it has 160 ha of red grapes and 100 ha of white grapes and is owned by Bostavan wines. (37) The company exports 40% of its wine, the rest is sold in Moldova. Their profile is to produce mostly premium wines from their modern production line. Purcari has a wine tourism complex. Their premium wine is sold at 8-9 $ per bottle from the factory. Today all the pomace is used as fertilizer on the fields, except for a small proportion that is used by the local farmers for animal fodder. The lees are sold to a company that produces alcohol for industrial uses.

2.6.1.2 Asconi

At Asconi's modern winery in the south of Moldova, mostly red grapes are processed. (35) The 400 ha vineyard will be expanded to 500 ha in the coming years. Another 500 ha will be cultivated for corn, which opens up possibilities for codigestion. The price of an average bottle is 2-3 $ at the factory.

2.6.1.3 Chateau Vartely

Chateau Vartely has an approximately equal amount of red and white wine, they also produce brandy and has wine tourism. (39) The stalks and lees are landfilled by trucks owned and operated by the winery; a gate fee for this is paid at the landfill. Most of the pomace is picked up by local villagers. The winery does not use any fertilizer on the fields, as they claim it is not needed. The wood waste from the vines is burned by the fields.

2.6.1.4 Cricova

At the Cricova winery outside Chisinau, mostly white grapes are processed. (40) Cricova is a state owned company. The pomace is either sold to local farmers at a low price or disposed to landfill. The amount of pomace used in a certain way are not known, which is the common case for Moldovan wineries. All of the lees, about 8% of the juice by weight, are disposed to landfill. The stems are also landfilled. At the plant outside Chisinau, no distillation takes place. Synthetic fertilizer is spread on the vineyards.

2.6.1.5 Dionysos-Mereni

At Dionysos-Mereni, about an hour outside of Chisinau, mostly red grapes are processed. (33) They produce mostly cheap wine with old equipment. Much of their grape juice is sold to a brandy production company. The pomace is disposed as most convenient, landfilled or used as animal fodder. The pomace has no value for the winery, which pays to get rid of it by truck transport. The current production level at Dionysos-Mereni is small compared to the levels reached during the USSR. There are therefore many empty tanks which could be used as reactors and storage for substrate, spent material, gas and hot water etc.

2.7 Biogas Plants in Moldova

All biogas projects that have been implemented in Moldova so far have failed, as can be seen in Table 2.3. To design a successful biogas plant it is important to study the reasons for previous plant failures.

Table 2.3. Biogas plants in Moldova, for production of CHP. None of these are in operation.

Site	**Substrate**	**Capacity kW$_{el}$]**	**Reason for not operating**
Colonita	cattle manure	80	ownership and electricity disputes
Bardar	distillery wastes	21	winery in economic problems
Tintareni	landfill gas	300	no CDM approval, ownership disputes
Vadul lui Voda	poultry manure	800	poultry farm in economic problems
Chisinau	sewage sludge	-	gas leakage problems

2.7.1 Colonita

In the village of Colonita half an hour outside Chisinau, there is a biogas plant since 2004, designed and built by the Belgian-Dutch company Biomass Technology Group, BTG. The plant produced biogas from cattle manure and generated electricity and useful heat from the biogas in a gas engine. The CSTR plant, which can be seen in Figure 2.9, has an electric capacity of 80 kW (41) and the farm can hold a maximum of 700 milking cows. (42) Since 2007 the plant is not operational due to lack of substrate supply and organizational shortcomings.

The cattle were owned by villagers in Colonita, each villager owned a few heads each. Many villagers decided to sell their heads and eventually all heads were sold or moved closer to the village. The villagers who owned the cattle did not own the biogas plant and therefore had little interest in the success of the project. The plant was not funded by the owners of the plant, but by BTG, so the economic risk taker was not the one that benefited from a successful operation of the plant. The company that should have bought the electricity did not do so; this was before the law of renewables. This illustrates the importance of secure supply of substrate and the importance of a binding product sales contract. The Colonita example also shows that it can be problematic if there are different owners involved and is these owners do not take investment risk.

Figure 2.9. The CSTR biogas plant in Colonita. Photo: Magnus Johansson.

2.7.2 Bardar

At Bardar winery there is a biogas plant for producing gas from vinasse from brandy production, maize ethanol production residues and other distillery wastes. (14) The distillation of brandy is carried out from December to March. The plant operates on vinasse from spring to fall, about 6 months per year. The rest of the year it uses distillation residues from other sources, such as maize. However it would be possible to use just vinasse for the biogas production. The plant has been operating for 4-5 years, but is now at a standstill because of economic problems for the Bardar winery. The reactor is a 40 m^3 filter reactor that operates at 32 °C and has a HRT of 1.5-3 days. (14)

2.7.3 Tintareni

Chisinau has during the last 20 years disposed all its waste at the Tintareni landfill, 35 km outside Chisinau. Since there is no separation at source in Moldova, the 20 ha landfill contains methane from the organic waste, currently leaking into the atmosphere. An extraction system and a flare were installed for an Italian CDM project, but the project was not approved. Later a CHP engine was installed to produce electricity. These is not yet a connection to the grid; there is a dispute going on regarding ownership of land, waste and gas between Tintareni, Chisinau and the energy company Tivas, who installed the equipment.

3 Data and Assumptions

For the calculations the following data and assumptions is used, general data in Table 3.1-3 and for Moldova in particular in Table 3.4.

3.1 General

Table 3.1 Data and assumptions for biogas calculations.

TS [% of fresh substrate]	45
VS [% of TS]	85
CH_4-content in biogas [%]	68
Gas yield [Nm^3 biogas/ton VS] (8)	665
CH_4 Energy Content [kWh/Nm^3]	10.9
Density CO_2 [kg/m^3] (43)	1.84
Density CH_4 [kg/m^3] (43)	0.67
Electric efficiency	0.33
Heat efficiency	0.33

The substrate data in Table 3.1 is taken from a German biogas company (29), the biogas potential is the same as presented in Table 2.2. The biogas is used to produce CHP, the reason for this is given in the Results section. The efficiencies are based on the Swedish farm scale biogas plant at Horshaga. (44)

Table 3.2 Specific investment costs and environmental data used in the calculations.

Investment cost [euro/m^3 reactor] (7)	660
Investment cost [euro/kW_e] (7)	5000
Emission coefficient NG [kg CO_2/kWh NG] (43)	0.23
Climate factor methane	23

The specific investment costs in Table 3.2 are based on German estimates, on reactor volume and engine size basis. The values applies for a one step CSTR plant fed on animal manure, it includes reactor, engine, mixing tank, shredding pump, gas storage, pumps, pipes and control system and construction. It does not include equipment and labor cost for substrate and fertilizer storage and education and training for the personnel operating the plant. The investment cost is valid for plants from 280-540 m^3, the average size is 420 m^3. The construction costs are likely to be lower for Moldova then for Germany, due to lower salaries. The equipment bought from outside Moldova will have the same cost as in (7), except for the transport cost. The reactor is likely to be cheaper since concrete has a lower price in Moldova. The investment cost given in (7) is 240-660 euro/m^3, with an average of 380 euro/m^3. Since the volume of the reactors for the wineries is smaller than the reactors in (7) and since some costs are not included the higher value is used for the calculations. Another reason for picking the higher value is the cost uncertainties for a biogas plant in Moldova. In the same way, a higher value for estimations on kW basis is also used. The O&M, Operation and Maintenance, cost is 2% of the specific investment cost per year (7), however this is likely to be an overestimation due to lower salaries in Moldova. An investment cost sensitivity analysis is carried out in section 5.1 Economic Analysis. The currency exchange rates used is given in Table 3.3.

Table 3.3 Currency exchange rates used in the calculations. (45)

Currencies in SEK	
US Dollar	6.77
Euro	9.12
Moldovan Lei	0.58

Reduction in carbon dioxide emissions comes from changing fuel for generation of heat and power from fossil fuels to biogas, both at local and global level. The biogas plant will also reduce the methane leakage from the pomace, which leads to a reduced climate impact. If less fertilizer is used in the new system, CO_2-eq savings can also be made from reduced fertilizer production, a process which mainly uses natural gas. The climate impact of the methane is assumed to be 23 times higher than carbon dioxide.

3.2 Moldova

Table 3.4 shows the data and assumptions that are specific for Moldova. The substrate includes pomace, stems and lees, of which the pomace is the dominating fraction. The electricity price in Table 3.4 is given by ANRE and is the same as for the biogas plant in Colonita. That price is used since the plant in Colonita is similar, in terms of scale and technology, to the plant designed in this thesis. The natural gas price includes VAT and is a calculated average of the consumer price in Moldova, which varies with gas consumption. Both electricity and gas price remains constant with time and season in Moldova. The prices are also assumed to be constant over the coming years, however in reality they are likely to grow.

Table 3.4 Data and assumptions for Moldova.

Substrate [% of fresh grape]	22
Electricity Price [euro/kWh] (11)	0.11
Average large consumer natutal gas price [euro/MWh] (46)	38
Marginal electric efficiency [%]	25
NG boiler efficiency	90
Grid losses [%]	10

The produced electricity is assumed to replace electricity produced from NG. NG is assumed to be on the margin in Moldova since 96% of the electricity comes from NG and the rest is hydro power. The efficiency of the marginal power plant is assumed to be 25%, which is slightly higher than the plants in Moldova. The useful heat produced at the biogas plant replaces heat from a hot water NG boiler, with an assumed efficiency of 90%. If the pomace would have been landfilled instead of used to produce CHP, it would partly be digested without oxygen and therefore emit methane into the atmosphere. It is assumed that 10% of the degradation at the landfill is anaerobic and that this part of the pomace is converted into the same amount of biogas as it would have done inside the reactor.

When no heat demand data is available, it is assumed that all useful heat produced can be used in the cold season and that no heat can be used during the warm season. This means that half of the useful heat that is produced is discarded and the other half can is used at the winery. This assumption is made since the heat demand is higher than the heat available for the wineries where heat demand data is available. That means that there will still be some natural gas heating at the wineries even after the biogas plant is built.

It is assumed that the plant runs at a constant load throughout the year, i.e. 8760 operating hours. However it can be beneficial to run the plant at a lower load in the summer and a higher load in the winter, to utilize more of the heat. The TS-level should be as high as possible while the substrate is still pumpable, therefore a TS-level of 9 % is chosen based on recommendations. (18) The retention time set to one month to give the substrate sufficient time to be digested. The density of the slurry is approximated with the density of water, since it contains 90% water.

The interest rate at a common Moldovan bank is around 10%, but varies according to risk level. (47) Since the inflation is about 7%, the real interest rate is 3%. An investment with a payoff time higher than 3-5 years will in general not be accepted in Moldova, despite high economical and technical lifetimes, since the Moldovan population has a mentality of trying to avoid risk taking and because of the insecurity about the future situation in the country. The project is assumed to be under MoSEFF, therefore an interest rate of 8.5% and a 15% investment grant is used for the winery biogas plant.

4 Calculations

The amount of energy that can be recovered from the pomace, per ton of grape, is given by eq. 4.1.

$$CH_4\ Potential\ = \\ Substrate\ [\%] \cdot TS\ [\%] \cdot VS[\%] \cdot GasYield \left[\frac{Nm^3\ biogas}{ton\ VS}\right] \cdot CH_4 content \left[\frac{Nm^3\ CH_4}{Nm^3\ biogas}\right] \cdot \\ EnergyContent \left[\frac{kWh}{Nm^3}\right] = 410\,\frac{kWh\ biogas}{ton\ grape}\ \ [eq. 4.1]$$

The biogas production at each winery is calculated by multiplying the CH_4-potential in eq. 4.1 with the total harvest. Then the electricity and heat production can be calculated.

$$Electricity\ Produced =\ \eta_{el} \cdot Biogas\ production\ [eq. 4.2]$$

$$Useable\ Heat =\ \eta_{heat} \cdot Biogas\ production \cdot 50\%\ [eq. 4.3]$$

The useful heat production is half of the actual heat production since the heat produced in the warm period of the year cannot be used. The output power is given by eq. 4.4.

$$Output\ Power = \frac{Electricty\ Produced}{8760\ h/year}\,[eq. 4.4]$$

The substrate inflow, F, is calculated from the amount of substrate available by eq. 4.5.

$$\dot{F}\ [ton/day] = \frac{Harvest\ \left[\frac{ton}{year}\right] \cdot Substrate\ [\%] \cdot TS[\%]}{365\ \left[\frac{days}{year}\right] \cdot TS_{reactor}\ [\%]}\,[eq. 4.5]$$

The reactor volume is calculated by eq. 4.6 with a retention time of 30 days.

$$V_{reactor}\ [m^3] = \frac{\dot{F}\left[\frac{kg}{day}\right]\cdot\rho_{slurry}\left[\frac{kg}{m^3}\right]}{HRT\ [days]}$$ [eq. 4.6]

The organic loading rate is also calculated, as a way of controlling if the reactor is large enough for all the substrate to be digested by the microorganisms.

$$OLR = \frac{\dot{F}}{V_{reactor}}$$ [eq. 4.7]

The amount of fertilizer produced is calculated by a mass balance over the reactor, as both substrate inflow and gas outflow are known. The approach described above is the same both at winery and country level.

4.1 Economic Calculations

The investment cost of the biogas plant is calculated by multiplying the specific investment costs in Table 3.2 with the reactor volume from eq. 4.6 and output power in eq. 4.4, respectively, and then taking the average of these. Then the 15% grant is subtracted from the investment cost; this investment cost therefore represents the cost for the winery, rather than the profit for the biogas company selling the plant.

In Moldova there is a feed in tariff given by ANRE for renewable electricity; the electricity price is calculated as

$$Electricty\ price\ \left[\frac{euro}{MWh}\right] = \frac{investment\ cost\left[\frac{euro}{year}\right]+operating\ cost\left[\frac{euro}{year}\right]}{electricty\ produced\ \left[\frac{MWh}{year}\right]}\cdot 1.2.$$ [eq. 4.8]

The tariff is set up so that the electricity price will cover the expenses of the plant and allow a 20% return on the investment. In this way, the investment always pays off, no matter the costs associated with the project. If two biogas plants with the same output power have different investment costs, they also get different price for their produced electricity. This makes cost-efficiency measures counterproductive, according to the formula. However, in reality a too high price would not be approved. The critical parameter for the electricity price is the payback time used to get the investment cost per year. The payback time is chosen rather than calculated, since the investment cost in eq. 4.8 is given per year. Shorter payback time gives a higher electricity price which is a benefit to the investor but a cost for ANRE and vice versa. The payback time is negotiated for each individual project between the investor, the bank and ANRE and at last has to be approved by ANRE before any electricity can be delivered to the grid. The way the formula in eq. 4.8 works, it is pointless to calculate payback time as a measure on how profitable a project is, since the payback time is decided by ANRE. Therefore, by recommendation of ANRE, the electricity price that was approved for the biogas plant in

Colonia, which is of similar type and scale as the plants at the wineries, is used to calculate an actual payback time that is a measure of how economic the investment is. This is the price given in Table 3.4.

Given the prices and the produced amounts of electricity and heat, the total annual cash flow is calculated by eq. 4.9.

$$Annual\ cash\ flow = Electricty\ produced \cdot Electricity\ price + Useable\ heat \cdot NG\ price - O\&M\ cost\ [eq. 4.9]$$

The Net Present Value, NPV, of future cash flows is calculated and summed up. The payback time is given as the number of years it takes for the net present value of the future annual cash flows and the total investment cost to breakeven. After the payback time has passed, the bank loans are paid off and the yearly profit from the biogas plant is the annual cash flow in eq. 4.9 for the rest of its lifetime.

4.2 Environmental Calculations

The specific emission savings from reduced fossil electricity and heat production are calculated according to eq. 4.10 and eq. 4.11, respectively.

$$Electricity\ emissions = \frac{0.23\ \frac{kg\ CO_2}{kWh}}{\eta_{grid} \cdot \eta_{el}} = 1022 \left[\frac{kg\ CO_2}{MWh_{el}}\right] [eq. 4.10]$$

$$Heat\ emissions = \frac{0.23\ \frac{kg\ CO_2}{kWh}}{\eta_{boiler}} = 256 \left[\frac{kg\ CO_2}{MWh_{heat}}\right] [eq. 4.11]$$

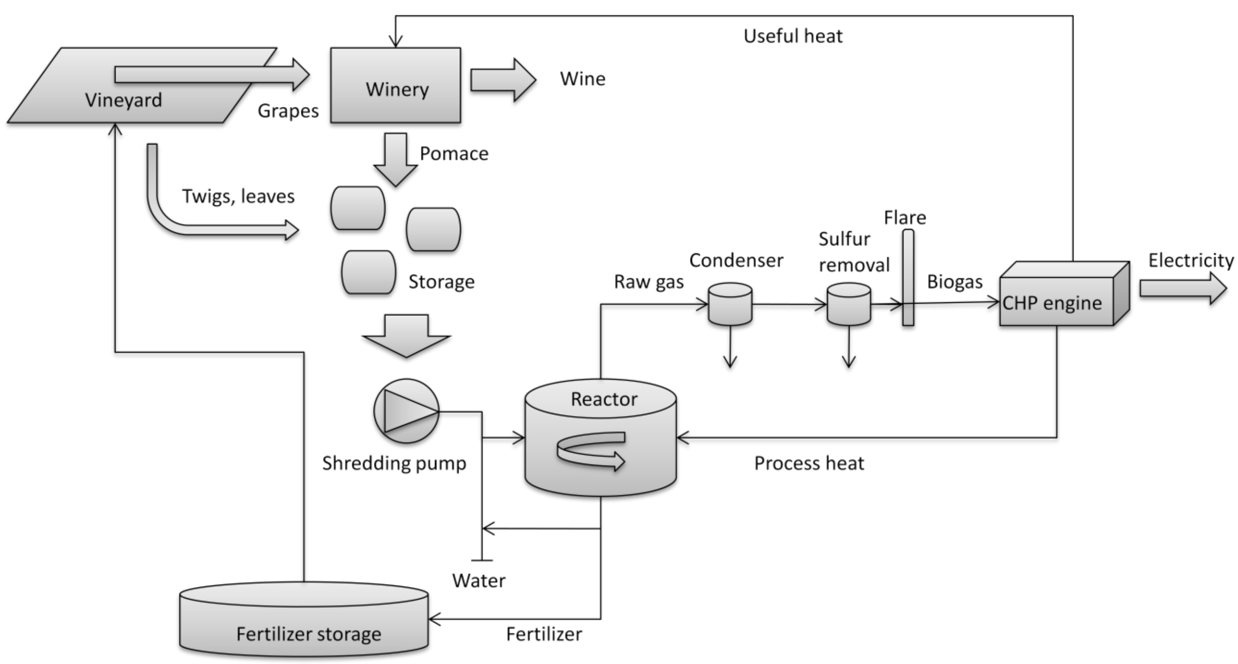
The methane emission savings are calculated according to eq. 4.12.

$$Methane\ emissions \left[\frac{kg\ CO_2eq}{year}\right] = Methane\ Production \left[\frac{m^3_{CH_4}}{year}\right] \cdot 0.1 \cdot Climate\ factor \cdot \rho_{CO_2} \left[\frac{kg}{m^3}\right] [eq. 12]$$

5 Results

The results are given first for the country as a whole and then at winery level, for each type of results. The process layout for the plant is presented in Figure 5.1 and includes pomace storage, reactor, gas cleaning, engine and fertilizer storage. The design is made for stability and ease of operation. Substrate storage is plastic bales is chosen over producing biogas in fall only to avoid the complicated startup procedure every year and to allow a smaller reactor and hence a lower reactor investment cost. Pomace is the only substrate available at the wineries. The biogas plant operates on pomace from the local vineyard to avoid substrate transports and to have one single owner for substrate, equipment and gas. A shredding pump is used to enhance the biogas production by making the substrate more accessible to digest for the microorganisms. A CSTR is chosen over an anaerobic filter reactor that requires a liquid substrate, rather than the pomace slurry which is the result of the pomace pretreatment. The reactor operates in the mesophilic range for stability. To avoid accumulation of water in the pipe system the raw gas passes through a condenser. Sulfur is removed to reduce engine corrosion. A flare is needed for safety reasons. The plant produces CHP since it is the most economical option due to the feed in tariff for renewable electricity. Biogas delivered to the grid or used as vehicle fuel has to compete with imported natural gas without subsidies, which is not feasible. The power is delivered to the grid and the heat is used to heat the process and the winery.

Figure 5.1. The process layout. Grapes are harvested to produce wine and the pomace is stored. The woody waste from the vineyards can also be used. The pomace is ground prior to digestion and mixed with water. Water and sulfur is removed from the raw gas before entering the gas engine. The residue can be dewatered before being put to the fertilizer storage. The nutrients are then fed back to the vineyard to close the circle.



From the annual harvest of grapes the material and energy flows for the biogas plant are calculated as described in the previous section, Calculations. The results are presented for the country and for the wineries in Table 5.1 and Table 5.2, respectively. The flow out of the reactor will have a TS-level of about 5% (18), but the value given in Table 5.1-2 is given on dry basis.

Table 5.1. The annual flow of grapes, energy and fertilizer for all the vineyards in Moldova and for the 20 largest ones. The harvest is the input data, the rest of the values are calculated according to eq. 4.1 – eq. 4.4.

	Moldova (48)	**20 Largest**
Harvest [ton]	290000	95000
CH_4 [MWh]	120000	39000
Electricity produced [MWh]	39000	13000
Useable heat [MWh]	19000	6500
Output power [kW_{el}]	4500	1500
Fertilizer production [ton TS]	12000	3800

The first column in Table 5.1 show how much energy that can be produced by AD from all grapes in Moldova, about 300 000 tons per year. However many of these sources are too small to be economical to extract, the figures in the left column of Table 5.1 can therefore be seen as the maximal potential. To produce electricity from all these grapes they have to be transported to a central plant since many of these vineyards are too small for local electricity production. Electricity production in a gas engine has low feasibility below 25 kW (49). The CSTR biogas plant solution in Figure 5.1 does therefore not apply in all of these cases. The right column of Table 5.1 gives the combined grape harvest of the 20 largest wineries in Moldova, about 100 000 tons per year. The CSTR biogas plant solution is applicable to all these cases. To produce biogas at these sites will in total generate 13 GWh of renewable electricity fed to the Moldovan grid each year. Apart from this, it is likely that a large share of the 200 000 tons of grapes not processed by the 20 largest wineries also are economical to extract.

Table 5.2. The annual flow of grapes, energy and fertilizer at the wineries. The harvest and the heat demand are the input data, the rest of the values are calculated according to eq. 4.1 – eq. 4.4.

	Purcari	**Asconi**	**Chateau Vartely**	**Cricova**	**Dionysos-Mereni**	**20 Average**
Harvest [ton]	1700	3800	3500	5500	1400	4800
CH_4 [MWh]	700	1600	1400	2300	560	2000
Electricity produced [MWh]	230	510	470	740	180	640
Useable heat [MWh]	120	260	240	370	92	320
Heat demand [MWh]	600	540	330			
Output power [kW_{el}]	26	59	54	85	21	74
Fertilizer production [ton TS/yr]	68	150	140	220	55	190

Table 5.2 shows the biogas potential for the studied wineries and an average of the 20 wineries from Table 5.1. Electricity production ranges from about 200 – 700 MWh per year, the amount of heat used is half of this. The gas engine size varies from 21 – 85 kW.

Table 5.3 gives the total reactor inflow and size required to convert the pomace into biogas. For example, the reactor at Asconi is 8 meters in diameter and 7 meters high. The OLR is calculated to 3 kg TS/m^3/day, which is within the operating range reported in (16) for mesophilic processes.

Table 5.3. The resulting flow of substrate to the reactors and the reactor size, calculated by eq.4.5 and 4.6, respectively.

Tank reactor specifications	**Purcari**	**Asconi**	**Chateau Vartely**	**Cricova**	**Dionysos-Mereni**	**20 Average**
Substrate feed [kg/day]	5100	11400	10500	16600	4100	14400
Reactor volume [m^3]	150	340	320	500	120	430

5.1 Economic Analysis

The total investment cost for the 20 largest wineries in Moldova is 6.4 million euro for the process design in Figure 5.1. This is therefore the export potential for biogas companies to Moldova and does not include the MoSEFF grant. The total annual cash flows for the 20 largest wineries are presented in Table 5.4. The total investment cost to produce biogas from all pomace in Moldova is not estimated, since the CSTR design in this thesis and the specific investment cost does not apply to all these cases.

Table 5.4. Annual cash flows for the 20 largest wineries in Moldova.

	20 Largest
Electricity sales [million euro/year]	1.4
Gas savings [million euro/year]	0.25
O&M cost [million euro/year]	0.13
Net annual cash flows [million euro/year]	1.52

The investment cost for the plants at the wineries ranges from 93 000 euro to 377 000 euro according to Table 5.5. The investment cost in Table 5.5 is 15% lower than the actual cost due to the MoSEFF grant. The same specific investment cost is used for all wineries; in reality it is likely to be lower for the larger plants and higher for the smaller plants, due to economics of scale. Due to investment cost uncertainties, the higher value in (7) has been used for the cost calculations, the costs are also compared with other sources. The scale dependant cost estimation from (15) gives a total cost of 400 000 euro for the Cricova plant, calculated on basis of Swedish CSTR manure CHP biogas plants. The Swiss biogas company Zorg Biogas estimates the total cost to 540 000 euro for a plant twice the size of Cricova (50), also a CSTR animal manure plant. The investment cost at Dionysos-Mereni does not take into account that there may be existing equipment that can be used since it is unknown what equipment that is available.

Table 5.5. Total investment cost for the wineries.

	Purcari	Asconi	Chateau Vartely	Cricova	Dionysos-Mereni	20 Average
Investment [euro]	116000	260000	240000	377000	93000	326000

The net annual cash flow for the wineries is between 22 000 and 87 000 euro per year according to Table 5.6. The dominating share of the profit comes from electricity sales. However, the gas savings can be higher if a local heat source is found near the wineries or if the plant runs at a higher load during winter.

Table 5.6. Annual cash flows for the wineries.

	Purcari	**Asconi**	**Chateau Vartely**	**Cricova**	**Dionysos-Mereni**	**20 Average**
Electricity sales [euro/year]	25000	56000	52000	81000	20000	70000
Gas savings [euro/year]	4000	10000	9000	14000	4000	12000
O&M cost [euro/year]	2000	5000	5000	8000	2000	7000
Net annual cash flow [euro/year]	+27000	+61000	+56000	+87000	+22000	+75000

The payback time is 4-5 years for all plants. This is the result coming from the previously described NPV calculations in section 4.1 Economic Calculations. It is the time it takes for the net present value of the net annual cash flows in Table 5.6 and the investment in Table 5.5 to break even. For the rest of the lifetime of the plant, the yearly profit will be the net annual cash flow in Table 5.6. 4-5 years is an attractive payback time both with Moldovan and international measures; a pomace biogas plant at a Moldovan winery is a profitable investment. Since the specific investment cost is the same for all plants, the payback time is also the same. The real payback time it is likely to be somewhat higher for the small plants and lower for the large ones.

The electricity price used in the calculations is the tariff of another plant. The actual tariff depends on the formula in eq. 4.8 and hence the negotiated payback time, rather than the calculated payback time above. Sensitivity analysis for different payback times is presented in Figure 5.2.

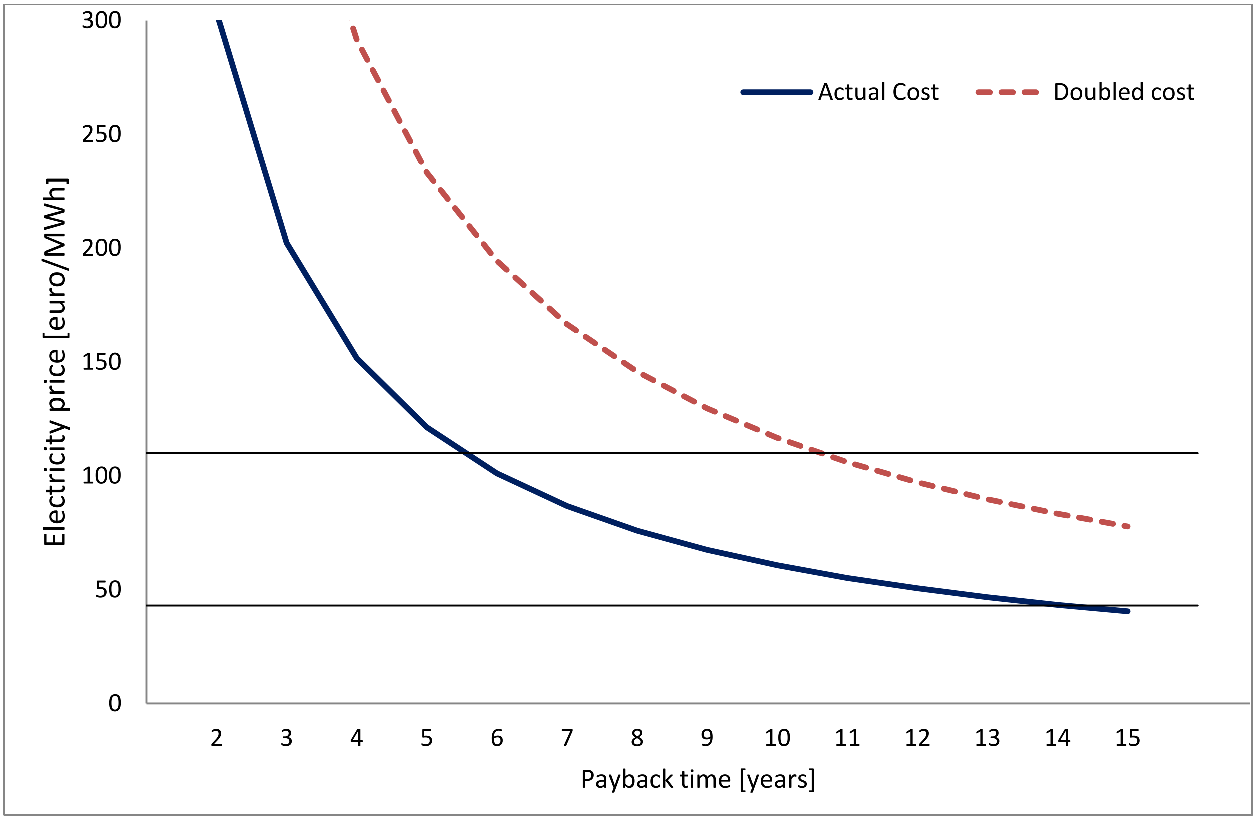


Figure 5.2. How the electricity price depends on negotiated payback time for a biogas plant at Asconi, for the actual cost and a fictive case with double project costs. A shorter time gives a higher price. The two straight lines represent the electricity price used in the calculations (110 euro/MWh) and the import price for electricity (43 euro/MWh), respectively. The intersection between the solid curve and the lower line, at around 14 years, can be seen as the payback time without the ANRE-tariff and is therefore the longest payback time possible. This illustrates that the ANRE-tariff is really needed for the project to have a reasonable payback time. The electricity price used in the calculations represents a negotiated payback time of 5.5 years, taken from the intersection of the solid curve and the upper line. This is an electricity price that ANRE is known to accept, so the negotiated payback time is likely to be close to this value. If the project cost would have been the double (dotted line), ANRE is likely to negotiate for a payback time close to 11 years, which is unreasonable for Moldovan investors. Therefore such a project is not likely to be realized. Since the calculated payback time of 4-5 years is close to a payback time that ANRE can approve, the project has large probability of success, since both the investor and ANRE would agree on a payback time in that range.

5.2 Environmental Analysis

The savings in climate emissions are given at country and winery level in Table 5.7 and 5.8, respectively. They are in the same order of magnitude for electricity and reduced methane leakage, however savings from the useful heat have little contribution. Biogas plants at the 20 largest wineries in Moldova would save almost 30 000 tons of CO_2-eq annually, for a single plant the savings ranges from 400 – 1600 tons per year.

Table 5.7. Climate emission savings for Moldova if plants are built at the 20 largest wineries.

	20 Largest
Emissions saved, electricity [ton CO_2/year]	13200
Emissions saved, heat [ton CO_2/year]	1600
Avoided methane emissions CO_2-eq emissions [ton CO2-eq/year]	13300
Total CO_2-eq savings [ton/year]	28000

Table 5.8. Reduction in climate impact for the wineries.

	Purcari	**Asconi**	**Chateau Vartely**	**Cricova**	**Dionysos-Mereni**	**20 Average**
Emissions saved, electricity [tonCO2/year]	235	526	484	761	188	660
Emissions saved, heat [ton CO_2/year]	29	66	61	95	23	82
Avoided methane emissions CO_2-eq emissions [ton CO2-eq/year]	237	529	487	765	189	663
Total CO_2-eq savings [ton/year]	500	1120	1030	1620	400	1400

6 Discussion

6.1 Choice of Technology and Scale

This thesis is done with assistance from the Swedish companies Borlänge Energi, Göteborg Energi and Sweco, which has little experience of dry digestion. To be able to benefit from the technical expertise of these companies, focus is put on wet digestion. It should however be noted that it is technically feasible to dry digest the pomace to produce biogas.

Focus of this thesis has been put on biogas plants at large wineries in Moldova, who would have a high probability to get accepted as a loan taker at the bank. Economic and technical results from such focus are applicable mostly to the larger wineries in Moldova, rather than Moldovan wineries in general. This is because of economics of scale and since the chosen process solution depends on the scale of the plant. A successful biogas plant at a Moldovan winery can lead to increased knowledge and public awareness about biogas, which may result in more projects.

To produce biogas from small wineries a different approach can be used, for example by contracting the pomace from several wineries and then transporting it to a central biogas plant. This may be difficult and risky, since it includes people with different interests and since the standard of roads in Moldova are poor. It has also been shown that biogas production at small farms is less feasible (51) while larger farms give reduced payback time. (52)

Cultural differences between countries often show in differences in prioritization among the people. Even though Moldova has some acute environmental situations connected to waste, energy, water and land contamination, there is in general little concern for these issues. People tend to prioritize a BMW or a Mercedes over a pellets burner or three glass windows. This applies to both private and business sectors and is an example brought up to illustrate that when a company is faced with an investment proposal with large environmental and social benefits, the company are not likely to take these factors into account but rather look at economics only. This means that to set up a biogas plant in Moldova, the critical issue is the payback time of the investment. To improve conditions in Moldova, money has to be made for the companies involved.

According to Figure 1.2 in the Method section, it takes technical know-how to design and operate a biogas plant. This requires knowledge transfer to the wineries to assure successful operation. The knowledge can come from the biogas company building the plant or from the free technical support given by MoSEFF.

6.2 Benefits of a biogas plant

There are benefits from a biogas plant that are difficult to value economically, both for the winery and for Moldova as a country.

6.2.1 For the Winery

Fertilizer is being used to a different extent at the vineyards. Asconi and Chateau Vartely uses no fertilizer at all, as they claim it is not needed. (39) (35) Purcari only uses its pomace as fertilizer. (37) Cricova and Dionysos-Mereni buys synthetic fertilizer for their vineyards, but it is not known how much. (33) (40) This makes it difficult to value the organic fertilizer produced at the biogas plant in monetary terms; both for the wineries that does not use fertilizer and for the ones who uses it since the amount is unknown. Therefore the fertilizer has not been valued in economically. The fertilizer from the biogas plant will, however, have a higher quality than the pomace itself, since the AD process makes the nutrients easier to take up for the vines. There is therefore an economic benefit both for the wineries that use synthetic and pomace fertilizer. In the long run there is risk of soil degradation of no fertilizer is used, the organic fertilizer can help to prevent this. The biogas plant will save the winery the costs of handling and disposing the pomace, as well as landfill gate fees.

Today branding is becoming more important and customer awareness grows. There are customers looking for green products from companies that take environmental responsibility. By building a biogas plant there is a benefit for the winery since they can attract these customers.

6.2.2 For the Country

Reduced use of synthetic fertilizer will reduce eutrophification and prevent soil degradation, which is a growing concern for Moldova, as well as reducing the climate impact of the country. Implementing biogas in Moldova will increase energy independency. This is a large political benefit, especially for the part of Moldova that wants to come closer to the EU. The energy security and reliability, which is an issue in Moldova, will also increase since the biogas plant will operate continuously. The biogas plant will reduce grid losses, since it produces electricity close to where it will be used. It will also provide jobs and contribute to economic growth.

An advantage of biogas produced from agricultural residues is the small environmental footprint. It is common that renewable energy comes from land cultivated for production of renewable energy, for example energy crops and forest. Renewable energy, like palm oil and corn ethanol, can have a severe environmental footprint due to cultivation of the land and the processing of the crop into fuel. There is an opportunity cost of producing biofuels at cultivated land and in many countries forest biomass is a scarce resource. This is not the case with agricultural residues like pomace; it is generates even though no biogas is produced from it and therefore has small footprint and low opportunity cost.

6.3 Comparison with Literature

A biogas plant operating on grape pomace only has not been found. However there are a codigestion plant being built in Canada (53) and several plants operating on vinasse, which is also a substrate from grapes.

In (28) it is concluded that biogas from grape pomace has potential to reduce the energy dependence and decrease climate impact in Italy. This coincides with the results of this thesis for Moldova. However, in terms of biogas productivity, grape pomace is the least feasible crop of the five tested, however the pomace were not ground.

Both (19) and (30) covers vinasse from wineries, which is a similar substrate to pomace in many ways, but not when it comes to particle size. AD in a UASB reactor is concluded to be a feasible alternative to deal with the waste, since it reduces its organic content and produces useful fertilizer. The value of the fertilizer is likely to be higher in the Moldovan case, since pomace contains more nutrients then vinasse.

In (27) nitrogen and sulfur removal techniques are developed for a UASB operating on vinasse. This would be contra productive in the Moldovan case, since these compounds are nutrients for the vines.

Combustion of pomace, as described in (31), is likely to be more interesting in Spain then in Moldova, since it requires larger units or a pellets market.

In (26) it is stated that grape pomace is suitable as animal fodder. To increase the resource utilization, it can therefore be used as animal fodder, then biogas can be produced form the manure. In Moldova it is likely to be more economical to produce biogas from the pomace directly, due to the feed in tariff, which may not exist in Iran.

6.4 Uncertainties for Investments

Part of the unwillingness in Moldova to take the risk of a large investment is the unstable political situation. Moldova has strong cultural and historical bonds with both Romania and Russia. Moldova may once again become a part of Romania and seize to exist as an independent country. It may also become part of the EU. Another possibility is that it once again will turn towards Russia. Almost the whole Transnistrian region and a large part of people in the rest of the country are Russia-friendly.

6.5 Development Cooperation as Business

In Moldova EBRD and Sida are convinced that development cooperation projects has to be closely connected to business to help the receiving country as much as possible. This explains the high interest rate at EBRD. The donors are interested in large projects and large impact, so most of the money is donated in large portions. For example it may be easier to get money to thermally insulate a village rather than a single house.

It would be possible to use the funds to implement projects for free, but it would not be advisable in the long term. If the person or company who plays the receiving part of the development cooperation also takes some of the risk of the investment, the project has a greater chance of success. People tend to be more careful with their own stuff.

6.6 Ownership

Codigestion often means that the reactor is fed with substrates coming from farms with different owners. At some level, this requires trust between the parts involved. Learning from the Colonita example, the biogas plant is preferred to be owned and operated by one single entity, who also owns all the substrate and all the land from which it comes to assure security of supply and stable operation. This entity should also take the risk of the investment and get all the profit, to have an interest to make sure it pays off. This in most cases excludes codigestion plants if the different substrates do not come from the same land owner. Codigestion also often means transporting of waste, which is not favorable in Moldova due to road conditions. Also the petrol is expensive (about 1 euro/l) compared to general income (160 euro/month).

6.7 Obstacles to Overcome for Biogas in Moldova

None of the recent biogas plants in Moldova failed for technical reasons. So the challenge of implementing biogas in Moldova does not seem to be technical, but rather related to understanding how the country works and what the conditions are in Moldova and adapting to these conditions. One cannot simply take a new biogas plant, give it to a farm in Moldova, hand them the keys to the gate, and expect it to work.

6.7.1 Financial Situation

Moldova is the poorest country in Europe, in terms of GDP per capita. (3) Low cost solutions, use of existing equipment, foreign investors or development banks are therefore needed. The question is also whether Moldova should really use their scarce resources to address global warming.

6.7.2 ANRE-Tariff

A feed-in tariff is needed to make a biogas plant feasible, in Moldova as well as in Sweden (7) and in the UK (54). The ANRE-tariff is difficult to get in a fast and direct manner. It is based on costs and expected sales and is negotiated individually for each project. The process of getting an approved tariff can take long. To get the tariff, the project must have a bank approval, which is difficult to get when the electricity price is not set.

6.7.3 Spare Parts

Spare parts can be difficult to get in Moldova and expensive to order from outside the country. Knowledge about the biogas system and language skills are needed. Long standstills have occurred due to lack of spare parts.

6.7.4 DH Networks

The DH networks are old and lack maintenance. This makes it challenging to get offset for the heat produced which makes the biogas plant less profitable.

6.7.5 Mindset and Attitude

Moldavians avoid risk taking and can be skeptical to new ideas. They see waste as waste, not as resource and might not appreciate the environmental benefit of a biogas project.

6.7.6 Corruption

This is a general issue for Moldova and therefore also includes the energy sector. Moldova is the third most corrupt country in Europe, with a corruption index of 2.9 of a ten grape scale where 10 is very clean and 1 is highly corrupt. (55)

6.8 Preferred Site

Each of the investigated sites comes with pros and cons, outlined in Table 6.1.

Table 6.1. Advantages and disadvantages of building a biogas plant at a certain winery.

	Pros	**Cons**
Purcari	Modern Large heat demand from hotel	Small Lees sold
Dionysos-Mereni	Existing equipment available Fertilizer savings possible	Small
Chateau Vartely	Large heat demand from hotel Modern	Villagers use some of the pomace
Asconi	Modern Codigestion possible	
Cricova	Large Fertilizer savings possible	State owned Villagers use some of the pomace

From an economic point of view, Cricova is the most suitable winery for a biogas plant followed by Asconi and Chateau Vartely. However a plant at Cricova cannot be financed through MoSEFF. A biogas plant at Cricova or Chateau Vartely becomes less favorable since local villagers use the pomace.

At Chateau Vartey diesel is used to produce process steam, the amount of diesel used is equally distributed during the year and consists of about one third of the gas heat demand. Since the price of electricity is higher than the price of diesel in Moldova, it will be more economical to export the electricity and continue using diesel for heating rather than replacing it with gas heating. The useful heat of the gas engine is of too low temperature to be used for process steam production.

When it comes to mindset and interest Asconi and Purcari are attractive. The investment cost will be lower than calculated for Dionysos-Mereni; a biogas plant there can be profitable even at a small scale. A biogas plant at Asconi enables codigestion, which is advantageous from a process perspective. At last, a biogas plant can only be built if the wineries want to; Asconi and Bostavan who owns Purcari want to build a biogas plant.

By building a biogas plant at a place where pomace is currently picked up by villagers, they have to replace the pomace with something else. However there is pomace readily available throughout the country as it is landfilled at many places. So the villagers will be able to get the pomace from other sources, but transport can be an issue. Since synthetic fertilizer is used on the fields at Cricova and Dionysos-Mereni, there is a potential for extra savings at these sites.

7 Conclusion

A large Moldovan winery landfills about 50 000 euro of energy every year. This energy should be used to produce biogas through anaerobic digestion. The technology to do this exists and is presented in this thesis. There is know-how available in Swedish companies. Financing can be made through the European Bank. Electricity sales are secured and electricity prices are high, 0.1 euro/kWh. Wineries are interested but need help with planning and implementation. Investment is recommended since the payback time is less than 5 years. If Swedish technology and equipment are used, the export potential for Swedish biogas companies is over six million euro. The investment cost for a biogas plant is 100 000 to 400 000 euro, depending on winery size.

The biogas is produced in a stirred tank reactor fed by a steady flow of pomace; this means that the pomace has to be stored in plastic bales to ensure all-year supply. The biogas is used to produce electricity and useful heat, which replaces natural gas heating, in a CHP engine. The plant should be owned by one single company, who takes the risk of the investment and gets all the profit. That company should also own the land and the substrate used. This setup will minimize the risk of ownership and profit-sharing disputes at the same time as it maximize the chance of project success since it is in the interest of the owner that the plant is in operation.

The plant would save 500 – 1500 tons of CO_2-eq annually, depending on size. The savings from the 20 largest wineries combined is almost 30 000 tons per year. A biogas plant increases energy independence and security. It also generates job opportunities and contributes to economic growth in Moldova.

The conclusion is that biogas produced at wineries in Moldova is an economical alternative with environmental and social benefits; biogas has a role to play in the transition towards a sustainable Moldovan energy system. Biogas from grape pomace can also be an interesting alternative for European wineries. Preferably it can be implemented at large wineries and in countries with support schemes for renewable energy.

8 Reflection

There are several opportunities to proceed with the topics covered in this thesis. A further case study with a higher level of detail can be conducted to achieve a detailed site specific biogas plant design and cost estimation. It would be advantageous if such a feasibility study was conducted in close collaboration with the winery, both for knowledge transfer and to get full understanding of the needs and viewpoints of that winery.

An opportunity to make the idea more profitable is to implement it in wine producing countries that have larger wineries, higher energy prices, higher feed in tariffs and higher heat demand than Moldova. Such a study is likely to reveal other gas offsets to be profitable than CHP due to differences in conditions.

Codigestion can be evaluated further, such a study should address ownership and transportation issues. The potential for substrate transports to a large central biogas plant or incinerator is also an interesting topic. A biogas plant operating on pomace can also be a CDM project or part of a completely organic farm.

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