Technical summary

Anaerobic Digestion
Turning Organic Waste into Energy and Fertilizer

A prefeasibility study of a biogas demonstration plant in the Entre o Douro e Vouga Region in Northern Portugal

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Thesis in the EUREC European Master Study in Renewable Energy 2002-2003
University of Zaragoza, Spain

In cooperation with:

EDV ENERGIA
Energaia
Anaerobic Digestion, Turning Organic Waste into Energy and Fertilizer

A pre-feasibility study of a biogas demonstration plant in the Entre o Douro e Vouga Region in Northern Portugal

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Abstract: In Europe land filling of organic waste will be increasingly restricted in the future (EU directive). The remaining options are AD (anaerobic digestion), aerobic composting, mechanical biological treatment (MBT), and incineration. AD of wet organic waste can be the best way to contribute to meet the EU targets concerning waste and renewable energy as well as the targets on emissions of greenhouse gases and long range transported air pollution (LRTAP).

In the Entre o Douro e Vouga (EDV) region in N. Portugal the existing handling of organic waste is land filling. Plans are under preparation to improve the situation and AD is considered as interesting. This study looks at the feasibility of an AD plant in the EDV region. The plant is supposed to have a size of 10-20 000 ton wet organic waste/year.

The study has assessed the economic feasibility as well as the environmental benefits of an AD plant of 15 000 tons feedstock/year. The plant could be slightly profitable with the existing prices for electricity (70 €/MWh) and gate fees (20-30 €/ton waste) assumed investment costs of 3.5 million € and annual operation and management (O&M) cost of 250 000 €, values which are relative uncertain. Higher costs could be compensated with higher gate fees. Incomes from selling fertilizer and emission reductions of GHG’s (green house gases) are possible but uncertain. It is recommended to carry out a detailed feasibility study for a given location and feedstock, with a proposed technical solution, and detailed investment and, O&M costs.

An AD plant in the EDV region could demonstrate the possibilities of AD in Portugal. AD of organic waste and manure could contribute significantly to Portugal’s obligations on GHG’s, air pollution, waste and renewable energy. The study shows a potential for emission reductions of 2-3 million CO2 equivalents/year with a value of 10 – 60 million Euros.

Keywords: Organic waste, anaerobic digestion, economy, environment, Green House Gases, Portugal.

1. INTRODUCTION

The handling of different kinds of organic waste in Portugal causes in many cases air pollution and water pollution and releases greenhouse gases. The valuable content of energy and nutrients is at the same time wasted. This is also the situation in the Entre o Douro e Vouga region where land filling (legal and illegal) and also uncontrolled burning are the existing solutions.

Several international obligations make it necessary to find better solutions for the handling of organic waste in Portugal and impact the choice of the solutions. EU-directives restrict land filling of organic waste and have very strict demands to incineration concerning emissions and monitoring. A new policy for the biological treatment of organic waste is under preparation. The Kyoto Protocol and the EU’s implementation of it limit the emission of Greenhouse Gases(GHG’s), the Gothenburg protocol limits the emissions of air pollutants like sulphur dioxide, nitrogen oxides, ammoniac and volatile organic compounds. EU’s directive on renewable energy states targets for increased use of renewable energy. Other directives set standards for water quality and limit the discharge of waste water. These obligations represent a strong challenge for most member states and Portugal is one of the countries far beyond its targets for i.e. waste treatment, emissions of greenhouse gases and air pollutants and renewable energy [1, 2]. The EU campaign for take off for biogas states ambitious targets for the development. [3]

Incineration and composting are, besides land filling, the most common treatment methods for organic waste. A significant part of the organic waste has however a high content of water. Incineration of this wet organic waste will therefore hardly generate useful energy. Further, the valuable nutrients will get lost in the process and there will still be the problem of the disposal of the ashes. Composting takes care of the nutrient value, but the energy content gets lost.

Through anaerobic digestion, the content of both energy and nutrients in the waste can be used. The products will
be biogas and a digestate, products that can substitute fossil fuel and mineral fertilizer as well as compost. The method is therefore in principle the most sustainable one and can contribute to meet the EU directives, targets and other international obligations in the area of waste, renewable energy, air pollution, water pollution and climate change.

Earlier experience in Portugal and several other countries with anaerobic digestion has not been so good, i.e. due to inappropriate plant design, lack of support during start up and economical problems[4]. Since then, there has been an improvement in this field and experiences in other countries like Germany, Denmark and Switzerland from the later years are generally good. The economy will depend on the framework conditions like electricity price, gate fees for waste and prices for heat and fertilizer. Pricing of externalities like emissions/emission reductions will play an increasingly important role and could gradually replace some subsidies. The starting of a European emission trading scheme for GHG’s in 2005 [5] is a clear example.

The energy agencies ENERGAIA in Gaia and the newly established EDV Energia in the neighbouring oCesSx€  ∈  p€Tj€  Γ  w€7jY  oxIT€E€ have a strong interest in the promotion of rational use of energy and renewable energy. Gaia is the the largest municipality of the Porto district (171 km²), with 280 000 inhabitants and theoCesSx€  Γ  w€7jY  oxIT€E€  Ñ€5x  Ñ  €7g  Ñ  €T€E€  3h€x  ÑS€E  comprises about 850 km² and 275 000 inhabitants. There exists a clear interest in both agencies and the municipalities in the region to study the possibilities for a demonstration project on turning organic waste from different sources into biogas and a fertilizer, using the biogas i.e. for the generation of electricity. A first step towards a decision is to carry out a pre-feasibility study of a biogas plant, taking in consideration the specific conditions in Portugal and the actual area, now and in the future.

The objective of the pre-feasibility study is to clarify the possibility to establish a biogas plant for the handling of different types of wet organic waste in the region, including sewage sludge. The study should clarify economic viability and environmental impacts, positive as well as negative. The plant should be able to demonstrate the technical, economic and environmental sustainability of this technology.

The size of the demonstration plant should be in the range of 10,000 – 20,000 tons of waste/sludge per year.

This study is the thesis of Harold Leffertstra, student in the EUREC European Master Course in Renewable Energy, 2002-2003.

2. METHODS

The quantities of suitable organic waste in the region are assessed by the use of statistics, and information from employees from the energy agencies ENERGAIA and EDV and the waste management company of the Suldouro land fill. The study is carried out for a virtual plant with several possible locations and a feedstock of selected wet organic waste, 15 000 ton/year. The production of biogas, electricity, heat and digestate is estimated by combining quantitative and qualitative assumptions about feedstock and figures from literature.

The factors deciding for the economy of the plant are assessed by combining the assumed figures for feed stock, expected production and information from EDV and the Suldouro land fill about prices for electricity, and gate fees. The price of heat was decided by using the oil price and the digestate by rough assumptions about content of N and P and their value [6, 7]. The investment cost and O&M costs are derived from literature [8, 9, 10] and adjusted after group discussions at the workshop “The Future of Biogas in Europe II” 2-4 October 2003 in Esbjerg in Denmark. Details can be found in appendix 1.

The environmental impact of the plant is estimated in the form of emission reductions of tons of CO2-equivalents, SO2, and NOx, compared with two baselines resulting in the options “Low” and “High”. Common for both options is the assumption that the baseline for waste handling would be land filling with capture and flaring of landfill gas. For this waste handling an emission factor of 0.5 ton CO2 equivalent/ton waste is considered reasonable [ 9,11,12]. Also common was the assumption that a part of the generated heat replaced fuel oil. In option “Low” the biogas generated electricity was assumed to replace electricity from the “Portuguese mix”, in option “High” substituting a mixture of oil and coal with higher emissions of all gases.

One can debate the correctness of assuming that land filling with capture of 50 % of the landfill gas would be the base line for 20 years. It is assumed that for the first years this base line would be less than 50 % capturing of methane, the later years more than 50 %. An average value of 50 % is therefore considered as an acceptable estimate for the purpose of this study.

The economic value of the emission reductions is estimated by multiplying the emission reductions with varying prices per ton CO2, NOx and SO2, reflecting the values on the emerging CO2 emission trading market in Europe, shadow costs, and costs of damage on environment and public health[13,14,15,16,17]. The following prices are used:

- CO2 5, 10 and 20 € /ton
- SO2 2 500, 4 900 and 5 400 €/ton.
- NOX 1 500, 5 900 and 6 500 €/ton.

The economic value of CO2 emission reductions is already “real”, since emission reduction have been traded i.e. within the Dutch ERUPT scheme for 3-5 €/ton since 2001 and 6.85 € in the German “Hesse bidding” in December 2002. The emission reductions of SO2 and NOx however, even if valuable for the society, will not
have a monetary value unless a market for these emissions should be introduced like in the USA. Their value for the society should justify grants, special favourable electricity prices etc.

**The economy of the plant** is calculated for different combination of values of the factors above, using an Excel spread sheet for calculating the IRR and NPV of the plant under different assumptions. Both the corporal economy of the plant as well as the societal economy is covered, demonstrating the impact of internalization of external factors on the viability of the plant. A sensitivity study of the economy of the plant for changes in some important factors is carried out.

At this stage, no decision is taken whether a biogas plant should be constructed, and in case where. Because of this, no specific and detailed information about the composition of the feedstock was available, which made it impossible to assess the appropriateness of different technical solutions like dry or wet, batch or continuous, high or medium temperature. The technology suppliers contacted were not willing to give information about likely levels of investment- and O&M costs, performance etc before detailed characteristics about i.e. feedstock were available. The study had therefore to be theoretical and generic.

The estimation of the emission reductions and their economic values had to build on the generic production data above, and data from literature for emissions and their values since only limited specific data for Portugal could be found. The combination of a relative wide range of values for the different factors is chosen to give a picture of which framework conditions could be necessary for the viability of a biogas plant. To present concrete figures including the economic value of emission reductions even with the given uncertainty is considered as useful in the further decision making process.

3. **RESULTS AND ANALYSIS**

In the EDV region and Gaia are annually generated roughly 210 000 tons MSW and 60 000 tons industrial waste. 35 % of this or about 95 000 tons are biodegradable organic waste.

This waste is today disposed in 2 landfills with increasing limitations in the future. Partly collection and flaring of landfill gas. A new incineration plant is under planning limitations in the future. Partly collection and flaring of This waste is today disposed in 2 landfills with increasing biodegradable organic waste.

35 % of this or about 95 000 tons are roughly 210 000 tons MSW and 60 000 tons industrial waste. In the EDV region and Gaia are annually generated 3. AD digestion with generation of energy and digestate was estimated, based on the figures above, the investment costs and operation&maintenance(O&M) costs by interpreting figures from [8,9,10,21]. Details can be found in appendix 2.

### Table 1. Assumed/estimated data of a possible AD plant

<table>
<thead>
<tr>
<th>Feedstock/year</th>
<th>12 000 ton wet organic waste + 3 000 ton sewage sludge</th>
</tr>
</thead>
<tbody>
<tr>
<td>Generation of biogas/year</td>
<td>1 500 000 Nm³</td>
</tr>
<tr>
<td>Total energy content/year</td>
<td>9 000 000 kWh</td>
</tr>
<tr>
<td>Electricity for sale/year</td>
<td>2 250 000 kWhel</td>
</tr>
<tr>
<td>Heat for sale /year</td>
<td>3 000 000 kWhtherm</td>
</tr>
<tr>
<td>Digestate, fertilizer value/year</td>
<td>0-30 000 €</td>
</tr>
<tr>
<td>Operation and maintenance cost (O&amp;M)/year</td>
<td>250 000 – 300 000 €</td>
</tr>
<tr>
<td>Investment cost</td>
<td>3,5 – 5 million €</td>
</tr>
</tbody>
</table>

3. AD digestion with generation and use of electricity and heat, in stead of land filling of wet organic waste with capture of the landfill gas will reduce the emissions of GHG’s and air pollutants. The aggregated emission reduction pr ton digested waste will be:

Alt: Low: 0.63 ton CO₂, 0.42 kg SO₂ and 0.15 kg NOₓ
Alt: High: 0.68 ton CO₂, 1.32 kg SO₂ and 0.35 kg NOₓ

The calculations are to be found in appendix 2. Other environmental advantages like reduced emissions of particles, N₂O, odours, water pollution can be of significant importance but are not quantified.

4. Emissions and emission reductions do have an economic value. By combining the emission reductions...
above and the values per ton emission reduction from chapter 2. Methods, we find economic values for ton waste varying from 3.15 – 23 €. A detailed description of the options “emission low, medium, high and very high” used in table 2 below is to be found in appendix 3.

5. The economy of the plant was studied for several combinations of investment costs, O&M costs, gate fees, electricity prices, digestate prices, and values of emission reductions. Also the effect of a 20 % grant on the corporal economy was studied. General assumptions: interest rate 5 %, inflation 2% and a discount rate of 6 % for the NPV. No gate fee for sewage sludge. The results are summarized in table 2 and commented in the following.

“Existing conditions”: investment costs of 3.5 million € and annual O&M costs of 250 000 €. Prices for electricity of 70 €/MWh, heat prices of 15 €/MWh and gate fees of 20-30€/ton for organic waste and 0 for sewage sludge (20.7 €/ton feedstock in average), values for digestate and emission reductions of zero reflect the existing conditions in the region. The project will be only slightly profitable with an NPV of 224 025 € and an IRR of 6.86 %

“Base case”: A raise of gate fees to between 25 and 35 €/ton waste will result in an average value of 25 €/ton feedstock, values that can be expected in Portugal in 2004/2005. The project will have a reasonable economy with a NPV of 1 096 121 € and an IRR of 10.05 % Gate fees are the most important source of income, thereafter the sale of electricity and than heat.

“Base case 1”: A raise of the gate fee to 29.33 €/ton and an income from selling the digestate corresponding to 1 €/ton waste will make the project quite profitable with a NPV of 2 114 421 € and an IRR of 13.76 %

Table 1. Examples of combinations of different levels of costs and incomes and their effect on the profitability of the project

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Gate fee, €/ton waste</th>
<th>Electricity price €/MWh</th>
<th>Heat price €/MWh</th>
<th>Digestate value €/ton waste</th>
<th>Investment, €</th>
<th>O&amp;M costs €/year</th>
<th>Emission value</th>
<th>NPV project €</th>
<th>IRR project %</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Existing conditions</td>
<td>20.7</td>
<td>70</td>
<td>15</td>
<td>0</td>
<td>3.5 million</td>
<td>250 000</td>
<td>0</td>
<td>512 797</td>
<td></td>
</tr>
<tr>
<td>2 Base case</td>
<td>25</td>
<td>70</td>
<td>15</td>
<td>0</td>
<td>3.5 million</td>
<td>250 000</td>
<td>0</td>
<td>577 797</td>
<td></td>
</tr>
<tr>
<td>3 Base Case 1</td>
<td>29.33</td>
<td>70</td>
<td>15</td>
<td>0</td>
<td>3.5 million</td>
<td>250 000</td>
<td>0</td>
<td>657 797</td>
<td></td>
</tr>
<tr>
<td>4 Base case, low CO2 emission value</td>
<td>25</td>
<td>40</td>
<td>15</td>
<td>1</td>
<td>3.5 million</td>
<td>250 000</td>
<td>2</td>
<td>625 047</td>
<td></td>
</tr>
<tr>
<td>5 Base case, medium emission value, low electricity</td>
<td>25</td>
<td>70</td>
<td>15</td>
<td>0</td>
<td>3.5 million</td>
<td>250 000</td>
<td>0</td>
<td>653 694</td>
<td></td>
</tr>
<tr>
<td>6 High cost, medium emission value</td>
<td>26.7</td>
<td>70</td>
<td>15</td>
<td>2</td>
<td>5 million</td>
<td>300 000</td>
<td>2</td>
<td>776 167</td>
<td></td>
</tr>
<tr>
<td>7 High cost, very high emission value, low electricity</td>
<td>29.33</td>
<td>40</td>
<td>15</td>
<td>2</td>
<td>5 million</td>
<td>300 000</td>
<td>2</td>
<td>950 894</td>
<td></td>
</tr>
</tbody>
</table>

“Base case, low CO2 emission value”: It is not unlikely that the emission reduction of GHG’s could be sold from 2005. With a price of 5€/ton CO2-equivalent there is a clear improve in the economy, compared with “base case”.

In “Base case, medium emission value, low electricity” the electricity price is reduced to 40 €/MWh whilst it is assumed that the emission reduction value is “medium” and that the digestate is sold for a price corresponding to 2€/ton waste. The subsidy from society on electricity from renewable resources is justified i.e. by the environmental advantages compared with fossil energy. When an economic value on emission reductions is introduced, there could be good arguments to remove the subsidy in order to avoid double payment. The project is profitable under these conditions with a NPV of 2 114 421 € and an IRR of 13.57 %

“High cost, medium emission value”: Higher project costs, e.g. 5 mill € in investment and 300 000 € in O&M have a strong impact on the economy of the project. A moderate rise of gate fee, subsidy on electricity price as before, payment for digestate and a medium value of emission reduction as assumed in this scenario are necessary to secure a reasonable economy of the project with an IRR of 10.31 %.

In option “high cost, very high emission value, low electricity”, are a gate fee of average 29.33 €/ton feedstock and high emission reductions combined with high prices for CO2, NOx and SO2 emissions sufficient to secure a good economy of the project even with a electricity price of only 40 €/MWh (no subsidy)
Notable is the decreasing importance of the income from energy for the economy of the project. This is shown in table 2 and figure 1. In the first scenario “Existing conditions” the income from energy has a share of 40%, gate fee 60%. In the last scenario, “High cost, very high emission value low electricity”, the income from energy has only a 14% share while gate fee (46%) and emission reduction (36%) together have a share of 82%. This demonstrates that biogas/AD not should be considered as only a source of renewable energy, and as such compared with wind or biomass for combustion. The direct energy efficiency of AD is lower, but it can in addition contribute to solve several other problems.

![Fig 1. Different sources of income of the AD plant, and their contribution under different scenarios.](image)

4. DISCUSSION

4.1. Economy

The figures for the economy, used in this study, build on specific literature for AD [8, 9, 10, 21], and are discussed with experts at the workshop “The Future of Biogas in Europe” 2-4.10.03 in Esbjerg, Denmark, and should include the latest developments. There can however be found much higher figures for the costs of waste treatment [22]. With costs of 80 – 125 €/ton waste for AD, 90 €/ton waste for incineration and 35-75 for composting, they exceed the costs used in this study(43-57€/ton waste). However these high figures include the extra costs of separate collection while this is not the case in this study and may not include the recent development in AD towards lower costs. Treatment costs in the range of 80-125 could be reached with e.g. investment costs of 7 million € and O&M costs of 500 000 €/year for the 15 000 ton plant in this study. These costs seem to be unrealistic high. A plant like this could be profitable with gate fees above 53 €/ton waste. Gate fees like this and higher are common in several European countries. To obtain a more certain picture of the economy of the plant it will be necessary to approach technology suppliers with more specific information about the composition of the feedstock. This can be done in an eventual feasibility study.

With investment costs of 3.5 million € and annual O&M costs, could the plant be slightly profitable under the existing conditions concerning energy prices and gate fees. The selection of special suitable waste without extra costs for collection and transport is an important condition in this context. With the implementation in Portugal of the EU directives on landfills and waste incineration, an increase of gate fees in the future is likely and this would contribute to a better economy..

The treatment of sewage sludge without a gate fee should be questioned since replacement by 3000 tons of waste could increase the income with 6000 to 12 000 €/year.

The emission reduction of methane by AD compared with land filling with 50 % capture of landfill gas constitutes the main part of the emission reduction of GHG’s and as such a potential important source of income in a emission trading scheme. It is still unsure in which degree this methane emission reduction, transformed to CO2-equivalents could be credited in the EU emission trading scheme from 2005. This makes the income from this source uncertain.

There are good arguments for reduction of special favourable payment schemes for electricity from renewables if and when emission reductions could be credited. This is taken in consideration in scenarios 5 and 7. However it is not likely that crediting will occur in near future for other emissions than GHG’s. For the AD
Incineration. Its negative effect on attempts for waste of contaminated ashes reduces the benefits of high. Emission of air pollutants and the need for disposal. [23] Incineration can have the highest utilization of the electricity consumption which is specially emphasized in the targets. [26] The conclusion differ somewhat, concerning incineration and composting. AD seems to have the highest environmental benefits, because of its utilization of both energy and nutrients in the waste. Reactor incineration has the disadvantage of its considerable electricity consumption which is specially emphasized in [23] Incineration can have the highest utilization of the energy content, if the water content in the waste is not too high. Emission of air pollutants and the need for disposal of contaminated ashes reduces the benefits of incineration. Its negative effect on attempts for waste reduction, reuse and recycling of resources makes it little consistent with a EU waste policy for the future. [22]

AD has other environmental advantages associated like reduced emissions of particles, N2O, odours, water pollution which can be of significant importance. The quantification and estimation of the economic value is possible and is carried out in e.g. Denmark for AD of manure and organic waste from industry and municipal waste. In the study of the AD plant in the EDV region it was not considered as possible.

To obtain the full potential of the emission reduction of CH4, NH3 and possibly N2O, the correct design and management of the plant is deciding. If not, it could result in significant emissions.

Besides the direct benefit of the AD plant, solving a waste problem in the region it can contribute to promote AD in Portugal. A rapid development of AD is necessary or useful in the following context:

The reduction of Green house gases could be 2-3 million CO2 equivalents/year with a value of 10 – 60 million Euros. Portugal is far behind its obligations to limit the emissions of green house gases. With the existing policy and measures the emissions are projected to be 32 % above Portugal’s target in 2010 [1]. Also the projected emissions for NOx and SO2 in 2010 are significant above the targets.[2 ] The EU directives in the areas of renewable energy and water pollution represent significant challenges.

4.3. Risk
The technical risk of the studied AD plant should be relatively low given the experience in countries as Denmark and Germany. It is strongly recommended to use a experienced technology provider, chose well proved solutions and demand sufficient training of personnel, assistance during the first years and guarantees. It will be necessary to establish quality securing systems for feedstock to avoid mechanical and biochemical problems as well as for the digestate in order to secure application as a fertilizer.

There is an economic risk because of the uncertainty about investment and O&M costs and the level of the gate fees, as shown earlier. The income from heat sale will be uncertain especially the first years. The electricity price is relative predictable for the first years but less certain. The socio economic value of the emission reductions is quite clear, but when, and in which degree this will represent a source of income is uncertain and it is not advisable to count on it. The economic value of the digestate could be clarified in an eventual feasibility study.

It could be difficult to obtain finance of studies and investments because of the lack of confidence in Portugal in AD. It will be important to convince the decision makers that the technology has matured and that the implementation of EU waste policy will secure a new source of income from gate fees. This income is likely to increase in the future and far exceed the income from energy sale.

5. CONCLUSION
In the EDV region and the neighbouring municipality Gaia, are annually generated more than 90 000 tons organic waste. Implementation of the EU landfill Directive makes it necessary to replace the existing landfill with other solutions like incineration, aerobic composting or anaerobic digestion(AD). Environmentally is AD the best of these. Establishing a 15 000 ton plant could contribute to the EU waste reduction target for the amount of organic waste going to landfills.

An AD plant in the EDV region could demonstrate the possibilities of AD in Portugal. AD of organic waste and manure could contribute significantly to Portugal’s obligations on GHG’s, air pollution, waste and renewable

plant in this study the economic values of i.e. NOx, SO2 reductions vary from 9€/MWh generated electricity in the option “low emission value” to 60 € in the option “high emission value”. The subsidy on “green electricity” in Portugal is about 30 €/kWh.

4.2. Environment
Land filling of organic waste is a solution which gradually will be phased out with the implementation of the EU landfill directive. The remaining solutions are incineration, aerobic composting and anaerobic digestion. A number of studies have compared the environmental impacts/benefits of these solutions. [9, 22, 23, 24, 25].

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energy. The study shows a potential for emission reductions of 2-3 million CO2 equivalents/year with a value of 10 – 60 million Euros. A plant could be slightly profitable with the existing prices for electricity and gate fees, assumed investment costs of 3.5 million € and annual operation and management cost of 250 000 €, values which are relative uncertain. Higher costs could be compensated with higher gate fees. Incomes from selling fertilizer and emission reductions are possible but uncertain. More certain figures for costs will necessitate offers from technology suppliers based on exact figures for amounts and composition of waste.

It is recommended to carry out a detailed feasibility study with i.e. a decision on location, feedstock, technical solution, and estimate of Investment- and O&M costs based on offers from technology suppliers.

5. ACKNOWLEDGEMENTS

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Appendices

Appendix 1:

Estimation of Investment- and operation & management costs

It has been difficult to find relevant specific information about investment and O&M costs for a plant of this size and the actual feedstock composition. Most useful have been the following studies:

Norwegian study (2002) [9]
Feedstock: 15,000 tons/year, source separated organic part of MSW (municipal solid waste), 32 % TS
Energy production: 9,400 MWh/year
Investment: 50 – 70 mill NOK = 6.3 – 8.8 mill €. (wet digestate is spread out on the fields respective free land, composting of digestate) without electricity generation. Reactor size: 3,800 m³. Investment cost pr ton waste capacity: 420 – 590 € /ton waste (32 % TS)

Danish CAD plants [8]
Feedstock: 110-300,000 tons/year, manure + industrial waste (20 %) 9 % TS
Investment: 41 – 72 mill DK = 5.4 – 9.6 mill € of which 10 % in transport equipment
In vestment cost pr ton waste: 270-400 DK = 36 – 53 €
O&M: 30-50 DK/ton waste = 4- 7 €/ton waste
However, several of these plants include boilers for wood chips.

A rough calculation of the average of the 8 CAD plants with only AD gives the following estimate:
Feedstock: 111,000 m³/year of which 80 % is manure, 20 % industrial and source separated municipal organic waste. 9 % TS in the overall feed stock
Biogas: 3.8 million m³/year
Investment: 5.1 million €
O&M costs total:

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Buying of el+heat+fuel</td>
<td>160,000</td>
</tr>
<tr>
<td>transport of waste and digestate</td>
<td>50,000</td>
</tr>
<tr>
<td>Remaining O&amp;M costs</td>
<td>460,000 €/year</td>
</tr>
</tbody>
</table>

This includes wages, maintenance and repairs, insurance, administration

Irish study of a CAD plant 2002 [10]
Feedstock: 55,000 tons/year, manure + industrial waste (20 %) 9 % TS
Biogas generation: 2.1 mill m³/year, 7.5 mill kWh, 3.2 mill kWhel
Investment: 2.6 mill Irish pounds for the plant + 2.1 mill I.pounds for 46 storage tanks and vehicles for transport. Altogether 4.7 mill I.pounds, corresponding to 6.1 mill €.
Investment without transportation equipment and storage tanks: 3.4 mill €
O&M: 130,000 €/year in year 1.

This includes wages, maintenance, transport and administration.
It is however to expect that in the course of the years the cost of repairs will increase the O&M costs

1 MW el (7000 MWhel /year
feedstock: 47,000 ton 20 % TS (calculated under the assumption of 150 kWhel/ton waste (ca 20 % TS)
Investment: 9, 1 mill €
Operating cost: 643 000 €/year

It is difficult to compare these figures since their assumptions are both different and some times less clear. However the Danish figures seem to be the best documented. Both investment and maintenance costs for an AD plant in Portugal will likely be lower than in Denmark due to i.e. significant lower cost of labour in Portugal and less need for insulation. Further will we not include transportation costs in the economic
analysis of the plant in this study, since these costs are covered today by the generators of the waste and we assume that they remain the same, independent of treatment method.

There will be no costs for buying electricity and heat since these are supplied by the biogas plant (internal consumption).

Based on the figures above and literature the following characteristics are assumed for the plant:

- 15 000 ton organic waste pr year
- 1 500 000 Nm³ of biogas
- 9 000 000 kWh total energy content
- 2 250 000 kWh electricity net for sale
- 3 000 000 kWh heat for sale
- Operation and maintenance costs: 300 000 Euros
- Investment costs: 5 mill Euros
- Nutrients in digestate: 5 kg N, 2 kg P and 1 kg K/ton waste

This figure was discussed with several participants at the workshop “The Future of Biogas in Europe II” from 2-5 October 2003 in Esbjerg in Denmark. As a result of this it was decided to keep this figures for the option “High cost”, but assumed for the option “Base Case” the following:

- **Operation and maintenance costs**: 250 000 Euros/year
- **Investment costs**: 3.5 mill Euros
Appendix 2

Calculations of the emission reductions of methane, SO2 and NOx per ton organic waste by introducing AD with generation of electricity and heat, compared with landfilling with methane capture

• **Reduction of emissions of CH4**.
  Concerning the CH4 reduction by AD of organic waste the following calculation could give an acceptable estimation:

  For a waste consisting of 50 % food waste (170 kg C per ton fresh waste) and 50 % park and garden waste (150 kg C per ton fresh waste) the theoretical production of methane was calculated to 0.167 ton per ton waste. If this waste were to be disposed to landfill 50 % could be converted to methane, approx 0.085 ton.[11] If we further assume that the landfill has methane collecting with an efficiency of 50 %, the methane emission would be 0.0425 ton methane. Multiply this by 21 to derive the CO2 equivalent emissions. For each ton of digested waste the greenhouse saving is 0.875 or about 0.9 ton of CO2 equivalent emissions. However this does not take in consideration that a part of the not collected methane will be oxidized in the surface layers of the land fill before emission. This will lower the emissions. Other figures for methane emissions/ton waste are are 0.21 ton[12], and 0.8 ton[9]. Differences occur with different values of methane/ton waste and efficiency of collecting the methane as well in how much methane get oxidized before emission. In this study we will use a value of **0.5 ton CO2-ekv/ton waste**.

• **Reduction of emissions of CO2, SO2, NOx, due to substitution of fossil fuels by biogas**
  The main environmental benefit of renewables like biogas is, that they reduce the emissions commonly associated with electricity production by displacing other generating plants (coal, oil, gas and nuclear). These emissions include the greenhouse and acidic gases from fossil fuel stations and the radioactivity associated with the nuclear fuel cycle.

  In addition can the substitution of fossil fuels like coal and oil by biogas reduce the emissions of particulates and the formation of ground ozone, what is especially important to improve local air quality.

  The emissions reduction by substituting fossil fuels with renewables like biogas can be found by calculating the difference between the emissions generated by the respective resources for the production of the same amount of electricity and heat. In this context, not only the energy generation should be taken in consideration but also the other parts of their life cycles (such as plant construction and decommissioning, extraction, transportation and refining of fuel, etc.

  Because of the different emission characteristics of the different fossil fuels and technologies, it is important to identify which type of plant is displaced by renewables. In this study we have used figures from an IEA report from 1997 "Benign Energy? The Environmental Implications of renewables[12] "[http://www.iea.org/pubs/studies/files/benign/full/00-bene.htm]

  1. Conventional coal plant, best practice
  2. Modern coal plant (pulverised fuel with flue gas desulphurisation and low NOx burners - PF+FGD)
  3. Oil power plant, best practice.
  4. Combined cycle gas turbines (CCGT)
Table 1. Life Cycle Emissions from Conventional Electricity Generation in the UK

<table>
<thead>
<tr>
<th></th>
<th>Coal</th>
<th>Oil</th>
<th>Gas</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Best Practice (g/kWh)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FGD &amp; Low NOX (g/kWh)</td>
<td>955</td>
<td>987</td>
<td>818</td>
</tr>
<tr>
<td>Best Practice (g/kWh)</td>
<td>430</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CCGT (g/kWh)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>


Table 2. Life Cycle Emissions from Renewables

<table>
<thead>
<tr>
<th></th>
<th>Energy Crops</th>
<th>Hydro</th>
<th>Hydro</th>
<th>Solar</th>
<th>Solar</th>
<th>Wind</th>
<th>Geothermal</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Current Practice (g/kWh)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Future Practice (g/kWh)</td>
<td>17-27</td>
<td>15-18</td>
<td>9</td>
<td>3.6-11.6</td>
<td>98-167</td>
<td>26-38</td>
<td>7-9</td>
</tr>
<tr>
<td>Small-Scale (g/kWh)</td>
<td>0.07-0.16</td>
<td>0.06-0.08</td>
<td>0.03</td>
<td>0.009-0.024</td>
<td>0.20-0.34</td>
<td>0.13-0.27</td>
<td>0.02-0.09</td>
</tr>
<tr>
<td>Large-Scale (g/kWh)</td>
<td>1.1-2.5</td>
<td>0.35-0.51</td>
<td>0.07</td>
<td>0.003-0.006</td>
<td>0.18-0.30</td>
<td>0.06-0.13</td>
<td>0.02-0.06</td>
</tr>
<tr>
<td>PV (g/kWh)</td>
<td>98-167</td>
<td>26-38</td>
<td>7-9</td>
<td>79</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thermal Electric (g/kWh)</td>
<td>1.1-2.5</td>
<td>0.35-0.51</td>
<td>0.07</td>
<td>0.003-0.006</td>
<td>0.18-0.30</td>
<td>0.06-0.13</td>
<td>0.02-0.06</td>
</tr>
</tbody>
</table>


For biogas, the appendix about Agricultural & Forestry waste in [12] operates with values of 30 g CO2, 1.1 g SO2, 2.0 g NOx, 2.0 g VOC and 0.09 g particles pr kWhel

The emissions reductions can be found as the difference between the life cycle emissions from fossil energy and the life cycle emissions from biogas.
Table 3: Emissions reductions by substitution of different fossil energy by biogas energy to generate electricity, using a life cycle perspective.

<table>
<thead>
<tr>
<th></th>
<th>Coal</th>
<th>Oil</th>
<th>Gas</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Best Practice (g/kWh)</strong></td>
<td><strong>FGD &amp; Low NOx (g/kWh)</strong></td>
<td><strong>Best Practice (g/kWh)</strong></td>
<td><strong>CCGT (g/kWh)</strong></td>
</tr>
<tr>
<td>CO₂</td>
<td>925</td>
<td>957</td>
<td>788</td>
</tr>
<tr>
<td>SO₂</td>
<td>10.7</td>
<td>0.4</td>
<td>13.1</td>
</tr>
<tr>
<td>NOₓ</td>
<td>2.3</td>
<td>0.9</td>
<td>2.0</td>
</tr>
</tbody>
</table>

The emissions reductions can be estimated to be in the range of:

pr kWh: 400-950 g CO₂, -1.0 - +11 g SO₂ and -1.5 - +10.3 g NOₓ, the lowest values for replacing gas the highest replacing coal, best practice.

It can be difficult to decide which fossil energy is replaced. For Portugal the electricity is produced with a mixture of coal, oil, natural gas, hydropower and “green electricity. This results in an average emission of 510 g CO₂- eqv/kWh el in 2005 and 456 g CO₂-eqv in 2010. The reduction is mainly due to substitution of coal/oil by natural gas and possibly a better efficiency in generation. It has not been possible to obtain information about the emissions of SO₂ and NOₓ pr kWh of the Portuguese mix.

We will study two cases to estimate the emission reductions by the establishment of the biogas plant:

Case 1 “low emission reduction”
We assume that biogas electricity will replace electricity generated by the mixture. emission reductions could be about 480 g CO₂- equiv in 2005, 420 g CO₂ in 2010. The exact emission reductions of NOₓ and SO₂ are hard to estimate because of the lack of information mentioned above., but we assume that the emissions from the mixture are not much above the emissions from biogas generated electricity so we use a value= 0

Case 2 “high emission reduction”
We assume that biogas electricity will replace coal and oil generated electricity. This has to be seen in context with Portugal’s strong need to reduce the emissions of both GHG’s and air pollutants like NOₓ and SO₂. On background of this we assume the emission reduction to be an emission value (800 g CO₂, 7 g SO₂, 3.5 g NOₓ) between the values for coal and fuel oil minus the values for biogas (30 g CO₂, 1.1 g SO₂ and 2.0 g NOₓ) = 770 g CO₂, 6 g SO₂ and 1.5 g NOₓ,

Pr ton waste the following figures can be calculated:
1 ton waste gives 150 kWh representing reductions of

option “low emission reduction”

150*0.42 kg CO₂ = 63 kg CO₂

Option “ high emission reduction

150*0.9 kg CO₂ = 116 kg CO₂
150*0.006 kg SO₂ = 0.9 kg SO₂
150*0.0015 kg NOₓ = 0.2 kg NOₓ
If the heat from the electricity generation is used, it can replace fossil fuels like oil and gas and in this way reduce the emissions still more. Given the economic advantage of fuel oil compared with natural gas we will assume that the heat in most cases would have been generated with oil.

Earlier we have assumed that one ton of waste can generate 200 kWh of heat in addition to the electricity. To achieve the same amount of energy it would be necessary to burn 200/11.2 kg = 17.9 kg of heavy fuel oil (1 % S) assumed 100 % boiler efficiency. With a normal boiler efficiency of 85 % these figures have to be increased with a factor 100/85= 1.18. Further we assume the following emissions pr ton fuel [29]:

- Fuel oil 1 % S; 3.2 kg CO2, 0.02 kg SO2, 0.007 kg NOx

The corresponding emission reductions pr ton waste are:

\[\begin{align*}
17.9 \times 1.18 \times 3.2 \text{ kg CO2} &= 68 \text{ kg CO2} \\
17.9 \times 1.18 \times 0.02 \text{ kg SO2} &= 0.42 \text{ kg SO2} \\
17.9 \times 1.18 \times 0.007 \text{ kg NOx} &= 0.15 \text{ kg NOx}
\end{align*}\]

Emission reductions from replacing fuel oil by biogas for both electricity and heat generation:

- Option “low” emission reduction” (1) + (3)
  131 kg CO2, 0.42 kg SO2 and 0.15 kg NOx

- Option “high emission reduction” (2) + (3)
  182 kg CO2, 1.32 kg SO2 and 0.35 kg NOx

*Added to the reduction of methane emissions (0.5 ton CO2-eqv/ton waste) the total emission reduction pr ton digested waste will be:*

- **Alt:low** 0.63 ton CO2, 0.42 kg SO2 and 0.15 kg NOx
- **Alt high** 0.68 ton CO2, 1.32 kg SO2 and 0.35 kg NOx

__________________________________________________________________________________
Appendix 3

4 Scenarios for combinations of 2 different sets of values for emission reductions, and 3 price levels pr unit emissions reductions.

**Emission value low** = low emission reduction +
low price CO₂, SO₂ and NOₓ

<table>
<thead>
<tr>
<th>Emission reduction/ton waste</th>
<th>Price/unit emission reduction</th>
<th>Economic value/ton waste</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.63 t CO₂</td>
<td>5 €/t CO₂</td>
<td>3.15 €</td>
</tr>
<tr>
<td>0.42 kg SO₂</td>
<td>2.5 €/kg SO₂</td>
<td>1.05 €</td>
</tr>
<tr>
<td>0.15 kg NOₓ</td>
<td>1.5 €/kg NOₓ</td>
<td>0.23 €</td>
</tr>
<tr>
<td>Sum</td>
<td></td>
<td>4.33 €</td>
</tr>
</tbody>
</table>

**Emission value medium** = low emission reduction +
medium price CO₂ + high price NOₓ and SO₂

<table>
<thead>
<tr>
<th>Emission reduction/ton waste</th>
<th>Price/unit emission reduction</th>
<th>Economic value/ton waste</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.63 t CO₂</td>
<td>10 €/t CO₂</td>
<td>6.3 €</td>
</tr>
<tr>
<td>0.42 kg SO₂</td>
<td>5.4 €/kg SO₂</td>
<td>2.3 €</td>
</tr>
<tr>
<td>0.15 kg NOₓ</td>
<td>6.6 €/kg NOₓ</td>
<td>1.0 €</td>
</tr>
<tr>
<td>Sum</td>
<td></td>
<td>9.6 €</td>
</tr>
</tbody>
</table>

**Emission value high** = high emission reduction +
medium price CO₂ + high price NOₓ and SO₂

<table>
<thead>
<tr>
<th>Emission reduction/ton waste</th>
<th>Price/unit emission reduction</th>
<th>Economic value/ton waste</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.68 t CO₂</td>
<td>10 €/t CO₂</td>
<td>6.8 €</td>
</tr>
<tr>
<td>1.32 kg SO₂</td>
<td>5.4 €/kg SO₂</td>
<td>7.1 €</td>
</tr>
<tr>
<td>0.35 kg NOₓ</td>
<td>6.6 €/kg NOₓ</td>
<td>2.3 €</td>
</tr>
<tr>
<td>Sum</td>
<td></td>
<td>16.2 €</td>
</tr>
</tbody>
</table>

**Emission value very high** = high emission reduction +
high emission price CO₂, NOₓ and SO₂

<table>
<thead>
<tr>
<th>Emission reduction/ton waste</th>
<th>Price/unit emission reduction</th>
<th>Economic value/ton waste</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.68 t CO₂</td>
<td>20 €/t CO₂</td>
<td>13.6 €</td>
</tr>
<tr>
<td>1.32 kg SO₂</td>
<td>5.4 €/kg SO₂</td>
<td>7.1 €</td>
</tr>
<tr>
<td>0.35 kg NOₓ</td>
<td>6.6 €/kg NOₓ</td>
<td>2.3 €</td>
</tr>
<tr>
<td>Sum</td>
<td></td>
<td>23 €</td>
</tr>
</tbody>
</table>