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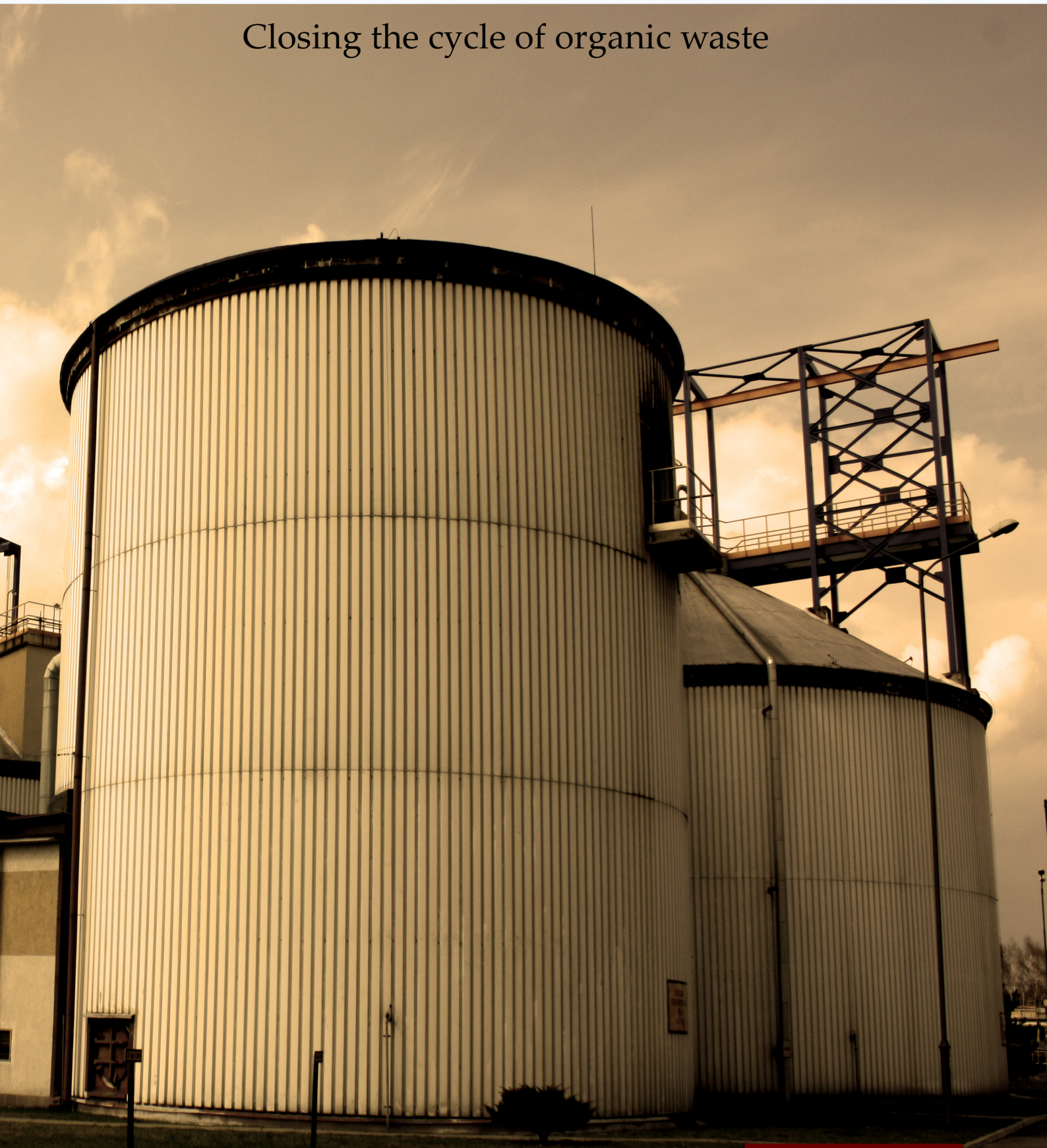
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BIOGAS PRODUCTION IN ZABRZE

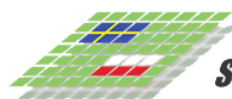
Closing the cycle of organic waste



J. Generosi, E. Machacek, R. Remigius, Ž. Poderienė

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***Swedish-Polish
Sustainable Energy Platform***



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Abstract

Both energy security and the demand for energy, particularly from renewable energy sources, as principle drivers, call for the investigation of renewable energy potential in Poland.

The city of Zabrze, located in the Upper Silesia province and urban zone of Katowice, dedicates continuous efforts to the improvement of its waste management against the background of European Union Directives requiring the increased reuse and recycling of waste and the gradual reduction of waste being landfilled.

Biogas production presents a rewarding solution by using organic waste as resource for energy production and thereby closing the loop in the life-cycle attached to organic products. This pre-feasibility study explores the potential for biogas production from pig manure and organic household waste, taking into account the prevailing local conditions in Zabrze.

From a thorough data analysis, field study visits in the vicinity of Lund in Sweden and in Zabrze and adjoining communities, as well as multiple stakeholder interviews, the feasibility of a 350 kW biogas plant fed by municipal organic household waste and a base load of pig manure, with an electricity generation potential of 2.9 GWh_e per year, is deduced.

The report concludes that the technical implementation will need to be accompanied, in addition to continuous public awareness raising and educational endeavours, by economic measures and a supportive legal framework, both of which need to be clearly defined for a medium to long term period to allow for predictability on behalf of potential interested operators and businesses.

Acronyms and Abbreviations

CHP	Combined Heat and Power
ERO	Energy Regulatory Office (lit. URE, Urząd Regulacji Energetyki)
IBRKK	Instytut BadańRynku, Konsumpcji i Koniunktur (Institute for Market, Consumption and Business Cycles Research)
kW	Kilowatt
kWh	Kilowatt hours
MSW	Municipal solid waste
MW	Megawatt
MWh	Megawatt hours
nREAP	national Renewable Energy Action Plan
RE	Renewable Energy
RED	Renewable Energy Directive
RES	Renewable Energy Sources
WTE	Waste to Energy

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Introduction

Environmental issues have been at the forefront of today's global development debates. As the energy sector is a major contributor to greenhouse gas emissions and climate change; changes in the energy production and consumption pattern are very important to ensure sustainable development and security. More use of renewable energy will ensure energy security and also enhance a better environmental quality. Policies that encourage the development of renewable energy instead of conventional fossil based energy carriers will play a vital role in the energy sector of the future.

Biogas is one of the many sources for renewable energy. Through an optimal use of the natural process of anaerobic digestion of organic matter, including organic wastes, biogas can solve problems related to both waste management and energy demand in some potential areas. However, the required involvement of many different stakeholders inherent to

establishing a biogas system makes the use of biogas as energy source a complex task to accomplish. For example, the availability of substrates will affect how much energy can be produced. And in a further step, the cost effectiveness of the practice will depend on the availability of substrates in the area.

Another important aspect is the waste separation practice in the area. Without a good waste separation practice that keeps organic waste uncontaminated, biogas production is very hard to realise. Further, there is a need for market demand for biogas.

Given a positive scenario in which the stakeholders could collaborate and explore synergies for the establishment of a biogas system, biogas will be very beneficial from both an economic and environmental perspective.

This report will present a pre-feasibility study for the establishment of a biogas system in the local context of Zabrze in Poland.

The city of Zabrze



Zabrze, located in the southern part of Poland, is member of the Metropolitan Association of Upper Silesia.

Zabrze is a small city with 186000 inhabitants. As a former coal mining city, Zabrze was known as the dirtiest and most polluted city in Europe. The mining industry has been decreasing with the closure of all mines except one, and since then, the environmental quality of the city has been improving.

However, some of the areas used for mining, known as brownfields, are still highly contaminated and they are causing many environmental problems such as salinisation of surface water and waste.

However, these areas can be restored and used for other purposes.

The closed coal mines are currently used as industrial tourism spots generating one of the city's sources of income. Recently, the authorities of the city applied for the Silesian coal mines to be taken up into UNESCO's heritage list.

Currently, Zabrze municipality, together with other local stakeholders, is working towards implementing a better waste management system and looking for biogas as a possible way to solve the problem of organic waste being put into landfills.

Environment



GUIDO COAL MINE, ZABRZE, POLAND.

Coal is a muddy source of energy and has been abandoned in many countries. [1]

However, coal still remains an attractive source for electricity or heat production, because it is cheap and widely available in the underground areas. Nevertheless, coal has high external costs: the underground mining can be dangerous and has potential to create health and safety problems for the workers. Although security regulations are stringent, many accidents still happen in coal mines each year. They are mainly caused by the leakage of gas, fires, explosions or water floods. [2]

Another serious impact on the environment is land subsidence, i.e.

when soil and rocks slip down into the hillside. Mining subsidence can influence the level of groundwater and terrestrial land. In highland areas mining is the cause for gradient failures consequently bringing losses of water and soil by the creation of surface cracks and overload fractures.

Water pollution

A consequence of the ground level decline is water pollution.

Due to soil slipping and water drainage, the underground water reservoirs are under threat.

Underground water bodies and mining areas connect through fracture overburden, groundwater changes flowing direction, and many different substances from the cracks leak into the water, react with or melt into it.

The contaminants cause changes of the chemical composition of water as well as of the amount of suspended

solid particles, leading to a sensible decrease in water quality.

Furthermore, mine drainage and pollutants arising from removing mining waste also have the potential for contaminating surface water. [1]

Waste from mines

Underground coal mining produces a vast amount of waste, which contains mine stones and many coal by-products and has a big impact on the environment.

This type of waste is produced during the washing process, which is performed to get access to the coal resources. Waste products are typically topsoil and waste rock ash that have to be properly handled in order to avoid the contamination. [1]

Air pollution

Air pollution is another consequence of coal mining. During the mining process that includes the processes of drilling, blasting, transportation, and collection and managing coal, dust particles, of methane (CH₄), sulphur

oxides (SO_x) and nitrogen oxides (NO_x) and other gases are emitted to the air. The amount of CH₄ emitted depends on the mining process (e.g. depth of mines, different content of coal).

It is relevant to underline that the impact of CH₄ on the atmosphere is 21 times stronger than the one of carbon dioxide (CO₂) in the calculation of greenhouse gas emissions.

Moreover, CH₄ is very explosive and poses a risk to workers' safety. Furthermore, burning coal can cause severe and immediate health problems (e.g. asthma, allergies, cancer) to humans and indirectly through acidification which contributes to a decrease of the pH level in water putting at stake the functioning of ecosystems and related services. [1]

Land change

As previously mentioned, coal mining radically damages land areas through waste creation and land slipping. [1]

Erosion increases and vegetation stops growing. Further, land slipping can require the relocation of entire cities.

Biogas

The exploitation of natural non-renewable resources (e.g. coal, oil, natural gas) is unsustainable: one day these resources will be exhausted. Therefore, energy security needs to be achieved through the use of renewable sources.

Renewable energy from biogas production is an alternative to fossil fuels and is increasingly used for power and heat production, and as fuel for transportation. [3]

Biogas is produced from the anaerobic digestion of organic matter, such as of manure, household and industrial food waste and slaughterhouse waste.

If compared to the direct disposal - landfill or incineration - the anaerobic digestion eradicates fugitive CH_4 emissions and reduces NO_x and SO_x emissions. For example, the field application of biofertiliser, a by-product of the digestion process and highly rich in nitrogen (N) and phosphorus (P), instead of direct manure, reduces NO_x emissions by 28%. [4]

The production of biogas also has potential for solving other problems, including the reduction of organic waste put into landfills, the disposal of livestock (landfilling dead animals can cause underground pollution, pathogen and water contamination) and GHG emissions. [5]

Biogas production



BIOGAS DIGESTER



STORAGE FACILITY OF BIOGAS

When organic matter, such as food and manure, is decomposed in an oxygen free environment, normally a gas that consists approximately of 40-70% methane is generated. When this gas is combusted, it undergoes a clean combustion process similar to natural gas. This gas is known as biogas and it is a source of renewable energy.

Biogas can be produced naturally in the landfill or inside the digester. The latter is currently becoming more popular in biogas production for commercial use.

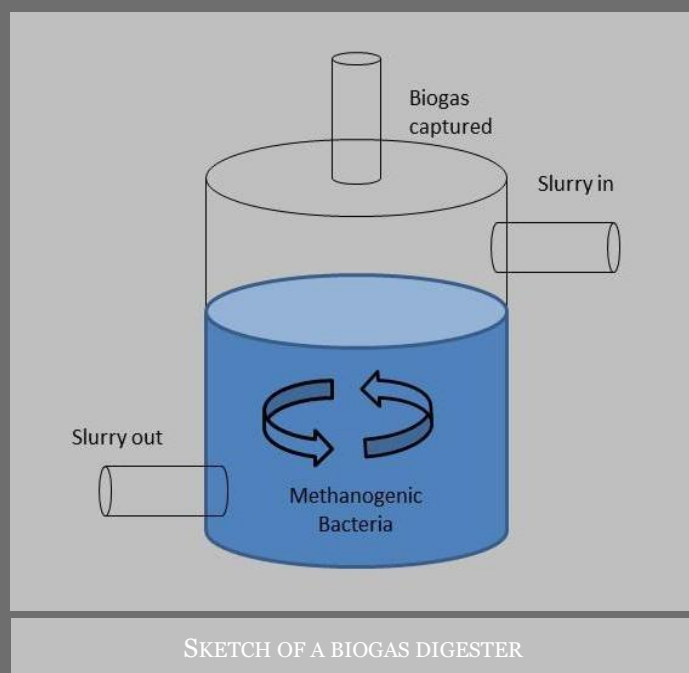
This report focuses only on biogas production from the digester. Countries like Sweden, Germany, Denmark, and Austria, counting numerous advanced biogas plants, are amongst the pioneers and the leading biogas producers in the world [6].

The process of biogas production itself is a fairly simple process that does not require advanced technology. The process involved is mostly a biological and chemical process. The sketch on the next page shows the process of biogas production in the digester.

“The process of biogas production itself is a fairly simple process that does not require advanced technology”

It illustrates that the substrate/feedstock/organic matter that will be used as a material to produce biogas will be pumped inside the digester through pipes. The substrate will be stored inside the digester for several days to be digested and decomposed, and the gas produced is captured and transported through the pipes into the upper part of the digester and collected and stored inside the biogas tank for further use. Biogas produced this way contains 40-70% methane and 30-60% carbon dioxide. Biogas is a clean combustion fuel and therefore becomes a good renewable energy source. Finally, the digested substrate will be pumped out through pipes. The digested substrate is rich in nutrients and can therefore be used as agricultural fertiliser. During the anaerobic digestion process, the

nutrients that are bound in organic compounds, such as nitrogen, are mineralized and can easily enter the soil solution and as a result can be easier absorbed by plants [7].

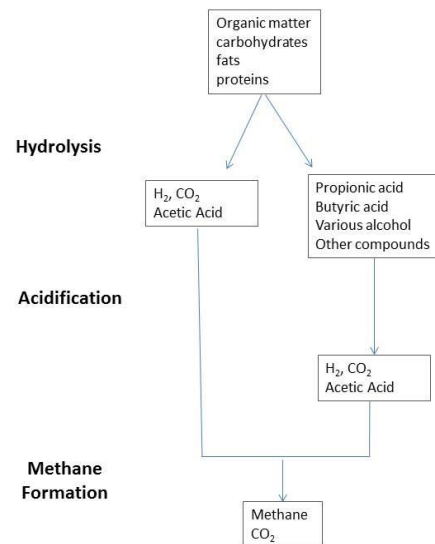


Anaerobic digestion: biological and chemical processes

Anaerobic digestion is a decomposition process of organic matter that takes place without the presence of oxygen. To produce biogas, organic matter has to be digested with the methanogens, a type of bacteria that produces methane. Anaerobic digestion that takes place in the digester to produce biogas undergoes three biological steps which are performed by the bacteria.

During the hydrolysis process, proteins, fats, and carbohydrates are broken down to acids such as amino acids, long-chain fatty acids, and sugar. Following the breaking-down into these acids, in the acidification process, acid producing bacteria convert them into acetic acid (CH_3COOH), hydrogen (H_2), and carbon dioxide (CO_2). Oxygen and carbon are needed to produce acetic acid, therefore the bacteria use the oxygen and carbon solved in the substrate mixture and bounded oxygen to produce acetic acid. This process creates the oxygen free

environment that is important for methane generation in the next step. During the final process, methane formation, the methane generating bacteria consume and digest acetic acid, hydrogen, and carbon dioxide and generate methane and carbon dioxide [7].



THE THREE STEPS OF THE BIOLOGICAL PROCESS

“Anaerobic digestion is a decomposition process of organic matter that takes place without the presence of oxygen”

Important parameters for anaerobic digestion

To ensure that the bacteria that perform the digestion process have a good living environment inside the digester, several parameters need to be controlled and maintained throughout the entire process of biogas production [7].

PARAMETERS

1 **Carbon/Nitrogen Ratio**

The proportional C/N ratio in the substrate/organic material to be digested is 20-30. If the C/N ratio is too high, the nitrogen will be consumed and depleted faster by the bacteria no longer available to react with the leftover carbon. If the C/N ratio is too low, the nitrogen might create a toxic environment for the bacteria.

2 **Temperature**

There are three different anaerobic digestion processes based on the temperature of the digester and substrate during the process: (1) Psychrophilic (below 200°C), (2) Mesophilic (200-400°C), and Thermophilic (above 400°C).

3 **Available nutrients**

The bacteria need more nutrients in addition to carbon, oxygen, and hydrogen to grow. Nutrients such as nitrogen, sulphur, phosphor, potassium, calcium, magnesium, iron, and zinc are necessary.

4 **Dilution and solid content**

The substrates to be digested have to be in the form of slurry, therefore dilution with water is necessary. The proportional solid content in this dilution is around 15-30% of solid content.

5 **Toxicity / purity of substrate**

Some mineral ions, especially from heavy metals, might have a toxic effect and kill the bacteria inside the digester. Therefore, it is essential that the substrates used in the digester are not contaminated by such materials.

6 **Retention time**

Retention time is the duration during which the substrates remain inside the digester to achieve the expected biogas yield.

7 **Acidic Level**

Methanogens cannot live in the highly acidic environment. Neutral or slightly acidic environments are best for methanogens to live and grow. Therefore the proportional pH level to produce biogas is between 7 and 8.5.

8 **Mixing/agitation**

Mixing the slurry inside the digester is important to keep the homogeneity level of the slurry and to ensure an equal mix of the slurry with the existing bacteria inside the digester.

Types of substrate

Fundamentally *all organic materials* can be used as substrate to produce biogas, however there are differences in energy content in each organic material, for example manure has a higher energy content than grass. Also, from an *engineering perspective*, some materials are easier to be handled by the equipment than others, e.g. roots of plants might carry along stones which might damage pipes in the long run.

One of the most common substrates used to produce biogas is *sewage water sludge*. This sludge contains many organic materials such as human excreta and urine which can yield high energy. *Animal manure and agricultural wastes* such as maize also are good substrates to produce biogas.

The most recent development is using *municipal organic waste* (food waste) to produce biogas. This practice can solve both municipal solid waste management and energy supply problems in a municipality.

Another important step to be taken for the substrate is *pre-treatment*. As explained earlier, for the substrate to be digested it has to be in the form of slurry and diluted with water. Solid material cannot be used to produce biogas inside the digester due to several technical problems. Therefore those solid organic materials have to be pre-treated and converted into slurry first before they can be used for producing biogas [7].

Biogas use



CLEANING FACILITY FOR RAW BIOGAS



DIESEL ENGINE FOR ELECTRICITY PRODUCTION

Biogas can be used for several purposes. The most common use of biogas is linked to direct combustion to produce heat, electricity generation, and biogas upgrading to bio-methane or biofuel. *Direct combustion* to produce heat is the easiest way to use biogas, and the heat generated can be used for cooking purposes (biogas stove) or space heating. Biogas combustion can be connected to a boiler and produce steam or hot water for district heating.

Combined heat and power plants (CHP) become the standard way of biogas utilization. CHP fuelled by biogas can have an efficiency of up to 90% and convert biogas into 35% electricity and 65% heat. Green

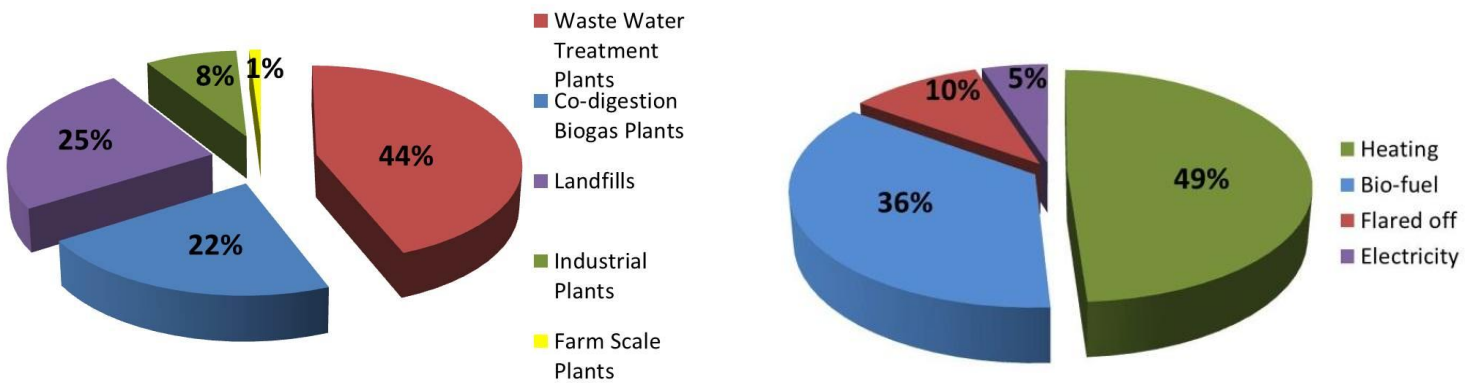
certificates for electricity generation from renewable sources also give additional benefit of using biogas for electricity generating purposes. Applying these instruments will provide the producer with incentives in the form of financial rewards.

Biogas can also be *upgraded to bio-methane* to be injected into the gas grid and used as biofuel for vehicles. After the upgrade, the bio-methane or biofuel will contain up to 97% methane. With this high level of purity, bio-methane can also be injected to the gas grid and delivered to the end user. It can also be used as vehicle fuel such as for a bus operating on biogas. Using of biogas buses for public transportation is very common in Sweden [6].

Swedish experience

The practice of anaerobic digestion to produce biogas in Sweden dates back to the 1940s where the sewage water treatment plant produced biogas using sewage water sludge. However, biogas production at that time was practiced as a means to reduce the volume of sewage water sludge rather than with the primary objective of producing biogas itself. The larger

scale of biogas production for commercial use in Sweden started around 1970s with the energy crisis being a trigger for the further development of biogas production. During this period, industries such as sugar refineries and pulp mills were starting to use the biogas process to purify water.

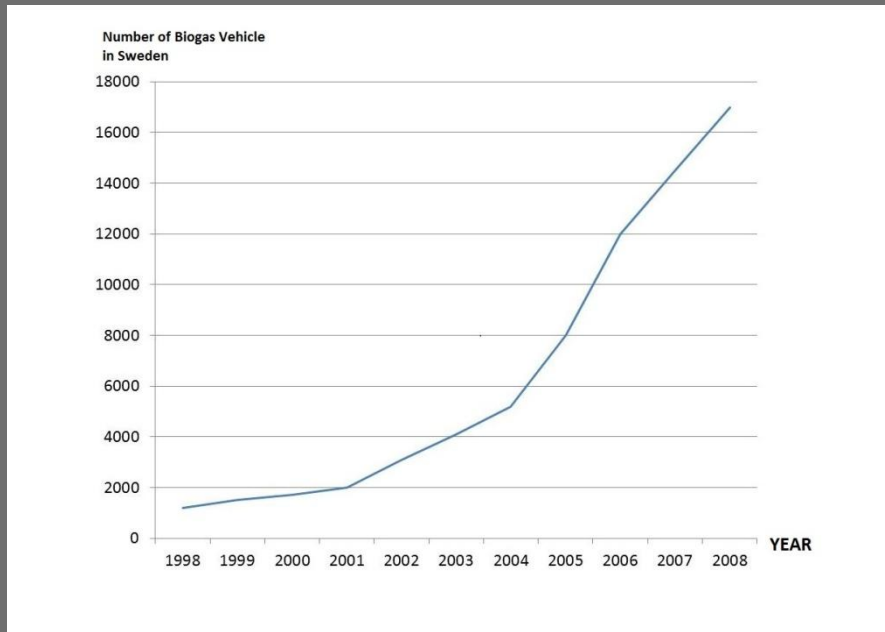


BIOGAS PRODUCTION AND USAGE IN SWEDEN

The agricultural sector also started to use animal manure to produce biogas. All the development of that time was focused on how to optimize industries' residues and wastes utilisation. In the 1980s the practice of capturing methane from landfills was introduced as a means to reduce the methane emission to the atmosphere. Finally, in the 1990s, co-digestion biogas plants were developed which used organic matter from different sources, such as from food industry residues and municipal organic waste, to produce biogas [8].

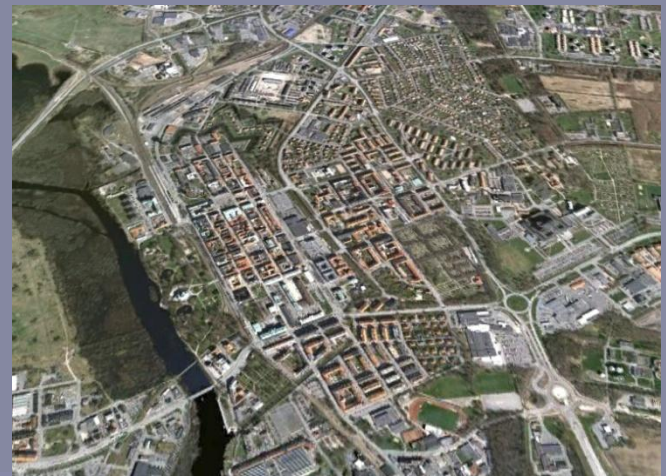
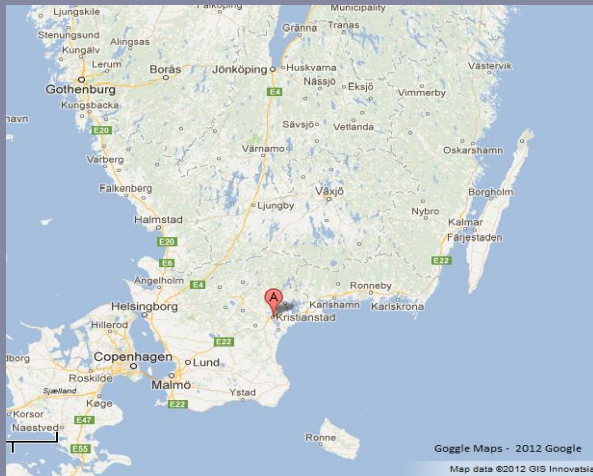
In 2008, the total biogas produced by 227 biogas facilities in Sweden reached about 1.4 TWh. The largest volume of biogas was produced in waste water treatment plants (44%). The other biogas production facilities that contributed to the total amount were landfills (5%), co-digestion biogas plants (22%), industrial plants (8%), and farm scale plants (1%). During 2006-2008 the number of biogas plants and production increased by 12%. This increase was generated mainly from waste water treatment plants, co-digestion plants, and industrial plants. On the other hand, the amount of biogas production

from landfill decreased and is expected to decrease even more in the future because of legislative requirements banning organic materials going to landfill since 2005 [8]. Biogas in Sweden is mostly used for heating purposes such as local heating, district heating and industrial heating, and upgraded into biofuel, very little is used to produce electricity in CHP plants. More than half of the biogas produced is used for heating purposes, and approximately 26% are upgraded into biofuels for vehicles. Biofuel production in Sweden has been increasing by an estimated 20% each year [8].



NUMBER OF VEHICLES IN SWEDEN FUELED BY BIOGAS

Case study: Kristianstad Kommun



KRISTIANSTAD, SWEDEN. IMAGE © 2012 LANTMÄTERIET/METRIA AND © 2012 GOOGLE

Kristianstad is a small city located in the Skåne region in southern Sweden. The population of the city is approximately 80000 and agriculture and food production account for the main industries.

Kristianstad has a very strong relation with biogas production in Sweden. This town produces a vast amount of biogas each year, and almost all of the energy consumption in Kristianstad is powered by biogas. Biogas in Kristianstad is produced in the waste water treatment plant, from the landfill, and the co-digestion biogas reactor plant (Karpalund Plant). In 2009, approximately 68 GWh of biogas were produced [9].

It was not until 1995 when biogas produced from landfill in Kristianstad was also used for commercial purposes. Before 1995, the biogas (methane) was burnt directly to prevent it from reaching the atmosphere. After 1995, the biogas from landfill was captured and used as fuel for district heating. It cannot be used for vehicle fuel due to the high content of impurities in the gas. Approximately 15 GWh of biogas are produced each year from landfill. Biogas production from waste water treatment in Kristianstad yields approximately 8 GWh per year. The biogas produced is used for district heating and upgraded to vehicle fuel [9].

In 1997, the Karpalund co-digestion biogas plant was built by the local waste management company (Renhållningen Kristianstad). The plant was built as a means to treat the industrial residues from food industries in the city, but later on extended to also treat municipal organic waste. Substrates used in this co-digestion biogas plant are food industry residues (46%), municipal organic wastes (30%), and animal manure from farms (24%). It produces approximately 42 GWh of biogas per year and almost all of this biogas is upgraded to biofuel for vehicles [9].

Laws applicable to biogas produced from organic waste

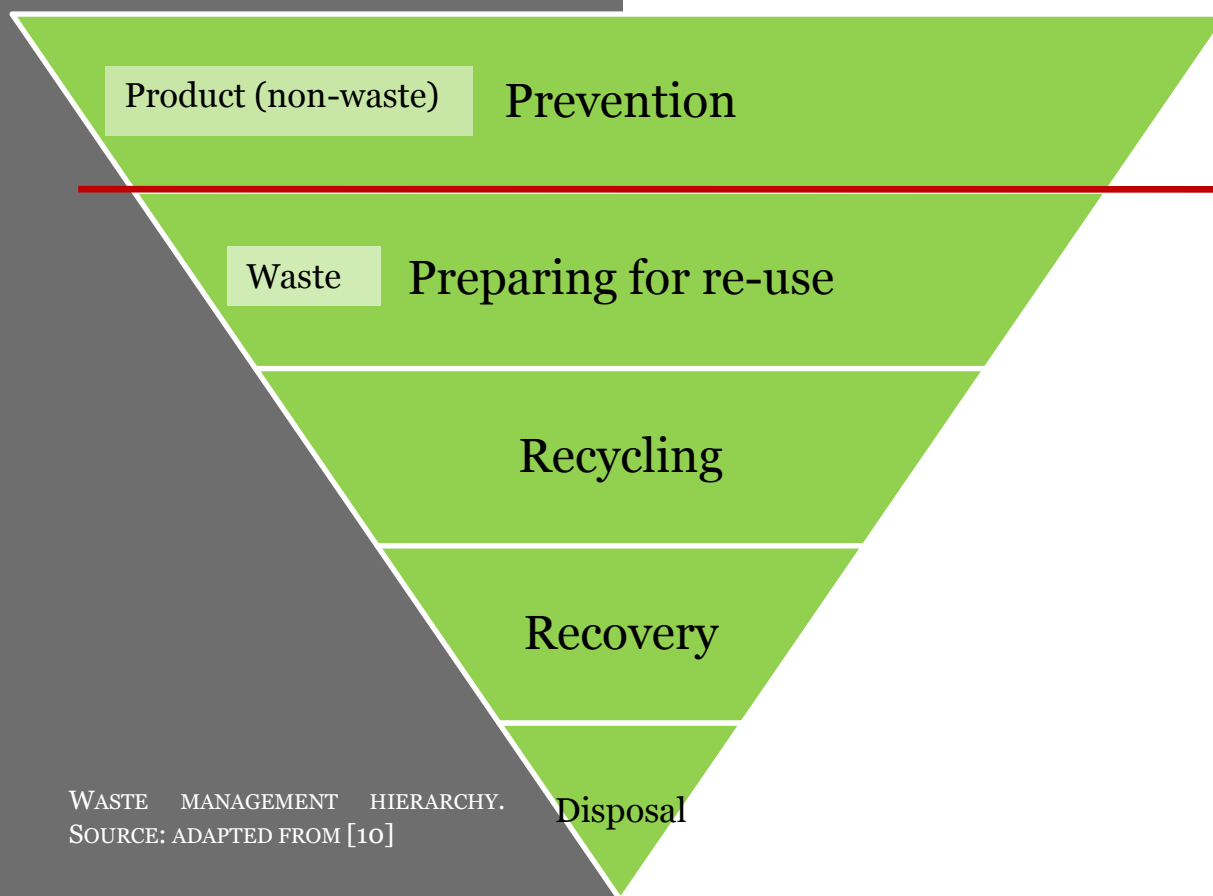
The legal framework, establishing the conditions and rules for the market, can be, if adequately designed, a major driver for renewable energy market development. With this background and this specific case of biogas generated from organic waste, the following legislative section of this research report sets out at providing an

overview of the European Union Directives which regulate waste and renewable energy. In sequence, the section explores the transposition of EU Directives into Polish national law and uncovers potential strengths and weaknesses with a view to supporting biogas development.

Applicable Directives of the European Union

The Waste Framework Directive 2008/98/EC provides main concepts of waste management and defines waste including when and under which conditions it is considered to be a secondary raw material. Most importantly, the Directive presents a waste management hierarchy in form of a reversed pyramid of five layers whereby the first layer addresses prevention and the material in this layer is still considered to be a product. From level two to five, the material discussed is classified as waste and is in level two prepared for re-use in level three to be recycled then recovered and finally disposed of. EU Member States are requested to implement this waste management hierarchy in their respective waste legislation and policy. [10]





WASTE MANAGEMENT HIERARCHY.
SOURCE: ADAPTED FROM [10]

Two targets are laid out in the Directive: (1) 50% of certain waste materials from households and other origins similar to households are to be prepared for re-use and recycling, and (2) 70% of construction and demolition waste are to be prepared for re-use, recycling and other recovery. It appeals to Member States to adopt *waste prevention programmes* and *waste management plans* [10].

The *EU Green paper* defines bio-waste as biodegradable garden and park waste, food and kitchen waste from households, restaurants, caterers and retail premises, and comparable waste from food processing plants. It describes current bio-waste management, explores environmental, economic and social issues related to bio-waste management, and provides for a discussion of bio-waste issues [11].

Biodegradable waste which is put into landfills generates greenhouse gas emissions which reinforce the natural greenhouse effect and in consequence accelerate climate change and trigger global warming. The Directive 1999/31/EC on the landfilling of waste, known as Landfill Directive, therefore obliges EU Member States to gradually reduce the quantity of biodegradable waste being landfilled to achieve a reduction by 35% of 1995 levels by 2016. [12]

The burning of young carbon, which is carbon contained in organic waste, as per EU definition, is considered to be climate-neutral when burned / incinerated. Against this background, the Directive 2000/76/EC on the incineration of waste is relevant for this report as incineration might be perceived by the respective Polish authorities as an option to achieve the outlined reduction in landfilling of organic waste and to mitigate against the EU fines Poland is facing in the transition phase towards a sustainable waste management system that complies with the earlier

described EU waste management hierarchy. [13]

Plans for several incineration plants are currently under discussion, whereby EU structural funds appear to play an essential role in the funding of these facilities. [14]

Based on several European experiences with incineration, including the Swedish and German, it

Waste Framework Directive 2008/98/EC

50% of certain waste materials from households and other origins similar to households are to be prepared for re-use and recycling

70% of construction and demolition waste are to be prepared for re-use, recycling and other recovery

It appeals to Member States to adopt *waste prevention programmes* and *waste management plans*. [10]

is worthwhile mentioning that incineration, apart from the extensive upfront costs of the facility, to be economically feasible, depends on the constant feed of waste and thereby might be, if installation capacities exceed actual needs over the long term, from a system perspective and with the background of the waste management hierarchy, a lock-in technology. While an incineration plant, once installed, will have the capacity to manage the specified quantities of waste, it will need to operate over a certain time period for the expected return on investment to be achieved. During this time, educational efforts might have led to increased successful waste source separation and a reduction in overall waste generation, however, the

amount of waste to be fed into the incinerator for its operational cost to be justified, will remain the same.

In the following section, the report elaborates on EU legislation regarding renewable energy.

The Directive 2009/28/EC on the promotion of the use of energy from renewable sources, commonly referred to as RED Directive sets mandatory targets on a national level for EU member states for the use of energy from RES with the aim to achieve the overall EU 20 per cent target of energy from renewable energy sources (RES) in 2020. The Directive calls upon Member States to adopt National Renewable Energy Action Plans (nREAPs). [15]

RED
Directive

20% target of energy
from renewable energy
sources by 2020

EU Directive transposition to Polish law

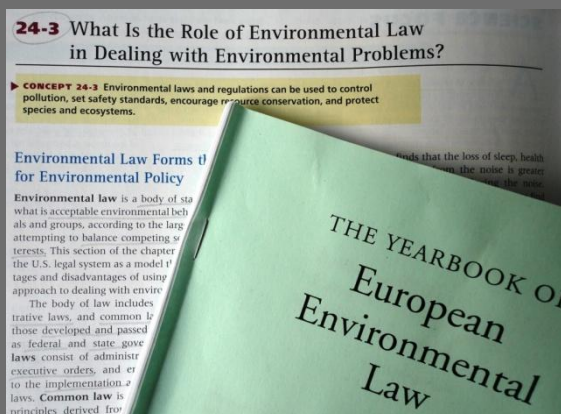
National Renewable Energy Action Plan

The National Renewable Energy Action Plan (nREAP) presents a transposition of the EU RED Directive into national law. It outlines a 15 per cent share of renewable energy as objective in the energy mix of Poland, following the targets stipulated in the Polish Energy Policy 2030. This objective translates into different targets for the energy sector, namely 8.6% for heat and cooling, 4% power production and 2.9% transport.

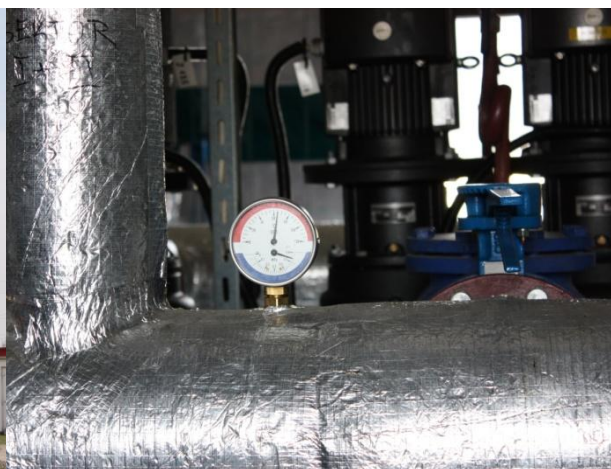
Regarding electricity production, the anticipated share of RES technologies

are as follows: 48 % of wind energy, 31 % of solid biomass, 12% of biogas and 9% of hydropower. In heating and cooling solid biomass is expected to play a prominent role with 78 % followed by solar energy with 9 %, biogas 8%, geothermal energy 3% and heat pumps 2%. In transportation, the emphasis is on biodiesel with 73%, bioethanol accounting for 22%, other 3% and electricity 2%. The role of biomass in achieving the targets of the RED Directive is evident. [16]

The transposition of the RED Directive provisions to national law is ongoing with the inauguration of a new department in charge of RES, the Renewable Energy Act and the draft of the new Energy Law and Gas Law. In order to achieve the targets of the nREAP, effective support measures are needed. [16]



Energy policy



BIOGAS DIGESTER AND BIOGAS UPGRADING FACILITY

The Polish energy sector is regulated by the Energy Policy which stipulates renewable energy targets up until 2030. The share of RES in final energy consumption is anticipated to be 15% in 2020 and to increase by another 5% by 2030. The 15% target reflects a transposition of the EU RES Directive target. A 10 % target for renewable energy in fuels used for transportation purposes in 2020 is envisaged in the Energy Policy, which is to be accompanied by the implementation of second generation biofuels. The Policy also recommends sustainable biomass production from agriculture and forestry which

refrains from impacting food production and protection of forest resources from intensive exploitation for energy. [17]

RE certificates of origin, which are also known as green certificates, are to be continued under this Policy. It also promotes tax relief for energy produced from RES. It recommends support for RE heating and cooling as well as a programme for agricultural biogas production to be implemented, whereby one biogas plant is to be present in each municipality in 2020. [17]

Energy Law Act



The Energy Law Act, which was adopted in 1997, delineates the development of state energy policy. It defines the operations of businesses in the energy sector and the fundamental principles and terms of supply of energy and fuels, including heat. The Act further specifies which authorities are responsible for fuel and energy economy such as the Energy Regulatory Office (ERO). [18]

The last amendment of the Energy Law Act, which was done for the same purpose as earlier ones, namely to promote renewable energy and cogeneration, was adopted in October 2011. It replaced the Energy Law

(Journal of Laws No. 205, pos. 1208). [19,20]

The current definition of agricultural biogas comprises a generation from the following sources: agricultural raw materials, by-products of agriculture, liquid or solid animal manure, by-products or residues from the processing of agricultural products, forest biomass and a methane fermentation process. [19]

Organic food waste does not form part of this definition. This represents an unexplored economic potential of biogas generated from this source since it is, as a result of not being

included in the definition, also not applicable for injection into the grid.

Electricity generators and suppliers are requested by the Act to achieve a certain quota of certificates of origin, also known as green certificates. (Art. 9a par. 1 no. 1 Energy Law Act). If it is not feasible for a company to achieve the quota, it can also pay a fee. If neither option is chosen, the ERO asks for a penalty payment. Producers of electricity may sell electricity on the market or offer it to an electricity supplier at previous year's market price. [18]

As of December 2011, the installed capacity of licensed biogas plants according to Muras [20] amounted to 103 487 MW. Muras [20] illustrates the development in the production of electricity and certificates of origin in the period 2005 - 2011 and shows a total energy production from Polish biogas plants of 427 645,947 MWh in 2011.

*The current definition
of agricultural biogas
does not include
organic food waste*

National Waste Management Plan 2010

The territorial division of Poland is in the form of three-tiers, namely 16 *voivodships* or provinces, as illustrated in the figure below, 314 land *poviats* or districts and 65 urban *poviats* or towns sharing the rights of districts and 2478 *gminas* or communes. The voivodship of Śląskie, or Upper Silesia, with Zabrze as the main geographical focus of this report, is located in the south of the country.

At the moment, the waste management plan of the province is being revised. [14]

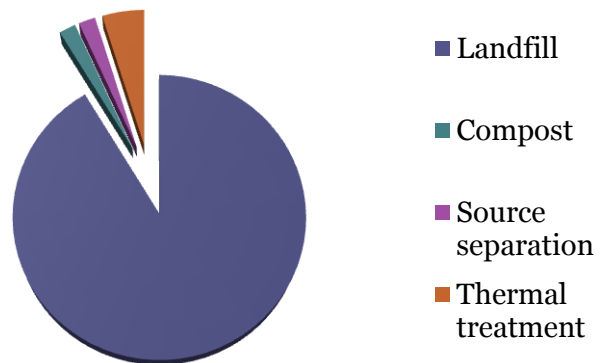
Waste to energy (WTE) plants are envisaged to play an increasingly important role in waste management

in Poland. This focus might be explained by exploring the current waste management system which relies for 95% of MSW (by weight) on landfilling, 2% on composting, 2% is separated at source and 0.5% is treated thermally. On average, 273 kg of MSW are generated per person per annum, whereby the MSW generated in urban areas is higher and is at 360 kg/per person and year.

The objectives laid out in the EU Landfill Directive, which will be explained in the following section, put limits to the permissible amount of organic waste put into the landfill.



MAP OF POLAND'S ADMINISTRATIVE DIVISION INTO VOIVODSHIP



SHARE OF DIFFERENT MUNICIPAL SOLID WASTE TREATMENT OPTIONS CURRENTLY APPLIED.

Act of Waste

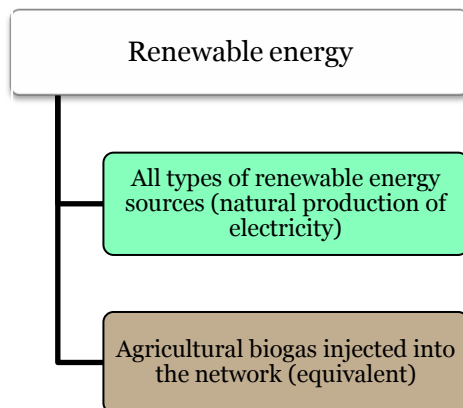
Objectives of the EU landfill Directive 99/31/EC are transposed in this Act in Article 16a, which establishes mandatory targets for Polish communities related to the reduction of biodegradable waste being land filled. Precisely, this Act specifies that the amount of organic waste being landfilled is to be reduced by 75% (by weight) by 2010, by 50% by 2013 and 35% by 2020 as compared to 1995 levels which were equivalent to 4.38 M t/yr in Poland. (Source: Polish Act of Waste. Source: Journal of Law No. 62, item 628)

The non-compliance with EU Directives addressing waste management costs Poland daily about EUR 40,000 in fines. [21]

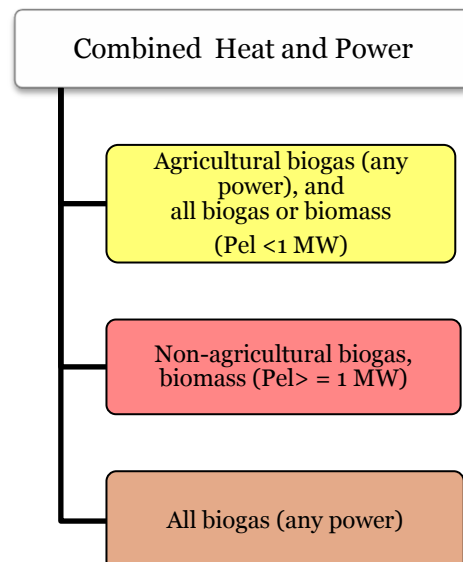
Renewable energy is supported through various mechanisms, an overview of which will be provided in the figure below. [17]

Regarding electricity, an obligation exists for companies to obtain a certain quota of green certificates, as explained earlier. Also, there is a purchasing obligation in place for electricity and heat which is produced from RES.

With a view to biofuel used in transportation, producers and importers of fuels are to perform with national indicative targets. A tax relief for biofuels is in place, as well as the option for farmers to produce liquid biofuels for own purposes.



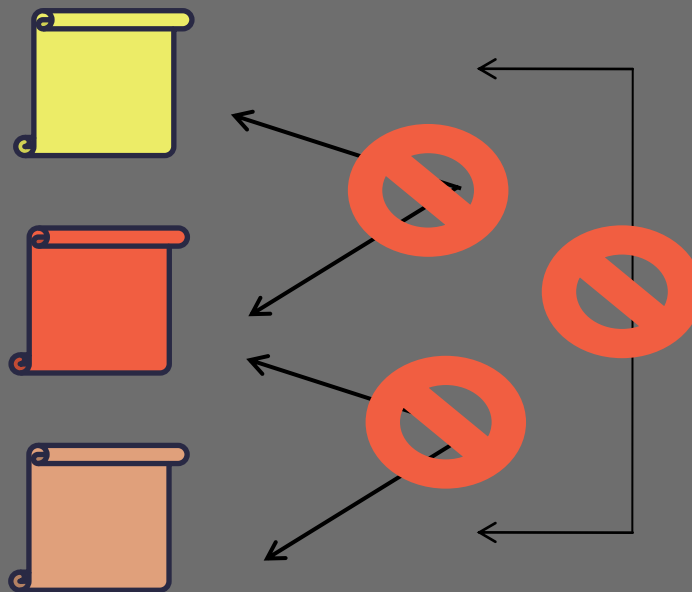
TYPES OF CERTIFICATES



Various kinds of certificates are currently on the market, an overview of which will be provided in the figure above.

A producer of renewable energy faces two options: (1) whether to produce electricity from RES or (2) whether to inject the agricultural biogas into the grid network. If the decision is to produce electricity, the next step is to decide on whether solely electricity will be produced or both heat and power (CHP). In the latter case, certificates of origin which are referred to as "cogeneration certificates" will be generated.

Depending on the RES fuel used or the installed capacity of the CHP plant, a different cogeneration certificate is applicable for the produced CHP: a yellow certificate refers to a CHP with is fuelled with gaseous fuels, or a total installed capacity of power sources less than 1 MW, a red certificate refers to other fuel sources and an installed power of more than or at least 1 MW and the violet certificate addresses CHP from a plant fuelled by methane released from underground mining works in active, closed down or abandoned coal mines or gas obtained from biomass processing as per the prevailing definition of bio-components and biofuels.



CERTIFICATE INCOMPATIBILITIES

It needs to be noted that the three cogeneration certificate types cannot all be applied together.

At the end of 2012 both yellow and red certificates are anticipated to be phased out. The violet cogeneration certificate is likely to remain in place until 2018. The table below points out the cost for energy from RES as per green and the previous described, different cogeneration certificates in 2012.

As of recent data, the yearly production of electricity from biogas amounts to approximately 8 000 MWh in Poland. In 2012, PLN 340 in revenues can be made from one KWel produced from biogas.

According to this data, electricity generated from biogas is ranked on the second place after biomass in terms of revenues to be achieved. [22]

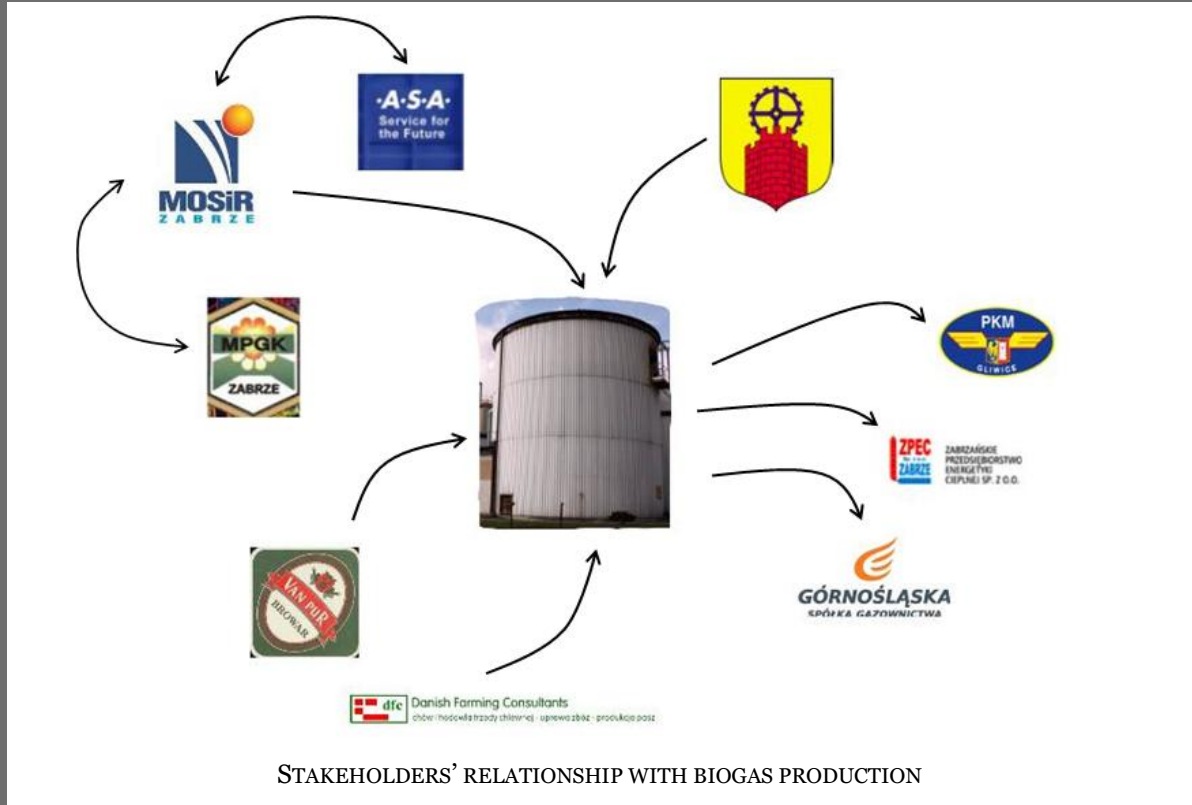
REVENUES FROM INDIVIDUAL UNITS OF RES AND RES IN THE CHP, 2012

PLN/MWh 2012			
Not high performance distributive electricity generation or CHP		< 286.74	202*
High performance CHP	< 128.80	< 286.74	202*
	< 29.30		
	< 60.00		

*Public announcement by 31 March 2012 by the ERO Chairman

Stakeholder analysis

Multiple actors are involved in the implementation of a biogas system, implying a careful investigation of the supply of inputs (raw materials for the digestion process) and the analysis of the output products' demand.



Supply

An assessment of the available sources of organic waste was performed for the city of Zabrze. Organic waste is addressed in this report as material appropriate for anaerobic digestion and excludes soil, sand, wood and other similar

products suitable for composting instead.

Generally speaking, waste is first produced, then collected and finally disposed. Each step involves a various number of stakeholders. In Zabrze and proximities, farms, industries, citizens, schools, hospital, supermarkets and restaurants are the

main (organic) waste producers.

Private companies manage the collection of waste from most of the above mentioned sources.

Farmland, landfill and composting sites represent the most common disposal sites. Majority of municipal solid waste (MSW) is put on landfill.

In Zabrze, only 7% of the waste is source separated and recovered for recycling. Moreover, waste from public parks and food remains from a limited number of households (pilot project) are converted into compost. Furthermore, the landfill site is equipped with a methane extraction

facility and a refuse-derived fuel (RDF) apparatus is on its way to be implemented. Within the consortium of 14 municipalities, the decision to build two incineration plants has been taken. The facilities will be located in Zabrze's neighbouring cities Ruda and Dąbrowa Górnicza.

With the specific target of feeding an anaerobic digester, our focus is set on the most reliable organic waste sources available: the pig manure from the farms in Rzeczyce, Gliwice (approximately 40 km from Zabrze) and the food waste from single family and semi-detached houses in Zabrze.

Waste type	Origin	Availability	Comments
Manure (Pig)	Danish Farming Consultants Sp. z o.o.	Partial	On the way to build own biogas plant
Manure (Pig)	Farm of Andrzej Sylwestrzak	Yes	Approximately 40 km from Zabrze
Food waste	Residential	Yes	Pilot project of 513 households, to be extended
Food waste	School	Yes	Too small amount to be considered
Grass clipping	Public parks	Yes	Seasonal fluctuations, risk of including unwanted elements, e.g. soil, branches, roots
WWTP Sludge	Zabrzańskie Przedsiębiorstwo Wodociągów i Kanalizacji Sp. z o.o	No	Already producing biogas
Brewery by-products	Van Pur S.A.	Partial	By-product of fermenting process sold to farmers.

Demand

Beside the production of biogas (with a methane content that ranges between 40% and 70%), biofertiliser is the second main product of a biogas facility. It can be employed as fertiliser on farmlands and is usually favoured against unprocessed manure.

On the other hand, biogas has three main uses: direct employment in a co-generation power plant to produce heat and electricity, upgrade to fuel for private and public transportation, and upgrade for gas grid injection.

Stakeholder views, national regulations, economic incentives and other relevant socio-political aspects have been taken into consideration to evaluate the most convenient utilisation of biogas in

PROCESSED BIOFERTILIZER VS DIRECT MANURE

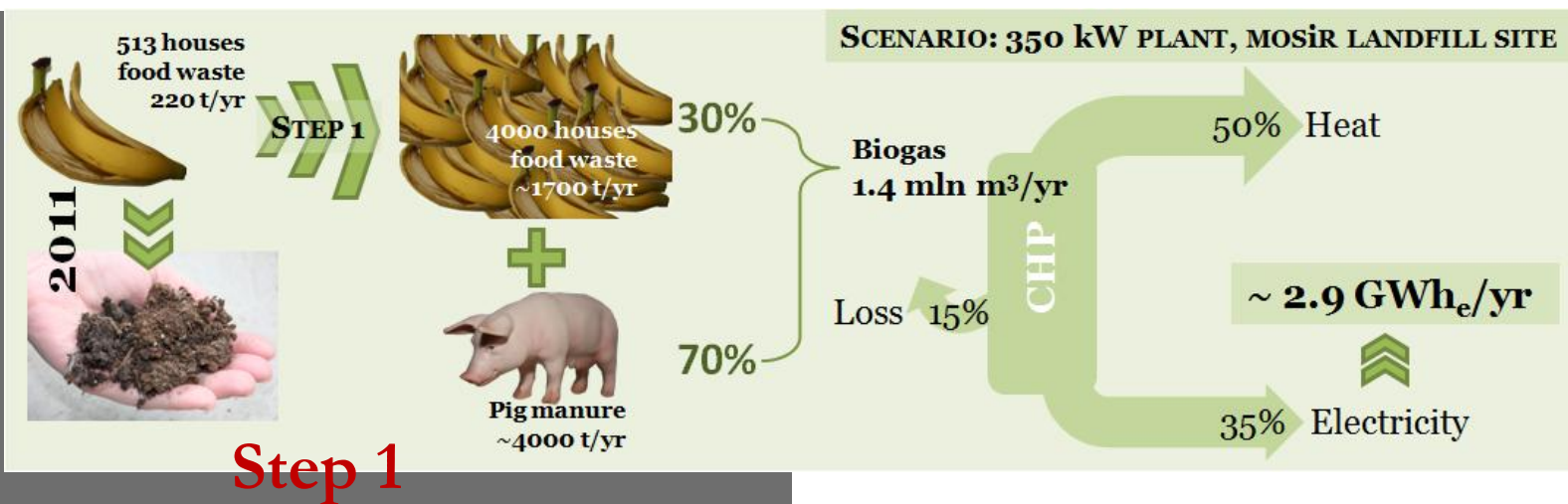
- ✓ Avoid health risks (presence of microbes in the excreta)
- ✓ Avoid ground water contamination due to excess nutrient presence (eutrophication)
- ✓ Avoid unpleasant odours
- ✓ Improve soil quality due to higher nutrient concentration
- ✓ Easier uptake for crops

Poland today. As a result, direct employment to generate electricity was chosen for the city of Zabrze.

Technology	Use	Cost	Efficiency	Drivers	Barriers
Co-generation Heat and Power (CHP)	Sell electricity to the grid	High	Medium	- Economic incentives - EU and national targets of RES - Independence from world market oil price	- Technology
Biogas upgrading	Vehicle fuel	Very high	High	- Cleaner combustion - Improved air quality - Independence from world market oil price - Stable fuel price	-No economic incentives - Replacement of bus fleet too expensive - Use of biogas does not pay back
Biogas upgrading	Sell gas to the grid	Very high	High	- Energy security - Independence from world market oil price	- Only upgraded biogas produced from agricultural waste can be fed into the gas grid

Future Scenario

Based on our research, we suggest the implementation of a small-scale biogas system in Zabrze. In this report, we describe a two-steps operational scenario; we include performance recommendations and share a vision on the biogas future perspectives in the municipality.



Step 2 consists in expanding the collection scheme of food waste to the remaining villas, to block houses and public institutions (e.g. schools, elderly houses).

Moreover, the substrate supply could be extended to other farms, the food industry and supermarkets.

Furthermore, a supply increase could consequently lead to the implementation of an additional biogas digester.

Step 2

Recommendations

Legal Framework

Biogas plants are subject to numerous regulations within the existing legal framework. These regulations might constitute a chance for biogas plant development but they can also turn into non-technical barriers. It all depends on their design and flexibility in adapting to local socio-economic and political conditions. [23]

In order to harness full economic potential of biogas, an extension of the biogas definition, as presented in the Energy Law Act, especially regarding the specification of sources suitable for biogas production to comprise organic waste would be beneficial.

Further, trans-departmental co-operations, such as between the Ministry of Economy, dealing with energy issues, and the Ministry of the Environment, in charge of waste issues, would also allow for synergies to be exploited on the pathway to achieving the objectives laid out in the RED Directive.

Organisational implementation

The Swedish case

Economic, physical and legal responsibility for different types of waste is allocated by the Swedish Waste Ordinance to municipalities, waste owners and producers. Waste owners, namely, any private individual or commercial operator who produces waste is also responsible for ensuring that it is dealt with in accordance with current regulations. With the exception of household waste, of which each of the 290 Swedish municipalities take responsibility except for product categories covered by producer responsibility, the waste owner decides who will be in charge of disposing of waste. [24]

Swedish producers are responsible for end-of-life packaging, cars, tyres, recycled paper and electrical and electronic products. This means that any producer who manufactures or imports a product needs to assume responsibility for its collection, processing and recycling.

This producer responsibility is to both create an incentive for producers to reduce waste quantities and to produce less hazardous waste and products which are easier to recycle. [24]

A total of 21 *county administrative boards* issue permits for most waste related operations, provide advice for municipalities regarding regulatory issues and assume responsibility for regional waste planning including the monitoring of available capacity. [24]

The *Swedish Environmental Protection Agency (EPA)* as the central environmental authority coordinates environmental protection and policy and protection. It supports the government in matters related to European Union environmental policy and protection. In 2004, a national Waste Council was established within EPA to provide support and consultation in the implementation of waste policy. [24]

The decision on how to handle waste management is left with the local authorities in Sweden, as per constitutional law which introduced municipal self-government. Joint or in

collaboration with other municipalities, which might also take the form of a joint committee or a local government federation, the management system and other municipal responsibilities are tackled. Also, on specific matters, such as for joint procurements, Swedish local authorities cooperate. The emphasis on collaboration is based on the conviction that best social and environmental results can be achieved in a cost-efficient manner while cherishing synergies, as e.g. competences available. [25]

About three quarters of Swedish municipalities' household waste collection is managed by external actors while only one quarter of municipalities manages waste on their own account. [25]

Waste collection fee

Swedish municipalities charge separate waste collection fees which comprises the producer's costs as a fee in the price of the product. The municipal waste collection fees are set by the local

councils while producers fix the product fee amount. [25]

In general, any deficits that occur and cannot be covered as a result of total costs resulting higher than waste collection fees, the latter of which need to cover the former but not exceed them as per the Local Government Act [26], are funded by taxes.

The charged waste collection fee is set so that it covers:

- administration including customer service, invoicing and information as well as waste planning
- service costs at recycling centres, which are set up in Sweden for the collection and handling of hazardous household waste and bulky waste

The rate comprises usually a fixed and a variable fee, whereby the fixed part would e.g. correspond to waste collection and the variable one to waste treatment. [25]

On average, a Swedish single-family home is charged an annual waste collection fee of SEK 1,990 or PLN 964. The average fee for apartment

households would equal SEK 1120 or PLN 543. [25]

Enhancing biowaste collection

Arbitrary analyses of household waste samples reveal that approximately 70 per cent of household waste is biodegradable. Further, 40 per cent of Swedish household waste disposed of in bins and bags consisted of food waste in 2004. The other large fraction is packaging waste. [24]

In the municipalities where food waste collection has been introduced on a voluntary basis, the waste collection fee is employed as a means of control in the sense that an overview can be obtained on the rate of organic food collection as those households would need to pay a lower fee as compared to those collecting their waste without separation into an organic and a general fraction, as mixed waste. [25]

Within the legislative requirement as per the Local Government Act, demanding the waste collection fee to equal its costs, it is up to the municipality to decide on the method of setting the fee in order to encourage

a desired behaviour by providing certain incentives such as through weight-based billing and environmentally differentiated waste charges. [25,26]

A weight-based waste collection fee, under which households pay per kilogram of waste which is collected from them, has been seen to trigger higher recycling rates. For this type of fee to work, the waste collection vehicles need both a scale and equipment to recognize each bin. The fee charged varies between SEK 1.2 to 3.2 (or PLN 0.58 to 1.55) per kilogram for bins and bags and is combined with a fixed basic fee and different types of bin fees. [25]

Technology

Substrate availability

With the described conditions for a biogas plant, we recommend to start with a small-scale installation. Despite technological progress and adaptability, several unknown factors such as those related to the efficiency and success in source separation, which will influence the amount and quality of the food waste available as

substrate, will determine the overall success of the plant.

It is necessary to highlight that continuous efforts to improve the waste collection system will yield positive results, not at least regarding the increase in available substrates for the biogas plant. As pointed out earlier, it is essential to collect hazardous waste separately to avoid a contamination of the wet and dry waste fraction of MSW.

Managing transition

The planned *refuse-derived fuel plant*, represents a transition technology which supports the waste management system on its way to become more efficient in achieving high source separation rates. The RDF plant, despite offering an option to separate the fed in mixed municipal waste into different fractions, will produce only fractions of organic waste which are contaminated with plastic, heavy metals and other matter and are therefore not suitable for anaerobic digestion in a biogas plant.

Incineration of some fractions of MSW might be a necessity. However, the

incineration of organic waste is not desirable for two reasons: (1) organic waste is, due to its high moist content, not a suitable fuel in this setting and (2) it is, seen from a life-cycle or systems perspective, a waste of resources to incinerate it, despite it being considered 'climate-neutral' when burned as per EU definition. Based on these two reasons, it is recommended to carefully consider the capacities of incinerators planned as the installation of these facilities carries not only a high upfront cost but also brings along a continuous commitment to feed it a certain volume of waste to keep operational costs reasonable.

With the background of the EU waste management hierarchy, and the high

likelihood that efforts in improving waste management on a national, regional and local level will yield better results in waste source separation over time, an increasing amount of uncontaminated organic waste will be available, which could best be used, from a life-cycle perspective, as substrate for biogas plants.

Economics

It remains questionable whether the stipulated renewable energy targets can be attained with fixed prices for RES and a stringent review of the support mechanisms might be needed.

Also with a view to reducing the focus on biomass for achieving the nREAP and to allow biogas to play a more prominent role, effective support measures need to be put in place.

Vision

Waste collection

With a view to long term development in the area of waste management, one of the objectives could be to achieve higher volumes of the substrate and extend the current collection of organic household waste to comprise all 8,000 villas in Zabrze as well as diversify the base load for the biogas plant from relying solely on pig manure to include food waste from public institutions, food industry and retail. Certainly, to obtain waste from these organisations will also involve further organisational and administrative efforts, including the establishment of contacts with decision makers of retail enterprises in the capital.

Another long-term objective is linked to the continuous efforts dedicated to improving source separation. These endeavours could be extended to collecting organic waste from apartment block houses, and as earlier mentioned, public institutions and industry.

Achieving the anticipated RES target in the Polish energy mix might also depend on the possibility to diversify sources for renewable energy generation. Biogas could play a role in attaining this objective, if the legal framework is adjusted to account for different sources for biogas generation. Specifically this refers to extending the biogas definition which is strongly based on agricultural input at the moment, to include biogas produced from organic waste. This inclusion would in sequence allow for a review of the regulations pertaining to the injection of biogas into the grid network. Simultaneously, the use of biogas in CHP plants could be fostered and a supporting step would be further research in improving options for heat storage. If electricity prices were to decrease over the long run and market conditions then provided for more incentives, or revenues, to be generated from biogas if it was upgraded, it could as well be used as vehicle fuel both for public and private transportation or injected into the grid network.

Education and public awareness



Any efforts, be they related to waste management and/or the support for renewable energies, including the generation of biogas from organic waste, will need to be accompanied by a well-balanced combination of continuous educational and public awareness raising initiatives. This is an important part of the overall work package that comes with any plans related to the establishment of a biogas plant, since it will create public understanding, and ideally, allow for reaching out to a critical mass which will support the decisions taken.

Good efforts are already undertaken in Zabrze and creating opportunities for public participation in the process will continue to be beneficial to obtain

approval and support from the wider public. This invitation for public participation could take multiple forms including, but not limited to, competitions calling onto individuals and schools to supply a design for e.g. organic waste collection bags, which could be handed out to households to foster the separation of organic waste from the remaining waste fraction, events including open days at certain facilities including, e.g. the biogas plant facility at the waste water treatment plant where guided tours for interested citizens could be provided or the organisation of a sustainability festival which focuses on consumption and waste, such as the first one organised by Lund in May 2012 [27].

Conclusion

From a mere technical perspective, the recommendation is to pursue the development of a small-scale biogas plant, both due to the substrate availability, in particular the volume of non-contaminated organic household waste which is feasible to be generated for feedstock at the moment and due to easier steering of the digestion process in a small-scale setting.

Several socio-economic and political factors will influence the realisation of the biogas plant. They will not only determine the success of it but also, the timeframe for the project implementation.

For example, adapting the legal framework to facilitate biogas production from organic waste, will be a crucial element in achieving Polish renewable energy targets and will allow for biogas to play a more substantial role. This will ideally include the amendment of the biogas source definition to comprise organic household waste and the adaptation of existing and introduction of new

economic incentives supporting biogas development over the long term including the upgrading to vehicle fuel and the feed-in to the gas-grid.

An accompanying part of the process will be the strive for continuous improvement of source waste separation and MSW collection. Over the long term, the source separated waste collection might have as objective to obtain higher volumes of organic household waste and efforts could be directed towards collecting organic waste also from apartment block houses and extending the collection to all villas within Zabrze.

It will also be beneficial to continue the efforts which are already being undertaken in the field of education and public awareness raising, such as through creative competitions inviting submissions from schools and individuals, open days at stakeholders such as the wastewater treatment plant and its biogas producing facility in Zabrze, and others, as well as

advertising campaigns targeted at civil society.

Anticipating a growing Polish economy and an increase in purchasing power, it is expected that the per capita generation of organic household waste will also augment steadily while the secondary use of organic waste for e.g. farming purposes and private small-scale composting will decrease. With these expectations and the EU Landfill Directive banning organic waste from landfilling as well as restricted capacities for incineration, along with increasing penalty payments Poland confronts for non-compliance, MSW management stands at the forefront of

municipal issues requiring increased attention and new approaches to address its handling.

Biogas production presents an opportunity incorporating a system thinking perspective, seeing waste as a resource and thereby closing the loop defined by organic food production, consumption, waste generation and use of waste as secondary resource for energy generation through biogas production. Biogas has a high potential for contributing to the achievement of Polish national overall renewable energy targets and can develop into a valuable element on the pathway to attaining energy security.

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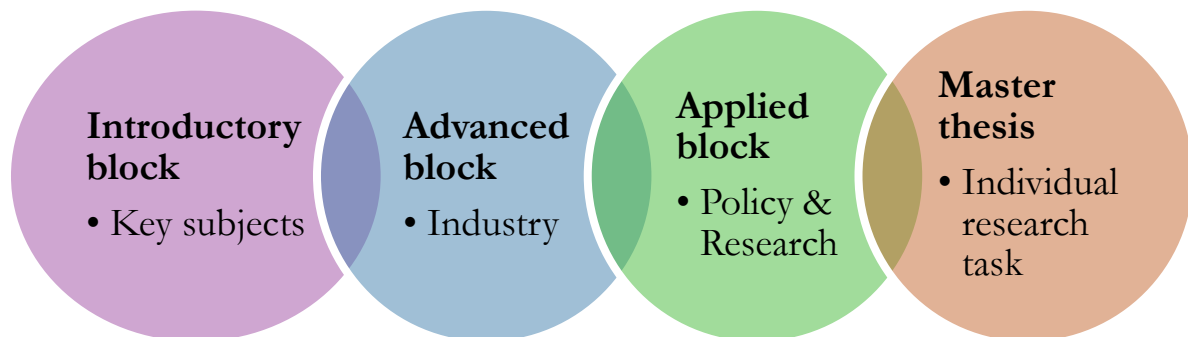
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The International Institute for Industrial Environmental Economics (IIIEE) Lund University

The International Institute for Industrial Environmental Economics (IIIEE) forms part of Lund University in Sweden and was founded in 1994 on the grounds of the environmental principle suggesting that 'prevention is better than cure'. Interdisciplinary research, a truly multi-cultural atmosphere and educational methods fostering a system-thinking approach distinguish the IIIEE within Lund University.

Two Master of Science (MSc) degrees, in Environmental Management and Policy (EMP) and in Environmental Sciences, Policy and Management (MESPOM), and doctoral studies are offered at the IIIEE. The MSc in EMP, which constitutes the core of the education offered by the Institute, is as to date designed for two years, whereby the first is conducted in the form of an online distance education, during which the basics of environmental issues are lectured. The second year takes place onsite in Lund and is dedicated to the advanced and applied block of the education.



A Strategic Environmental Development (SED) course forms part of the applied block, during which, in the course of four weeks, students are grouped to teams of four with one IIIEE supervisor per team, to perform a literature review on the assigned topic area of the project, collect empirical data from stakeholders during field visits in the vicinity of Lund and conduct interviews with stakeholders. These preparatory activities are then complemented with a one week field visit to the

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