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Zero-waste energy-efficient agricultural communities in the Greece-Republic of North Macedonia cross-border area

DELIVERABLE 3.3

Guidelines for effective bio-waste management

4/2020

Sub-Deliverable 3.2.3a – Representative Good Practices based on the influence of biogas establishments in the local circular economy.

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1. Introduction

The present sub-deliverable has been written to highlight the diversity of benefits from anaerobic digestion (AD) and biogas establishments. Biogas from anaerobic digestion is not merely a concept of production of renewable energy; it cannot be compared to a wind turbine or a photovoltaic array. Nor can anaerobic digestion be bracketed as just a means of waste treatment or as a tool to reduce greenhouse gases in agriculture and in energy. It cannot be pigeonholed as a means of producing biofertilizer through mineralisation of the nutrients in slurry to optimise availability, or as a means of protecting water quality in streams and aquifers. It is all these and more. The multifunctionality of this concept is its clearest strength. Sustainable biogas systems include processes for treatment of waste, for protection of environment, for conversion of low-value material to higher-value material, for the production of electricity, heat and of advanced gaseous biofuel. Biogas and anaerobic digestion systems are dispatchable and as such can facilitate intermittent renewable electricity.

The target group for the deliverable is represented by biogas stakeholders in general, and by decision makers and the biogas business actors. The ideal reader should have a conceptual understanding of biogas, anaerobic digestion, the energy and fuel system and the circular economy. Throughout the document, the concepts' pieces fit together and the multifunctionality interlinks of all relevant aspects are becoming apparent. The scope of the document is to create a narrative, on the topic of how anaerobic digestion and biogas fit into the concept of the circular economy.

The biogas plant and its basic functions are described, as are the concept of biorefineries and how they interlink to biogas production. The multiple functions of biogas in the circular economy are discussed under the following headings:

1. Energy-related uses of biogas
2. Biogas's reduced environmental impact
3. On the impact of biogas in sustainable energy supply
4. Biogas in various supply chains
5. Biogas as a vehicle for the exploitation of bio-waste
6. Biogas's contribution to important societal needs
7. Biogas's particular relevance to the agricultural communities

To show how closely related anaerobic digestion and biogas are to the concept of circular economy, the intimate relation is exemplified through ten Good-practices, representative of alternative establishments' impact dimensions as:

a) Sweden – An international "hub" and local growth example

b) Finland – Community-integrated example

c) Denmark – A biogas upgrade case

d) Norway – A carbon capture example

e) Croatia – Waste for energy and fertilizer

f) Czech Republic – Biowaste to power industry and heat the local municipality

g) France – Slurry use in Green Gas

h) The Netherlands – Manure-Silage co-digestion

i) Poland – Biogas plant and heat provision to the local community

j) Belgium – An expanded pocket digestion pilot plant

These examples are just a few of the many more currently active and in the planning stage. They show how simple it can be to take a significant step towards circular economy concepts with the aid of biogas and anaerobic digestion.

Circular economy is nowadays in its advent. Products from bio-based resources will grow in both absolute and relative terms in the coming years. In the future bio-economy, wastes will be transformed to high-value products and chemical building blocks, fuels, power and heating, biogas facilities will play a vital role in this development, and in the implementation of the novel production paths that arise in the transition to a bio-economy. The future of the biogas facility is a factory where value is created from previously wasted materials, this ensures sustainability of the environment and potential for financial gain for the local community. The flexibility of the anaerobic digestion system and its ability to digest a multitude of organic feedstocks, while producing a significant range of products ensures the role of anaerobic digestion and biogas in the circular economy.

1.1. Transition to circular economy and the role of biogas establishments

The biogas plant is the hub in the future circular economy. Streams of excess materials, previously regarded as waste, from industrial processes, agriculture and other human activity can be channeled through biogas digesters and converted to useful energy carriers, nutrient-rich organic fertilizer and novel materials.

The “linear economy” may be summarized as follows:

• take (the resources you need)

• make (profit and goods)

• dispose (of everything not needed, also the product at the end of its lifecycle).

As the world population grows and new industrial and developed areas expand, both in absolute and relative terms, the linear economy will move towards constraint of supply of materials, including food. This may lead to economic hardship, human suffering and conflict (Sariatli, 2017).

A "circular economy" (Figure 1.1) is restorative and regenerative by design, and aims to keep products, components, and materials at their highest utility and value, at all times. The concept distinguishes between technical and biological cycles (Ellen McArthur foundation, 2015).

"Bio-based economies" can be defined as: "technological developments that lead to a significant replacement of fossil fuels by biomass in the production of pharmaceuticals, chemicals, materials, transportation fuels, electricity and heat" (Sariatli, 2017). The very closely related concept of "bio-economy" usually focuses on the utilization of biomass in primary production processes in forestry, fisheries and agriculture and increased valorization of raw materials used. The term bioeconomy will be used to encompass both definitions (biobased economy and bio-economy) in this text. The higher the recycling and re-usage of waste in an industrial foundation, the more it comes in-line with the concept of the circular economy while being less harmful to its surroundings and more profitable (Sariatli, 2017). Wastes, materials and energy consumption need to be minimized in the circular economy. In pre-industrial times, natural and circular economy systems were applied while the linear economy was introduced during industrial times. It is incumbent on us to return to the circular economy. The quality and value of the unit or subject of circular flows is the key in the circular economy.

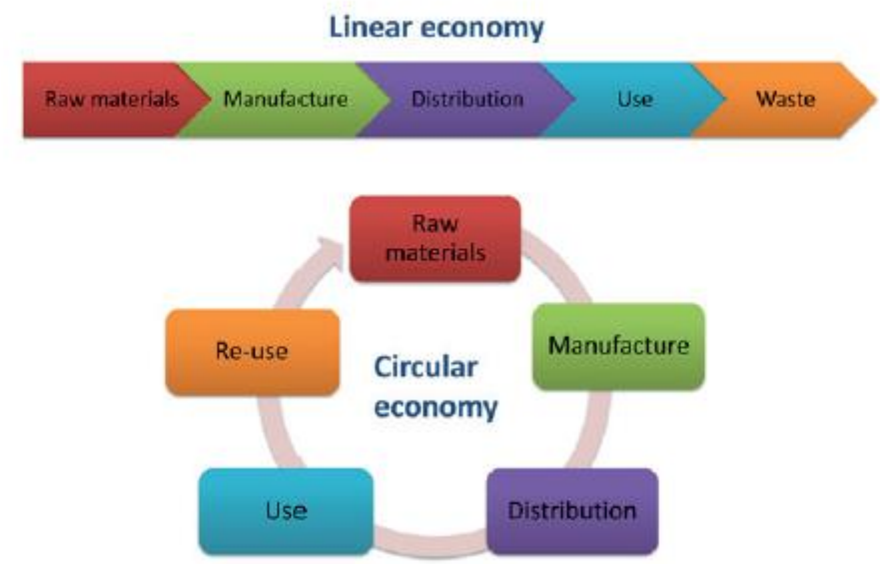

Figure 1.1. "Linear" and "Circular" economies

The anaerobic digestion process is a fermentation process, which takes place in a closed airtight digester where organic raw materials such as manure, food waste, sewage sludge and organic industrial waste are converted into biogas and digestate as products. The produced biogas is a mixture of 50 – 70% methane and 30 – 50% carbon dioxide and smaller amounts of water vapor, hydrogen sulphide and other minor components and trace elements. The wet digestate results from anaerobic digestion of the substrates, which are pumped out of the digester tank, after the extraction of biogas.

The digestate consists of slow degradable, stable organic components such as lignin, nitrogen and phosphorous in various forms, inorganic salts containing phosphate, ammonium, potassium, and other minerals.

Very simple biogas digesters have been used in China, India and many other Asian countries for many years. A recent report IEA Bioenergy report (McCabe et al., 2018) discusses local applications of anaerobic digestion (AD) in more detail. These type of digesters, produce heat for cooking and flames for lighting as well as digestate for fertilizer. A simple example of a digester is shown in Figure 1.2.

Industrial applications of biogas production started well over 50 years ago as a means of stabilizing sewage sludge at waste water treatment plants. The biogas industry expanded in the 1970's and 1980's as increased production of different organic materials (such as manure and industrial wastewater from sugar refinery and pulp mills) became more widely used. Starting in the mid 1990's extraction of landfill gas (low quality biogas) came to the fore, along with the construction of farm-based biogas plants and anaerobic digestion of solid wastes from food industry and food waste.

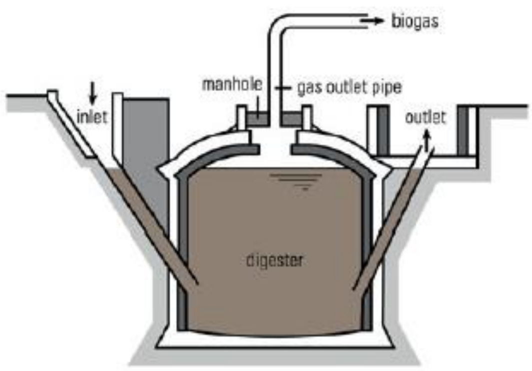

Figure 1.2. Representation of a simple digester used for manure treatment

From the turn of the new millennium increased interest in, and an acceleration of, construction of farm-based biogas plants took place and an industrial sector was established. There is a strong linkage between the bio-based economy, the circular economy and the biogas plant as depicted in Figure 1.3.

Two views are prominent:

- Biogas production is the last step in a cascading biomass system, where a renewable energy carrier (biogas) is simultaneously produced with sanitized bio-fertilizer (digestate).
- Alternatively, and often in conjunction with the former, anaerobic digestion is viewed as a process step where value is created from waste. Hence, a problem of disposing waste is transformed through upcycling (Martin and Parsapour, 2012) to a high-value product stream, via the biogas production facility. Linked to this latter view is the concept of anaerobic digester based biorefineries.

Biorefineries can be designed in many ways and can utilize a variety of raw materials to produce a variety of products for different markets. Biorefineries include for example: paper and pulp mills; sugar factories and ethanol plants; as well as biogas plants. In the future, as biomass will be the source for even a wider array of products such as materials, chemicals, fuels and new food and feed products to an increasing population, the biorefinery concept needs to develop and penetrate an ever-increasing part of the manufacturing industry. For biomass to meet the needs of food and energy, the biorefineries must be resource-efficient. The products must therefore be reused or used as a resource in new processes in a circular manner (Willqvist et al., 2014).

De Jong et al. (2012) presents a blueprint of the wide array of products that can be produced in a biorefinery; they describe various possibilities for raw material platforms and building block chemicals that form the basis of a very large

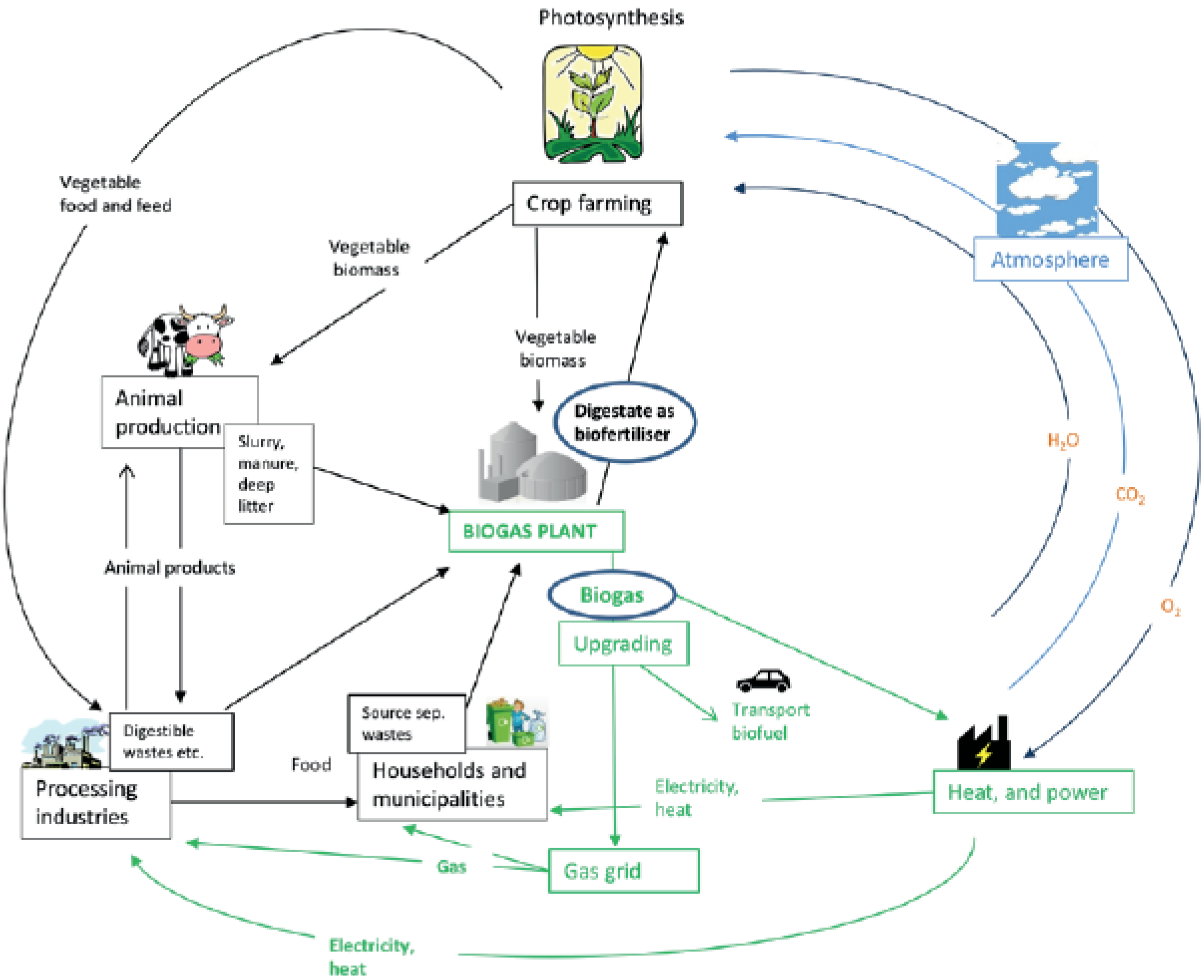

Figure 1.3. Biogas plant placed at the center of a circular economy

2. On the influence of biogas into local biorefinery cycles

2.1. Energy-related uses of biogas

The use of biogas, made from organic waste streams, does not add to the carbon dioxide load in the atmosphere, carbon dioxide produced during combustion of biogas is offset by either the carbon dioxide consumed by the biomass, which is digested or by avoided fugitive methane emissions from open slurry storage. Biogas is thus a "green" sustainable energy vector and has a significant role in shifting to a sustainable decarbonised society. Biogas has many uses in the sustainable society that can be utilized in a broader perspective than today. Industries, as well as households, can use biogas for heating and hot water supply.

Biogas can be used to supply warm air for drying, for example, in laundries, carpentries, industrial coating facilities and other places where there is a need for fast and efficient drying. The exhausts from upgraded biogas combustion are/ clean and do not generate odours or particles. In the food industry, the need for clean fuel is important. Increased use of cleaned upgraded biomethane could be available for further applications in, for example, catering and industrial kitchens, bakeries, and in the food industry where instantaneous, continuous heat and fast regulation are demanded.

Natural gas is the choice of thermal energy for evaporation processes in breweries, distilleries and creameries; this is easily replaced by renewable gas leading to decarbonisation of these industries. Due to the clean exhaust gases of gas combustion, gas is already used to a considerable extent, for example in, roasting of coffee beans, biscuits or chips. At present, fossil Liquefied Petroleum Gas (LPG) is often used for the latter examples, but green LPG or biomethane could be used in lieu. When renewable gas or green gas is used instead of fossil alternatives, industrial applications become significantly more environmentally friendly, decarbonised and sustainable. A relevant report relevant to green gas was very recently published (Wall et al., 2018).

The most common use of biogas is in a non-upgraded form for production of electricity and heat production. The default use of biogas is for CHP (Central Heat and Power) production, which is in fact production of renewable electricity and heat, also known as cogeneration. The heat from the CHP engine can also be used to drive an absorption chiller to give a source of cooling, resulting in a combined cooling, heat and power (CCHP), also known as trigeneration.

The CHP technology is based on the bock heat and electricity plants (BHPP), where electricity is produced by a combustion engine. The electricity is used locally, or it can be supplied to the grid. The thermal energy (renewable heat) is a by-product produced by the engine, and it is normally used locally (such as in district heating). There are various kinds of power generation units, such as four-stroke engines, micro turbines or Stirling engines; their electrical efficiency ranges between 25-45%, depending on the type of co-generation set (Persson et al., 2014; Kaparaju and Rintala, 2013). The CHP generation unit can be placed at the biogas facility, or the biogas can be transferred through a piping system, usually at low-pressure, to a CHP plant or a district heating unit in the area. The utilization of the renewable heat is very important, as it brings about significant additional economic and environmental benefits, on top of the utilization of biogas for renewable electricity production (Hengeveld et al., 2016).

Raw biogas can be upgraded in a process which removes hydrogen sulphide, water, particles and CO_2 present in the gas. The process creates a gas consisting mainly of methane and thus increases its energy content. Clean upgraded biogas is used as fuel for cars, buses and trucks of various sizes. In several countries, there is a well-developed infrastructure for vehicle gas, and it is possible to fuel natural gas vehicles (NGVs) in the most densely populated areas of such countries. Today, vehicle gas is used mostly for buses, trucks and passenger cars. The interest of using Compressed Natural Gas (CNG) and Liquified Natural Gas (LNG), or the corresponding biogas-based alternatives CBG and LBG, in heavy transport has increased and this could bring new opportunities for biogas. Upgraded biogas is completely interchangeable with its fossil equivalent. The real challenge for the transport sector lies in abandoning fossil fuels and decarbonising energy. In the conversion, this means that all renewable fuels, including biogas, electricity, fuel cells, and many others, have a role to play. In practice, NGVs are one of several realistic renewable alternatives, for heavy transport and long-distance travel.

Biomethane from renewable sources is also fed into the national transmission network for natural gas in several countries. Through this network, renewable gas or "green gas" reaches customers in households and industry as well as vehicle fuel stations (Wall et al., 2018). As the number of biogas to grid systems has increased, the level of renewable gas in the transmission networks has also increased. The composition of the gas in the grid is not homogeneous. Depending on where the gas is taken from the grid, the molecules have various levels of fossil and renewable origin. It is however possible to purchase 100% renewable gas anywhere on the gas network by ensuring that as much renewable gas is fed into the grid as sold to the customer through a mass balance system. This market is normally managed by a green gas certification system.

2.2. Biogas's reduced environmental impact

Biogas can be produced in many ways and from many different substrates, with different targets in gas quality. The production facilities may be of varying design and specification and the operation of the process may differ between producers. Hence, the contribution of biogas production to GHG emission reduction may also vary significantly (Liebetrau et al., 2017).

One of the main reasons for a transition from fossil energy and fuel to renewable energy and fuel is the reduction in greenhouse gas (GHG) emissions. Displacing fossil fuels is, independent of the biogas produced, always a win, but it is important that the production of biofuels and bioenergy contributes to a significant reduction of GHG emissions. Liebetrau and co-authors (2017) employed a methodology and used data from the European Commission (EC) Joint Research Centre (JRC) to assess the impact of fugitive emissions on the sustainability of biogas. In this process they assumed target for sustainability of 30% of the GHG emissions of the Fossil Fuel Comparator (FFC) for electricity. They found for example that mono-digestion of energy crops will struggle to meet these reduction targets, however manure-based systems readily meet these targets due to the savings in fugitive emissions from displaced open slurry tanks. Co-digestion of slurry and energy crops can be effected at mix ratios that allow sustainability.

Biogas from AD is a multifunctional technology, offering solutions for, *inter alia*, treatment and management of digestible wastes of crop and animal origin, as well as animal manures and slurries. In many areas around the world, organic substances, considered as waste, are still deposited in landfill sites where they decompose, releasing methane (CH_4) with a global warming potential (GWP) 21 times that of CO_2. When these streams of organic waste are redirected from landfill to a biogas facility, a significant reduction in methane emissions from landfills occurs (Bogner et al., 2008). Use of animal manure and slurries as feedstock for AD, reduces the emissions of CH_4 from manure and slurry storage and application. In theory this can lead to carbon negative energy and fuels as the CO_2 emitted in combusting biogas has a lower global warming potential that the methane emitted to the atmosphere in a do-nothing scenario without a biogas system (Murphy et al., 2004). Along with this, the possibility of better nutrient management in digestate, combined with good agricultural practices (Holm-Nielsen et al., 1997), contributes to reduction of ammonia and NOx emissions from the storage and application of manure as fertiliser.

Intensive agriculture is one of the major greenhouse gas sources worldwide; these emissions are associated with enteric fermentation, management of manures and production of synthetic fossil fuel based fertilizers. Anaerobic digestion systems remove the easily degradable carbon compounds in feedstocks such as slurries and manures and converts them to biogas (Clements et al., 2012). When the remaining digestate is applied as biofertiliser, the slow to degrade carbon is recycled back to soils, contributing to build up of the humus content of the soil and its long-term suitability for agriculture. Digestate improves the soil organic carbon of agricultural land. At the same time, macro- and micro- nutrients contained in digestate are predominately in mineral form. This makes them more easily accessible to the plant roots, compared with nutrients in raw manure and slurry, which are mainly organic compounds, and must be mineralized in order to be up-taken by the plants. As such digestate has a higher nutrient uptake efficiency, compared with raw manure and slurries. (Al Seadi et al., 2018).

AD plants, able to handle substantial amounts of crop feedstock, are very beneficial for organic farming, in particular those in need of nutrients. Use of organic digestate as fertilizer has the potential to ensure the future development of organic agriculture. Additionally, organic matter in digestate can build up the humus content in the soil; this is a benefit unique to organic fertilizers, which is particularly crucial for arid and semi-arid lands with low carbon content. The destruction of weed seeds in the AD process is another significant benefit to organic farmers.

2.3. On the impact of biogas in sustainable energy supply

Fossil energy is still in abundant use around the world. This energy comes in the form of coal, oil and natural gas from a relatively limited geographical region and is used worldwide. Many countries are thus dependent on a few countries for energy supply. A transition to a bio-based/renewable energy production system would better balance the energy supply situation around the world; more countries and regions would be able to become energy self-sustainable. Depending on their boundaries, these energy systems can be of varied scale. When producing energy such as biogas, it is more likely for a municipality to become more energy independent and industries can benefit from creating more of their energy themselves. Centralized energy production can be more sensitive to the risk of interruption of energy distribution in case of storms or other nature events. Distributed energy production could balance energy production, when grids are vulnerable, such as with significant weather events. Both gas grids and available biomass can act as energy storage and balance other renewable intermittent energy sources such as wind and solar (Persson et al., 2014).

2.4. Biogas in various supply chains

Biogas consists mainly of methane and carbon dioxide. Generally, methane is used as an energy source with the carbon dioxide element of the biogas released to the atmosphere. Bioenergy, carbon capture and sequestration (BECCS) is seen as essential to keep the world's temperature below 1.5°C (EASAC, 2018). This is very applicable to biogas. When biogas is used as a natural gas substitute in gas to grid systems the CO_2 needs to be separated from the CH_4 in the biogas. Sequestration of this CO_2 is an expensive process, but in the short term (and the long term) the CO_2 may be reused.

In future energy systems, including circular economy concepts, both components (CO_2 and CH_4) may be used as raw materials for production of food and feed as well as various kinds of materials. Carbon dioxide capture can be either from off gas from a co-gen set producing CHP or from the CO_2 separated from CH_4 in biogas upgrading.

Depending on the purity of the CO_2, it can be cleaned and used to increase the carbon dioxide concentration in greenhouses for increased plant and food production, it can be used as a carrier in cooling systems or as a raw material for chemical production. Very clean carbon dioxide might also be used in the food industry, for production of mineral water, and in breweries to add gaseous bubbles to beer. The production of micro-algae in closed loop systems also needs substantial amounts of carbon dioxide. Indeed, micro-algae may be used as a means of capturing CO_2 from biogas and upgrading the biogas to biomethane (Xia et al., 2015).

By adding hydrogen to a biogas plant the biogas may be upgraded to almost 100% methane; the hydrogen reacts with the CO_2 in the biogas converting it to more CH_4 ($4H_2 + CO_2 = CH_4 + 2H_2O$). This may be carried out either in situ, whereby the hydrogen is directly injected into the digester where the AD process is carried out, or ex situ, where the produced biogas is reacted with the hydrogen in an additional reactor. This microbiological process is called biomethanation, whereby the microorganisms (hydrotrophic methanogens) reduce the carbon dioxide to methane (Guneratnam et al., 2017). Employing this process in an ex-situ process may produce biogas with a sufficiently high content of methane as to reach vehicle fuel quality in the future. If the hydrogen used in this process is sourced from electricity, via electrolysis, the concept is referred to as power to gas. Carbon capture is achieved as CO_2 is combined with hydrogen to create renewable methane; this may be termed gaseous fuel from non-biological origin. There are also thermochemical versions of this concept. The power to gas system has many attributes, including balancing of the electricity grid (McDonagh et al., 2018).

Instead of combusting the methane as an energy source, the methane might be used as an organic chemical component in the same way as natural gas in the chemical industry. Methane is a possible source to produce single cell bioproteins. This is already possible in large scale and will probably be a part of the future circular economy.

When biogas is used as raw material for further production of food, feed and materials, the biogas process acts as a carbon dioxide sink, not only as a carbon dioxide neutral energy source.

2.5. Biogas as a vehicle for the valorization of bio-waste

Organic waste streams occur in many places in society. In the food supply chain, food waste is generated in households as well as in supermarkets, restaurants and food production facilities. In a sustainable society where resources are used efficiently, what previously was considered to be waste is instead included in a production circle where organic material and nutrients such as nitrogen and phosphorus are returned to the soil to replace chemical fossil fuel sourced fertilizer. When digesting municipal and industrial food waste such as waste from super markets and restaurants or slaughterhouse waste, biogas is produced, and valuable nutrients accumulate in the digestate where they are easily used as fertilizer.

The Food and Agricultural Organisation (FAO) within the United Nations (UN) published a report in 2011 on global food waste, indicating that roughly a third of food produced for human consumption is lost or wasted glob globally, amounting to 1.3 billion tons per year (discussed in: Al Seadi et al., 2013). This corresponds to a huge resource of feedstock for biomethane systems. Some countries already have targets for energy recovery from food waste. The Swedish government, for example, has a target that at least half of all generated food waste from households, shops and restaurants be separated and treated to recover nutrients and that 40% is treated to recover energy by 2018. In 2016, through implementation of mainly food collecting systems and treatment by mostly anaerobic digestion, 40% of food waste was treated to recover nutrients and 32% treated to recover both nutrients and energy (Avfall Sverige, 2018). One ton of digested food waste produces 1,200 kWh biogas energy, which is enough fuel to drive 1,900 km with a gas fueled car. The food waste from 3,000 households can fuel a gas bus for a year.

Waste contains many usable substances and materials, which can be utilized and transformed into something reusable. However, some waste also may contain unwanted substances or material such as pathogens, antibiotics, pharmaceutical residues, micro plastics or heavy metals. Some of these entities do not pose a problem when the waste is converted into something inert and is not consumed by animals or humans. If it is converted to food and feed, however, or to something degradable, in contact with humans or animals, the story changes. If wastes are to be converted to food or feed or products, it needs to be certain that the novel product is unharmful. Moreover, in a circular economy, where the same material is recirculated many times, the possibility of accumulation or enrichment of unwanted substances in the loop needs to be considered and addressed. The usage of waste as raw material for feed or food is currently highly regulated and is subjected to numerous laws in most countries. These regulations may need to be updated to keep pace with the development of the circular economy so as not to hinder its wider implementation in society.

2.6. Biogas's contribution to important societal needs

When organic streams are treated in biogas plants and the produced digestate is used as fertilizer, eutrophication of local streams, lakes and fjords due to leakage from organic waste disposal can be avoided or reduced. Treatment of organic waste in biogas plants instead of disposal at landfills will reduce local water contamination and emission of methane from the landfills. Biogas treatment of manure in areas with high stocking rate reduces eutrophication of local rivers and lakes, which is problematic in many countries. The mineralization of the nutrients in the digested manures and the potential to separate digestate into nitrogen rich liquors and phosphorous rich solids facilitates optimal management, application and usage of the manure based nutrients.

The fish farming industry can be made more sustainable by incorporation of an anaerobic digester into the system. Fish farms generate substantial amounts of sludge, faces and feed surplus, which up to now has generally been disposed at the bottom of the fjords or found its way to local streams and lakes; these materials may be digested to produce biogas.

Circular economy is a broad concept, which can be hard to comprehend. The biogas plant is a concept which could also be used for education purposes to give children concrete examples of a circular economy concept. Showrooms in farms have been used to show “where the food comes from” to school groups. These same concepts could be used more widely to explain how separate collection of food waste in homes can be used to produce green energy or fertilizer production.

The biogas plant itself is not labour intensive but it can create new business opportunities in rural areas which otherwise suffer from depopulation. Through collaboration with different farms, the biogas plant can create different job opportunities along the process chain, such as raw material cultivation and collection. By increasing local energy production, income stays in the local area instead of going to global energy markets. The challenges are high investment costs and, in some countries, low energy prices. Moreover, the different and varying incentives creates uneven markets in and between different counties. This emphasizes the fact that biogas plants create two different end products (energy and fertilizers) and both should be utilized as efficiently as possible to facilitate business opportunities.

2.7. Biogas’s particular relevance to the agricultural communities

Centralised manure co-digestion is circular economy in practice. Centralized manure co-digestion is an example of a present-day circular economy concept. Already in the 1990s, it was considered a multifunctional technology, providing intertwined benefits in the fields of energy and transport, agriculture and waste management and for the overall environment/

climate sectors (Al Seadi et al., 2018). The economies are in the form of:

a) production of biofuel and of renewable energy

b) reduced emissions of greenhouse gasses (CH_4, CO_2, NOx)

c) improved manure management and nutrient uptake efficiency

d) veterinary safety through sanitation

e) reduced nuisances from odors and flies

f) financial savings for farmers

g) sustainable treatment and recycling of organic wastes

h) less pollution of air and water environment

i) improved local/rural economies

Organic residual fractions from industry, households and the service sector are treated in biogas plants together with livestock manure and slurries. The result is a countryside / city co-operation, a utilization of energy potential in the form of biogas, recirculation and recycling of nutrients, including phosphorus, potassium and nitrogen. At the same time, a significant part of the carbon in manure and waste is recycled, which maintains the humus content of the soils and their long-term suitability for agriculture. Biogas plants produce a dual climate effect, through reduction of methane emissions from animal farming (through removal of open storage of slurry and optimal digestate management), and by producing a decarbonised biofuel. Co-digestion improves the value of manure as fertiliser. The concept is based on the cooperation between communities of farmers, who supply their manure to a centrally located biogas plant, receiving back digestate, to be used as a high quality plant biofertiliser (Figure 1.3).

The application of digestate as crop fertiliser must be done during the growth season of the specific crop, to maximise the nutrient uptake by the plants and to prevent nutrient leaching and run off. Utilisation as fertiliser requires a specific quality, apart from the declared nutrient content. The quality refers to sanitation and pathogen reduction, as well as to the prescribed limits of chemical (heavy metals, organic compounds) and of physical plastic and other physical contaminants. For more information about utilisation see also IEA Bioenergy Task 37 reports (Lukehurst et al., 2010; Al Seadi and Lukehurst, 2012).

As a minimum measurement, the digestate is analysed for dry matter content and for nutrient content (NPK). The digestate is transported back to the farms to the storage tanks located in the fields, where digestate is to be applied as fertiliser. Compared with raw slurry, the nutrients in digestate are easily accessible to plant roots, increasing the nutrient up-take and reducing the risk of surface and ground water pollution, when it is applied through good agricultural practice. Use of digestate eliminates malodours and flies from application of raw slurry, improving air and quality of life in rural areas. The slurry suppliers can take back only that amount of digestate, which they can use on their agricultural land. Surplus digestate can be sold to crop farms, who need nutrients. In both situations, digestate can be fully integrated in the fertilisation plan of the farm, displacing significant amounts of expensive and fossil mineral fertilisers. Delivery of digestate directly to the fields and the sale of excess digestate to crop farmers contribute to a significant redistribution of nutrients in the respective agricultural area, solving the farmer's problem of excess manure, and lowering the environmental pressure from intensive animal farming. To achieve the environmental and economic benefits from the application of digestate as fertilizer, some basic principles of good agricultural practice must be fulfilled (Holm Nielsen et al., 1997; Lukehurst et al., 2010). As a principal rule, digestate should only be applied during the crop growing season. The risk of ammonia volatilization is reduced by using the right equipment (dragging hoses, soil injectors) and by taking the weather into consideration. The optimum conditions are when it is raining or there is very high humidity and no wind. Dry, sunny and windy weather reduces the N-efficiency considerably. When digestate is applied to grass crops, direct injection into the top soil gives the highest N-efficiency. Digestate storage tanks should be placed in the shade, sheltered from wind. It is important to ensure a crusting surface on the liquid, in the storage tank. The digestate should always be pumped from the bottom of the tank, to avoid unnecessary stirring. Stirring is done only prior to application. It is possibility to acidify the digestate on application, decreasing the pH-value and thereby limiting the volatility of ammonia (Holm Nielsen et al., 1997).

Animal slurry contains more than 300 different smell compounds. Each of them contributes to creating odour nuisance when slurry is stored or applied as fertiliser. Inside the AD reactor, many of these compounds are degraded, so AD contributes to reduction of odour nuisance from slurry. The smell reduction is proportional to the retention time inside the reactor; longer retention times lead to greater reductions in malodour. The intensity and the persistence of odours from digestate application as fertiliser are lower, compared with raw slurry. Digestate smells like ammonia, but the smell persists only a few hours after application as fertiliser. Smell reduction by AD of animal manures and slurries is very important for the acceptance of biogas technologies and of animal farming as it improves the air quality in rural areas (Al Seadi et al., 2018).

3. Representative good practices

3.1. Sweden – An international "hub" and local growth example

Vera Park, in Helsingborg, Sweden, claims to be the only fully functional completely circular solution for waste management in the world. Everything that enters is taken care of, processed and upgraded to new products, which are sold for profit. Vera Park is not just a physical place, it is just as much a way of thinking and acting in a circular economy. The concept means that NSR (the local public waste company) has opened its facilities around the region for different players. Vera Park serves as an industrial park (and test bed for research projects) for waste and recycling. Today, Vera Park has sixteen companies including NSR. The process around Vera Park is led by the Sustainable Business Hub, which is a cluster of sustainable and environmental technology with approximately 100 members, including all companies at Vera Park. What was previously a municipal waste facility, today is a highly profitable industrial centre where private companies with their own employees run profitable commercial activities with "waste" as their raw material. All organic material that enters the facility is converted into biogas, which is upgraded to vehicle gas and liquid biogas (LBG). The digestate fraction, which possesses good fertilizer properties is pumped in pipelines to farmers in the area. Within the industrial park, several other companies carry out biogas production. In addition to this, Vera Park also has its own research, which is conducted together with Lund University. Because of this, the facility expects to introduce their own products, which will improve the yield in biogas production. Non-organic fractions are also taken care of in Vera Park. Glass, plastics and paper are upgraded, and new products marketed by a separate company. Hazardous waste is handled, and metals are recycled by two other companies. Combustible fractions are utilized by the energy company Öresundskraft in their CHP-plant where research on energy-storage is carried out. Woody materials are converted by NSR to fibreboards in a unique process without use of formaldehyde. In addition to the regular activities, Vera Park also arranges courses in circular economy within waste management together with Lund University. These courses deal with how to work efficiently and profitably with residual products as a resource and commodity, instead of managing it as a costly waste. Soon, Vera Park, will introduce their Certificate of Circularity (CoC) a certificate that proves that a product really is fully circular; from production through distribution, use, disposal and handling in the recycling system. Vera Park is also involved in international co-operation in Georgia, Kenya, Chile and Estonia, to distribute know-how on waste management and fully circular biogas production.

Figure 4. Vera Park in Helsingborg – Sweden. Panoramic view.

3.2. Finland – Community-integrated example

Biogas plant BioKymppi (www.bio10.fi) in eastern Finland collaborates with several local farms and other companies, both with raw material collection for biogas plants, as well as end product use. The plant is a mesophilic wet digestion process with two production lines, one for sewage sludge and one for organic materials suitable for organic fertiliser production. Used raw materials include separately collected household bio-waste, packed bio-waste, side streams from the food industry, sewage, waste fat (from cooking), fish and manure. The total treatment capacity ranges from 15,000 to 19,000 t/a. The gas from the biogas plant is used, together with landfill gas collected nearby, for heat and power production. The plant has a CHP plant at the site but some of the gas is distributed via a gas pipeline to a nearby heat production plant where the gas is used for district heating for local communities. The biogas plant collaborates with an energy company from Oulu, who sells green electricity to the national grid. The green electricity is traded via the Eko-Energy certificate from the Finnish Association for Nature Conservation. The annual heat production is about 8,000 MWh with electricity production of 2,000 MWh. The digestate is separated and liquid fertiliser is used for organic farming. Solid fertiliser is used for organic farming and household gardens. The digested sewage sludge is also used for farming. In total between 1,000 to 1,500 ha of land uses the digestate from this plant. BioKymppi plant has been actively involved with several research projects to improve the efficiency of the plant and the products. For example, in a project Bio-Raee BioKympi is developing with other project partners safe and efficiently recycled fertilizers. The goal is to ensure that the tested fertilizers are environmentally friendly and economically feasible compared to conventional fertilizers.

Figure 5. BioKymppi biogas plant establishments.

3.3. Denmark – A biogas upgrade case

The high tech anaerobic digestion plant in Bevtoft started operation in April 2016. With its treatment capacity of more than 600,000 tons biomass per year (some 450,000 tons of animal slurries from local farms and 150,000 tons straw and of other digestible waste materials) the biogas plant is an important contributor to meeting the policy objectives of processing half of the Danish livestock slurries by anaerobic digestion. The biogas plant is owned and operated in a 50-50 joint-venture between E.ON and the farmers owned Sønderjysk Biogas Invest A/S. The produced biogas containing 54% methane is upgraded to 99% biomethane, in an upgrading plant with a capacity of 6,000 Nm^3 biogas/h, leading to a biomethane production of 21 million m^3/ year. This represents the equivalent of the annual energy consumption of 15,000 households, 571 city buses or 10,000 cars, and provides a reduction of 51,000 tons CO_2 emissions per year. The biomethane is injected directly into the natural gas grid. There are no additional costs or energy consumption associated with treating the tail gas, and harmful emissions to the environment are avoided. The produced digestate is returned to farmers in the area, to be recycled back to the soil, as fertilizer. Application of digested slurry as fertilizer reduces significantly the nuisance from odors and flies in rural areas. Digestate application is associated with higher nutrient efficiency and less nitrate leaching, compared with application of raw slurry as fertilizer. The biogas plant created 10 new jobs at the plant and contributes to creating and maintaining 20 – 30 derived jobs in the local area. The biogas plant is located on a 16-hectare area located approx. 2 km north of Bevtoft. The location was chosen in co-operation with Haderslev Municipality, with great emphasis on fitting the installation into the surrounding landscape, with suitable distance to neighbours and good access conditions.

Figure 6. Bevtoft biogas upgrade plant. Panoramic view.

3.4. Norway – A carbon capture example

The Magic Factory - close to Tønsberg in the south-east part of Norway recycles food waste and manure into biogas, green CO_2 and valuable biofertilizer for the production of new food. The food waste comes from households and the manure comes from farms in Vestfold county. Currently some 110,000 tons of food waste and manure are recycled annually at the plant. The produced biogas is upgraded and fed into a gas grid and is primarily used as vehicle fuel replacing about 5 million liters of diesel.

The close collaboration with agriculture has contributed to the plant receiving status as a National Pilot Plant. Agriculture in Vestfold county (2,157 km^2 and about 250,000 inhabitants) reached the government's goal of 30% of all manure being digested to produce biogas before 2020, by 2016. The Magic Factory's goal is to become an international pioneer for green carbon capture. Carbon capture takes place through renewable and green CO_2 from the factory being used inside industrially-adapted greenhouses for food production, together with bio-fertiliser from the factory. A Magic Pilot Greenhouse is under construction, with a plan for rolling out industrial greenhouses for local food production. Work is also under way on a knowledge and visitor centre next to The Magic Factory.

Figure 7. Magic factory's biogas and carbon capture facilities.

3.5. Croatia – Waste for energy and fertilizer

The biogas plant of Bioplinsko Postrojenje Gradec has been constructed in 2012 at the municipality of Gradec, Vrbovec and is managed by Agrokor-Energija (www.eihp.hr).

The guideline of this project was the company's Waste to Energy Strategy. As the plant is very close to the Croatian capital Zagreb, many food processing industries offer a large spectrum of wastes which can be treated in a biogas plant. Also, Agrokor group, a vertically integrated agricultural and food processing, retail entity in the Republic of Croatia, has a series of strategically important locations with extremely large amount of different resources that ensured high-quality raw materials, by-products and wastes for the AD production process. It also owns com-panies which are consumers for part of the output of the production process (heat and organic fertilisers) on mutual benefit.

This plant was the demonstration/learning plant for a string of biogas investments (9.8 MW in 5 plants). The plant's main characteristics are shown in Table 3.1.

Table 3.1. Biogas plant characteristics

Plant size	2,134 MW_{el}
Digester volume	• Fermenters – 6,000 m^3 • Post-fermenter – 2,500 m^3 • Two hydrolysis tanks – 1,256 m^3
Gas Storage	2,000 m^3
Hydraulic retention time (HRT)	35-40 days
Process temperature	Mesophilic at 42°C
Digestion technology	CSTR, two-stage digestion

Agrokor Energija had to gain public acceptance by organising numerous discussions with the local community and a study tour for local people to biogas plants with digestate lagoons. The existing pig farm gained the acceptance when the smell nuisance was decreased in vicinity after building a biogas plant.

This project is very interesting because many different technologies which are used in the biogas industry are implemented at one place. The hydrolysis-step of the two-phase fermentation makes sure that substrates are digested most efficiently. Additional thermomechanical equipment is installed (heat exchangers, thermal oil and storages) to allow as much heat utilisation as possible. The sterilisation and other specialised equipment makes the use of many different wastes possible. The plant generates income from sold electricity, thermal energy, waste collection and agricultural soil fertiliser which makes this project highly feasible to be applied in many different regions.

Figure 8. Bioplinsko Postrojenje Gradec biogas plant. Top view.

At first, the Biogas Plant Gradec was built as a 1 MW_{el} plant with a CHP but was advanced with two separate hydrolysis tanks and a 2nd CHP in 2015. Production with 2 MW capacity started in the 4th quarter of 2015.

It is built next to the pig farm and meat processing industry, within Agrokor Group. The maximum efficiency of the CHP engine can be reached by utilising most of the heat: There are two heat storages for heat from biogas CHP: two water tanks (2 x 100 m^3) and two thermal oil tanks (2 x 20 m^3). Heat from exhaust fumes at the exhaust pipe with use of additional thermo-technical equipment is stored at thermal oil tanks at up to 300 °C. The heat, combined with natural gas (as back up), is used for pressure sterilisation (133 °C at 3 bar at 20 minutes) of slaughterhouse waste. Heat is also used as process heat to support hydrolysis in pre-fermenter and AD in the main fermenter and for the digestate thickener.

Pig slurry is connected to an underground gravity piping system from the farm to the AD to avoid smell nuisance. Maize silage is only used to balance AD process.

The plant processes 80,000 tons per year mixture of 11-20 different types of substrates. The largest share in volume (55-60%) refers to pig slurry, while the other is related to animal by-products and waste from various stages of food processing industry and food retail within the Agrokor Group and third parties waste (ex-food, slaughterhouse waste, flotation sludge, glycerine, beer yeast, various grains not intended for human consumption etc.) Maize silage is used for balancing the process with 11-15% volume share.

Total investment costs were **€** 9.2 M. The investor is a private company Agro-kor-Energija ltd. (inc. 2010), member of Agrokor Group which is a vertically and horizontally integrated in the food & beverage company. A part of the investment was covered under a facility provided by the EBRD. The plant receives operational support under the FiT scheme with a 14-years-guaranteed price of € 0.17 per kWh_{el} incl. ‘local community’ bonus for mandated 50% energy efficiency of the CHP unit.

The biogas is used as electricity and heat. The plant produces annually 10,177 MWh_{el} and 6,288 MWh_{th}. Part of the heat is utilised as process heat for fermenters, post-fermenter, hydrolysis tanks, digestate thickener, management offices and pig stables. Heat from oil tanks is used for sterilisation of slaughterhouse waste.

Digestate is collected at lagoons and used as fertiliser within the own cropping system. One part of digestate is treated in mechanical separators to get solid phase which is also used as a fertiliser.

3.6. Czech Republic – Biowaste to power industry and heat the local municipality

The plant was constructed in 2010 in the town of Vysocina. It has an installed capacity of 0.6 MW_{el} with 0.608 MW_{th}. The plant has a 1,050 m^3 digesting volume and gas storage capacity of 457 m^3. It applies one-stage digestion in batch mode, dry fermentation with 7 digesters batch regime. The plant is mesophlic at 38 ºC process temperature, while its Hydraulic retention time (HRT) is 120* days. The work cycle of one fermenter is 28 days. In this, ca. 70% of the digestate is used as inoculum and is mixed with new substrate.

The idea was to provide a possibility to the surrounding municipalities to treat biowaste without limitations of the standard composting facilities and with higher added value – energy production. The investor assumed that legal obligation to treat biowaste would come earlier for the municipalities than it actually did in the end. The biowaste has not been separated or treated almost at all in the region until the facility has been built.

This project's materialization involved a great deal of risk. This was partially due to the lack of legislation on biowaste treatment in the Czech Republic at the time of start-up. In addition, public motivation was stronger for treating energy crops instead of treating waste.

Batch dry fermentation is a suitable technology for biowaste treatment. The project also has a very high efficiency of energy use (both heat and electricity). Biogas plant is very beneficial for the region bringing reduction of the organic waste being landfilled, electricity for a local industrial company as well as heat for the municipality. Nutrients are also recycled as the digestate is being spread on the arable land.

The municipality as well as the region had no direct involvement as per the set-up and construction of the plant. However, the town is cooperating with the organisation of the biowaste separation pre-digesting. The town is also the heat consumer.

Five years after the operation's start-up of the plant, the municipality of Vysocina separates and treats more than 35% of waste otherwise destined for landfill.

The plant processes up to 18,300 tons of biowaste per year. The streams processed are: Cemetery waste (300 t/a), Kitchen waste (900 t/a), Separated municipal waste (9,800 t/a) and Agricultural residues (7,300 t/a). The produced biogas is transported by a 1.5-km-long pipeline to an industrial enterprise ZDAS a.s, where the CHP unit is located. All heat and electricity is used on-the-spot for the first time in Czech Republic. The electricity is used by the industrial company ZDAS, a.s., which is an energy-hungry industry having main focus on production of forming machines, forging presses, metal scrap processing equipment, rolled product processing equipment, castings, forgings, ingots and tooling, especially for the automotive industry. The produced heat is consumed by the Central heating system of the municipality of Zdar nad Sazavou.

Total investment cost of the plant was € 3.8 M. The investor was the Waste treatment company ODAS ODPADY, Ltd., while € 1.33 M came from the European Structural and Investment Fund - Cohesion Fund (35%), 6% came from the State Environmental Fund of the Czech Republic and € 1.1 M were received as a bank loan.

Figure 9. Representative view of Zdar nad Sazavou plant.

3.7. France – Slurry use in Green Gas

The biogas plant was constructed in 2013 in Cholet, France and implements a mesophilic Anaerobic Digestion process at 37 ^{o}C with a hydraulic retention time of 45 days. The plant includes two digesters (a primary and a secondary one) with total digesting volume of 2,731 m^3. It produces 447,209 m^3 of biogas on a yearly basis applying a wet-fermentation technology processing manure and fats.

The driver for the materialization of the project was a decision made by local farmers for a joint effort to improve the nutrient management in the region. As the investment for a common slurry treatment is the same as for one farm, investors decided to find a shared solution. Another driver was the fact that farmers needed to line up for the creation of storage capacities.

This biogas project is serving as a model for other regions because it is a result of a shared investment. For farms, it offers diversification of production and a new source of income, while it helps to keep-up and enforce livestock breeding in the area. For the farmers it offers a new personal endeavour under new industry's perspectives and helps them to discover and to exchange fresh experience not know before. For the cooperative structure, it is a local treatment solution for organic waste with the avoidance of much transportation means.

The plant is situated close to a district border and the district council made a decision for the support of the project's construction through public subsidies under the term/condition the plant to be built in a site inside the district.

Before the plant's construction, AgriBioMethane, the plant's management entity, has been working on its development for 3 years. The plant was the first in the region producing biomethane and injecting this biomethane into the grid. An important aspect is that the farmers keep the organisational and financial majority of the project. The first three years of operation of the plant have proven that a collective farmers project can be successful when the project's development is based on a sound and detailed way. 10 farmers from four different agricultural co-operatives invested in the construction of the plant. It is worth noting that digestion mix includes also substrates delivered from slaughterhouses belonging in the same agricultural cooperatives.

Feedstock amounts 59 tons per day. Substrates are: Dairy cow and pig slurry, dairy cow manure and waste from grease of decantation (slaughterhouse, precooked meals, pork butchery or the grease and oil from restaurants). Manure and slurry is delivered by the investors. The overall treatment charge is € 34,000 per year for the benefit of the biogas plant and € 25,000 per year to buy substrates from waste producers. On annual basis the plant processes 4,927 tons of waste from grease of decantation, 7,586 tons of Dairy cow slurry, 4,713 of pig slurry, 1,743 tons of duck excrements and 2,818 tons of Dairy cow manure.

The plant's total investment costs were € 3.4 M. Investors were 10 farmers in four farms in Terrena and Lyonaise des eaux areas. The investment was supported by the National Waste and Energy Agency (ADEME) (with € 760,000), the District Council (€ 60,000), Federal funds attributed to the district council (€ 195,000) and by the water supply agency Loire Bretagne (€ 70,000). Investors had support from consultants for technical and social/economic planning. They also had support on how to ask for public financing. The price paid for the injection of the upgraded biogas (biomethane) into the natural gas grid is € 0.12343 per kWh HHV (higher heating value).

The plant's operation also receives tax exemption as being a one with more than 50% of capital investors possessing agricultural activity and using at least 50% of substrate of agricultural origin. Such plants are exempt of local taxes.

Figure 10. Cholet, France biogas upgrade plant. A public visit instance.

3.8. The Netherlands – Manure-Silage co-digestion

The plant possesses a capacity of 2 MW and its operation is based on co-digestion, including the treatment of digestate, which results in commercially interesting end products. The plant is located in Heeten and has been running since 2007 under the management of Bieleveld Bio-energie B.V.

Originally, this installation was initiated by 50 pig farmers, who wanted to reduce the cost for disposal of pig manure. Unique about this installation is that the digestate is transformed into commercially interesting products, such as liquid replacement for artificial fertilizer. The installation has been built by Certified Energy (biogas installation) and VP Kasag (digestate treatment). Apart from the builders, Spexgoor, Bureau Blauw, Biogas Plus and CCS B.V. have advised the owners before, during and after the building phase.

The digestion installation consists of 2 plug flow digesters, each with a capacity of 600 $m^3$and 5 continuously stirred vertical digesters (main reactors), each with a capacity of 1,800 m^3.

On a yearly basis, the installation is fed with 43,500 m^3 pig manure, 5,000 m^3 cow manure, 7,000 m^3 poultry manure and 22,500 tons of maize silage. The biogas is consumed by a 1,965 kW CHP-installation, which leads to a yearly production of 9,700,000 kWh.

The digestate is transformed into commercially interesting products. The first step is mechanically separating the solid fraction from the liquid fraction. The solid fraction is then dried, using the heat from the CHP. The liquid fraction is processed by means of ultrafiltration and reversed osmosis. The resulting products are a liquid replacement for artificial fertilizers, and water.

The investment amount for the installation was € 6,000,000. Two people are employed to run the installation. The electricity resulting from the plant's operation is subsidized with € 0.096 per kWh_{el} produced and the plant produces 9.7 GWh of electricity per year. The production is CO_2 neutral, leading to an annual saving of almost 5,500 tons of CO_2. Furthermore, the plant provides heat to the residential area in the village of Deventer.

During the first period of the operation of the installation, there were problems with the gas production and complaints about the odour which came from the installation. The substrate menu of the installation was improved, after which the problems were solved.

Another difficulty faced was the integration between the biogas installation and the digestate treatment equipment. This had led to extra costs, whereas the revenues from the liquid artificial fertilizer replacement were not as high as initially anticipated. Profitability of the installation was only recently achieved via better overall process control and the heat provision to the residential area of Deventer.

Figure 11. Heeten, Netherlands biogas plant. AD reactors' view.

3.9. Poland – Biogas plant and heat provision to the local community

The plant operates in Naclaw, a village located in the north-western Poland, Zachodniopomorskie Voivodship, Powiat Koszalinski, Polanow Municipality. The plant is managed by Poldanor, an animal and crop production company, possessing experience from building six biogas plants in the vicinity of agricultural farms managed by the same company. The biogas plant in Nacław operates since 2010.

The plant is the seventh biogas plant put in operation by Poldanor in Poland, while it is the first one in Zachodniopomorskie Voivodship region. This plant is the first Polish biogas plant supplying heat to the local community, including housing estates and schools.

The plant was set up to produce a better quality fertilizer from manure and to decrease the odours related to fertilizing the crop fields with manure. The company is realizing its environmental policy objectives, producing energy from a renewable source and reducing greenhouse gas emissions.

Official opening took place in June 2010, while the Construction permit had been issued on March 2009. Construction works begun on June 2009, a year before the opening.

The plant's annual energy production is 4,928 MWh_{el}. The management company has been following an ecological policy since 2005, when the board of directors made the decision to build several agricultural biogas plants in the vicinity of farms managed by the company.

In order to materialize the idea and achieve results fast, the company established a Biogas Department which had been led by a Danish expert. A team of highly qualified specialists in power production from biogas and in handling plant construction and biogas production was also created and was responsible for the planning, design and supervision of the construction and operation of the biogas plants. The department is also actively cooperating with the Polish Institute for Renewable Energy as well as with research and development centres of universities in Denmark.

The basic activity of the company is breeding pigs, plant production and production of equipment for use in buildings for livestock. Breeding takes place in 17 own farms and in 5 cooperating farms under contracts with the farmers. The area of the arable lands in use is more than 15,000 ha.

The main input for the biogas plant is manure from farms in Naclaw (approximately 29,200 t/year), maize silage (8,760 t/year) and other agricultural residues (730 t/year). Manure and other agricultural products are converted into odor-free, environmentally friendly fertilizers. During the process, electricity and heat power are produced. Some of the power is used by the facility, while surplus is sold. The income from energy sales comprises more than 2-3% of the overall income of the company.

The AD process of the plant is mesophilic at 37 °C. The process of fermentation by methanogenic bacteria results in biogas containing 58-64% of CH_4. The biogas produced in the process is burned in a CHP module.

The main facilities of the biogas plant are:

- ✓ 2 biomass tanks – 34.6 m^3 each
- ✓ Technical building with electric power and boiler room
- ✓ Pre-tank for slurry – 1,000 m^3
- ✓ Digestion tank – 1,250 m^3
- ✓ Post-digestion tank- 2,000 m^3
- ✓ 2 lagoons – 10,000 m^3 in total

Basic plant's specifications:

- ✓ Liquid manure input – 29,200 tons/year
- ✓ Maize silage input – now 8,760 tons/year
- ✓ Others input – 730 tons/year
- ✓ Electric power - 625 kW_{el}
- ✓ Gas boiler with the thermal power of 690 kW

Annual output if the biogas plant:

- ✓ Biogas production – 2,400,000 m^3
- ✓ Electric energy – 4,928,000 kWh/year

- ✓ Thermal energy – 5,460,000 kWh/year

Investment cost was € 2 M. The payback time was 7 years. A state subsidy was used for construction, amounting for 40% of the total equipment costs. GHG-saving potential refers to 20,000 tons of CO_2 per year.

Other major plant's characteristics/benefits achieved are:

- ✓ electricity production and delivery to company's farms (through electricity transmission lines owned by the company)
- ✓ heat production delivering post-digestion fraction to the fields (improving soil structure, supplying fertilizer)
- ✓ creating new jobs
- ✓ primary energy savings

Major technical problems met are:

- ✓ administrative problems - Energy Company administration required additional safety measures against power loss
- ✓ agreements with veterinary inspection bodies were time consuming
- ✓ agreements with sanitary inspection bodies were time consuming
- ✓ necessity of installing heat energy meters (to demonstrate high-performance cogeneration) led to budgetary deviations
- ✓ frequent breaks in energy distribution by energy company ZE Koszalin due to inefficient transmission infrastructure caused severe downtimes

Non-technical barriers met were:

- ✓ problems faced with the utilisation of post-digestion product (own arable area was too small compared with the amount of post-digestion product obtained)
- ✓ obligatory requirement of having a back-up biogas boiler in case of a generator failure led to budgetary deviations

Figure 12. Naclaw, Poland biogas plant. Representative view.

3.10. Belgium – An expanded pocket digestion pilot plant

The plant is located in Zevekote farm, which is owned by the management company based on Gistel-Belgium. The plant lies inside an own company's site operating a combination of a pig farm and a manure treatment installation. The farm has a capacity of 11,000 production pigs. Each year, about 29,000 pigs are fattened. The capacity of the manure treatment installation is about 60,000 tons per year. In the manure treatment process, the raw manure is separated into a solid fraction and a liquid fraction. The solid fraction is converted into high-quality compost by maturation in the composting plant. The liquid fraction is purified in the biological tank and stored in a buffer basin. The effluent from the biological tank is purified by a system of cascading wetlands (reed beds).

Through this process the characteristics of the effluent comply with the standards for discharge into surface water. The incoming manure is completely converted into compost and dischargeable water.

The company was founded in 2000 with the launch of the first manure treatment plant in Eernegem. The processing of raw manure is the company's main activity and is either done with proprietary manure from the private stables or with manure from external pig farmers. The compost is an important (by)product and is sold to the market.

Since the beginning, the company had a clear pioneering role within the sector: in 2006, the first reed bed was installed allowing to convert the processed manure into dischargeable water.

The same activities (manure treatment and reed bed) are also carried out on the site in Zevekote. The pocket digester was installed in Zevekote in 2013. In parallel with the construction of the small-scale digester, a major capacity expansion of the pig stables was realized in the site.

The pocket digester is mainly fed with pig manure. Initially, a license was granted for 5,000 tons of fresh biomass / year, which consisted of a combination of pig manure (raw and solid fraction) and energy corn. To increase the profitability, the company applied for a permit to increase the capacity to 12,500 tons/year. A limited fraction of this 12,500 tons consists of organic vegetable waste. After this expansion, the installation is no longer considered a small-scale installation.

Before the construction of the digestion installation, most of the electricity on the site of Zevekote was generated by solar panels. The starting point of the pocket digester was not to cover the company's own electricity costs and therefore the installation might not be considered "pocket digestion". For example, all calculation models for this project take into account 100 % grid injection (with accompanying lower injection rate) for the produced electricity. In practice, this is not the case since the CHP also provides power at night when the solar panels do not produce electricity. As for the heat utilization, there is a clear "win" thanks to the digestion plant.

The Zevekote site has several heat demands:

- The piglets stable (equivalent to 20,000 liters of heating oil / year)
- The house
- The composting plant: formerly a CHP on rapeseed oil (125 kW) was used on the site to accelerate the drying process in the composting plant. Because of the high cost for oil, the plant was removed. The residual heat from the CHP is a useful energy source for the drying process.

The plant started operation in 2013 and applies a single digester of 1,000 m^3 volume. The biomass's retention time was initially 73 days and subsequently (i.e. after the increase in capacity to 12,500 tons/year) 30 days. It possesses a 190 kW_{el} installed capacity and an actual yearly production of 774,000 kWh_{el}. The actual yearly produced heat energy is 1,304,000 kWh_{th} and is used in the digester, the composting hall, the living quarters and in the piglets stall. The lessons learned from the plant's operation are the Intensive follow-up needed, especially at the initial operational phase of the project and the high quality flows (high biogas potential) needed in order to fast-turn into profitability. The digestate resulting from the plant's operation is processed in the proprietary manure treatment facilities of the site.

The investment needed for the plant's construction and commissioning is broken down as follows:

- ✓ € 250,000 for the digester

- € 200,000 for the CHP
- € 100,000 for other expenses (i.e. studies, administration, site pre-treatment, earthworks and civil works)

The basic categories of the running costs of the plant are analyzed as follows:

- Engine: € 18,000/year
- Installation: € 10,000/year (estimate)
- Administrative support: € 12,000/year (including manure treatment)
- Labor intensity: 2 hours/day
- No relevant additional costs to process the digestate because of the limited supply of additional nutrients (e.g. energy corn) to the digester
- Incoming injection tariff (medium voltage, Infrax West): approximately € 1.60/MWh_{el} injected and annual fee of € 825 (for both solar panels and pocket digester)

Basic revenue streams are analysed as:

- All electricity is injected into the grid: currently € 35,600/year (the goal is a theoretical optimum of € 53,820/year)
- Substitution heat: € 26,000/year
- Green power certificates: approximately € 110,000/year
- Green heat certificates: approximately € 50,000/year (decrease after 4 years)
- € 150,000 investment aid (as being a demonstration project)

Best practice was used to integrate the small-scale digester into the farm. On the supply side, there is a synergy with the existing pig farm, the manure from the piggeries is extracted from the manure pit very freshly and utilized in the digester. The manure either goes directly to the digester, or is separated first into a liquid and solid fraction. Only the solid fraction is used in the digestion plant. In addition, energy crops are supplied (maize or corn cob mix) in order to have an optimal C/N-ratio.

On the output side, there are also synergetic opportunities with the existing agricultural activities. The digestate can be separated and processed in the composting unit (solid fraction) and the biologic plant (liquid fraction). The green power is used on the farm and the residual heat of the CHP plant is used to heat the piglet house and support the composting process.

Figure 13. Zevecote farm, Belgium with pocket digestion establishment. Top view.

4. Conclusion

We are still in the advent of the circular economy. Products from bio-based resources will grow in both absolute and relative terms in the coming years. In the future bio-economy, wastes will be transformed to highvalue products and chemical building blocks, fuels, power and heating; biogas facilities will play a vital role in this development, and in the implementation of the novel production paths that arise in the transition to a bio-economy. The future of the biogas facility is a factory where value is created from previously wasted materials, this ensures sustainability of the environment and potential for financial gain for the local community. The flexibility of the anaerobic digestion system and its ability to digest a multitude of organic feedstocks, while producing a significant range of products ensures the role of anaerobic digestion and biogas in the circular economy.

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