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Opportunities for producing biogas in the MOFTMO area of Poland

A pre-feasibility study of biogas in Municipal Functional Area Tomaszów Mazowiecki-Opoczno

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Preface

This pre-feasibility study is a deliverable from the project *Green transition in practice: Demonstrating and disseminating the benefits of producing biogas from bio-waste*, financed by the Fund for Bilateral Relations within the European Economic Area Financial Mechanism 2014-2021 and the Norwegian Financial Mechanism 2014-2021. The general idea of the project is to compare similarities and differences in the challenges facing biogas in Poland and Norway. The pre-feasibility study identifies challenges and opportunities in the MOFTMO area of Poland. The study has been prepared October 2023 – July 2024. The authors would like to thank representatives of Tomaszów Mazowiecki Municipal Office and Water and Sewage Management Plant in Tomaszów Mazowiecki for their kind support during project preparation, as well as Zbigniew Gieleciak (IOŚ-PIB) and Barbara Petrykowska (KOWR) for sharing their knowledge, consultation and valuable comments. We thank Leif Grandum and Jonas J. Lie (Vista Analyse) for providing excellent research assistance.

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Executive summary

We examine the opportunities for producing biogas in the Municipal Functional Area Tomaszów Mazowiecki-Opoczno (MOFTMO) in Poland. The area has significant biomass resources. Based on an analysis of available resources, as well as regulatory and technical conditions, we develop a business case for investing in biogas production at the wastewater treatment plant managed by Water and Sewage Management Plant in Tomaszów Mazowiecki. The first investment phase utilizes wastewater sludge and grease trap sludge. The second phase adds municipal and industrial waste as substrates. Compared to the present practice we find the first phase to generate an expected internal rate of return (real) of 4.7 percent. Adding the second phase the internal rate of return increases to 7.8 percent. Therefore, to increase profitability, it is important to include a second phase despite the higher costs and extended investment implementation time.

Biogas is part of the strategy for European climate neutrality

European Union leaders have agreed to achieve climate neutrality by 2050. Biogas is important for meeting this goal. The EU Renewable Energy Directive (Directive (EU) 2023/2413) says that by 2030 at least 42.5 % of gross final energy consumption should come from renewable sources. It emphasises the role of energy production from biomass and bio-waste. The EU target for biogas and biomethane production is 35 billion cubic meters per year by 2030. In 2022, almost 20,000 biogas plants and more than 1,300 biomethane plants operated in Europe, producing 16.8 billion cubic meters of biogas and 4.2 billion cubic meters of upgraded biogas (biomethane) (data from The European Biogas Association).

Poland and Norway are committed to increasing the role of biogas in their energy mixes since both have low biogas production compared to the potential. The broader use of biogas will help Poland fulfil its Paris commitments and improve energy security. Poland has a well-established national network of gas pipelines into which biomethane can potentially be fed to increase the flexibility of biogas end-uses. District heating is another potential use of bio-waste in Poland.

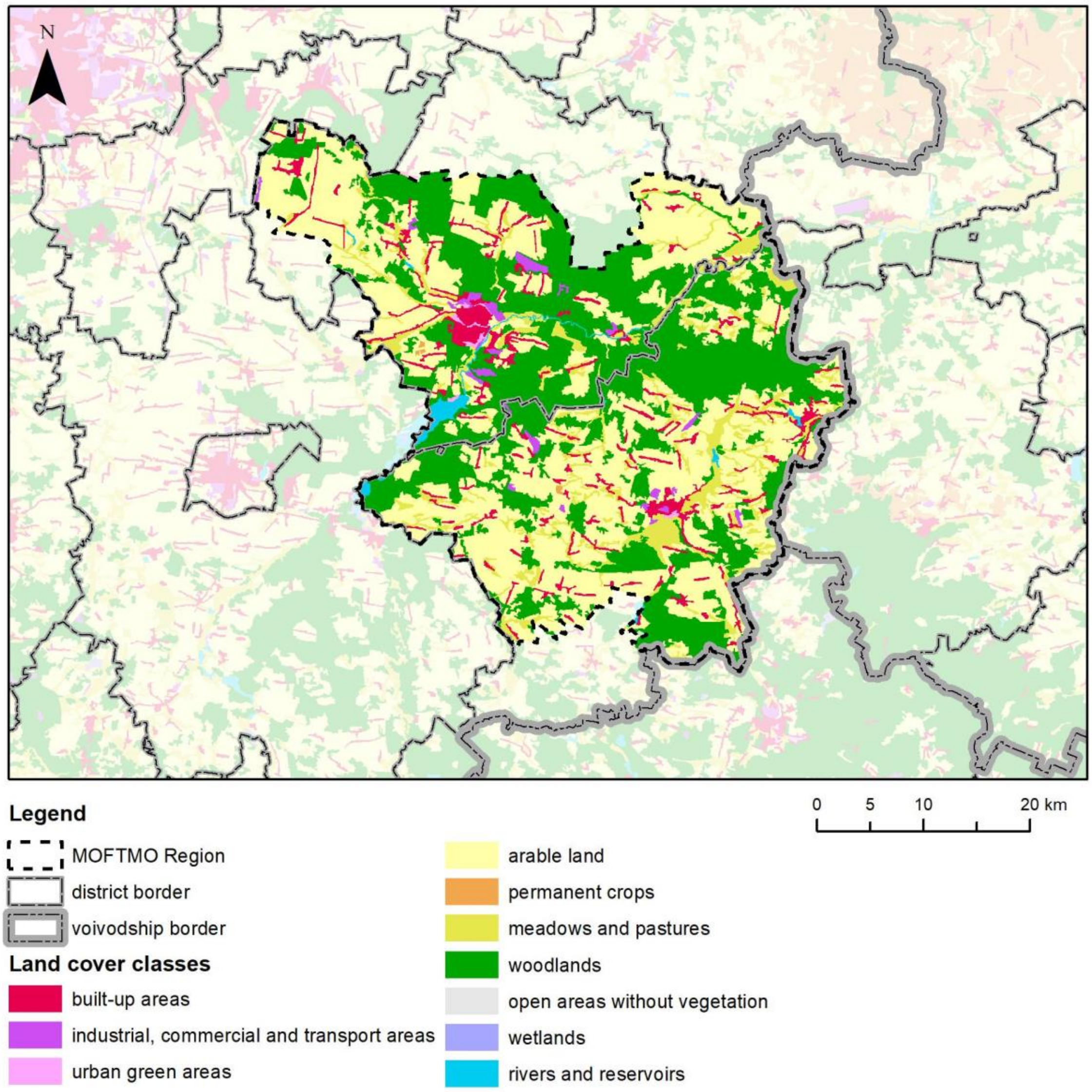
The government's plans for green transformation in Norway (Meld. St. 13 (2020-2021)) repeatedly indicate bio-waste and bioenergy as key resources in achieving the goals. Norway has no national gas grid, but a potential for liquefied biogas for transportation, and a potential for more heating based on bio-waste.

The similarities and differences in the challenges of each country suggest that Norway and Poland can learn from each other in this area. This report contributes by exploring the opportunities for biogas production in the Municipal Functional Area Tomaszów Mazowiecki-Opoczno (MOFTMO) in Poland. It is hoped that the study of MOFTMO will act as an example and inspiration for other municipal units and areas of Poland. At the same time, the study showcases certain barriers that currently limit the MOFTMO area from utilizing the full potential for producing biogas. These are both regulatory, technical and economic in nature.

The MOFTMO has little built-up area

The MOFTMO consists of 14 municipalities of the Tomaszowski and Opoczyński districts in the Łódzkie Voivodeship. An inter-municipal association has been established to develop a joint strategy for integrated territorial investments and its implementation. In terms of land use, the MOFTMO area is a predominantly agricultural (figure S.1). Agricultural land, with a predominance of arable land, covers more than half of the area. Further, the MOFTMO has close to 40 per cent forest cover. Forests are located in the central part of the area, along the valley of the Pilica River, the region's main river, and smaller streams.

Figure S.1 Land cover in the MOFTMO



Source: IOŚ-PIB based on Corine Land Cover (EEA) and Head Office of Geodesy and Cartography (GUGiK)

The area is inhabited by approximately 160,000 people (as of 2021). The largest city is Tomaszów Mazowiecki (the largest red area in figure S.1), which houses 1/3 of the region's population. The MOFTMO has three smaller towns and numerous small towns and villages.

We have performed a mapping of available biomass resources in the area. The results are as follows:

- Biodegradable waste from industry: 7 600 Mg/year.
- Sludge from municipal wastewater treatment plants: ca 2 300 - 2 700 Mg dry mass/year
- Municipal bio-waste (food and kitchen waste): ca 590 Mg/year
- Plant biomass: About 128 000 Mg/year, mostly corn and straw.
- Animal biomass: About 675 000 Mg/year, of which ca 430 000 Mg of manure and 245 000 Mg of slurry.

These are significant resources. Quantitatively speaking the largest potential obviously lies in agricultural waste.

Barriers cut into the potential

Polish regulations distinguish between biogas plants and agricultural biogas plants. Biogas plants other than agricultural are registered at the Energy Regulatory Office (URE), a central government administration body established to carry out tasks related to fuel and energy management regulation and competition promotion. Biogas plants other than agricultural are not limited by the choice of substrates. Depending on the technology, they can accept diverse feedstock materials such as sewage sludge and industrial or municipal bio-waste.

Agricultural biogas plants are registered in the National Support Centre for Agriculture (KOWR), the executive agency of the Ministry of Agriculture and Rural Development responsible for the implementation and application of instruments supporting active agricultural policy and rural development. The Act on facilitating the preparation and implementation of investments in agricultural biogas plants and their operation applies to facilities managed by farmers, and it introduces a number of legal restrictions regarding maximum yearly biogas production and acceptable substrates. In short, municipalities and intermunicipal organisations have limited options in influencing the development of agricultural biogas plants. Therefore, despite its big potential agricultural biogas is not the focus of this prefeasibility study.

Due to its properties, biogas could be fed into the country's existing gas network after appropriate processing. Unfortunately, access to this network is limited as the gas network is not widespread throughout the country. In addition, the high costs of connection to the network and the need to match the biogas parameters to those required by the network can present a formidable technological and financial challenge. Electricity produced from biogas could be fed into the country's electricity network. However, connecting to the electricity grid may involve high costs. High costs and a lack of connection capacity at distribution network operators lead to refusals.

There are other economic and financial barriers as well. A biogas plant requires a high investment cost, particularly if it includes upgrading raw biogas to biomethane. There are economies of scale and unit costs are generally lower in larger plants, but larger plants require the logistics for a larger inflow of biomass.

Recently, there have been more and more public campaigns to raise the ecological awareness of citizens and increase the level of social acceptance for this type of investment in local communities.

Support systems enlarge the potential

National regulations provide several support systems dedicated to biogas plants, namely a feed-in tariff (FIT), feed-in premium (FIP), and auction system. The rules also allow obtaining a guarantee of the origin of electricity generated from biogas (these do not constitute public aid). The support for biomethane is in the form of the FIP system. Poland has a feed-in-tariff system for renewable energy installations that feed energy into the electricity grid. The system is designed for installations with a total electrical capacity of less than 0.5 MW, producing energy from, among others, agricultural biogas, biogas from landfills or biogas from sewage sludge. It guarantees the sale of all, or part of, the energy not used by the producer at a fixed price equal to 95% of the reference price to a mandated supplier or a chosen entity. The second system is a feed-in-premium, dedicated to larger installations (from 0.5 MW to 1 MW in the case of biomass energy production). The feed-in-premium allows the sale of electricity from biogas at a fixed price equal to 90% of the reference price exclusively to an entity selected by the producer. The possibility to benefit from the indicated support is limited to 17 years. The reference price varies depending on the specific technology and capacity of the installation and is determined by regulations at a level higher than the market price of energy. The auction system, generally used by energy producers in biogas plants with a capacity above 1 MW, involves competing producers submitting bids to sell a specified amount of energy in a given calendar year. The producer who wins the auction gains the right to cover the negative balance, which is the difference between the market price of electricity and the winning bid submitted in the auction, for a period not exceeding 15 years. The system is known as “contract for difference”.

The business case for producing biomass at the Tomaszow Mazowiecki wastewater treatment plant

We examine the business case for producing biogas at the Tomaszow Mazowiecki wastewater treatment plant. Following examples from other wastewater treatment plants in the region, in Poland, Norway and internationally, the plant has plans to develop biogas production in two phases.

- Phase 1 is a biogas plant with sewage sludge as substrate
- Phase 2 is an expansion to include municipal and industrial bio-waste and as substrates for biogas production

Phase 1: Biogas from sewage sludge

In recent years between 2100-2700 Mg of dry matter of sewage sludge have been produced annually during the wastewater treatment. Until 2020, the generated sewage sludge was dewatered and transferred to an external company for further treatment. Since 2021, the sludge has been dewatered and dried at 130 degrees, and a soil improver has been produced. A sudden increase in gas prices in 2022 caused the treatment plant to limit sludge drying and forced it to transfer unprocessed sludge directly after dewatering for further treatment.

In phase 1 the investment would consist of a modernization of the sewage treatment plant, allowing for:

- stabilization of sludge in the methane fermentation process supported by thermal-pressure hydrolysis and production of electricity and heat from biogas
- water recovery from treated sewage
- recovery of phosphorus in the form of struvite

The outcome of the project will be:

1. Reconstruction and extension of the sludge treatment line as a sludge treatment facility with sludge sterilization, biogas production and utilization (Task 1) and phosphorus recovery in the form of granulated struvite (Task 2) and treatment and disinfection of treated wastewater to recover water for industrial purposes (e.g., washing streets or watering greenery) (Task 3),
2. Expansion of the command-and-control system to include equipment for the new sludge line, phosphorus recovery and water recovery facilities.

The investment cost of phase 1 is projected to be 65 million PLN. The annual cash flow compared to the baseline, under different assumptions, is estimated at 3.6-5.1 million PLN, for an internal rate of return of 0-4.7 percent annually. The 4.7 percent rate of return results when part of the biogas is used to dry digestate and produce soil-improving product, while the remaining biogas is used for electricity and heat production. The electricity produced will replace electricity from the grid.

Phase 2: Municipal and industrial bio-waste

Anaerobic co-digestion of wastewater sludge with other biodegradable materials can offer several benefits, encompassing environmental, economic, and operational aspects.

The biogas yield from digesting wastewater sludge alone planned in phase 1 will not enable energy self-sufficiency, which wastewater treatment plants are obliged to strive for. Expanding the biogas plant and adding co-substrates could improve the energy balance of the installation.

In several studies, the anaerobic co-digestion of wastewater sludge with an organic fraction of municipal solid waste (OFMSW) was shown to result in higher biogas production than digesting sludge alone while enhancing the quality of biogas by increasing the methane content. Similar effects are achieved with the co-digestion of biodegradable waste from the agri-food industry.

The additional benefits are connected to improved municipal waste management in the area. Implementing a separate collection of an organic fraction of municipal solid waste and using it as one of the substrates would result in closing the biomaterial loop of the waste system in the area.

In phase 2, the investment would encompass the installation of pretreatment facility for biodegradable waste from municipal and industrial sources and additional biodigester.

The outcome of this phase would be:

1. Improved biogas and methane yield and better energy balance of the wastewater treatment plant.
2. Improved management of organic fraction of municipal solid waste

The investment cost of phase 2 is projected to be 69-72 million PLN depending on scenario. The annual cash flow compared to the baseline, under different assumptions, is estimated at 5.3-7.2 million PLN, for an internal rate of return of 4.5-7.8 percent annually. The 7.8 percent rate of return results when industrial bio-waste is added to the food and kitchen waste from municipalities. Two additional digesters are needed in this case, adding to investment cost, but the extra investment cost is more than paid for by income from treating bio-waste, from gate fees and from lower electricity expenses. This is a preliminary assessment at the pre-feasibility stage. Further study is needed to evaluate what is practically achievable.

Observations

Based on the analysis we make the following observations:

- The profitability of biogas production at Tomaszow Mazowiecki increases significantly when municipal waste and industrial waste is included. The additional costs of including waste is relatively low, and the plant will cover much of its electricity needs, saving considerable costs in the process.
- A grant is needed to achieve private profitability of 10-12 percent. For phase 1 the grant should be in the range of 22-29 million PLN. For phase 2 the grant is smaller, 10-23 million PL This is another way of stating that the profitability increases in phase 2.
- There is no way that smaller wastewater treatment plants can become self-sufficient in terms of energy without using other substrates than sludge. The Tomaszow Mazowiecki wastewater treatment plant requires 5.5 GWh of electricity per year, and based on sludge the plant will produce about 2.6 GWh. Adding household and industrial bio-waste electricity production increases to 4.4 GWh. This observation means that available grants/loans should not limit the substrate to one stream (eg. only agricultural, only sludge, only municipal bio-waste) as sometimes is the case.
- There is a need to find the use for excess heat. In phase 1 profitability increases when heat is used to dry digestate. Still in this scenario, and in phase 2 there is heat that goes unutilized. Finding a use for the heat could improve profitability and social acceptance. It may also reduce environmental and climatic impacts as excess heat just warms the air. One may consider to include the full use of heat as condition in loan agreements.
- How the digestate is treated (as a bio-fertiliser or as a waste) has an impact on profitability. This is brought out clearly both in phase1 and phase 2 at the Tomaszow Mazowiecki wastewater treatment plant. It is necessary to improve the regulations and conditions for using digestate in agriculture.
- External grants or concessionary loans will improve investor profitability at the Tomaszow Mazowiecki wastewater treatment plant.

1 Background and scope

Our aim with this report is to demonstrate the feasibility and benefits of using bio-waste and biomass for biogas production in the Municipal Functional Area Tomaszów Mazowiecki-Opoczno (MOFTMO). The report is meant to lay the groundwork for scaling-up in other municipal units and areas.

This chapter sets the stage by discussing the political and regulatory context for biogas production, the necessary infrastructure for the biogas value chain, and financial aspects of biogas production. Chapter 2 discusses the potential for producing biogas in the MOFTMO, both currently and in the future. Chapter 3 discusses restrictions and barriers to realizing the potential in the MOFTMO. Chapter 4 focuses on opportunities, as well as best practice examples from other regions of Poland, from Norway, from Germany and from Denmark.

A conclusion to emerge from chapters 1-4 is that realistic opportunities for commercial biogas production in the MOFTMO currently lie in using sludge and municipal waste. Hence, in chapter 5 we develop the business case for constructing a biogas plan in two phases. Phase 1 uses sewage sludge as a substrate. Phase 2 is an expansion to allow the use of municipal and industrial bio-waste.

1.1 European political context

The European Union leaders have agreed to achieve climate neutrality by 2050. As a stepping stone towards this goal, they have decided to reduce the EU's greenhouse gas (GHG) emissions by more than half compared to 1990 levels by 2030. Achieving these objectives requires significant reductions in EU countries' greenhouse gas emissions and strategies to address any remaining unavoidable emissions. Another critical aspect of the EU's efforts towards climate neutrality is the 'Fit for 55' package, which encompasses regulations on energy, transportation, emission trading and reductions, as well as land use and forestry. Investment in renewable energy sources (RES) is essential for realising climate neutrality.

Increasing biogas and biomethane production in the EU can help meet climate neutrality and other targets in water and wastewater management, nature conservation, and waste management.

The Renewable Energy Directive (Directive (EU) 2023/2413) sets a target of at least 42.5 % of the Union's gross final energy consumption in 2030 for energy from renewable sources. It also emphasises the role of energy production from biomass and bio-waste.

The water and wastewater management sector is also expected to contribute to climate goals and the circular economy. According to the proposed policy (COM/2022/541 final), municipal wastewater treatment plants must achieve energy neutrality by 2045. In addition to producing energy for their own use, they will also be obliged to use tertiary treatment, i.e. phosphorus and nitrogen removal. Sludge-fuelled municipal biogas plants can help meet both obligations.

The EU's Farm-to-Fork Strategy (COM/2020/381 final) highlights the role and potential of a circular economy for farmers, who can and should take advantage of the opportunity to reduce methane emissions from livestock farming and the opportunity to manage agricultural waste and residues, including manure. A proposed solution in the strategy is to develop renewable energy and invest in biogas plants. The strategy also sets the course of action in nature conservation, obliging EU countries to reduce nutrient loss by at least 50% while ensuring no loss in soil fertility and reducing fertiliser use by at least 20% by 2030.

A study commissioned by the European Commission's Directorate General for Climate Action (2023) investigates possible ways to price GHG emissions from agricultural activities along the agri-food value chain, in order to reduce emissions from this sector. The study presents five options for an Emission Trading System (ETS) that could incentivise climate mitigation action in agriculture. Since the largest sources of GHG emissions come from enteric fermentation from livestock, nitrous oxide emissions mainly from the use of synthetic fertilisers, and manure management from livestock production, all these areas will be impacted by potential regulations. Implementing the ETS in agriculture will be an incentive to change how manure is managed. Using it to produce biogas is one way to reduce GHG emissions.

The EU target for biogas and biomethane production is 35 billion cubic meters per year by 2030. In 2022, according to the European Biogas Association, almost 20,000 biogas plants and more than 1,300 biomethane plants operated in Europe, producing 16.8 billion cubic meters of biogas and 4.2 billion cubic meters of biomethane (EBA 2023).

1.2 Polish policies and regulations

The biogas sector in Poland is influenced by EU directives and regulations on climate change mitigation, renewable energy, waste management, wastewater treatment, and environmental protection. At the same time, national conditions, such as resource availability, infrastructure, national legislation and policy, shape it. Due to its cross-sectoral characteristic, policies and regulations within several administrative areas influence the biogas system.

Poland, as a member of EU, is committed to increasing the role of renewable energy sources, including biogas, in its energy mix. The National Energy Policy 2040 (NEP2040) sets targets for increasing the use of renewable energy sources to 21% of gross final energy consumption and limiting emissions by 30% by 2030 (compared with 1990 levels). Due to its properties, biomethane derived from biogas can successfully replace natural gas as a source of heating or fuel. The NEP2040 also assumes that in 2030, the ability to transport through gas networks a mixture containing around 10% of decarbonised gases (in particular biomethane derived from biogas and hydrogen) will be achieved.

According to estimates by European Union (Guidehouse, 2022), but also national institutions (Jacyszyn, 2021), Poland has a large potential for biogas production due to the large share of agriculture in our country. The by-products and waste generated during agricultural production are suitable inputs for the methane fermentation process. According to researchers at Poznań University of Life Sciences (Kowalczyk-Juśko, Dach, 2022), the potential for agricultural biogas production in Poland is approximately 13.5 billion cubic meters of raw material per year (7.8 billion cubic meters of biomethane). Managing waste and biomass will also improve the quality of the environment.

The main sources (substrates) of inputs for biogas production are agricultural biomass and waste (animal and plant), municipal and industrial biodegradable waste, and sewage and wastewater sludge. These sources have different characteristics, as well as different purposes of their use and legal regulations.

Both the Ministry of Climate and Environment and the Ministry of Agriculture and Rural Development influence the possibility of using biomass and waste in biogas production. In the direction of intervention, the "Strategy for Sustainable Development of Rural Areas, Agriculture and Fishery 2030" lists investments to use locally available energy raw materials and other resources per territorial potential (including biomass and waste). The "National Waste Management Plan 2028" (KPGO 2028) sets out the directions of activities in biodegradable waste (municipal and other) and municipal sewage sludge management. One of the goals in managing biodegradable waste other than municipal waste is to increase the share of processing waste from agriculture and food processing industry in the fermentation process, including that in agricultural biogas plants. Regarding municipal solid waste, the goal is to ensure selective collection of bio-waste from residents and catering establishments and limit the landfilling of biodegradable municipal waste. The document explicitly mentions the management of bio-waste in biogas plants as one of the directions for handling municipal waste.

The current regulations oblige municipalities (Act on Maintaining Cleanliness and Order in Municipalities) to:

- limit the landfilling of municipal waste to 30% yearly in the period 2025-2029, to 20% yearly in the period 2030-2034, and to 10% yearly from 2035 onward
- limit the landfilling of bio-waste to max 35% of the amount of bio-waste generated in 1995
- prepare for re-use and recycling the following percentages of municipal waste: in 2023 – 35%, in 2024 – 45%, in 2025 – 55%, then every year 1% more till 2035 – 65%

Regarding municipal sewage sludge, the KPGO 2028 sets the goal to reduce the amount of municipal sewage sludge generated as waste, abandon landfilling completely, and increase the amount of sludge treated before it is released into the environment. The course of action proposed in the "National Wastewater Treatment Programme" (VI update) (AKPOŚK 2022) for sludge reduction includes intensifying the anaerobic stabilisation process (and biogas production) and intensifying the final sludge dewatering process. Sewage sludge, after appropriate treatment, can be used for compost production and fertilisation in agriculture.

At the stage of biogas production, there is a distinction between biogas plants and agricultural biogas plants, resulting from the type of substrates processed and the resulting division of responsibilities and competencies between different administrative areas. Agricultural biogas plants produce agricultural biogas (or electricity, heat, and biomethane from agricultural biogas), where agricultural biogas is defined as gas obtained in the methane fermentation process of a limited catalogue of substrates of agricultural or food processing origin. Agricultural biogas plants are registered in the National Agriculture Support Center (KOWR)[1], the executive agency of the Ministry

[1] To visit the registry, go here: https://www.gov.pl/web/kowr/rejestr-wytworcow-biogazu-rolniczego

of Agriculture and Rural Development responsible for the implementation and application of instruments supporting active agricultural policy and rural development.

The Act on facilitating the preparation and implementation of investments in agricultural biogas plants and their operation introduces many simplifications that speed up the construction and facilitate the management of the existing agricultural biogas plants, such as preferential terms for location and simplification for the use of digestate as fertilizer. However, the act does not apply to all facilities, but only to those managed by farmers, and it introduces a number of legal restrictions regarding maximum yearly biogas production and acceptable substrates.

Biogas plants other than agricultural ones are not limited by the choice of substrates. Depending on the technology, they can accept diverse feedstock materials such as sewage sludge and industrial or municipal bio-waste. These biogas plants are registered at the Energy Regulatory Office (URE)[2], a central government administration body established to carry out tasks related to fuel and energy management regulation and competition promotion.

The market for electricity generation from biogas, excluding agricultural biogas, is supervised by the President of URE. The office grants a license to conduct business activities in this field and verifies compliance with its conditions. It also makes an entry in the register of small installations of renewable energy sources and verifies compliance with the statutory requirements for conducting regulated business activity in this area. Supervising the market of agricultural biogas, biocomponents, and bioliquids, as well as the functioning of energy cooperatives and the production of liquid biofuels by farmers for their use, is exercised by the General Director of KOWR.

Investments in biogas plants in Poland are gaining popularity due to emerging solutions that facilitate implementation, such as legal frameworks for small agricultural biogas plants and funding opportunities. National regulations provide several support systems dedicated to biogas plants, including feed-in tariffs (FIT), feed-in premiums (FIP), and an auction system. These regulations also allow for electricity generated from biogas to obtain guarantees of origin (these do not constitute public aid).

Poland has a FIT system for renewable energy source (RES) installations that feed energy into the electricity grid. This system is designed for installations with a total electrical capacity of less than 0.5 MW, producing energy from sources such as agricultural biogas, landfill biogas, or sewage sludge biogas. It guarantees the sale of all, or part of, the energy not used by the producer at a fixed price equal to 95% of the reference price to a mandated supplier or a chosen entity. The second system, the FIP (feed-in-premium) market price subsidy system, is dedicated to larger installations (from 500 kW to 1 MW in the case of energy production from biomass). The FIP system allows the sale of electricity from biogas at a fixed price equal to 90% of the reference price exclusively to an entity selected by the producer. The possibility to benefit from this support is limited to a maximum of 17 years. The reference price varies depending on the specific technology and capacity of the installation and is determined by regulations. Currently, the highest reference price applies to the smallest installations using agricultural biogas in high-efficiency cogeneration, amounting to 1025 PLN per MWh, which is more than two and a half times higher than the market price of energy. For a biogas plant with a capacity of less than 500 kW using only biogas obtained from sewage treatment plants, the reference price is PLN 572/MWh. If the energy is produced in

[2] To visit the registry, go here: https://rejestry.ure.gov.pl/o/21

high-efficiency cogeneration, the price is PLN 714/MWh. For biogas plants with capacities between 0.5 and 1 MWh, the reference prices are PLN 520 and 663/MWh, respectively.

The auction system, generally used by energy producers in biogas plants with a capacity greater than 1 MW, involves competing producers submitting bids to sell a specified amount of energy in a given calendar year. The producer who wins the auction gains the right to cover the negative balance, which is the difference between the market price of electricity and the winning bid submitted in the auction, for a period not exceeding 15 years. The scheme is known as "contract for difference". However, due to the less attractive reference prices for biogas plants greater than 1 MW compared to those for smaller biogas plants, the enforcement of competition by rejecting extreme bids, and the significant increase in investment costs and the purchase of substrates for biogas production, auctions dedicated to large biogas plants have remained unresolved for years[3].

Support for biomethane is based on a FIP mechanism. The support period in this system is 20 years from the first day of biomethane sales covered by the support, but not longer than June 30, 2048. The reference price of biomethane is determined by regulations. Currently, the reference price of biomethane for a renewable energy source installation producing biomethane from biogas is 538 PLN/MWh. In the case of producing biomethane from agricultural biogas, the reference price is 545 PLN/MWh.

Recently, there have been more and more public campaigns to raise the ecological awareness of citizens and increase the level of social acceptance for this type of investment in local communities.

1.3 Infrastructure, technology, and logistics

In anaerobic digestion, microorganisms metabolise organic-rich biomass (e.g., agricultural, industrial and municipal wastes) to produce biogas, a mixture of mainly methane and carbon dioxide. The anaerobic digestion of organic matter is a four-step process, including hydrolysis, acidogenesis, acetogenesis, and methanogenesis. Every step is associated with different microbial populations. The time needed for biomass degradation to biogas, or macromolecules to mainly methane and carbon dioxide, varies depending on the nature of the chemical bonding of the carbohydrate in the biomass.

1.3.1 Infrastructure for substrate collection

One of the substrate sources for biogas production is the biodegradable fraction of municipal solid waste. In Poland since 2012, the responsibility for collection and management of municipal solid waste lies with municipalities. In each municipality, waste management is organized according to the rules established by the relevant resolutions of municipal councils. The responsibility to improve infrastructure, particularly waste collection and recovery, and achieving reuse and recycling targets also lies with municipal authorities. Municipalities in Poland, like in the rest of Europe, are obliged to ensure selective collection of municipal waste, including at least paper, metals, plastics,

[3] https://codozasady.pl/p/aktualne-uwarunkowania-rynku-biogazu-w-polsce; accessed 27.06.2024

glass, multi-material packaging waste, and bio-waste. The collection of municipal waste is financed by the waste fee paid by the inhabitants to the municipalities and, in the case of municipal waste from other sources, paid by owners to the collection companies. The main principle in determining the waste fee is the necessity to ensure the self-financing of the waste management system. The waste fees should cover the costs of collecting waste from inhabitants, its transport and treatment, but also the administrative costs and cost of educational activities. Segregated municipal waste is collected from properties according to a schedule established by the municipality, using special vehicles and transported to a waste management site, e.g. sorting plant, composting plant, incineration plant, or landfill. Municipalities are also setting up collection points for municipal waste, where residents/businesses can individually deliver their waste, including bio-waste. The condition for using bio-waste in anaerobic digestion is the separate collection of food and kitchen waste, which is an appropriate substrate for the process. At the same time, implementing separate collection is difficult. Local governments face many problems in this area. In addition to the organizational (the need to equip households with additional bins) and logistical aspects (bio-waste requires more frequent collection), the lack of finances is also a problem. Currently, in many municipalities, the high fees charged to residents for waste collection do not cover the costs of managing the system.

Biodegradable industrial solid waste, e.g., from the food industry, which also is an appropriate substrate for biogas production, is transported by special trucks, based on mutual agreements between producers and transport companies, to appropriate waste treatment facilities such as composting or biogas plants. Liquid biodegradable waste, e.g., from dairies or food processing plants, is delivered by barrel trucks to specially prepared storage tanks at the treatment plants.

Another group of substrates for biogas production is sewage sludge produced at wastewater treatment plants. Collecting and treating municipal wastewater, like waste management, is one of the municipality's own responsibilities. Municipal wastewater from a defined area is transported via sewer pipelines (or, in the case of a lack of sewage systems, by septic trucks) to a wastewater treatment plant, where it undergoes a treatment process. The generated preliminary and secondary sludge can be transported by pipelines to the sludge treatment part of the plant. For industrial wastewater, two main approaches can be distinguished. Wastewater meeting the requirements (limits) of a municipal wastewater treatment plant in terms of its pollutant content can be discharged to this plant. If the pollutant content is exceeded, it may be necessary, for example, to build an on-site wastewater treatment plant. The sludge from the on-site wastewater treatment plant is then transported to a waste treatment plant.

A significant source of substrates for biogas plants is agricultural biomass. It includes animal by-products, vegetable by-products and crops for silage production. Some of this biomass can be used by farmers for their purposes, e.g. manure and slurry can be used as fertiliser on their land. However, with a large cattle or pig farm, the resulting volumes of manure and slurry can be problematic to manage. Generated biomass used in agriculture or forestry is not classified as waste and recorded in any database. Excessive biomass, requiring further treatment, becomes waste. To transfer the waste to be managed/processed by another party, farmers must enter into appropriate contracts and agreements for the transfer and treatment of waste according to the law. Such waste is transported by suitable vehicles to the place of treatment, e.g. a composting plant, incineration plant or biogas plant. Until collection, the waste must be stored appropriately, e.g. the manure must be stored on impermeable ground to prevent environmental pollution.

1.3.2 Biogas production infrastructure

Three types of biogas plant can be distinguished depending on the type of substrate used:

- biogas plant using biodegradable municipal or industrial waste,
- biogas plant at a wastewater treatment plant using sewage sludge,
- agricultural biogas plant using agricultural biomass or waste from agri-food processing.

Each biogas plant, regardless of the type of substrate to be processed, consists of several basic segments:

- segment I – substrate storage and pre-treatment segment (this segment includes, among others, substrate tanks, pumps, macerator, hygienization system and raw material storage/removal system, batch averaging);
- segment II – digester (may be constructed of various materials, e.g. concrete, two-fibre plastics, steel sheet; the digester is usually equipped with an agitator, foam detector and catcher, liquid level meter inside the digester);
- segment III – heating system (to maintain the correct temperature for the selected fermentation process, equipped with heat exchangers);
- segment IV – gas installation system (responsible for collection, purification and storage of the biogas produced, a very important part of this system is the desulphurization unit);
- segment V – storage or processing segment for the digestate (e.g. digestate tank, installation for further processing of the digestate into fertilizer, digestate dehydration installation – centrifuge or press);
- segment VI – combined heat and power plant, equipped with cogeneration units producing electricity and heat which will be used to heat digestate in the digesters and as central heating and to power electrical equipment in the treatment plant. Surplus electricity and heat may be sold. A heat exchanger is a key element in this system, which heats the digestate in the digesters.

Location is essential when building a biogas plant. The choice of location depends on several factors, including the area needed for the investment, access to substrates (including the possibility of transporting them on paved roads), access to electricity infrastructure for connection to the grid and, in the case of the production of biomethane from biogas, access to the gas grid.

In the case of an agricultural biogas plant, the entire investment, including the storage area for substrate and digestate, covers an area of more than 1 ha. Due to their construction in the vicinity of large farms, i.e. sites of substrate production (e.g. manure, silage), agricultural biogas plants are dispersed throughout the country. Agricultural biogas plants can also be located near food processing plants, where there is a lower demand for space. Municipal or industrial biogas plants located next to food processing plants, wastewater treatment plants, or waste treatment facilities demand little space because they are part of a more extensive technological system/infrastructure complex. These facilities already have space for the storage of substrate and digestate. In this case, the biogas plant is only one component of the overall plant.

Depending on the type of substrate and their location, biogas plants are characterised by varying parameters. These parameters include, among others, the availability and energy value of substrate (feedstock), ease of fermentation, annual capacity (cubic meters/year), electrical and thermal capacity because cogeneration is often the method of choice for energy production. The possibility of using post-fermentation residues (digestate) is also an important aspect.

The efficiency of a biogas plant depends, among other things, on the choice of substrates, which have different organic content and methane productivity. Many substrates can be used to produce biogas. They differ primarily in origin, consistency, composition, and density. The primary substrates for biogas production are:

- by-products and waste from the food industry (e.g. from the distillery, meat and dairy industries, fruit and vegetable processing)
- agricultural biomass and waste (e.g. manure, slurry, straw, hay)
- sewage sludge from wastewater treatment
- biodegradable municipal waste
- energy plants intended for fermentation (e.g. corn, sunflower, grass, sorghum)

The issues that need to be considered regarding substrates, besides their origin, are:

- composition (dry matter content, organic matter content, carbon to nitrogen ratio)
- possible contaminants with inorganic materials, wood, bones, feathers, soil, disinfectant, pesticides, antibiotics
- seasonal fluctuation
- need for storage in terms of quantity and duration

Proper substrate preparation is necessary for the anaerobic digestion process to run smoothly. Therefore, pre-treatment is required to ensure process efficiency, maximise product yield, and reduce operation costs. The pretreatment aims to remove non-biodegradable materials and homogenise the feedstock. There are different types of pretreatment methods:

- physical: mechanical, thermal, ultrasound, electrochemical
- chemical: alkali, acid, oxidative
- biological: microbiological, enzymatic
- combined process: extrusion, thermochemical

Contaminants in substrates are separated through screening. The maceration of feedstock aims to create the right consistency for further processing. Particular feedstocks, such as sewage sludge or animal by-products, require a sanitisation stage, eg. through pasteurisation.

Depending on the feedstock, the pretreatment can be a simple process, as in the case of manures and slurries or a more complex, multistage process, as in the case of municipal bio-waste or commercial and industrial biodegradable wastes. In the case of source-separated food waste, depackaging and screening are required, similar to waste from the commercial sector containing expired or unfit-for-consumption products. Adequate elimination of contaminants is crucial for the process to be efficient and failure-free. Contaminated feedstock can cause abrasion in the hydraulic line and the pumps and reduce the available reactor volume in case of deposition (Jank et al. 2015).

Besides removing non-biodegradable materials and homogenising the feedstock, the pretreatment process aims to improve biogas yields. In the case of sewage sludge, the pretreatment of sludge is expected to help reduce its high resistance to both dewatering and biodegradation. The increase in nutrients accessible to microbes enhances the digestion rates, reduces the retention time, and increases biogas production (Kasinath et al. 2021). What is necessary to consider is that any pretreatment is an additional step in the digestion process, and the improvement of biogas production should cover its capital and management costs.

Another method of optimising the biogas production process and increasing its efficiency is co-digestion. According to research (Kowalczyk-Juśko, 2013; Grosser et al., 2017; Kasinath et al., 2021), using a mix of substrates can significantly enhance biogas production compared with mono-digestion.

Biogas plants can be divided according to their size and amount of substrate:

- large-scale, centralised biogas plants - plants with a substrate input of 50 to 500 tonnes per day; substrates are obtained from several sources, often located in close proximity to substrate producers, e.g. large livestock farms or food processing factories,
- small-scale, stand-alone biogas plants - plants usually using substrates from a single source.

A biogas plant's main elements are the separate digesters, where the digestion process and biogas production occur. These are characterised by different volumes, depending on the amount of substrate to be processed. In medium-sized biogas plants, digesters with a volume of around 1,000 cubic meters are most common. They are connected in systems (e.g., 2-4 chambers). Higher-capacity plants have large separate digesters with more than 5,000 cubic meters volumes. In agricultural biogas plants, the typical volume of the digester is around 1,000-1,500 cubic meters.

When determining the biogas plant’s electrical capacity, it is important to consider whether the energy produced will meet only the facility's needs or be produced in larger volumes for sale and fed into the grid. In the case of agricultural biogas plants, the typical electrical capacity of the installation is 1 MW. Still, there are also plants with a capacity of 2.4 MW or 3.5 MW. Due to special legal facilitations for establishing agricultural biogas plants of less than 0.5 MW, more installations of this size may appear on the market.

The technical lifetime of a biogas plant is estimated to be more than 20 years (up to 30 years), but this depends on a number of factors, including the regular carrying out of all necessary maintenance work and the replacement of individual parts or equipment in the plant.

1.3.3 Biogas production technology

The choice of biogas production technology depends primarily on the type of substrates selected. Technological solutions are divided according to specific criteria, which include:

- dry matter content of the substrates
- process temperature
- the number of process steps
- the degree of separation of the individual digestion phases

- the method of substrate injection into the digester

Table 1.1 Classification of biogas production technologies

Criteria	Type of technology	Characteristics
Process temperature	Mesophilic	35-37 degrees Celsius, most commonly used
	Thermophilic	55-60 degrees Celsius, less commonly used. Higher capacity, but process more sensitive to disturbance
Dry matter content of the digester	Wet fermentation	Dry matter content of substrates does not exceed 15%, and the fermented substrate is liquid
	Dry fermentation	Very high dry matter content in the feedstock, solids in the digestate
The number of process steps	Single-stage	The installation includes one digester
	Multi-stage	The installation comprises several chambers, where different processes are carried out in the individual stages, e.g. preheating in the 1st stage
The degree of separation of the individual digestion phases	Single-phase	Substrate hydrolysis and methanogenesis take place in one reactor with equal intensity
	Multi-phase	Substrate hydrolysis and methanogenesis take place in separate reactors
The method of substrate injection into the digester	Continuous	Substrate dosing is carried out evenly and continuously to maintain a constant biogas production rate
	Batch	The digester is filled once and emptied at the end of the process. The biogas production rate is higher at the beginning of the process, decreasing over time

Source: Kwaśny, Banach and Kowalski (2012)

1.3.4 Infrastructure for (raw) biogas demand

There are various utilization pathways for both raw and upgraded forms of biogas. Commercially feasible biogas utilization methods include electricity and heat generation with combined heat and power (CHP), electricity generation in fuel cells, multigeneration of heat, steam, electricity and cooling in industry, injection in the gas grids, transport fuel, and production of chemicals (Budzianowski 2016). Biogas purification, aimed at removing trace components adversely affecting the gas transmission grid, appliances, or end-users, is necessary before its use. The process of biogas upgrading, aimed at removing carbon dioxide to adjust the calorific value and relative density, is an optional step but is necessary for injecting biogas into the gas grid or producing transport fuel. Biomethane or bio-synthetic natural gas (bio-SNG) is a clean fuel for transport or injection into natural gas grids. Biogas can be upgraded to biomethane by separating carbon dioxide or converting carbon dioxide to methane. Biomethane can be injected into the gas grid and/or converted to compressed biogas or liquefied biogas (bio-CNG and bio-LNG, respectively) to serve as a transport fuel. Bio-CNG and bio-LNG are chemically equivalent to compressed natural gas (CNG) and liquefied natural gas (LNG) respectively. The decision on how to best utilize the energy largely depends on the facility's size, available infrastructure and technology, and costs.

On-site electricity and heat generation and use

Very often the primary purpose of building a biogas plant is to achieve energy self-sufficiency, both electrically and thermally. The most common solution is to use an engine or power station to generate electricity and heat simultaneously (cogeneration, CHP). For example, for all agricultural biogas plants operating in Poland, the most common pathway of biogas utilisation is the combined generation of heat and power (CHP) (Holewa-Rataj and Kukulska-Zając 2022). The biogas plant is equipped with a cogeneration engine, where the combustion of biogas results in electricity and heat, which are used in the operation of the plant and the associated facilities. The efficiency of electricity production can reach 45% or more for gas engines and micro-gas turbines. CHP efficiencies of over 80% can be achieved if both the exhaust gas heat and water heated within the cylinder jacket are utilised (Budzianowski 2016). Usually, there are no problems with the production and use of own electricity. However, the use of heat produced in cogeneration is problematic. Many biogas power plants utilise the heat generated as a byproduct solely for internal purposes, specifically to sustain the anaerobic digestion processes. They do not meet any external heat demand. When the biogas plant has a connection with district heating systems, the heat can be used in district heating (see more below). Some biogas plants install dryers to use the excess heat for drying digestate or various types of agricultural products (crops, especially legumes and cereals), which is an essential treatment for storing and selling these products. Such installations are becoming increasingly popular in Poland and Europe. Another possible use of excess heat is to heat the greenhouses.

Use in district heating

If heat energy is produced in greater quantities than the biogas plant's requirements, it is possible to sell it to the local district heating network. Such a solution is advantageous in the case of large surplus heat and the proximity of a district heating hub, to which the biogas plant would have to make a connection. However, this is rarely the case, as biogas plants are often far from residential buildings. The construction of a connection to a heat network significantly increases investment costs.

Grid feed-in

In Poland, purified and upgraded biogas (biomethane) can be fed into the natural gas distribution grid. According to the law, the injected biomethane must meet the energy and quality requirements for the given gas type. Before feeding biomethane into the grid, besides purification and upgrading, the gas grid operator issues a decision stating the conditions for connecting the biogas installation to the gas grid.

Transport fuel

A viable and increasingly popular option is using biogas as a transport fuel. The biogas can be converted to compressed biogas (CBG) or liquified biogas (LBG). The key steps involve upgrading biogas to biomethane and compression of biomethane to CBG, which can then be used in vehicles. CBG is distributed through pipelines or transported in tanks to fuelling stations. Vehicles must be compatible with CNG or dual-fuel (CNG and diesel) systems. In the case of LBG, biogas is first upgraded to biomethane and then it is cooled to cryogenic temperatures (-162°C) to convert it into a liquid state. LBG is stored in cryogenic tanks and can be transported in insulated tankers over longer distances than CBG. LBG can be used as a fuel for vehicles that run on liquefied natural gas (LNG), especially heavy-duty trucks and marine vessels.

1.3.5 Digestate for soil improvement

Due to its properties and its content of nutrients suitable for plant cultivation, the biogas-derived digestate is most often used in agriculture as a substitute for artificial fertiliser.

The digestate can be introduced to the market as a by-product of the fermentation process or as an organic fertiliser. The use of digestate as a fertiliser requires a permit from the Ministry of Agriculture and Rural Development. The digestate should be used in accordance with the recommendations/instructions.

Due to the seasonality of fertilizer use under Polish climatic conditions, digestate must be stored between fertilization seasons in appropriate conditions that will maintain its properties and limit its potential negative impact on the environment (from e.g. leakage, smell).

1.3.6 Technological developments and potential

As biogas production levels increase above a producer's own energy need, the economic feasibility of biomethane production increases, opening up new opportunities for plant development and use of the resulting product. Biomethane, which can successfully replace natural gas, is produced by upgrading biogas. There are several methods for upgrading biogas and obtaining biomethane, among which we can distinguish (Podgórska and Narloch 2022):

- physical absorption
- chemical absorption
- pressure absorption
- membrane separation
- cryogenic separation
- biological conversion
- in situ method (very rare).

The most common method is physical absorption, where a water scrubber and solvent are used. In this method, the biogas is compressed and delivered to an absorption chamber through which it flows from the bottom to the top. In the chamber, the water seeps from the top to the bottom, through which it will encounter a counter-current of gas. Using a solvent, the biogas is compressed again and then cooled to around 10-20ºC, allowing some of the steam to condense. Contact between the compressed biogas and the organic solvent results in the absorption of CO_2 and H_2S. The purified gas, already biomethane, contains about 98% pure CH_4.

A frequently used method for the purification of biogas from sewage treatment plants or landfills is the membrane separation method, which allows the separation of impurities, again mainly CO_2 and H_2S. The membrane acts as a filter through which some components of the gas mixture to be separated pass and others are retained. In this method, there are usually two membranes.

The biological conversion method, which involves the biological treatment of biogas, remains at the research stage. According to the available literature, results to date demonstrate the high potential of the method, assuming simplification of technological installations and lower equipment and operating costs.

Available biogas purification technologies allow, among other things, three stages of biogas purification and upgrading to be distinguished.

Table 1.2 Biogas upgrading stages according to the directions of use

Stage of biogas upgrading	Description of the upgrading process	Possible use of the product
First stage	Water vapour removal and H2S removal (below 1000 ppm)	Combustion in furnaces to produce heat or steam Combustion in microturbines or Stirling engines
Second stage	Steam removal and H2S removal (below 1000 ppm) and CO2 removal (below 5% by volume)	Combustion in microturbines, CHP or Stirling engines
Third stage	Steam removal and H2S removal (below 1000 ppm) and CO2 removal (below 5% by volume) and Removal of various pollutants below target/required levels	Injection of biogas into the natural gas grid Production of CBG (compressed biogas) or LBG (liquid biogas) fuels for vehicles Production of chemicals

Source: Podgórska and Narloch (2022)

The potential of biogas for biomethane production is relatively widely exploited in Europe. By 2021, there were almost 1,000 installations operating on the continent. In Poland, no biomethane plant is in operation as yet, although work on installations has begun. According to one of the investors we have spoken to, the first biomethane plant in Poland is to be commissioned in the Warmińsko-Mazurskie Voivodeship in the second half of 2024. The investor also has plans to convert three other existing biogas plants into biomethane plants.

The development of biogas and biomethane production, and ultimately biofuels, will involve the need to expand vehicle fuelling infrastructure.

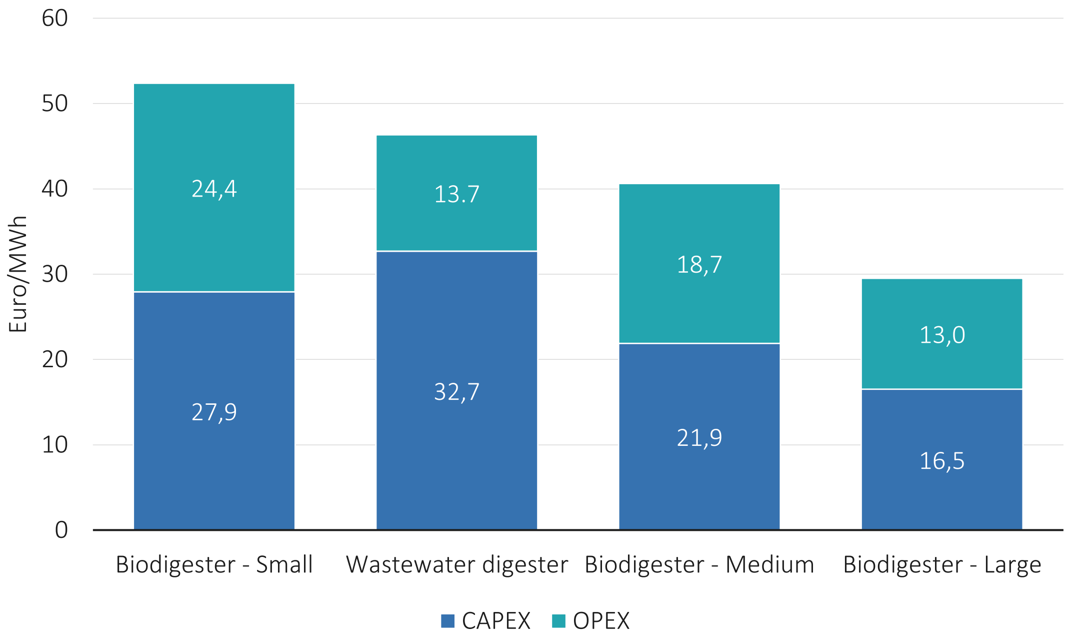
1.4 Financial aspects

The financial aspects of biogas production are influenced by capital (CAPEX) and operational (OPEX) costs, which vary across different facility sizes and feedstock types. Capital expenditure

(CAPEX) refers to the funds a company allocates to acquire and upgrade physical assets, such as buildings, equipment, machinery, and vehicles. Operating expenses (OPEX) include the ongoing costs that a company incurs for running its day-to-day operations, such as maintenance and repair of production equipment and facilities, expenses related to electricity, heat and other inputs, labor costs, pre-treatment of feedstock, etc.

International Energy Agency's (IEA) average costs of biogas production technologies are presented in Figure 1.1. There are two main categories included in the figure: biodigesters and wastewater digesters. Biodigesters, referring to systems that use organic waste materials such as agricultural waste, animal manure and food waste, are sorted into three size categories: small, medium, and large, with capacities of 100 cubic meters/h, 250 cubic meters/h and 750 cubic meters/h. The wastewater digester category refers to existing wastewater treatment plants adapted to process sludge produced at a municipal level with a capacity of 1,000 cubic meters/h (IEA, 2020). The expected production lifetime of each technology is factored into the capital investment calculations. The expected production lifetime is 20 years for both biodigesters (small, medium, and large) and wastewater digesters. It's important to note that these figures exclude the cost of feedstock.

Figure 1.1 Average costs of biogas production technologies per unit of energy produced (excluding feedstock), 2018



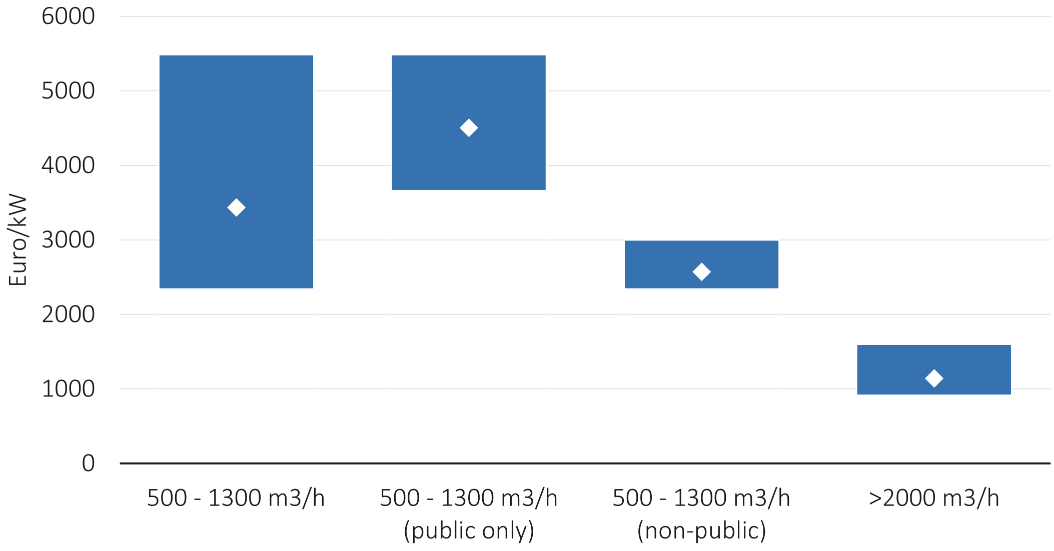
Source: (IEA, 2020)

Wastewater digesters have the highest capital cost, with a CAPEX of approximately 33 euros per megawatt-hour. Biodigesters have decreasing capital costs as the capacity of the digester increases, starting at 27.9 euros/MWh for small digesters, 21.9 euros/MWh for medium digesters and 16.5 euros/MWh for large digesters. The capital costs show economies of scale for biodigesters, but this is not the case across technologies. The wastewater digester has a capacity of 1,000 cubic meters of gas per hour, surpassing that of the largest biodigesters. However, it incurs higher capital costs per megawatt-hour. Operational costs for biodigesters also demonstrate economies of scale. Small biodigesters incur an average OPEX of 24.4 euros per megawatt-hour, compared to 18.7 for digesters with medium capacity, and 13 euros for large biodigesters. According to the IEA, a wastewater digester has an average OPEX of 13.7 euros per megawatt-hour, comparable to a large biodigester.

Looking at total cost, small biodigesters have the highest cost per megawatt-hour, followed by wastewater digesters. For biodigesters, OPEX as a share of total costs decreases as plant capacity increases, suggesting that scaling up the plant does not proportionally increase man-hours and maintenance requirements. CAPEX as a share of total costs is slightly above 50 percent for all biodigester capacity; 56 percent for large digesters, 54 percent for medium digesters and 53 percent for small digesters. The cost structure for wastewater digesters distributes differently, with CAPEX comprising about 70 percent of total costs. This highlights a relatively high initial capital investment for wastewater digesters, though their operational costs align closely with those of large biodigesters.

In 2023, the Biomethane Industrial Partnership (BIP) collected company data from several European biomethane producers. The report based on this data collection contains data on feedstock cost, biogas production cost, biogas upgrading cost, down-stream biomethane costs, and by-products. Capital and operational costs related to biogas production is presented in Figure 1.2 and Figure 1.3 , respectively.

Figure 1.2 Biogas facility CAPEX range by facility capacity and feedstock type

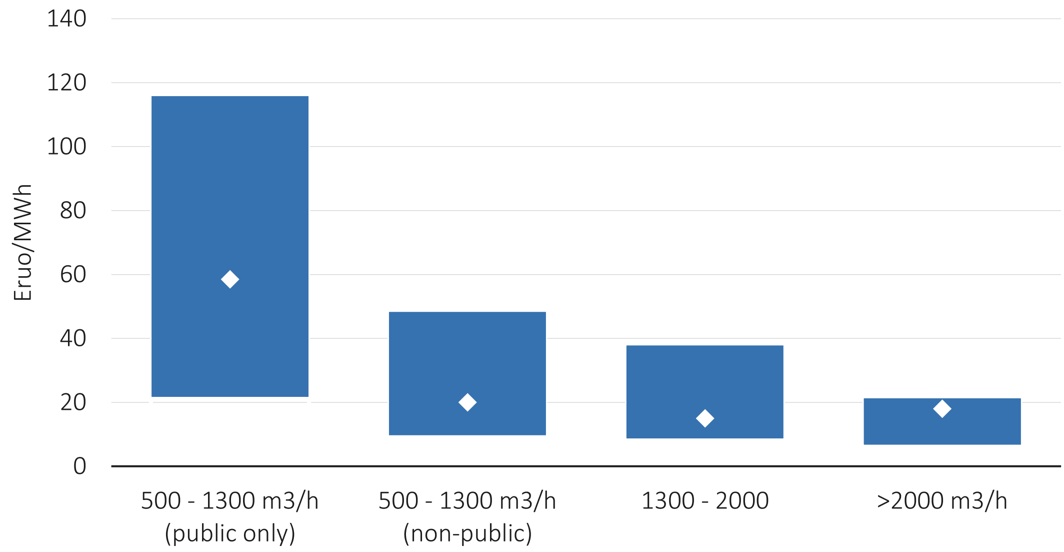


Source: Based on figures from The Biomethane Industrial Partnership, 2023

As seen in Figure 1.2, plants with a capacity between 500 and 1300 cubic meters of gas per hour have CAPEX ranging between approximately 2300 and 5500 euros per kilowatt, with an average of 3400. However, for larger plants, with a production capacity of more than 2000 cubic meters per hour, CAPEX ranges between 900 and 1600 euros per kilowatt, with an average of 1140. The cost per kilowatt installed decreases as the capacity of the plant increases, suggesting significant economies of scale. This aligns with the IEA data in Figure 1.1. Due to few observations, facilities with capacities below 500 cubic metres per hour and those between 1300 and 2000 cubic metres per hour were excluded from the CAPEX overview.

CAPEX also varies depending on the type of feedstock that goes into production. The Biomethane Industrial Partnership survey finds significant variation in capital costs between plants that use public feedstock and those that use non-public feedstock. In this case, public feedstock refers to both municipal solid waste (MSW) and wastewater treatment plant sewage sludge. Biogas plants in the 500-1300 cubic meters/h capacity range that use non-public feedstock face capital costs ranging between 2200 and 3000 euro per kilowatt. On the other hand, plants in the same capacity range using public feedstock face significantly higher capital costs, ranging between 3800 and 5500 euros per kilowatt. According to the numbers reported to the Biomethane Industrial Partnership, biogas plants that use public feedstock require approximately 80% more investment than other plants.

Figure 1.3 Biogas facility OPEX range by facility capacity and feedstock type

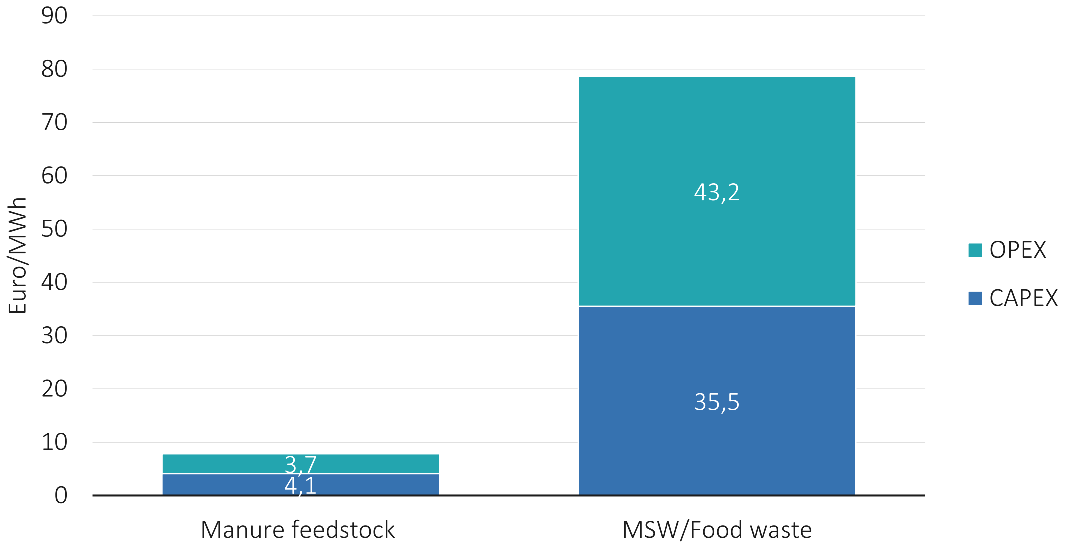


Source: Based on figures from The Biomethane Industrial Partnership, 2023

Figure 1.3 provides an overview of operational costs (OPEX) for biogas production, categorized by size and type of feedstock. According to this 2023 data on from the Biomethane Industrial Partnership, larger biogas plants typically incur lower operational costs per MWh produced. However, the economies of scale are not as pronounced as those observed for capital costs, with the average remaining around 20 euros/MWh for facilities of all sizes using non-public feedstock. Whether the facility use public or non-public feedstock appears to be the most significant factor influencing OPEX. Facilities with a capacity of 500 to 1300 cubic meters per hour that use public feedstock have an average OPEX three times higher than those using other feedstock in the same capacity range.

According to the numbers from BIP, biogas production facilities using public feedstock tend to incur higher capital and operational costs than other facilities. The biggest difference between facilities that use public feedstock and those that use non-public feedstock is the kind of pre-treatment the feedstock requires. Figure 1.4 shows the average costs related to pre-treatment of feedstock for facilities using manure, a non-public feedstock, and municipal solid waste, a public feedstock. Total costs related to pre-treatment of feedstock in a facility that uses manure as its main feedstock is approximately 8 euros per megawatt-hour. The total is evenly split, with CAPEX accounting for 4.1 euros and OPEX for 3.7 euros per megawatt-hour. For facilities using municipal solid waste or food waste as feedstock, the total costs are significantly higher, approximately 79 euros per megawatt-hour. The split between CAPEX and OPEX is similar to that of non-public facilities, with CAPEX accounting for approximately 45 percent of total costs.

Figure 1.4 Costs related to pre-treatment of feedstock



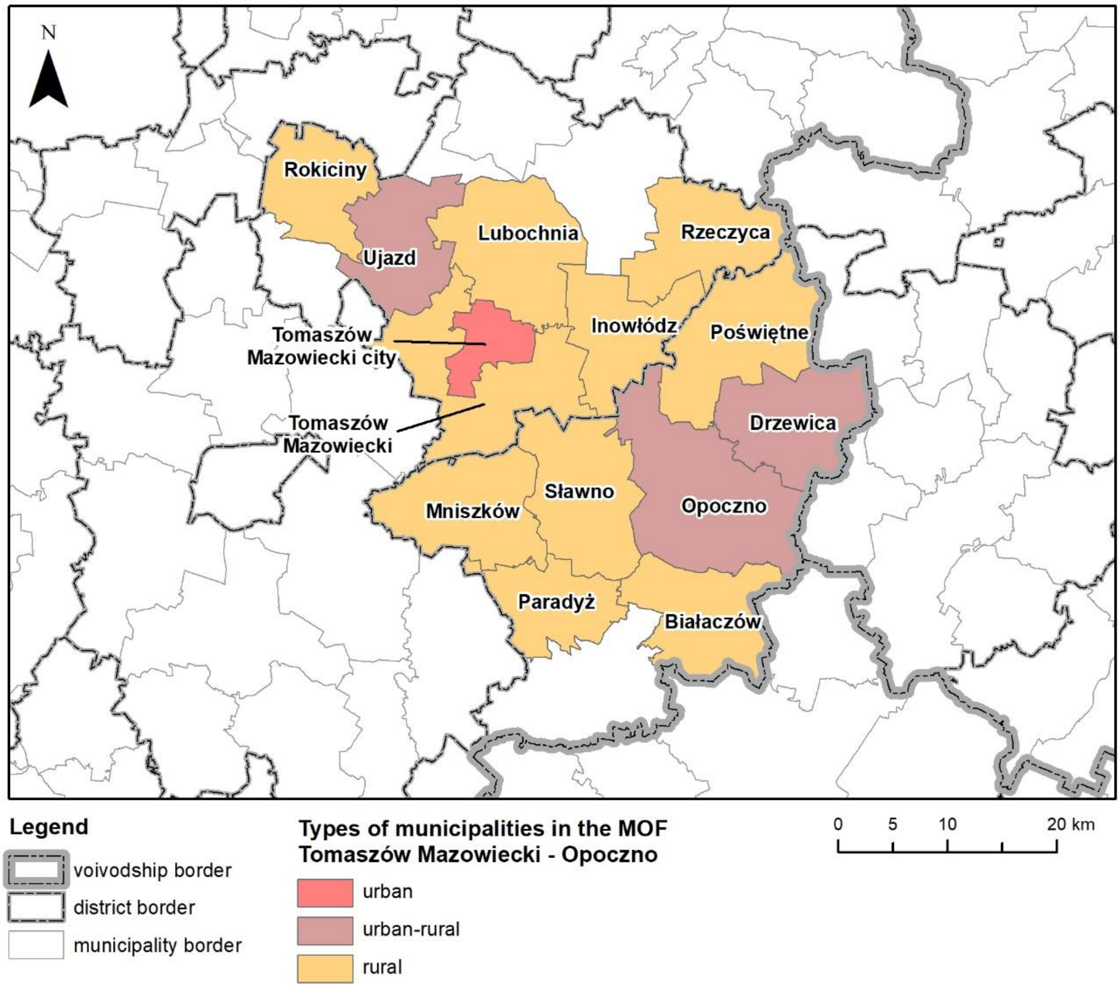
Source: Based on figures from The Biomethane Industrial Partnership, 2023

2 Resource evaluation of MOFTMO

2.1 The MOFTMO

The subject of this study is an analysis of the possibilities of developing biogas production from biomass and bio-waste in MOFTMO. The area consists of 14 municipalities of the Tomaszowski and Opoczyński districts in the Łódzkie Voivodeship. An inter-municipal association was established in order to develop a joint strategy for integrated territorial investments and its implementation. Figure 2.1 shows the municipalities included in MOFTMO.

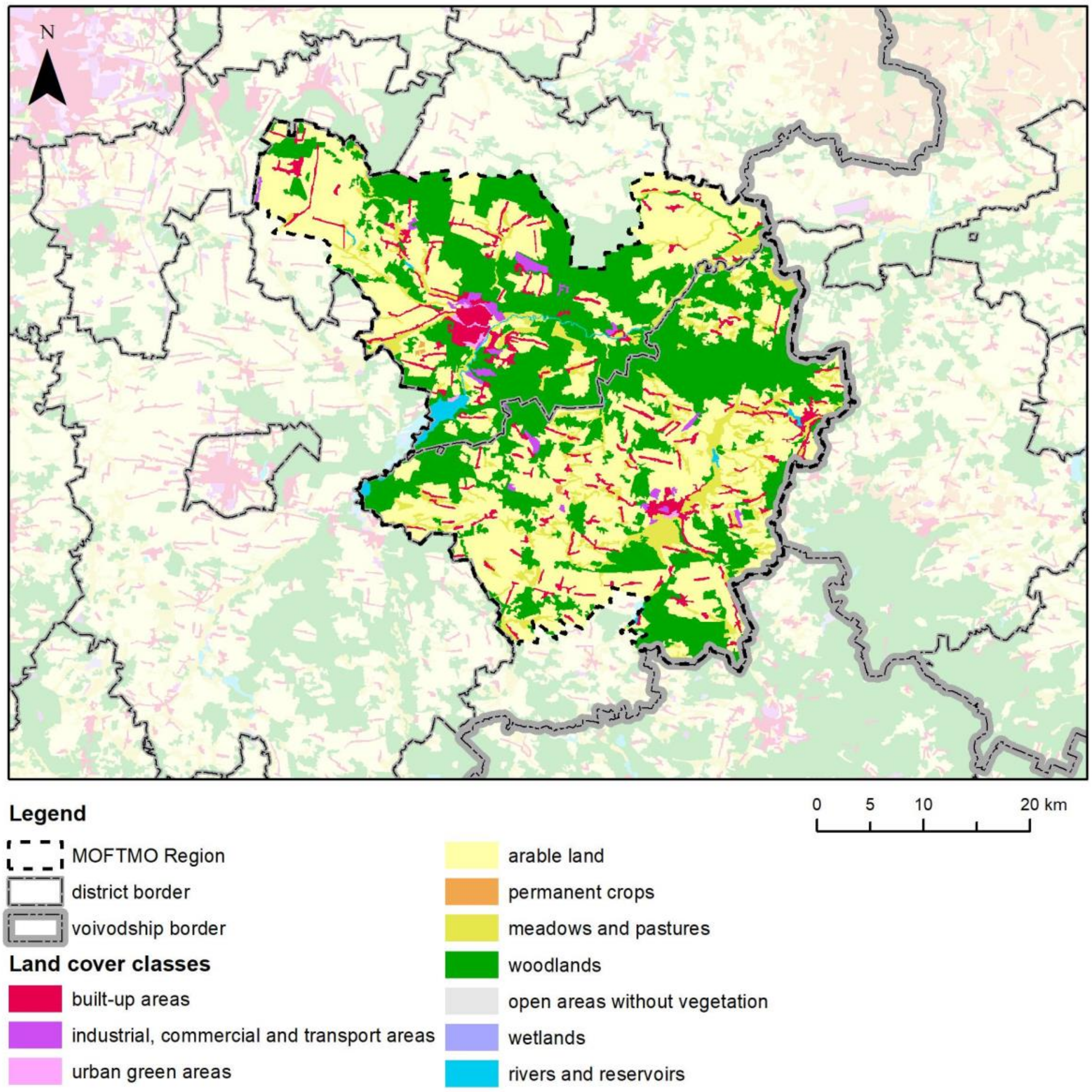
Figure 2.1 Administrative location of the MOFTMO



Source: IOŚ-PIB based on Head Office of Geodesy and Cartography (GUGiK)

MOFTMO is located in central Poland. In terms of land use, it is a predominantly agricultural area (see Figure 2.2). Agricultural land, with a predominance of arable land, covers just over 53% of the area. The MOFTMO has high forest cover (around 38%). Forests are located in its central part, along the valley of the main river – Pilica River, and smaller streams.

Figure 2.2 Land cover in the MOFTMO



Source: IOŚ-PIB based on Corine Land Cover (EEA) and Head Office of Geodesy and Cartography (GUGiK)

The MOFTMO area is inhabited by approximately 160,000 people (as of 2021). The largest city is Tomaszów Mazowiecki, which is inhabited by 1/3 of the region's population. The area has three smaller towns and numerous small towns and villages.

The MOFTMO's economy is based on industry and services. Companies in the mineral and chemical industry, which are involved in, among other things, the production of building materials and ceramics, and companies in the food industry play important roles in the economy of the region and the individual municipalities. Agriculture is important for the food processing companies operating in the area.

2.2 Mapping of available feedstock in the MOFTMO

Assessing the MOFTMO's biogas production potential requires analysing the available substrates. The possible sources of substrates are:

- organic (biodegradable) fraction of municipal solid waste
- sludge from municipal wastewater treatment plants
- biodegradable waste from industry
- biomass and bio-waste from agriculture (of animal and plant origin)

2.2.1 Organic fraction from municipal solid waste

According to IOŚ-PIB (2022), a study on municipal waste generated in Polish municipalities, the content of organic fraction in municipal solid waste generated (bio-waste) is on average 28.68% (from 28 to 31% depending on whether it is an urban or rural area and also on the population of the urban area). The municipal bio-waste generated consists of green waste (grass, leaves, branches) and food waste (residues from food preparation and waste from food consumption). In 2021, in the MOFTMO a total of 54 861 Mg of municipal solid waste was collected (Polish BDO, 2021). Based on the data regarding the municipal solid waste generated and population, the potential for bio-waste generation in the area was assessed to be ca 16.6 thousand Mg. According to the same study, food waste accounts for 61% of the generated bio-waste so **the potential for generation of bio-waste is ca 10.1 thousand Mg of food waste and 6.5 thousand Mg of green waste yearly.**

2.2.2 Source-separated municipal bio-waste

In MOFTMO in 2021, in 11 out of 14 municipalities the municipal bio-waste was separately collected. Kitchen and food waste was collected together with green waste from gardens and parks. The amount collected was 2 957 Mg (Polish BDO, 2021). In this category, in the case of selected municipalities, waste from other sources than households were included (schools, offices, restaurants and other small business etc.). Of the biodegradable waste collected from the area, the city of Tomaszów Mazowiecki had the largest share (78%). Taking into account the potential for bio-waste generation of 16.6 thousand Mg, the bio-waste collected separately in 2021 amounted to 17.8% of that theoretical value. According to a recent study (Favoino and Giavini, 2020), based on the performance of various collection schemes and the composition of municipal bio-waste, it can be assumed that in MOFTMO 20% of collected bio-waste was food/kitchen waste. With this assumption and given the current collection rate, **of the bio-waste collected in the area ca 590 Mg was food/kitchen waste and ca 2 360 Mg green waste.**

2.2.3 Sludge from municipal wastewater treatment plants

In the MOFTMO, there are 19 municipal wastewater treatment plants with a total capacity of 40.5 thousand cubic meters per day. Between 2020 and 2022, the average amount of municipal sewage sludge produced during wastewater treatment amounted to 2.6 thousand Mg of dry mass yearly, of which on average 14% was used in agriculture (Statistics Poland, BDL). Most of the sewage sludge generated is produced at the wastewater treatment plant in Tomaszów Mazowiecki (ca. 80%). Assuming that whole or part of the sewage sludge could be fed into biogas plant, **the potential of municipal sewage sludge for use in biogas production is from 2.3 to 2.6 thousand Mg of dry mass yearly.**

2.2.4 Industrial biodegradable waste

In 2021 in the MOFTMO, 7.8 thousand Mg of biodegradable waste other than municipal bio-waste and municipal sewage sludge was produced (Polish BDO, 2021). The largest share had waste from the baking and confectionery industry (52.8%), food products that are expired or unsuitable for consumption (23.3%), and waste from the preparation and processing of meat, fish and other foods of animal origin (15.1%). The greatest potential for biogas production has plant-tissue waste (ca 340 Mg/year), animal-tissue waste (ca 630 Mg/year), sludge from on-site effluent treatment in plants processing meat, fish and other foods of animal origin (ca 550 Mg/year), materials unsuitable for consumption or processing (ca 4 000 Mg/year), and food products that are expired or unsuitable for consumption (1 800 Mg/year). Of the municipalities of the MOFTMO, the biggest potentials in terms of substrates for biogas production have the cities of Tomaszów Mazowiecki and Opoczno. **The total amount of biodegradable industrial waste generated in the area is ca 7 600 Mg yearly.**

2.2.5 Animal by-products

Animal by-products (ABPs) are materials obtained from animals which are not intended for human consumption. ABPs include[4]:

- slaughterhouse waste (skin, bones, horn and hooves, blood, fat and offal)
- catering waste
- fallen stock
- dead pets
- materials produced by animals such as manure, eggshells, feathers, wool, beeswax
- former foodstuff of animal origin such as milk, eggs, meat that is no longer suitable for human consumption (commercial reasons, quality, production failures etc.).

Animal by-products are covered by regulation (EC) No 1069/2009 and, if they are also classified as waste, by relevant waste legislation. The animal by-products which are not classified as waste are not covered by compulsory waste statistics and are not included the Polish Database on waste management (Polish BDO).

Of the animal by-products that are generated in the MOFTMO, animal manure constitutes the dominant amount. As this kind of biomass is not covered by the waste statistic, for mapping of materials produced by animals, estimates based on theoretical values were done. According to the 2020 Agricultural Census in Poland, the MOFTMO had 29,000 heads of cattle, 57,000 pigs, and 1.7 million poultry, with chickens accounting for 96% of the total poultry population (Statistics Poland, BDL). Based on the indicators specified in agricultural production standards (Agricultural Production Standards - Normatywy produkcji rolniczej), considering that ca 80% of animals in Poland are kept in shallow litter barns (Kuś, Madej and Kopiński, 2006), **the potential can be assessed as ca 430 000 Mg of manure and 245 000 Mg of slurry.**

[4] https://www.efsa.europa.eu/en/topics/animal-by-products

2.2.6 Vegetable by-products

The total area of farmland in MOFTMO is 60.6 thousand ha. The dominant crops are cereals, which occupy 46% of the total cultivated area (ARiMR Database). Permanent pasture and grasses occupy 21.5% of the arable area. Corn is grown on 6% of the area. Assuming that 5-10% of hay, 50-70% of straw, and 60% of corn can be used as a substrate for biogas production, based on the available indicators (Jasiulewicz and Janiszewska, 2013; Jarosz, 2016; Niekurzak, 2022), the potential for biomass from agriculture production in MOFTMO was assessed as:

- hay: 2 600 – 5 200 Mg/year; average 3 900 Mg/year
- straw: 55 800 Mg/year
- corn: 68 000 Mg/year

2.2.7 Energy crops

Currently, in MOFTMO, only 8.6 ha (0.014% of the area's arable land) is dedicated to growing willow. There are no other energy crops grown.

2.2.8 Available feedstock for biogas production

Based on biomass and bio-waste mapping, the following feedstock from the MOFTMO can be used for biogas production (Table 2.1):

- Biodegradable waste from industry: plant-tissue waste (ca 340 Mg/year), animal-tissue waste (ca 630 Mg/year), sludge from on-site effluent treatment in plants processing meat, fish and other foods of animal origin (ca 550 Mg/year), materials unsuitable for consumption or processing (ca 4 000 Mg/year), food products that are expired or unsuitable for consumption (1 800 Mg/year). Altogether about 7 600 Mg/year.
- Sludge from municipal wastewater treatment plants (ca 2 300 - 2 700 Mg dry mass/year)
- Municipal bio-waste (food and kitchen waste): ca 590 Mg/year
- Plant biomass (ca 3 900 Mg/year of hay; ca 55 800 Mg/year of straw, ca 68 000 Mg/year of corn). Altogether about 128 000 Mg/year.
- Animal biomass (ca 430 000 Mg of manure and 245 000 Mg of slurry)

Table 2.1 Available feedstock for biogas production in MOFTMO

Municipality	Biodegradable waste from industry [Mg]	Sludge from municipal WWTPs [Mg dry mass]	Municipal bio-waste (food/ kitchen waste) [Mg]	Plant biomass [Mg]	Animal biomass - solid manure [Mg]	Animal biomass - slurry [Mg]
Białaczów	123	22	2	10 273	10 877	6 046
Drzewica	21	23	-	4 916	15 941	8 395
Inowłódz	-	16	14	1 002	4 339	1 194
Lubochnia	6	42	14	5 616	18 312	13 846
Mniszków	5	10	4	9 349	30 715	18 034

Opoczno	1 071	344	62	11 642	27 377	14 482
Paradyż	16	2	1	11 173	25 913	14 741
Poświętne	3	7	1	3 920	14 622	7 761
Rokiciny	19	18	-	25 666	72 254	46 487
Rzeczyca	8	2	-	8 965	55 538	41 909
Sławno	6	3	2	11 949	24 880	15 157
Tomaszów Mazowiecki (city)	6 753	2 165	462	399	7 605	1 929
Tomaszów Mazowiecki (rural area)	20	28	22	7 414	65 740	26 431
Ujazd	581	43	8	15 423	56 293	28 336
TOTAL	7 633	2 725	591	127 707	430 404	244 748

Source: Own calculations based on Polish BDO, Statistics Poland BDL

The dominant types of substrates for biogas production in the area are plant and animal biomass from agriculture, with the municipality of Rokiciny assessed to have the highest availability (ca 144 thousand Mg/year) and Ujazd, Rzeczyca and Tomaszów Mazowiecki (rural area) slightly lower (between 100 and 106 thousand Mg/year). The second stream of substrates consists of industry waste, with the cities of Tomaszów Mazowiecki and Opoczno having the highest potential availability. From the municipal sector, the city of Tomaszów Mazowiecki has the highest potential for biogas production by utilizing sludge from the wastewater treatment plant and collected bio-waste.

2.3 Perspectives on future feedstock potential

The future feedstock availability for biogas production in the area depends on bio-waste and biomass's generation and collection potential. The proposed revision of the waste framework directive, requiring reduction of food waste generated can influence the amount of bio-waste generated by industry and households, limiting the availability of substrates from these sectors. Improved collection schemes for municipal waste can increase the amount of bio-waste available. Changes in the diet pattern towards less or more meat can influence the amount of animal biomass available.

Assuming that in the coming years the MOFTMO’s municipalities will implement separate collection of food/kitchen waste and the amount of separately collected bio-waste could increase to ca 75% of the maximum generation potential, the amount of bio-waste collected in the form of food/kitchen waste could reach ca 7 600 Mg yearly. Table 2.2 shows the potential amounts of bio-waste (food and kitchen waste) assuming increasing collection levels of 25, 50 and 75%.

Table 2.2 Potential bio-waste (food and kitchen waste) amounts assuming increasing collection levels

Municipality	Municipal bio-waste (food and kitchen waste) [Mg]

	25% of max potential	50% of max potential	75% of max potential
Białaczów	45	90	136
Drzewica	85	171	256
Inowłódz	70	140	210
Lubochnia	103	206	309
Mniszków	46	92	138
Opoczno	433	865	1 298
Paradyż	37	74	112
Poświętne	27	53	80
Rokiciny	98	196	294
Rzeczyca	40	80	120
Sławno	57	115	172
Tomaszów Mazowiecki (city)	1 166	2 333	3 499
Tomaszów Mazowiecki (rural area)	169	337	506
Ujazd	153	305	458
TOTAL	**2 529**	**5 058**	**7 587**

Source: Own calculations based on Polish BDO and Statistics Poland, BDL.

As more than 60% of the bio-waste (food and kitchen waste) in the area is generated in the cities of Tomaszów Mazowiecki and Opoczno, implementing the separate collection of food and kitchen waste in both municipalities would provide a valuable stream of substrates for the biogas plant.

2.4 Biogas and energy potential of the available feedstock

The assessed theoretical potential for methane production from bio-mass and bio-waste in MOFTMO is presented in Table 2.3. Methane production potential from selected substrates is shown in Appendix A.

Table 2.3 Theoretical potential for methane production in MOFTMO

Data unit	**Methane production potential [cubic meters/years]**					
	biodegradable waste from in-dustry	municipal WWTP sludge	food/kitchen waste (min – max)		plant bio-mass	animal bio-mass
Białaczów	9 331	5 535	103	144	1 243 835	589 730
Drzewica	1 653	5 109	-	-	961 174	860 664
Inowłódz	-	3 832	722	1 008	270 260	227 561
Lubochnia	421	14 263	722	1 008	1 383 565	1 022 861
Mniszków	374	4 045	206	288	1 750 510	1 677 745
Opoczno	22 032	83 664	3 199	4 465	2 075 068	1 479 702

Paradyż	1 252	639	52	72	1 614 988	1 407 475
Poświętne	101	1 490	52	72	819 649	789 567
Rokiciny	1 499	4 045	-	-	2 579 590	3 971 338
Rzeczyca	388	639	-	-	2 175 512	3 099 825
Sławno	366	1 277	103	144	2 055 400	1 359 290
Tomaszów Mazowiecki (city)	1 418 569	409 592	23 836	33 274	111 487	398 500
Tomaszów Mazowiecki (rural area)	935	6 599	1 135	1 584	1 448 647	3 511 718
Ujazd	51 699	9 154	413	576	1 714 873	3 043 549
TOTAL	**1 625 214**	**549 883**	**30 543**	**42 637**	**20 204 558**	**23 439 526**

Source: *Own calculations based on Polish BDO, Statistics Poland BDL, ARiMR Database, Curkowski et al, 2009, AL-PROJEKT, 2023, Krasucka and Oniszk-Popławska, 2013.*

The total potential from all sources combined is close to 38 million cubic meters per year. Animal and plant biomass has the biggest potential for methane production in the area, with the municipalities of Rokiciny, Rzeczyca, Ujazd and rural area of Tomaszów Mazowiecki municipality dominating (52% of total methane potential from agricultural biomass).

In the municipal sector, waste from sludge from municipal wastewater treatment plants in Tomaszów Mazowiecki and Opoczno has the biggest potential. In industrial sector, industrial waste from Tomaszów Mazowiecki has the biggest potential. The lowest potential lies with separately collected municipal bio-waste (food and kitchen waste). However, the use of separately collected bio-waste for biogas production, despite the low yearly methane production potential, can support the sustainable management of municipal solid waste and the achievement of recovery and recycling targets imposed on municipalities. Additionally, anaerobic co-digestion with an organic fraction of municipal solid waste as a co-substrate can enhance the process. The addition of organic fraction of municipal solid waste to wastewater sludge leads to increased methane yield, the removal of volatile solids, and a higher content of methane in biogas (Grosser et al., 2017).

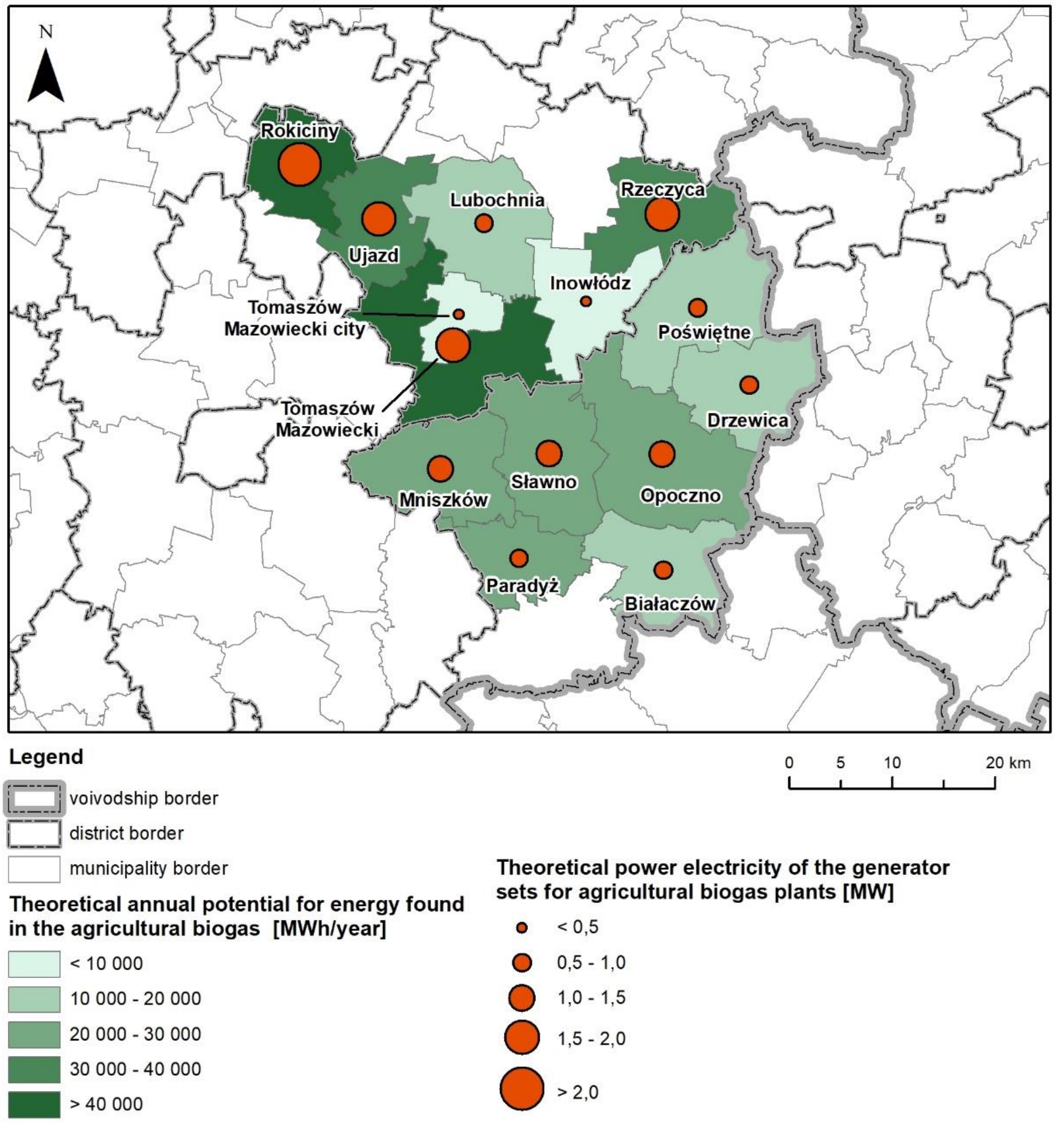
To analyse the theoretical production of energy from substrates available in MOFTMO, the following assumptions were made:

- the biogas plants have installed a combined heat and power system (CHP); electric efficiency 38%, heat efficiency 43%
- the heating value of biomethane of 9.3 kWh/Nm^3
- generator runtime 8000 h/year
- heat consumption for process purposes 30%; electricity consumption for process purposes 10%

In theory, from the amount of methane presented in Table 2.3, ca 111 GWh of net electrical energy and 350 GWh of net heat energy per year can be obtained. With an electricity demand of the MOFTMO households of ca 109 GWh per year, the electrical energy produced could cover this demand.

Based on the analysis of the potential of different sectors, in Figure 2.3 the theoretical annual potential for energy found in the biogas and theoretical power electricity of the generator sets is presented.

Figure 2.3 Theoretical annual potential for energy found in the agricultural biogas and power electricity of the generator sets.



Source: Own calculations based on Statistics Poland BDL, ARiMR Database, Curkowski et al, 2009, Krasucka and Oniszk-Popławska, 2013.

Given estimates from Poznań University of Life Sciences[5], that the lower limit of profitability of a biogas plant is ca 200 kW, and for agricultural biogas plants the optimal size is 250-499 kW, in every municipality except Inowłódz and city of Tomaszów Mazowiecki at least one agricultural biogas plant could be established (see 4.4 for examples of existing infrastructure). In case of industry, only the agri-food sector in the city of Tomaszów Mazowiecki generates enough substrates to justify building a biogas plant. The potential of the municipal sector is much smaller than the agricultural sector, but the profitability could be significant due to the high costs of waste management. We study this in chapter 5. In the municipal sector, the construction of a biogas plant may be considered by the wastewater treatment plant in Tomaszów Mazowiecki, provided

[5] https://www.teraz-srodowisko.pl/aktualnosci/kazda-gmina-ma-potencjal-produkcji-biogazu-Jacek-Dach-wywiad-13289.html; accessed 27.06.2024.

that it will have access to additional substrates. In particular, it should examine the co-digestion with other biodegradable waste to optimize the process.

The cooperation between different stakeholders is needed to exploit opportunities of biogas in the MOFTMO. The next section outlines which stakeholders to consider.

2.5 Stakeholders (in the) agricultural sector and municipalities

The development of a network structure around biogas plant investments could contribute to the growing importance of biogas in the MOFTMO energy economy. The organisation of an ecosystem of partners (stakeholders) could be centred around a central biogas hub (biohub) with multiple nodes (bioknots). The partners would be suppliers of the substrates for biogas production, while at the same time getting rid of the ballast of their production or operations, and the by-product converted into energy is distributed to distributed consumption points. Energy partnerships enable the mutual balancing of energy production and demand. A grid and distributed structure offer the possibility of energy produced from local resources and consumed locally, reducing transmission losses as well as intermediary costs. It serves to improve local energy security in an economically efficient and environmentally friendly way.

Partnership is the key to the development of biogas investments. Such an initiative has also been taken at MOFTMO. In 2018, the 'Tomaszów Energy Cluster' was established in Tomaszów Mazowiecki under a civil agreement. The members of the Cluster are:

- local governments: the city of Tomaszów Mazowiecki, municipalities: Tomaszów Mazowiecki (rural), Rzeczyca, Sławno;
- enterprises of thermal, electric and RES energy industry;
- municipal companies;
- scientific, research institutions: Polish Academy of Sciences Institute of Mineral and Energy Economy; Institute of Projects and Analysis;
- other members: Housing Association 'Przodownik'.

The cluster has an open character, i.e. new members may join it (according to the geographical limitation). The office of the Tomaszów Energy Cluster is run by Water and Sewage Management Plant in Tomaszów Mazowiecki.

The main goal of the initiative was to build energy self-sufficiency based on renewable energy sources, as well as to reduce air pollution. However, it should be noted that in the document developed in September 2022: 'Tomaszów Energy Cluster Development Strategy' practically neglected the potential of including biogas in the new energy architecture and achieving the indicated goal.

The full identification of potential stakeholders in a biogas investment is hampered by the lack of access to contact databases of actors in the MOFTMO. This makes it difficult to network potential partners, as well as information and promotion policies.

Among the identified stakeholders for the implementation of a biogas investment in the MOFTMO region, the following groups of actors can be distinguished:

- Government administration

- Regional administration
- Local government, including all municipalities in the MOFTMO
- District Office of the Agency for Restructuring and Modernisation of Agriculture Opoczno
- District Office of the Agency for Restructuring and Modernisation of Agriculture Tomaszów Mazowiecki
- Business clusters and cooperatives, including the Energy Cluster Tomaszów Mazowiecki
- Municipal economy enterprises
- Private sector
- Industry players
- Representatives of science

In addition, potential stakeholder groups may include:

- Business environment institutions
- Formal social partners: social organisations, trade unions
- Individual social partners: councillors
- Residents
- Local and regional media

3 Restrictions and barriers

Barriers and constraints to the realisation of biogas investments relate to many aspects, which can be divided into technical, organisational, institutional, economic and social barriers.

3.1 Technical barriers

One of the basic barriers is the limited availability of technology for biogas production in Poland. In addition, one has to reckon with limited possibilities of servicing the installation or replacing parts, which result from the lack of appropriately trained staff and the need to import technology from outside the country.

Due to its properties, biogas could be fed into the country's existing gas network after appropriate processing. Unfortunately, access to this network is limited as the gas network is not widespread throughout the country. In addition, the high costs of connection to the grid and the need to match the biogas parameters to those required by the grid can present a formidable technological and financial challenge. Another barrier is the underdeveloped market for natural gas vehicles (NGVs) and infrastructure. Biogas produced in a biogas plant has similar properties to natural gas and could therefore be used successfully as a propulsion fuel. The problems concern the immaturity of the market in terms of biomethane plant infrastructure and biogas supply to the transport sector in Poland.

3.2 Economic barriers

Among the economic barriers, the survey of biogas economics in chapter 1.4 indicates a high investment cost for biogas plants. Additional costs are associated with the connection to the electricity grid, which is required for the production of electricity from a biogas plant. Scale is a significant barrier, as indicated by the data in chapter 1.4.

Economic results would also improve with the ability to manage a larger spectrum of waste than is currently the case, which is affected by legal barriers. A further problem is the instability of the market. This concerns the conditions for its development in terms of the formal and legal environment. With regard to the operational process, the imbalance is due to uncertainty in the continuity of supply chains and stable feedstock for biogas plants. This situation limits the capital capacity of the biogas market and the involvement of potential investors.

A relatively under-recognised issue limiting the development of the biogas market is the lobbying towards the development of waste incineration plants, which, when these investments are scaled up, can potentially exert economic pressure to limit the waste stream to biogas plants.

3.3 Institutional barriers, organizational and legal barriers

To date, the lack of programmes and projects to promote investment in biogas and biomethane has been identified as one of the institutional barriers. The situation has improved somewhat in recent years, but still requires promotional and educational measures. Biogas and biomethane are insufficiently appreciated and taken into account in the balancing of the country's energy or transport system, which is questionable with such a huge estimated biogas production potential. One of the main organisational and legal barriers is the lengthy process of project preparation and obtaining decisions and permits for investment implementation. The construction of a biogas plant is complicated and the plant, due to its nature, may potentially have an impact on the environment. In addition, a further organisational barrier is the lack of adequate preparation and approach of officials to the specifics of the installation, applied technologies and produced processes, who issue decisions and permits. This barrier is slowly being overcome due to the growing interest in biogas plants. An important aspect is also the acquisition of certificates for the biogas digestate, which will allow its use in agriculture.

Another important problem is the unequal treatment of agricultural biogas plants (usually small-scale) and other biogas plants (e.g. municipal) in the legal system. The legal facilitations introduced for agricultural biogas plants do not translate into an increase in biogas production on a sufficient scale. Related to this is the lack of uniform regulations for the use of certain substrates in biogas plants (not every substrate is considered waste in different situations). The difficulty of interpreting regulations is a major barrier to the development of non-agricultural biogas plants.

Planning documents of municipalities, where biogas plants are not included or their location is prohibited, are also sometimes a barrier to the location of biogas plants. Changing a planning document is time-consuming and costly.

With regard to organisational issues, it is also worth keeping in mind the formal and legal constraints associated with the creation of partnerships, especially cluster structures or energy cooperatives. They are territorially limited initiatives and the objectives of their activities should be defined around local needs and opportunities. The effectiveness of partnerships depends on the rational and effective use of the potential: locally available energy resources, energy infrastructure, renewable energy sources, innovation, entrepreneurship in the area of energy generation, transmission, distribution and consumption management. The networking of partners and thus the organisation of partnerships in the bio-waste and biogas sector in general is a problem. These are indirectly due to a number of other conditions and barriers identified, but also directly in organisational terms due to difficulties in obtaining information and data and thus contacts. An identified difficulty is the lack of available databases, the lack of platforms for relationship building by potential investors and the coordination of biogas development by the administration. Overcoming difficulties in mapping business partners and stakeholders in general is important to build awareness of the potential of the bio-waste and biogas market.

3.4 Social barriers

The most difficult barrier to overcome can sometimes be the social one - the reluctance of local communities to have investments built in their vicinity. Despite the potential benefits of biogas plants, people do not agree to the construction of investments in their surroundings due to potential nuisances, especially odours (the NIMBY phenomenon). However, it should be noted that thanks to developments in biotechnology, various technologies and substances are being introduced that significantly reduce the environmental impact of biogas investments. Recently in Poland, as a result of increased investor interest in the construction of biogas plants, there has been a noticeable increase in negative public perception. A very important measure to overcome this barrier is the reliability and transparency of the biogas plant decision-making and approval process, which must include public participation. In addition, information and education campaigns targeting different stakeholder groups play an important role in order to raise awareness of biogas plant operation and public acceptance of this type of investment.

4 Opportunities and best practice

The construction of a biogas plant, depending on the scale of the project, can support the investor's energy self-sufficiency, but also bring benefits to a wider range of consumers. Biogas plants can process different substrates and the multiplicity of directions in which biogas can be used opens up many possibilities for development. The chapter discusses examples of various investments from Poland and European countries, which present development opportunities and good practice in investment implementation.

4.1 Examples from other regions in Poland

4.1.1 Tychy-Urbanowice Wastewater Treatment Plant (Tychy, Silesian Voivodeship)

The Tychy-Urbanowice Wastewater Treatment Plant stands out from other municipal wastewater treatment plants in Poland and even in the European Union, primarily due to its innovative technology enabling total energy self-sufficiency of 194% (as of 2019) and the powering of the nearby Water Park with surplus energy. The Tychy Water Park was put into operation in 2018, fully powered with biogas produced through sludge fermentation by the Tychy Wastewater Treatment Plant. Although the wastewater treatment plant had been producing biogas since 2006 and was energy self-sufficient by 2010, its subsequent upgrades, including the implementation of processes for co-digesting sewage sludge with biodegradable waste (at first with waste whey, later expanding its catalogue of accepted biodegradable waste) and refining the produced biogas, allowed the treatment plant to increase the amount of biogas produced by 4 million cubic meters between 2009 and 2018 and to achieve such a high energy potential that it was able to meet the demand of a second, very energy-intensive public facility. The still obtained surpluses are sold to the city's power grid and provide an additional source of income for Regionalne Centrum Gospodarki Wodno-Ściekowej S.A. (RCGW SA).

RCGW SA is the company that manages the Tychy-Urbanowice Wastewater Treatment Plant, located in the southeastern part of the city of Tychy in Silesia Province. The company is 100% owned by the City of Tychy. The wastewater treatment plant accepts wastewater from the whole city, handling sewage both from its residents and its industrial plants, including Tyskie Browary Książęce (part of Kompania Piwowarska - the largest brewer in Poland owned by Asahi Europe & International in the structure of Japan’s Asahi Group) and the Fiat Auto Poland car factory, among others.

The average inflow of wastewater is 32,731 cubic meters/d with a P.E. of 171,878. It is a mechanical-biological type treatment plant with chemical support for phosphorus reduction. Raw wastewater flows into the treatment plant via four interceptors, where there is no partition between industrial and municipal wastewater. Both types of wastewaters from all four interceptors reach the grating hall in a single stream. At a further stage, during mechanical treatment, the wastewater passes through sand traps, where after separation of its organic part, the sand is recovered and used for the company's own purposes as its good quality has allowed the revocation of its waste status. Wastewater later passes through the biological part of the treatment – first through a sequence of C-TECH technology reactors (patented by the Austrian company SFC UMWELTTECHNIK GmbH.), then through the activated sludge chambers, after which the treated and clarified wastewater is released into the nearby river Gostynia. Finally, the pre-sludge and surplus sludge disposal stage is carried out by means of an anaerobic stabilization process, with the sludge section of the treatment plant equipped with an airtight biofilter system that cleans the air of pollutants and odours before it is released into the atmosphere. First, the sludge is thickened to 5-6% d.m., and then directed to two separate digesters with a total volume of 11,000 cubic meters, where methane fermentation of the sludge takes place under mesophilic conditions (38°C). This sludge is later dewatered and, if necessary, hygienized with lime; the resulting stabilized waste is taken off-site and transferred to external entities. The biogas obtained from the fermentation process is first desulfurized using adsorbers filled with turf ore, then temporarily stored in a membrane and "wet" tank that have 6370 cubic meters and 2000 cubic meters in volume respectively. The produced biogas undergoes a carbon dioxide purification process at the Biogas Purification Station (Stacja Oczyszczania Biogazu, SOB) thanks to technology implemented by T4B EKOTECHNOLOGIE, thus increasing the methane content of biogas from 45% to about 70%. A portion of the gas is burned on site in three generators (two with an electrical output of 345 kW and a thermal output of 531 kW each, one with an electrical output of 400 kW and a thermal output of 394 kW) so as to provide the whole plant with 100% of its energy needs (thermal for heating the digesters and the plant’s buildings, electrical for powering its machinery) and any excess is sold to an external power distributor. The rest of the obtained biogas is compressed and transferred via a 6-kilometer pipeline to the Tychy Water Park, built in 2018 by RCGW SA in relation to the expansion of the sludge treatment facilities and the ensuing increase in biogas and energy production. Biogas flaring takes place only in a situation of overflow, in which a backup low-temperature gas boiler with a capacity of 895 kW would prove insufficient. The biogas production at the treatment plant saves 77,000 tonnes of coal per year, which, in terms of atmospheric pollution, results in a reduction of 770 tonnes of particulate matter, 154,000 tonnes of carbon dioxide, more than a tonne of sulphur and 161 tonnes of nitrogen. For the implementation of such innovative green solutions, RCGW SA was awarded the EMAS Awards in 2015 by the European Commission (thus becoming the first Polish recipient of this award) and received a nomination for the European Business Award for the Environment (EBAE) as well as numerous awards in business and eco-friendliness competitions (Eco-laurels of the Polish Chamber of Ecology, National Ecological Competition “Friendly to the Environment”, “New Impulse” award, etc.).

4.1.2 Miejski Zakład Komunalny Sp. z o.o. w Stalowej Woli (Stalowa Wola, Podkarpackie Voivodeship)

The Municipal Utilities Company (MZK) in Stalowa Wola deals expertly and comprehensively with all kinds of municipal utilities – within the company there are such divisions as the Water and Sewage Division, Mechanical-Biological Processing of Municipal Waste Division, Waste Transport Division, City Cleaning Division, Thermal Power Division, Urban Green Spaces Division, Waste Disposal Division, Wastewater Treatment Division and even a Public Transport Division. This allows for the integrated management of the city's technical infrastructure. In addition, there are two wastewater treatment plants in Stalowa Wola: the Central Wastewater Treatment Plant (COŚ) -

which accepts industrial wastewater and is managed by HSW - Wodociągi Sp. z o.o., and a Municipal Wastewater Treatment Plant (MOŚ) - which accepts municipal wastewater, handled by MZK. Treated wastewater from both plants is later discharged into the San River via a common discharge collector. It is the cooperation of the above-mentioned divisions that ensures an efficient closed-loop management of the city and its waste. What is more, the Municipal Mechanical and Biological Waste Treatment Plant and the Municipal Wastewater Treatment Plant, which produce biogas, together with the Energy Recovery Facility, which deals with the process of thermal transformation of the energy fraction of municipal waste, provide heat and electricity for the MZK's own needs and those of the city's residents.

In operation since 1993, the Municipal Wastewater Treatment Plant underwent modernization between 2006 and 2009, during which it was equipped with two Separate Fermentation Chambers (WKF), where anaerobic digestion of sewage sludge by mesophilic bacteria takes place. The stabilized sludge is dewatered, hygienized and stored. The biogas captured from this process contains from 55 to 60% methane; after desulfurization, it is burned in two generators, each with an electric power capacity of 104 kW and a thermal power capacity of 154 kW. The Municipal Wastewater Treatment Plant also occasionally provides additional services in the form of processing and disposal of post-production waste from the dairy, brewing and distilling, sugar and bakery industries, and disposes of contraband alcohol at the request of tax and customs authorities.

The Municipal Waste Mechanical and Biological Processing Facility in Stalowa Wola (ZMBPOK) aims primarily to reduce the amount of biodegradable waste sent to the Stalowa Wola landfill, managed by MZK’s Waste Disposal Facility. Approximately 60,000 tons of municipal waste arrive at ZMBPOK annually, from which 3 million kWh of electricity and heat are produced after its organic fraction is separated on the Sorting Line and fermented. Anaerobic stabilization takes place in a digester, to which a biogas tank is connected, along with a purification and storage module. On the other hand, in another part of ZMBPOK there is an aerobic stabilization module, which consists of 6 compost tunnels with an air purification plant and a compost maturation yard. All the above processes also yield a wide range of recycled, secondary materials, the sale of which is offered by ZMBPOK as part of its additional services. These include paper and cardboard, metal and plastic packaging, a soil conditioner "Glebowitka" that can be used in agriculture and horticulture, as well as a pseudo-compost intended for the biological reclamation of landfills.

4.1.3 Zakład Unieszkodliwiania Odpadów Komunalnych „Orli Staw” (Prażuchy Nowe, Wielkopolskie Voivodeship)

The opening of a biogas plant in Prażuchy Nowe near the city of Kalisz took place in 2023. Previously equipped only with a sorting plant, composting plant and landfill, the “Orli Staw” waste treatment plant, which has existed at the site since 2006, has been upgraded with a bio-waste methane digestion plant with a target capacity of up to 30,000 tons per year. This facility handles the municipal waste of more than 300,000 residents from 23 cities and municipalities in the Wielkopolska and Łódź provinces. The Municipal Association of Municipalities "Clean City, Clean Commune", whose members are also the target recipients of the service, is responsible for its construction. The cost of the investment was about 150 million PLN, financed partly from the Association’s own funds and partly from EU funds.

The new plant is one of the first in Poland designed for continuous processing of selectively collected municipal bio-waste into biogas. Both garden bio-waste (cut grass, leaves) and kitchen waste (peelings, expired food, swill, liquid fats) will be accepted. It is also innovative in terms of the technology used: dry, horizontal, continuous, thermophilic (55°C). STRABAG Umwelttechnik is responsible for the design of this new technology called STRABAG LARAN Plug Flow. Annual biogas production will reach more than 1 million cubic meters of biogas, and in the long term, biomethane production is planned. As of now, biogas is burned in a 560-kW cogeneration unit, producing 4,500 MWh of electricity and a similar amount of heat annually. This makes ZUOK self-sufficient in energy from now on. The obtained electricity will be used entirely on site, whereas thermal energy, after covering the plant's needs, will be resold to external entities. In addition to energy, the fermentation process will also produce post-ferment that, like the "HUM-OS" compost currently produced by ZUOK, will be sold as an effective soil conditioner.

4.2 Examples from Norway

Norway differs from most other European countries by having a very limited gas infrastructure. This makes injection into the existing natural gas network, which is common in all countries with gas networks, less relevant in Norway. In many countries, biogas has also been used for electricity production. In Norway, the combination of low electricity prices and an already high share of renewable energy sources has made this application less widespread. There is a Norwegian market for liquid and compressed bio-methane, used as fuel for heavy vehicles such as buses and trailers, but this requires upgrading of the biogas.

Upgrading biogas to bio-methane can be a costly process and requires a minimum amount of biogas produced to be economically viable. In order to produce enough biogas to justify an upgrading facility the biogas plant would need a certain amount of substrate to go into production. Den Magiske Fabrikken ("the Magical Factory"), a biogas plant in Vestfold County, Norway, uses household food waste and animal manure from local farms as substrates in its production. This serves as an excellent example of how industrial cooperation can foster profitable biogas and biomethane production.

Due to few designated applications of biogas in Norway it is important to exploit all resources and by-products of biogas production that can be made into valuable products. Veas wastewater treatment plant has designed its business plan to ensure that all resources derived from biogas production are effectively utilized to enhance the plant's economy.

4.2.1 Den magiske fabrikken («The magical factory)

Den magiske fabrikken (DMF) receives sorted household food waste from the 17 municipalities that own the plant (approximately 1.2 million inhabitants). The food waste is delivered to the plant by Vesar, a municipal company that provides solutions in waste management and recycling. Vesar also operates the plant's educational centre, which provides tours of the plant and educational material for the county's students. Households collect food waste in bags. Once at the plant the food waste is transported to a grinder that rips the bags open and grinds the food waste. The waste is then transported to a pulper where process water is added, and the waste is further grounded. The mass goes through a sieve plate which removes larger particles, such as plastic, pieces of metal and glass.

The farms in the county deliver animal manure to the biogas facility and receives bio-fertilizer in return. In 2023 DMF received 78 000 tonnes of animal manure and produced approximately 150 000 tonnes bio-fertilizer used in food production in Vestfold County. The manure from cattle and pigs is transported to the biogas plant in a truck and is pumped into a storage facility. At the storage facility, the manure is put in a mixing tank and is then transported to a hydro cyclone that removes sand and other heavier particles.

The food waste and manure are mixed together in a buffer tank and is then sanitized for one hour at 70 degrees Celsius. The substrate is then distributed to the two digesters of the plant. Biofertilizer is drained from the digesters and goes to storage. Raw biogas is extracted from the top of the digesters and transported to the upgrading plant. As of 2023, the upgrading plant produces over 10 million cubic metres of bio-methane yearly, which equates to approximately 100 gigawatt hours. The bio-methane is sold and distributed as compressed biogas (CBG) and liquefied biogas (LBG) by Air Liquide Skagerak AS. Air Liquide Skagerak operates a distribution network that supplies gas to both the industrial and transportation sectors.

4.2.2 Veas wastewater treatment plant

Veas is Norway’s largest wastewater treatment facility. It cleans the wastewater from over 800 000 citizens in the surrounding municipalities: Oslo, Asker, Bærum, and Nesodden. An important part of Veas’ business plan is to see wastewater as a resource and a raw material for industrial use, rather than as a waste problem. Veas’ long-term goal is to generate enough revenue from the wastewater to cover the operation of the treatment.

Veas’ organization and business plan

Veas was established by the municipalities in 1976 to build, own and operate their shared wastewater treatment plant. To ensure that the fee each resident in the owner municipalities pays Veas to provide these services is fairly priced, Veas has been operating by the full cost principle. Full cost is the total cost of producing a service, and the total fees the municipality charges the residents for the service cannot exceed this cost. This means that the municipalities, and thereby Veas, cannot generate a profit from the water and wastewater services. Veas saw this as a barrier in the further development of their business plan and in their goal to fully utilize the water resources.

In 2022, Veas changed their business entity type from an inter-municipal cooperation operated according to the full cost principle, to a joint-stock company. Veas AS is the holding company with three subsidiaries: Veas Marked (Veas Market), Veas Selvkost (Veas Full Cost), and Veas Næringspark (Veas Business Park). Veas Selvkost delivers the water and wastewater services to the municipalities by operating the wastewater treatment plant and the associated infrastructure. This subsidiary is still run according to the full cost principle, ensuring as low fees as possible for the residents. The main purpose of Veas Market is to sell products obtained from the wastewater treatment and contribute to the circular economy. This subsidiary is operated on commercial principles and without guarantees from the municipalities that own Veas AS. Veas business Park owns and manages all property for Veas AS.

Liquified biogas (LBG)

Veas has produced biogas from its wastewater resources since 1995, initially generating heat and electricity for internal consumption using a gas engine. In 2017, the company made the decision to construct a biogas upgrading plant. The upgrading plant was put into operation in 2020, and Veas Market has been responsible for the operation since 2022.

The biogas is transported from the wastewater treatment facility to the upgrading plant where the CO_2 is removed, and bio-methane is produced. The gas is then liquified, making liquid bio-methane (LBM), also referred to as liquid biogas (LBG), which is suitable as fuel for buses and trucks. Veas Market is responsible for selling LBG to the market through a distributor.

Bio-CO2

In the upgrading plant, CO_2 is separated from biomethane. Veas is now assessing how best to exploit CO_2 as a resource and has established a subsidiary of Veas Marked for this purpose, HOOP CO_2. HOOP CO_2 is currently looking into both carbon capture and storage (CCS) and carbon capture and utilization (CCU) technology.

Veas Soil

The sludge extracted during the wastewater treatment process contains nutrients that can improve soil quality and be used as fertilizer. "Veas soil" is made from sewage sludge that has been stabilized, sanitized, and mixed with lime. It also contains organic material, phosphorus, and nitrogen, which can help boost crop yields. Today, Veas soil is used as a fertilizer and soil amendment on grain cultivation areas across much of Eastern Norway. The product is produced in accordance with fertilizer regulations and is a registered product with the Norwegian Food Safety Authority. Veas produces nearly 40 000 tons of Veas-soil each year.

Ammonium sulfate

Ammonium is often present in wastewater after the decomposition of organic matter. Veas uses the ammonium to produce sustainable ammonium sulfate, a chemical compound that can be used as raw material to produce chemical fertilizers or sprayed directly onto to fields as a soil improver. Additionally, it can be used to boost the nitrogen content in manure and other types of natural fertilizer. Removing ammonium from the wastewater through simple filtration can be difficult, necessitating the use of an acid to effectively precipitate ammonium sulfate. Previously, Veas used an acid with a fossil origin, but now Acinor, a company that imports and sells chemical products, provides them with industrially recycled sulfuric acid, further improving Veas' carbon footprint.

District heating

The sewage and wastewater transported from Oslo municipality to Veas contribute to heating approximately 13 000 apartments. In the tunnel that transports wastewater from Oslo to Veas the energy companies Oslofjord Varme ("Oslofjord Heat") and Hafslund Oslo Celsio extract heat from the wastewater. The sewage water initially maintains a temperature between 10 and 15 degrees Celsius. In the tunnel between Oslo and the facility in Slemmestad, the wastewater passes through a large heat pump system, which extracts some of the heat and redirects it back into the district heating network. Veas also uses heat from the wastewater in its own facility.

4.3 Examples from other countries

Copenhill waste-to-energy, Denmark

As mentioned in chapter 3.4, social acceptance can often be a barrier for energy-related infrastructure, where facilities are often met by "not in my backyard" (NIMBY) attitudes. The Copenhill waste-to-energy plant in Copenhagen, Denmark, serves as an illustrative example of how such facilities can gain widespread social acceptance and even take a leading role in developing a residential area.

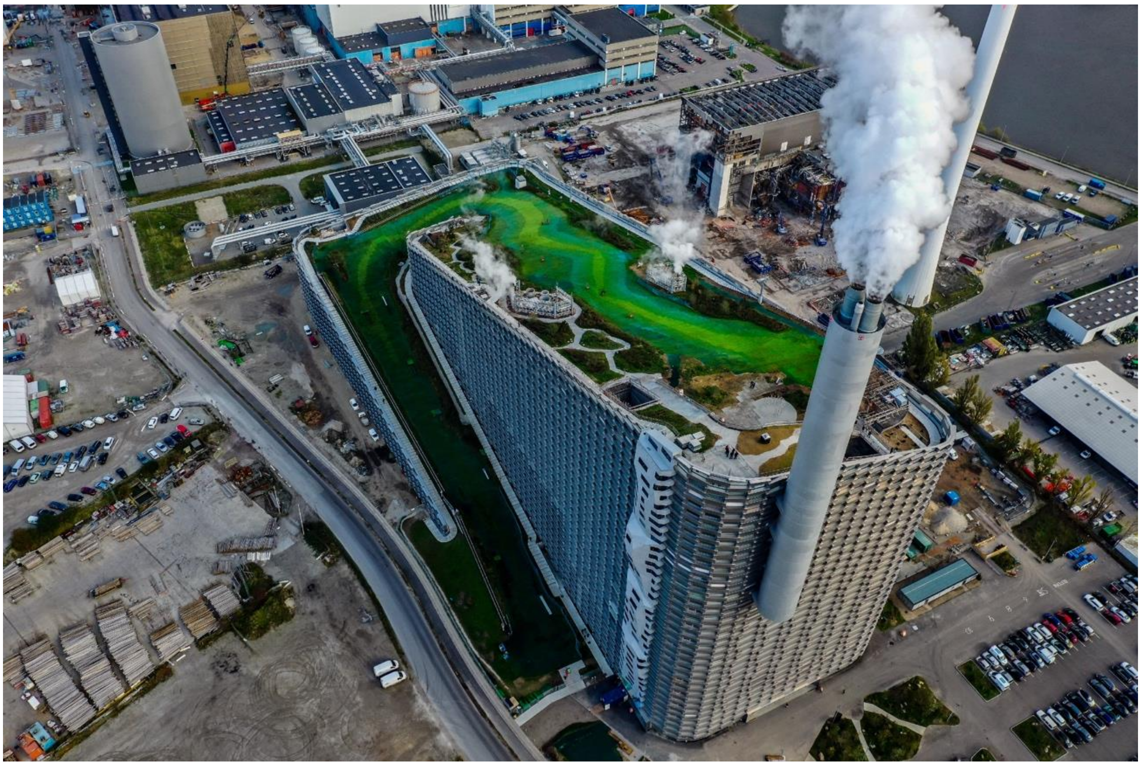
The Copenhill facility is a relatively large waste-to-energy plant that has the capacity to convert roughly 560 000 tonnes of waste each year into electricity and heat. Approximately one fourth of the plant's feedstock originates from waste from local households, with the remainder coming from industrial and commercial waste.

The plant is located in a suburban area of Copenhagen, just 200 meters from nearest residential building. The location is very beneficial from an economic point of view. It is close to the feedstock sources, which reduces transportation costs and CO_2 emissions, but it also exploits the existing district heating network to save costs. However, being in an area with existing residential buildings and more planned, it was prone to NIMBY-problems. Two important lessons can be gained from the project: inclusive design and having a good dialogue and inclusion of local communities.

The architectural tender for the plant stated that the facilities should be made accessible to the public. The idea was that the plant should not be built as an isolated unit, but as an integral part of the community, with no barriers between itself and its surrounding area.

The winning proposal included a multi-purpose facility that offers recreational opportunities for the public. The open design includes a rooftop with a park, an artificial ski slope made from plastic, operational throughout the year, and a rooftop bar. In addition, the side of the building is adorned with an 80-meter-tall climbing wall. The project invited around 30 local sports organizations to collaborate in the development of these recreational areas, further highlighting its community engagement.

Figure 4.1 The Copenhill power plant.



Source: Max Mestour and Amelie Louys.

Moreover, the construction plans were included in the municipal plan such that all information was openly available for the public to see and provide feedback. This transparency and the ensuing dialogue with the closest residents' association helped in addressing any potential concerns from the outset. The project also put emphasis on providing good information to locals about any events that might affect them.

The Copenhill facility is an exemplary model showing that with thoughtful design, inclusive planning and transparent communication, energy facilities can overcome the typical barriers to social acceptance and serve communities creative ways.

BSR biogas plant in Berlin-Ruhleben, Germany

Europe is growing in terms of biogas and biomethane production. Germany has the highest number of biogas plants in Europe (more than 11,000 biogas plants in 2022) and the second highest number of biomethane plants behind France (242 biomethane plants). Agricultural substrates remain the basis for biogas and biomethane production there, but there are successful efforts to use bio-waste on a larger scale. The main use of the produced raw biogas is the generation of electricity in power and CHP plants, there are other uses as well.

A comprehensive example of biogas production that fits in with the idea of a circular economy is the Berlin municipal waste management company (Berliner Stadtreinigung, BSR). Located in Berlin's Ruhleben district, the company digests more than 70,000 tonnes of selectively collected organic waste from households every year to produce climate-neutral biogas.

The organic waste-to-energy plant in Berlin produces biogas using a dry fermentation process. The choice of process is based on the properties of the available substrates: the collected kitchen organic waste has a water content of between 58 and 65 percent.

Once purified, the resulting biogas consists of 98% methane, making its chemical composition identical to natural gas and, after appropriate processing, it can be fed into the gas grid. The annual production of raw biogas is more than 6,000,000 m^3, resulting in approximately 3,000,000 m^3 per year of biomethane. Currently, biogas is used to refuel gas-powered waste-collecting trucks at the company's own petrol stations (more than 60% of the entire fleet).

Biogas is also used to produce electricity and heat through combustion. The quantities of energy obtained make it possible to supply more than 5% of Berlin households with sustainable energy. The resulting steam from combustion is transferred by pipelines to the nearby Reuter power plant, where the steam is converted into electricity and the heat is fed into the district heating network supplying the city. The indicated local cooperation saves fossil resources (coal) and reduces the impact on the climate.

It should be noted that, like any investment, the one in Ruhleben encountered problems. The location of the biogas plant close to housing estates and other urban infrastructure was problematic at the planning stage of construction, when public resistance was encountered. Conducting an extensive information and education campaign had the desired good effect. At the design, implementation and also operation stage of the project, the role played by residents and proper recycling in the whole waste treatment process is emphasised.

It is worth remembering that there is not just one right way to develop the biogas sector in all countries and local markets. The Berlin example shows the multiplicity of directions in which biogas can be used and the possibilities for cooperation between companies. In addition to the production of electricity, it is possible to produce thermal energy, green gases for supply to the grid or liquefaction into bio-LNG or bio-CNG, the use of recovered CO_2.

4.4 Local ideas

There are already several facilities in the MOFTMO where bio-waste and other substrates suitable for the biogas plant's anaerobic digestion process are managed. The existence of such facilities does not exclude the possibility of building new biogas plants. Indeed, the existing biogas plants are small and micro installations which do not make use of the full biogas potential in the area.

As one of the first installations in the area, a biogas plant in Sobawiny (Opoczno municipality) was established in 2014. The privately-owned agro-industrial biogas plant operates in the vicinity of a meat processing factory. The main input to the biogas plant is a mixture of substrates: maize silage, slaughterhouse waste and expired food. The installation allows the plant to meet its electricity and heat demand. Surplus electricity is sold to the grid.

Bio-waste in the area is also managed in more traditional installations. In the village of Różanna, located in the municipality of Opoczno, there is a composting plant where biodegradable waste from for instance public greenery and plant waste from municipal markets is composted. The waste is deposited on a composting plate and aerated. The mature compost is sieved and stored on the compost maturation plate. The resulting compost is used solely in slope shaping at the landfill. The composting plant is relatively small. The plant produces negligible amounts of biogas - too small for energy storage and combustion. The biogas is therefore currently flared.

In the municipality of Rokiciny, located at the western end of the MOFTMO, there are agricultural microbiogas plants at farms in the villages of Łaznowska Wola (22 kW capacity), Kolonia Łaznów (33 kW capacity) and Michałów (22 kW capacity). All the installations indicated are compact, containerised agricultural microbiogas plants producing biogas from manure. The microbiogas plants are technically and technologically integrated into the on-farm dairy farming infrastructure. These installations have a measurable environmental effect - in addition to the use of renewable energy, the odour nuisance associated with the resulting manure and the emissions of methane, nitrogen oxides and hydrogen sulphide into the atmosphere are reduced locally. Another advantage of agricultural microbiogas plants and the processing of manure is the resulting digestate, which is a good and environmentally safe fertiliser with better parameters than the original manure, as it does not acidify soils due to the ammonium form of the nitrogen it contains. The electricity and heat produced by the combustion of biogas meets the farms' own needs, and the surplus electricity is fed into the low-voltage grid and used locally.

Biogas plants are also located in the close vicinity of MOFTMO. There are two biogas plants in the rural municipality of Rawa Mazowiecka. The first is a typical agricultural biogas plant in Konopnica with a relatively large capacity of 1.99 MW. The main substrate in the plant is apple juice pressing residues and maize silage, with other agricultural raw materials completing the mix. So far, the plant has generated electricity and heat for its own use and the local market. In 2020, the biogas plant was taken over by a new investor with plans to expand and convert it into a biomethane plant. The second example is a municipal biogas plant for sewage sludge, located in Żydomice as part of the local wastewater treatment plant - Rawskie Wodociągi i Kanalizacja Sp. z o.o.. Due to the small amount of sludge, the biogas plant has a small capacity (0.25 MW). Thanks to the cogeneration of electricity and heat produced, the energy needs of the treatment plant derived from renewable sources are optimised. The third biogas plant is located in the town of Rawa Mazowiecka. This is also an agricultural biogas plant, located on the site of a meat processing plant where animal by-products are processed. The 1 MW installation reduces primary energy consumption and increases the plant's energy security.

4.5 Conclusion

Success stories like the Tychy-Urbanowice Wastewater Treatment Plant, the two plants in Stalowa Wola and the biogas plant in Prażuchy Nowe show that technological barriers and infrastructure challenges may be overcome in Poland. The plants are economically sustainable and contribute to reaching environmental policy goals. They also perform important social functions, including ecological and climate education. Seemingly "technical" investments are therefore multifunctional.

The Tychy-Urbanowice Wastewater Treatment Plant and the Copenhill waste-to-energy energy plant in Denmark show that a biogas plant can gain widespread social acceptance through delivering services that the public appreciates (water park in Tychy, ski slope and park in Denmark). The Magical Factory in Norway and the BSR biogas plant in Germany show how upgrading to biomethane can be done in an economically and technologically feasible way, while the Veas wastewater treatment plant in Norway shows how the business plan can be optimized for maximum profitability and social impact. Both the Norwegian plants run extensive education and outreach programs, which may be another learning point. Meanwhile the local initiatives and ideas in the MOFTMO show that there are several small- and micro scale biogas units in the area, many of which are agricultural biomass facilities or associated with the food industry.

Furthermore, the analysis of the Norwegian experience shows that changes in the energy market and increasingly demanding climate conditions are taken into account in planned investments. The climate-friendly aspect is a strong argument in biogas plant investments in Norway.

5 Biogas at the Tomaszow Mazowiecki wastewater treatment plant – a business case

5.1 Biogas production in two phases

The mapping of available feedstock for biogas production in chapter 2.1 and assessment of biogas potential in chapter 2.4 indicate that the MOFTMO has a significant potential for biogas production from biomass and bio-waste. The city of Tomaszów Mazowiecki is an optimal investment location for biogas production due to the availability of substrate from the municipal and industrial sector. The potential substrates are sludge from the wastewater treatment plant in Tomaszów Mazowiecki, municipal bio-waste (food and kitchen waste if separately collected) and biodegradable industrial waste. In terms of agricultural waste, the municipalities of Rokiciny, Rzeczyca, Ujazd and rural municipality of Tomaszów Mazowiecki have the highest potential for biogas production from plant and in particular animal biomass. Due to the regulations that distinguish between biogas and agricultural biogas outlined in chapter 1, the options for biogas production in different sectors (municipal, industrial, agricultural) should be regarded separately.

In the MOFTMO, the local governments have signed an agreement aimed at ensuring the sustainable development of their municipalities. Actions to promote renewable energy sources, including biogas production from biomass and bio-waste, will contribute to achieving sustainable development goals in the MOFTMO.

To realize the biogas potential, it is important to outline the business case for biogas production. The subject of this chapter is to present the possibilities for biogas production from the stream of substrates coming from the municipal and industrial sector of the MOFTMO. Two phases will be analysed.

Phase 1: Construction of a biogas plant at the wastewater treatment plant in Tomaszów Mazowiecki with sewage sludge as a substrate

The Water and Sewage Management Plant in Tomaszów Mazowiecki is preparing to implement an investment consisting of comprehensive modernization of sewage sludge management. This will allow for the stabilization of sludge in anaerobic digestion, supported by a thermal hydrolysis process and the production of electricity and heat from biogas. The substrates for biogas production will be sewage sludge generated during wastewater treatment in the plant, grease trap sludge, and sewage sludge delivered from nearby wastewater treatment plants.

The construction of a biogas plant would enable the production of biogas and its use for energy production. This would allow the plant to:

- limit the amount of sludge generated and reduce the cost of sludge management

- produce electricity and heat from biogas and thereby reduce the cost of energy at the plant
- use digestate to produce a soil-improving product
- reduce GHG emissions

Phase 2: Expansion of the biogas plant at the wastewater treatment plant in Tomaszów Mazowiecki to use biodegradable waste as a supplementary substrate

Expansion of the biogas plant will allow the use of municipal bio-waste (food/kitchen waste) and industrial biodegradable waste from the MOFTMO for biogas production. In the assessment, addition of sludge from the wastewater treatment plants not included in the phase 1 could is also included.

The expansion will allow the plant to:

- produce more electricity and heat and further reduce of the cost of energy
- support meeting the local municipalities' waste recovery and recycling targets
- further reduce GHG emissions.

5.2 Phase 1: Sewage sludge as substrate

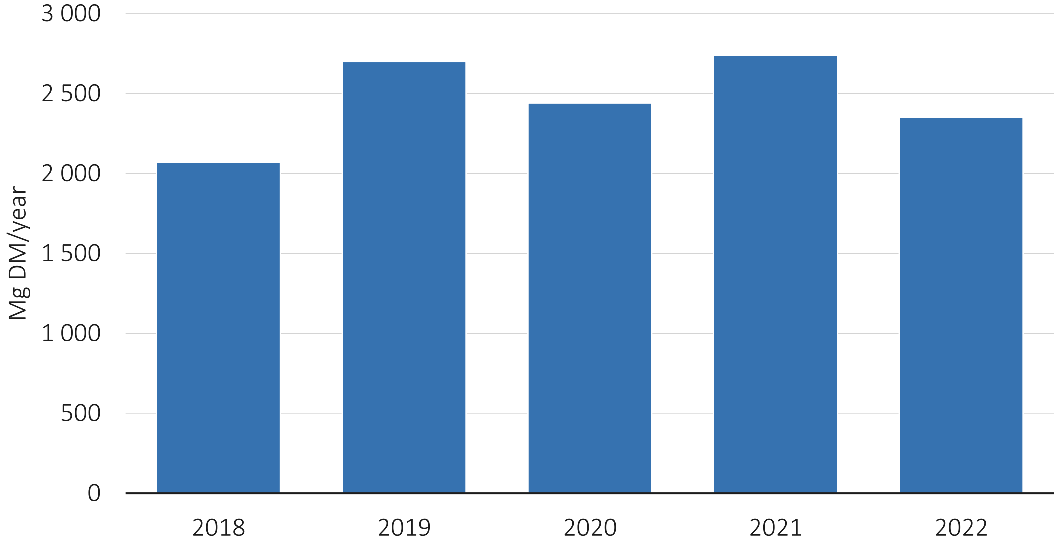
5.2.1 Sludge quantities and current treatment

The wastewater treatment plant managed by Water and Sewage Management Plant in Tomaszów Mazowiecki is located in the town Tomaszow Mazowiecki in Łódź Voivodeship, in central Poland. The city has a population of 58.8 thousand.

The wastewater treatment plant was modernized between 2013 and 2016. The modernization of the treatment plant, completed in 2016, enabled the application of biological technology for the removal of biogenic compounds, automatic control and steering of the technological process, as well as the introduction of a final sludge treatment process based on sludge thickening, dewatering, and drying.

The plant was designed for a maximum hourly capacity of 1,600 cubic meters of wastewater. In terms of population equivalents, the maximum capacity is 126,940 PE, however, the actual loads reach up to 180,000 PE. In 2015-2022, on average, the amount of incoming wastewater was 3.74 million cubic meters per year (about 427 cubic meters per hour), of which septic tanks delivered 6% (mainly from food processing plants).

Figure 5.1 Amount of dry matter of sewage sludge produced in a year in WWTP in Tomaszów Mazowiecki



Source: AL_PROJEKT (2023).

In recent years between 2100-2700 Mg of dry matter of sewage sludge have been produced annually (Figure 5.1). Until 2020, the generated sewage sludge was dewatered and transferred to an external company for further treatment. Since 2021, the sludge has been dewatered and dried at 130 degrees, and a soil improving product has been produced. A sudden increase in gas prices in 2022 caused the treatment plant to limit sludge drying and forced it to transfer unprocessed sludge directly after dewatering for further treatment.

The characteristics of sewage sludge generated in the wastewater treatment plant are presented in Table 5.1.

Table 5.1 Characteristics of sludge after thickening

Data unit	Content of dry mass [%]	Content of dry organic mass [% of dry mass]
Primary sludge	3.8	84.0
Excess, secondary sludge	4.9	82.9

Source: AL_PROJEKT (2023).

5.2.2 Current problems and possibilities

There are several problems in the wastewater treatment plant operations in Tomaszow Mazowiecki:

- a large amount of sludge generated in the wastewater treatment process without the possibility of reducing it in further processing before final dewatering and drying
- high load on the sewage line with delivered concentrated sewage
- high energy consumption of sludge processing when operating a sludge dryer
- increasing costs of sludge management

- lack of sludge stabilization when the sludge dryer is shut down
- decreasing possibilities for further sludge management
- lack of space for storage of dewatered or dried sludge

The construction of a biogas plant could solve the identified problems.

In phase 1 the investment would consist of a modernization of the sewage treatment plant, allowing for:

- stabilization of sludge in the methane fermentation process supported by thermal-pressure hydrolysis and production of electricity and heat from biogas
- water recovery from treated sewage
- recovery of phosphorus in the form of struvite

The outcome of the investment will be:

1. Reconstruction and extension of the sludge treatment line as a sludge treatment facility with sludge sterilization, biogas production and utilization (Task 1) and phosphorus recovery in the form of granulated struvite (Task 2) and treatment and disinfection of treated wastewater to recover water for industrial purposes (e.g., washing streets or watering greenery) (Task 3),
2. Expansion of the command-and-control system to include equipment for the new sludge line, phosphorus recovery and water recovery facilities,
3. Construction of renewable energy installations (solar panels) with connection to the operator's electrical grid.

We focus here on item 1 and 2, which are necessary components of a biogas plant. By contrast the construction of renewable energy installations is a separate decision.

5.2.3 CAPEX and OPEX

Construction of a biogas facility at the wastewater treatment plant gives several options for how to utilize the biogas and treat the remaining digestate. The first analysed option (1A) involves using the biogas to produce electricity and heat using a combined heat and power (CPH) system. The electricity generated will then be used on-site to power the wastewater treatment and biogas production, thereby replacing the electricity currently purchased from the grid. Part of the heat is used on-site. The digestate that remains as a byproduct of biogas production will be transported to an external company for further treatment. In the second option (1B), a part of the biogas will be used to dry and treat the digestate on-site. This also includes producing and selling a soil-improving product. The remaining biogas will be used for combined heat and electricity production, and the electricity and part of the heat will be utilised on-site to run the wastewater treatment and biogas production. In the third option (1C), all biogas produced will be used for combined electricity and heat generation. The digestate will still be treated within the wastewater treatment plant, but by utilising gas from the grid. The soil-improving product resulting from digestate treatment will be sold.

Table 5.2 Options for phase 1

Option 1A	Option 1B	Option 1C
Biogas is used to produce electricity and heat, replacing electricity from the grid; part of the heat is used on-site; the digestate is treated by an external company.	Part of the biogas is used to dry digestate and produce a soil-improving product which is later sold. The remaining biogas is used for electricity and heat production, replacing electricity from the grid; part of the heat is used on-site.	Biogas is used for electricity and heat production, replacing electricity from the grid; part of the heat is used on-site. Digestate is dried using gas from the grid and the soil-improving product is sold.

Source: Vista Analyse and IOS-PIB

The investment cost, which is given in Table 5.3, remains constant regardless of which of the three options the wastewater treatment plant chooses. The implementation and design cost consists of preparation of the tender estimated to 600 000 PLN and 3 million PLN in design work. Material and construction cost entails all costs associated with the installation of the biogas facility and the storage and treatment of digestate. The planned biogas facility will be located within the boundaries of the land currently belonging to the wastewater treatment plant, including undeveloped land, such as green areas and paved areas used for manoeuvring or as storage yards. Development and adaptation of this land will amount to 3 million PLN. The existing wastewater treatment facility requires some changes and enhancements in order to connect it to the biogas facility. This work is estimated to cost 2.5 million PLN. Electrical installations, control and measurement equipment and automation of the biogas facility will cost 3.5 million PLN, and the technological start-up costs are estimated to be 800 000 PLN. The general contracting costs, such as financial costs and guarantees, is set at 11.4 million PLN.

The total capital expenditure for all options in phase 1 is approximately 65.2 million PLN. This is significantly higher than the CAPEX presented in chapter 1.4 due to the relatively high cost of thermal hydrolysis unit that wastewater treatment plant is planning to install.

Table 5.3 CAPEX for all options in phase 1 (in PLN)

	Option 1A, 1B and 1C
Implementation and design cost	3 600 000
Material and construction cost	40 310 000
Reconstruction of existing facilities and development cost	5 500 000
Electrical installations and technological costs	4 430 000
General contracting costs	11 350 000
Total	**65 190 000**

Source: Vista Analyse and IOS-PIB based on AL-PROJEKT (2023)

The operational costs vary between the different options for phase 1. We assume that the wastewater treatment plant would need the same amount of labour, maintenance and electricity for wastewater treatment regardless of which option they choose. The main difference between the options lay in the digestate treatment. In option 1A the digestate is treated by an external company for estimated 2.8 million PLN each year. In option 1B the digestate is dried and treated by the wastewater treatment plant, but the cost of this treatment is set to 0 as the plant uses the biogas it produces for the process. In option 1C the wastewater treatment plant buys gas from the grid to treat the digestate, and the estimated cost of this gas is 260 PLN per MWh (May 2024), which amounts to approximately 1.6 million PLN per year. Following these differences in digestate treatment the operational expense for option 1A, 1B, and 1C totals to approximately 7.5 million, 4.7 million and 6.3 million PLN, respectively.

Table 5.4 OPEX for each option in phase 1 (in PLN)

	Option 1A	Option 1B	Option 1C
Labour cost biogas facility	720 000	720 000	720 000
Maintenance biogas facility	200 000	200 000	200 000
Electricity for WWTP operation	3 811 500	3 811 500	3 811 500
Digestate treatment by external company	2 800 000	-	-
Digestate treatment at the plant	-	-	1 582 718
Total	**7 531 500**	**4 731 500**	**6 314 218**

Source: Vista Analyse and IOS-PIB based on AL-PROJEKT (2023)

5.2.4 Resource evaluation

In this first phase of the project, the main substrate to be used for biogas production is sewage sludge. The sludge is categorized as either primary or secondary sludge. Primary sludge, also known as raw sludge, is produced by allowing solids to settle by gravity in the primary tank. Secondary sludge is a result of the biological treatment of wastewater and is thickened mechanically. After thickening, the sludge will be mixed and fed into the biogas production process. Also, sewage sludge from neighbouring wastewater treatment plants will be used in biogas production: approximately 40% will be sourced from wastewater treatment plants outside MOFTMO. The final piece of substrate will be grease trap sludge.

The proportion of sewage delivered by slurry tankers to the total volume of sewage flowing into the plant is approximately 6%, which, considering the size of the plant, is a significant figure. This wastewater comes from, among other things, the operation of food processing plants.

The amounts of individual substrates planned for use in the biogas production process are presented in Table 5.5.

Table 5.5 Substrates for the biogas production process

Substrate	Amount	Amount [Mg dry mass/year]
Primary sludge	30 783 cubic meters/year	1 170
Excess / secondary sludge	37 053 cubic meters/year	1 810
Grease trap sludge	920 cubic meters/year	92
Wastewater delivered by septic tanks	23 686 cubic meters/year	474
Sewage sludge from other wastewater treatment plants	2 511 Mg/year	452
Total		3 998

Source: AL-PROJEKT (2023).

5.2.5 Revenues and reduced expenses

Tomaszów Mazowiecki wastewater treatment plant is planning to install a combined heat and power (CHP) system in the first phase of their project. The CHP system uses biogas to produce heat and electricity simultaneously. The generated electricity and heat will be used on-site, for both the wastewater treatment and biogas production.

Electricity and heat

The wastewater treatment plant consumes 5.5 GWh of electricity annually. The cost of this electricity when purchased from the grid is 693 PLN per MWh (May 2024), which totals to 3.8 million PLN. In the biogas production process, as well as in the electricity and heat generation, additional 0.5 GWh will be required annually. The anticipated electricity production from biogas is 3.1 GWh per year, which gives a net electricity production of 2.6 GWh per year. If the entirety of the produced biogas is utilised for electricity and heat production, it will cover nearly half of the plant's demand, saving 1.8 million PLN in energy expenses each year. In option 1B, part of the biogas is used to treat digestate, and the share of biogas utilised for electricity and heat production is thereby lower. The total savings in electricity expenses for this option is approximately 450 000 PLN per year.

The wastewater treatment plant currently utilizes electricity for heating purposes and as of now there is no opportunity to transfer the heat to a district heating system. If opportunities to utilize excess heat on-site or in a district heating system arise in the future, there will be an additional potential to either sell the heat or reduce energy expenses for the wastewater treatment plant.

Digestate treatment

The current wastewater treatment process generates approximately 12 500 Mg of digestate each year. The digestate is transported to an external company for further treatment, which costs the wastewater treatment plant 5 million PLN yearly. Using the sludge that remains as a byproduct of wastewater treatment for biogas production reduces the organic dry matter significantly (IEA Bioenergy, 2015). In phase 1 of the project, the amount of digestate generated in the biogas production process is estimated to 7000 Mg. By reducing the volume of digestate, the wastewater treatment plant lowers cost related to treatment, storage, and transportation of digestate. The exact cost reduction depends on whether the wastewater treatment plant chooses option A, B, or C. As stated in chapter 5.2.3, option 1A still entails the digestate being treated by an external company, but the volume of digestate is significantly reduced, which lowers the price to 2.8 million PLN annually. Option 1B has the cost of digestate treatment set to zero, as the treatment is based on biogas produced at the plant. However, there is an indirect cost, as the share of biogas used for electricity and heat production is lower. In option 1C the plant treats the digestate themselves at a cost of 1.6 million PLN each year. Treating the digestate on-site gives the wastewater treatment plant the opportunity to sell the resulting soil-improving product. It is assumed that the product can be sold for 25 PLN/Mg, generating a yearly income of 57 500 PLN.

Accepting sludge from neighboring wastewater treatment plants

Establishing a biogas facility at Tomaszów Mazowiecki wastewater treatment plant makes it possible to accept sludge from other plants in the area, to be used as feedstock in the biogas production process. It is estimated that the plant will be able to accept an additional 2 500 Mg of sludge each year. If the gate fee for delivering sludge is set at 200 PLN per Mg, 2 500 Mg generates an income of 500 000 PLN per year. Surrounding waste treatment plants charge a gate fee of between 389 and 626 PLN per Mg for accepting sludge, so there might be an opportunity for the wastewater treatment plant to increase its income by charging a higher gate fee.

Yearly income

Table 5.6 gives an overview of the annual income and reduced expenses for each option in phase 1. Option 1C has the highest yearly income, of 2.4 million PLN, consisting of income from treating sludge from neighboring wastewater treatment plants, income from selling a soil-improvement product, and reduced electricity expenses as a result of biogas production. In addition, there is an upside if the gate fee becomes higher. The second-best option is 1A, with a yearly income of 2.3 million PLN. Since the digestate is treated by an external company this option does not include income from selling the soil-improving product. Option 1B has the same income sources as 1C, but the reduced electricity expenses are significantly lower, resulting in the lowest yearly income of 1 million PLN.

Table 5.6 Annual income and reduced expenses for each option in phase 1 (in PLN)

	Option 1A	Option 1B	Option 1C
Income from treating sludge from the neighbouring wastewater treatment plants	500 000	500 000	500 000
Income from selling the soil improvement product	-	57 500	57 500
Reduced electricity expenses	1 818 065	456 570	1 818 065
Sum income	**2 318 065**	**1 002 844**	**2 375 565**

Source: Vista Analyse and IOS-PIB based on AL-PROJEKT (2023)

5.2.6 Profitability

Table 5.7 summarizes Table 5.4 which gives yearly income and Table 5.6 which gives the yearly costs for each option in phase 1 and the baseline. The investment costs for the three different options in phase 1 are the same; 65.2 million PLN. Since the variable costs and income differ, these are the decisive components for which option is the most profitable.

Table 5.7 Sum costs, income and annual cash flow for each option in phase 1 (in million PLN)

	Baseline	Option 1A	Option 1B	Option 1C
Total investment cost	-	65.19	65.19	65.19
Total variable cost	8.81	7.53	4.73	6.31
Total income	-	2.29	1.00	2.35
Annual cash flow	- 8.81	- 5.24	- 3.73	- 3.97
Annual cash flow compared to baseline	-	3.57	5.1	4.8

Source: Vista Analyse and IOS-PIB based on AL-PROJEKT (2023)

Based on the overview in Table 5.7, we see that of the three investment options in Phase 1, option 1B is the best, closely followed by option 1C, while option 1A is by far the least profitable option. Even though all the options have negative annual income flow (i.e., not taking the investment costs into consideration), it might still be reasonable to implement some of these options, if they are a better solution than the current situation. Thus, we should compare the various options to the baseline, where sludge is treated by an external company and without biogas production.

In addition to the investment costs and annual cash flow, we should also consider the project's lifespan and the discount rate.

The role of the discount rate

To make an investment, the investor requires a certain rate of return on his funds, also called a discount rate. When there is some uncertainty about the income and cost of the project, e.g., risk of higher investment cost, technological difficulties, low prices, regulatory uncertainty, in short, there is a risk that the investor may lose some or all of his money, the investor usually requires a higher expected rate of return. How much higher depends on the risk factors, but also on his own knowledge and skill to understand the project, his aversion to risk, and how diversified his investment portfolio is.

For this report we calculate the net present value at different discount rates. All discount rates are "real" as opposed to nominal, as we don't consider inflation. Had we included inflation of e.g., 3%, the cash flows of Table 5.7 would have increased 3% annually and the real interest rates of Table 5.8 and onwards would have meant nominal interest rates that were 3% higher.

Net present value

The net present value (NPV) includes all variable costs and income, and investment costs for option 1A, 1B and 1C. As can be seen in Table 5.8, the net present value is negative for all options, including the baseline.

Table 5.8 NVP for various discount rates when projects lifespan is 20 years (in million PLN)

	Baseline	Option 1A	Option 1B	Option 1C
10 %	-75.02	-109.83	-96.93	-98.98
8 %	-86.51	-116.67	-101.80	-104.16
6 %	-101.07	-125.33	-107.96	-110.71
4 %	-119.75	-136.45	-115.86	-119.13

Source: Vista Analyse and IOS-PIB based on AL-PROJEKT (2023)

Table 5.9 shows the net present value for all options compared to the baseline. Option 1A has a lower net present value than the baseline for all discount rates, which means that this option is less profitable than the current situation. Both option 1B and 1C has a higher net present value than the baseline when we set the discount rate to 4 percent. Option 1B is the obvious best option with a net present value 3.89 million PLN higher than the baseline.

Table 5.9 NVP for various discount rates when projects lifespan is 20 years, compared to baseline (in million PLN)

	Baseline	Option 1A	Option 1B	Option 1C
10 %	-	-34.82	-21.92	-23.96
8 %	-	-30.16	-15.29	-17.64
6 %	-	-24.27	-6.89	-9.65
4 %	-	-16.70	3.89	0.62

Source: Vista Analyse and IOS-PIB based on AL-PROJEKT (2023)

Project's lifetime

Table 5.10 below summarizes the minimum duration in years when we assume a discount rate of 6 %. Option 1A will never be a better option. Option 1B becomes profitable at a 6 % discount rate if the project's lifetime is at least 26 years and Option 1C if the duration is at least 29 years.

Table 5.10 Project's minimum duration for options in Phase 1 to be more profitable than the baseline

	Baseline	Option 1A	Option 1B	Option 1C
Project's minimum duration in years	-	Never	26	29

Source: Vista Analyse and IOS-PIB based on AL-PROJEKT (2023)

If the discount rate were to be slightly higher, the project would have to last considerably longer for the other options to be more profitable than the baseline. For example, if the discount rate is 10%, none of the options in phase 1 are more profitable than baseline even if the project's duration is 100 years.

Internal rate of return

Table 5.11 summarizes how low the discount rate must be for the other options to yield a positive return compared to the current situation.

Table 5.11 Internal rate of return for the options in Phase 1

	Option 1A	Option 1B	Option 1C
IRR (%)	0.09	4.66	4.10

Source: Vista Analyse and IOS-PIB based on AL-PROJEKT (2023)

For option 1B to be a more profitable option than the baseline, the discount rate needs to be no higher than 4.66 %. While for Option 1C the discount rate must be no higher than 4.10 %. We see that option 1A has an internal rate of return of 0.09 %, indicating that the discount rate cannot be higher than that, i.e., it is never a better option than the baseline in the real world.

Increased costs or income

If we only increase the costs, and keep incomes constant, option 1B continue to be the best of the investment options. When we compare option 1B to the baseline, we can assess what the internal rate of return (IRR) must be given a certain percentage increase of the investment costs.

Table 5.12 Internal rate of return (IRR) for option 1B if costs increase, compared to baseline

Increased Cost	0 %	3 %	4 %	5 %	7.5 %	10 %	15 %	20 %
IRR (%) Option 1B	4.66	4.32	4.21	4.10	3.83	3.58	3.09	2.63

Source: Vista Analyse and IOS-PIB based on AL-PROJEKT (2023)

As seen in Table 5.12 a percentage point increase in variable costs entails approx. a decimal decrease in internal rate of return for option 1B. If costs where to increase with 5 %, the IRR compared to baseline would be 4.1%.

Table 5.13 Internal rate of return (IRR) for option 1B if income is increased, compared to the baseline

Increase Invest. Cost	0 %	3 %	4 %	5 %	7.5 %	10 %	15 %	20 %
IRR (%) Option 1B	4.66	4.73	4.75	4.77	4.83	4.89	5.00	5.11

Source: Vista Analyse and IOS-PIB based on AL-PROJEKT (2023)

In Table 5.13, we see that increasing the income for option 1B only marginally improves the internal rate of return. A 15 % increase in income entails an internal rate of return of 5.0 %, while a 20 % increase in income gives an internal rate of return of 5.11 %.

5.3 Phase 2 – Municipal and industrial waste

In the second phase, the investment would consist of expanding the biogas plant, allowing for:

- accepting municipal bio-waste
- accepting industrial bio-waste

5.3.1 CAPEX and OPEX

Phase 2 of the project at Tomaszów Mazowiecki wastewater treatment plant involves municipal and, in some cases, industrial bio-waste as substrate for biogas production. For this phase of the project, we have included two options 2A and 2B, and several scenarios for option 2A. In option 2A municipal bio-waste is included as substrate for biogas production, and the scenarios account for various levels of available feedstock. Scenario 1 shows calculations based on the assumption that municipalities implement separate collection of food/kitchen waste, and all food/kitchen waste (with the current level of collection) can be used in production. The remaining scenarios represent various levels of the theoretical potential of municipal bio-waste (see table 2.2). In option 2B industrial bio-waste is added in addition to the food and kitchen waste from municipalities.

Table 5.14 Options and scenarios for phase 2

	Option 2A	Option 2B
Scenario 1	Addition of food and kitchen waste as substrate	Addition of food, kitchen (75% of potential) and industrial bio-waste in the AD process
Scenario 2	Addition of food and kitchen waste as substrate (25% of potential)	
Scenario 3	Addition of food and kitchen waste as substrate (50% of potential)	
Scenario 4	Addition of food and kitchen waste as substrate (75% of potential)	

Source: Vista Analyse and IOS-PIB based on AL-PROJEKT (2023)

Table 5.15 gives the capital investments for each option in phase 2. Adding municipal and industrial bio-waste to the substrate mix means that the plant will have to invest in additional pre-treatment facilities. The municipal waste arrives at the plant in bags, and will need to be removed from the bags, sorted and grinded before it can be transported to the biogas digesters. Industrial bio-waste also requires pre-treatment. This investment will need to be made across all options and scenarios. The pre-treatment facility is estimated to cost 1 million PLN, which comes in addition to the 65.2 million invested in the biogas facility in phase 1. As the volume of feedstock used in production increases, the plant will need additional digesters in the biogas facility. In option 2A1, 2A2 and 2A3, we estimate one additional digester is needed, while two additional digesters are needed for option 2A4 and 2B. The capital expense amounts to 69 million PLN for options 2A1, 2A2 and 2A3 and 71 million PLN for options 2A4 and 2B. If the feedstock increase is higher than expected or there are other variables that lead to the need for another digester this will lead to a 3.9 percent increase in investment cost for options 2A1, 2A2 and 2A3 and a 10.9 percent increase in investment costs for options 2A4 and 2B.

Table 5.15 CAPEX for each option in phase 2 (in PLN)

	Option 2A1, 2A2 and 2A3	Option 2A4 and 2B
Phase 1 investment	65 190 000	65 190 000
Pre-treatment facility for municipal bio-waste	1 000 000	1 000 000
Additional digesters	2 800 000	5 600 000
Total capital expenses	**68 990 000**	**71 190 000**

Source: Vista Analyse and IOS-PIB based on AL-PROJEKT (2023)

Table 5.16 contains the yearly operational expenses for all the options and scenarios in phase 2. We have assumed the same labour and maintenance cost as in phase 1. If the expansion of feed-stock acceptance in phase 2 leads to 50 percent higher labour or maintenance costs this will increase the variable costs by 8.9 percent. In phase 2 of the project, the digestate will be treated using biogas and there are therefore no directs costs associated with this process.

Table 5.16 OPEX for all options in phase 2 (in PLN)

	All options in phase 2
Labour cost biogas facility	720 000
Maintenance biogas facility	200 000
Electricity for WWTP operation	3 811 500
Total operational expenses	**4 731 500**

Source: Vista Analyse and IOS-PIB based on AL-PROJEKT (2023)

5.3.2 Resource evaluation

In the phase 2, municipal bio-waste (food and kitchen waste) from MOFTMO would be used in biogas production (Resource evaluation of MOFTMO), industrial bio-waste from MOFTMO, and sewage sludge from wastewater treatment plants not included in the phase 1. The amounts of individual substrates that could be used in the biogas production process are presented in Table 5.17.

Table 5.17 Substrates for the biogas production process in phase 2

Substrate	Amount [Mg/year]
Municipal bio-waste (food and kitchen waste)	7 587
Industrial bio-waste (food products that are expired or unsuitable for consumption, code 16 03 80)	1 450
Sewage sludge from other wastewater treatment plants	289
Total	

Source: own calculations based on Polish BDO

5.3.3 Revenue and reduced expenses

In phase 2 of the project, Tomaszów Mazowiecki wastewater treatment plant will still accept sludge from neighbouring wastewater treatment plants and use this in the biogas production. The volume of sludge accepted is assumed to be the same as in phase 1 and the income from this activity therefore remains at 500 000 PLN per year, if we assume a gate fee of 200 PLN per Mg.

The annual income will increase if the wastewater treatment plant decides to charge a higher fee. By accepting municipal bio-waste, the plant helps solve a waste problem for the municipality and can charge a gate fee for the waste. This gate fee is set at 300 PLN/Mg. The gate fee for municipal bio-waste at regional neighbouring waste treatment plants ranges from 389 to 522 PLN per Mg. Therefore, the wastewater treatment plant could potentially charge a higher gate fee than 300 PLN, thereby increasing their income. The amount of municipal waste collected varies between the options, from least in option 2A1 to most in option 2A4 and 2B. The income from gate fees therefore varies in the same way between the options. In option 2B the plant also accepts industrial bio-waste, for which they also can charge a gate fee, and thereby this option entails an additional income of 435 000 PLN/year. As each option involves the plant treating the digestate itself, all options have an additional income from selling soil-improving product. The exact income again depends on the amount of feedstock that goes into production. For all options in phase 2 part of the produced biogas is utilized for the treatment of digestate. The remaining biogas is used to produce electricity and heat, which is used within the wastewater treatment plant. By producing its own electricity, the plant can reduce the amount it buys from the grid, and thereby reduce its electricity expenses. The net electricity production varies between 1.35 GWh per year for option 2A1 and 4.36 GWh for option 2B. Similarly, the estimated reduction in electricity expenses vary between approximately 900 000 and 3 million PLN each year.

Table 5.18 Annual income and reduced expenses for each option in phase 2 (in PLN)

	Option 2A1	Option 2A2	Option 2A3	Option 2A4	Option 2B
Income from treating sludge from the neighbouring wastewater treatment plants	500 000	500 000	500 000	500 000	500 000
Income from treating bio-waste	177 428	758 705	1 517 409	2 276 114	2 276 114
Income from treating industrial bio-waste	-	-	-	-	435 000
Income from selling the soil improvement product	58 699	64 019	70 856	77 692	98 431
Reduced electricity expenses	932 117	1 298 379	1 841 167	2 454 380	3 020 570
Sum income and reduced expenses	**1 668 244**	**2 621 103**	**3 929 432**	**5 308 186**	**6 330 115**

Source: Vista Analyse and IOS-PIB based on AL-PROJEKT (2023)

Table 5.18 shows that the total annual income increases with the amount of feedstock, making option 2B, which has the highest feedstock volume, the best option. While this represents the theoretical possibility, phase 2 of the project would need an assessment of what is practically achievable.

5.3.4 Profitability

Table 5.19 summarizes Table 5.18 which gives yearly income and Table 5.16 which gives the yearly costs for each option in phase 2 and the baseline. The investment costs for options in phase 2 varies depending on the amount of substrate that goes into biogas production. The profitability of the options in phase 2 therefore depends on both the investment cost and annual cash flow.

Table 5.19 Sum costs, income and annual cash flow for each option in phase 2 (in million PLN)

	Baseline	Option 2A1	Option 2A2	Option 2A3	Option 2A4	Option 2B
Total Investment Costs	-	68.99	68.99	68.99	71.79	71.79
Total Variable Costs	8.81	4.73	4.73	4.73	4.73	4.73
Total Other Income	-	1.23	1.53	1.95	2.41	3.15
Annual Cash Flow	- 8.81	-3.50	-3.20	-2.78	-2.32	-1.58
Annual cash flow compared to baseline	-	5.31	5.61	6.03	6.49	7.23

Source: Vista Analyse and IOS-PIB based on AL-PROJEKT (2023)

Based on the overview given in Table 5.19, option 2B is the most profitable compared to the baseline. The additional investment costs entailed, due to the higher volume of substrate, are outweighed by the income it generates. All the options have a negative annual cash flow, meaning that the investment cost combined with the annual operational expenses is higher than the annual income. Even though all the options in phase 2 have a negative annual cash flow the investment might be reasonable as they are better than the current situation. Option 2B is the most profitable compared to the baseline.

Net present value

When calculating the net present value (NPV) for both the baseline and all options in phases 1 and 2, we assume a discount rate of 6 percent and a project lifetime of 20 years. As seen in Table 5.20, all options in both phase 1 and phase 2 have a negative net present value.

Table 5.20 NPV in million PLN

	Baseline	**Phase 1**			**Phase 2**				
	Baseline	Option 1A	Option 1B	Option 1C	Option 2A1	Option 2A2	Option 2A3	Option 2A4	Option 2B
NPV	-101.07	-125.33	-107.96	-110.71	-109.15	-105.71	-100.88	-98.44	-89.96

Source: Vista Analyse and IOS-PIB based on AL-PROJEKT (2023)

Table 5.21 gives the NPV for each option in both phase 1 and phase 2 compared to the baseline. When assuming a discount rate of 6 percent and a project lifetime of 20 years, all options in phase 1 have a lower NPV than the baseline. Looking at phase 2, the options become better as the volume of feedstock increases. Options 2A1 and 2A2 still have a lower NPV than the baseline, and would therefore, with the assumptions we make, not be profitable. Option 2A3, 2A4 and 2B are all profitable investments, with an increasing NPV and 2B being the best option with a net present value of 11 million PLN.

Table 5.21 NPV compared to baseline (in million PLN)

	Baseline	**Phase 1**			**Phase 2**				
	Baseline	Option 1A	Option 1B	Option 1C	Option 2A1	Option 2A2	Option 2A3	Option 2A4	Option 2B
NPV	-	-24.27	-6.89	-9.65	-8.09	-4.65	0.19	2.63	11.10

Source: Vista Analyse and IOS-PIB based on AL-PROJEKT (2023)

Table 5.22 depicts the NPV for the options in phase 2 for various discount rates compared to baseline when projects lifespan is 20 years.

Table 5.22 NVP for various discount rates when projects lifespan is 20 years, compared to baseline (in million PLN)

	Phase 2				
	Option 2A1	Option 2A2	Option 2A3	Option 2A4	Option 2B
12 %	-29.33	-27.09	-23.94	-23.33	-17.81
10 %	-23.78	-21.23	-17.64	-16.55	-10.26
8 %	-16.86	-13.91	-9.77	-8.09	-0.83
6 %	-8.09	-4.65	0.19	2.63	11.10
4 %	3.17	7.25	12.98	16.39	26.43

Source: Vista Analyse and IOS-PIB based on AL-PROJEKT (2023).

Project’s lifetime

Table 5.23 below, summarizes the minimum duration in years when we assume a discount rate of 6 %. We see that Option 2A3, 2A4, and 2B are all better options than the baseline if the project’s duration is 20 years. For Phase 2A1 to be a better option, the project’s lifespan must be at least 26 years, while for Phase 2A2 the duration must be at least 23 years.

Table 5.23 Project’s minimum duration for options in Phase 1 and Phase 2 to be more profitable than the baseline

	Phase 1			Phase 2				
Option	1A	1B	1C	2A1	2A2	2A3	2A4	2B
Project’s minimum duration in years	Never	26	29	26	23	20	19	16

Source: Vista Analyse and IOS-PIB based on AL-PROJEKT (2023). When the discount rate is 6 % and all costs and incomes are constant.

Internal rate of return

Table 5.24 summarizes the internal rate of return for each option in phase 1 and phase 2 when compared to the baseline. The internal rate of return indicates the maximum discount rate that can be assumed and the project still being a better option than the baseline.

Table 5.24 Internal rate of return for options in Phase 1 and Phase 2 when compared to baseline

	Phase 1			Phase 2				
Option	1A	1B	1C	2A1	2A2	2A3	2A4	2B
IRR (%)	0.09	4.66	4.10	4.51	5.15	6.03	6.44	7.84

Source: Vista Analyse and IOS-PIB based on AL-PROJEKT (2023). When project’s lifespan is 20 years, and all costs and incomes are constant

Increased investment costs

Table 5.25 shows the maximum allowable cost increase for each option in phase 2 that would still render the option more favorable than the baseline. As seen in the table below, option 2A1 and 2A2 will never be more profitable than the baseline. Option 2A3 currently makes about the same profit as the baseline (e.g., the same loss at a 6% discount rate, compare Table 5.20), but if costs increase slightly, it could become less profitable than the baseline. Option 2A4 has a slightly higher margin, and 2B seems to be the safest option.

Above we noted that an additional digester will increase the cost of option 2A4 and 2B by close to 11 percent. Option 2B will remain profitable even if this happens.

Table 5.25 Increased investment costs (in %) compared to the baseline

	Phase 2				
Option	2A1	2A2	2A3	2A4	2B
% Increase	Never	Never	0.03	3.7	15.5

Source: Vista Analyse and IOS-PIB based on AL-PROJEKT (2023). When the project's lifespan is 20 years, and all other costs and incomes are held constant.

5.4 Minimum grant for a 10-12 percent real rate of return

While the internal rates of return of the best options in phase 1 and phase 2 are significant, they may be still appearing low from the perspective of a private investor. In social investments such as a biogas plant it is reasonable for the public sector (at the local, national and/or EU level) to contribute a grant covering a part of the investment cost. A grant may release private funds that "leverages" the public contribution, while securing for the private sector an expected rate of return that motivates for investment. The grant may take on different appearances. An upfront grant is one option. A concessionary loan is another option, with the present value of the rate of return differential making up the grant. When there are several potential operators of a biogas plant, the public sector may host an auction to see who requires the lowest grant. When the biogas plant is able to sell electricity, the grant element may take the form of a feed-in-tariff or feed-in-premium (see section 1.2 for Polish regulations). The Tomaszów Mazowiecki biogas plant would not sell electricity on a net basis but may do so on a gross basis.

For our purposes we calculate the grant element as an upfront grant necessary for a private rate of return of 10 and 12 per cent (real). Table 5.26 shows what the minimum grant for the two best options in phase 1 and 2 must be for them to yield a positive return when compared to baseline and the projects lifespan is 20 years.

Table 5.26 Minimum grant for the two best options in phase 1 and 2 to be profitable (in million PLN)

	Phase 1		Phase 2	
	Option 1B	Option 1C	Option 2A4	Option 2B

	Phase 1		Phase 2	
12 %	27.22	29.02	23.33	17.81
10 %	21.92	23.96	16.55	10.26

Source: *Vista Analyse and IOS-PIB based on AL-PROJEKT (2023). Minimum grant when compared to baseline and the projects lifespan is 20 years.*

Note from the table that a grant for phase 1 should be in the 22-29 million PLN range to secure an expected private return of 10-12 percent. The corresponding grant for phase 2 should be in the range of 10-23 million PLN.

In other words, the grant for phase 2 is significantly lower than the grant for phase 1. This is another way of saying that the profitability of phase 2 is significantly higher than phase 1.

Another way of putting it is that the *addition* of municipal and possibly industrial bio-waste in phase 2 compared to phase 1, in other words the *change* from phase 1 to phase 2 is profitable in its own right. A comparison of the internal rates of return in phase 1 and 2 tells us the same: The internal rate of return is higher in phase 2 than in phase 1, hence the addition of municipal and industrial bio-waste is profitable in its own right.

5.5 External benefits of biogas production at Tomaszów Mazowiecki

Biogas production in the anaerobic digestion process offers many environmental benefits. One of the primary benefits is the capture of methane (CH_4) that would otherwise be released into the atmosphere. Methane is a potent greenhouse gas, with a global warming potential (GWP) 28-36 times that of carbon dioxide (CO_2) over 100 years. By capturing and utilizing methane from biomass and bio-waste, anaerobic digestion prevents its escape into the atmosphere, mitigating its impact on climate change. It is especially important in the agricultural sector where livestock manure is a significant source of methane emissions. Processing manure in AD plants reduces emissions from traditional manure management practices such as open lagoons or piles.

Another benefit is the offsetting of fossil fuel use. The methane captured during anaerobic digestion is converted into biogas, which can be used to generate electricity and heat. Biogas is a renewable energy which can directly replace fossil fuels such as coal, oil, and natural gas, leading to a reduction in CO_2 emissions from energy production.

The by-product of the anaerobic digestion process, digestate, is rich in nutrients and can be used as a biofertilizer supporting sustainable agricultural practices. The use of digestate recycles nutrients back into the soil, reducing the need for synthetic fertilizers, whose production is energy-intensive and associated with high CO_2 emissions. Digestate enhances soil structure and increases organic matter. It also improves water retention, nutrient availability, and carbon sequestration in soils.

In this chapter, we analyse the benefits of biogas production from sewage sludge and municipal bio-waste (food/kitchen waste) in terms of GHG and ammonia (NH3) emission reduction.

The following analysis presents estimates of greenhouse gases and ammonia emissions from processes involved in the biogas production in a projected biogas plant in the wastewater treatment plant in Tomaszów Mazowiecki and its further use. Analyses were conducted for three phases of facility and management development:

- Baseline – current situation. Based on data from 2021-2022 regarding the amount of sludge generated and sludge treatment considering periodical deactivations of the drying facility.
- Phase 1 – building the biogas plant. In biogas production, the sludge and grease trap waste from wastewater treatment plant in Tomaszów Mazowiecki and sludge from neighbouring wastewater plants are used. Biogas is used to produce electricity and heat; electricity replaces the electricity from the grid; part of the heat is used on-site:
  - Option 1A. The digestate that remains as a byproduct of biogas production is used in agriculture without drying;
  - Option 1B. The digestate is processed on-site by drying using part of the produced biogas, remaining biogas is used to produce electricity and heat; the biofertilizer/soil improving product is used in agriculture.
- Phase 2 – expansion of biogas plant. In biogas production, in addition to substrates used in Phase 1, sludge from remaining neighbouring wastewater plants and separately collected food/kitchen waste from the municipal waste stream are used as co-substrates. Like in phase 1, biogas is used to produce electricity and heat; electricity replaces the electricity from the grid; part of the heat is used on-site. The digestate is processed on-site by drying using part of the produced biogas, remaining biogas is used to produce electricity and heat and biofertilizer/soil improving product is used in agriculture:
  - Option 2A Scenario 1. The municipalities collect separately food/kitchen waste, and all food/kitchen waste (with the current level of collection) is used in biogas plant;
  - Option 2A Scenario 4. It is assumed that the separate collection of food/kitchen waste increases to 75% of theoretical potential and all is used in biogas plant.

The presented options and scenarios correspond to the ones described in Chapter 5.2 and 5.3.

Estimations of GHG emissions are based on methodology of IPCC (2006) and IPCC (2019). Identified gas emission processes were assigned to dedicated subcategories from Sector 1.A. Fuel combustion activities and 5. Waste management. Methodology provides emission factors and IPCC Waste Model is used for estimation of emissions from substrate storage, which compiled with case specific activity data deliver estimates of carbon dioxide (CO2), methane (CH4), and nitrous oxide (N2O) emissions.

Estimations of NH_3 emissions are based on methodology described in EIG (2023), subcategory 5.B.1 Biological treatment of waste.

Values of activity data are based on the following assumptions:

- due to the deactivation of the sludge drying facility, 50% of sludge generated in the baseline phase is treated outside WWTP by an external company by composting and 50% is dried on-site and then used in agriculture;
- average product (dried sludge in baseline situation and digestate or bio-fertiliser/soil improving product in phases 1 and 2) storage duration is 4 days;
- 100% of the generated product (dried sludge in baseline situation and digestate or bio-fertiliser/soil improving product in phases 1 and 2) is distributed to the market and used in agriculture;
- 100% of the electric energy produced from biogas combustion will be utilized on-site;
- in phases 1 and 2, the average route of product transport will be similar to the average route of transported substrates (30 km);

- in options and scenarios where digestate is dried on-site, the produced biogas is primarily used in the drying process and from the remaining biogas energy is generated which then is used in the wastewater treatment process, replacing the electric energy from the grid;
- the biofilter efficiency is taken from EIG (2023).

During the analyses, the following ten processes were assumed to be the sources of GHG emissions:

- Substrates supply (wastewater, sludge, food/kitchen waste transport);
- Pre-treatment of food/kitchen waste;
- Wastewater treatment (without sludge treatment);
- Sludge treatment outside the WWTP by composting;
- Phosphorus recovery from sludge;
- Thermal hydrolysis of pre-treated sludge;
- Anaerobic digestion in biogas facility with energy recovery (combustion of biogas in cogeneration engine);
- Treatment of sludge and digestate by drying with natural gas or biogas;
- Product storage in an open area in WWTP;
- Product (dried sludge in baseline situation and bio-fertiliser/soil improvement product in phases 1 and 2) distribution to the market (transport).

In case of NH_3, the processes no 4 and 7 are the sources of emissions.

Estimates of carbon dioxide, methane, nitrous oxide and ammonia emissions from separate processes and emission sources in phase 1 are presented in Table 5.27 and in phase 2 in Table 5.28. Recalculation to carbon dioxide equivalent is based on Global Warming Potential AR5 values, released by IPCC (2013). Activity data and emission estimates results were cross-checked with data collected in the KOBiZE National database on greenhouse gases and other substances emissions and NIR (2024).

Table 5.27 Estimations of GHG and NH_3 emissions in phase 1 and comparison to baseline

Gas	Baseline	Phase 1 Option 1A	Reduction	Phase 1 Option 1B	Reduction
CO_2 [Mg]	2 588.8	1 713.9	34%	2 730.4	-5%
CH_4 [Mg]	610.3	153.9	75%	255.8	58%
N_2O [Mg]	184.4	27.0	85%	30.7	83%
Total GHG [Mg CO_2 eq]	**3 383.5**	**1 894.8**	**44%**	**3 016.9**	**11%**
Total NH_3 [Mg]	**3.31**	**0.89**	**73%**	**0.89**	**73%**

Source: IOS-PIB.

Table 5.28 Estimations of GHG and NH_3 emissions in phase 2 and comparison to baseline

Gas	Baseline	Phase 2 Option 2A Scenario 1	Reduction	Phase 2 Option 2A Scenario 4	Reduction
CO_2 [Mg]	2 588.8	2 607.8	-1%	2 507.1	3%
CH_4 [Mg]	610.3	257.2	58%	308.7	49%
N_2O [Mg]	184.4	29.6	84%	27.3	85%
Total GHG [Mg CO_2 eq]	**3 383.5**	**2 894.5**	**14%**	**2843.2**	**16%**
Total NH_3 [Mg]	**3.31**	**0.90**	**73%**	**1.25**	**62%**

Source: IOS-PIB.

The construction of a biogas plant and the use of sludge as substrates in each of the analysed phases and options leads to a reduction in total GHG and NH_3 emissions. The biggest reduction can be seen in phase 1 option 1A when the sludge, instead of being composted, is used as a substrate in the anaerobic digestion process, electricity produced from biogas replaces the electricity from the grid, and generated digestate is used in agriculture without drying. The reduction in GHG emissions (1 488.7 Mg CO_2 eq, 44% compared to baseline) is driven mostly by replacing almost half of the high-emission energy from fossil fuels with energy from biogas. In the case of NH_3 emission, the 73% reduction compared to the baseline is achieved by managing sludge in a closed anaerobic digestion process instead of open composting.

In option 1B, the reductions in GHG are much smaller (11% compared to baseline), due to the energy-intensive process of drying the digestate to produce soil-improving product. In phase 2, when the biogas production is higher and it could be possible to replace a bigger share of the electricity from the grid with energy from biogas, the reductions in GHG are higher than in option 1B – 14% and 16% in option 2A scenario 1 and option 2A scenario 4, respectively.

In Table 5.29, the estimates of emission of GHG and NH_3 and possible reduction in phase 2 for situations without digestate drying, are presented.

Table 5.29 Estimations of GHG and NH3 emissions in phase 2 and comparison to baseline, without digestate drying

Gas	Baseline	Phase 2 Option 2A Scenario 1	Reduction	Phase 2 Option 2A Scenario 4	Reduction
CO_2 [Mg]	2 588.8	1 598.9	38%	1 158.6	55%
CH_4 [Mg]	610.3	154.5	75%	165.3	73%
N_2O [Mg]	184.4	26.0	86%	22.5	88%
Total GHG [Mg CO_2 eq]	**3 383.5**	**1 779.4**	**47%**	**1 346.4**	**60%**
Total NH_3 [Mg]	**3.31**	**0.90**	**73%**	**1.25**	**62%**

Source: IOS-PIB.

The situation in which the digestate could be managed without the need for drying would allow to increase in the GHG reductions compared to the baseline from 14% and 16% (Table 5.26) to 47% and 60% when increasing the amount of biogas produced.

The electricity sector is covered by EU ETS, hence the price of purchased electricity should include payment for CO_2-emissions. Electricity constitutes a main share of energy cost savings (section 5.2.5). CO_2 and CO_2 equivalents associated with heat may be inside or outside of ETS depending on circumstances. CH_4 and N_2O are outside of the EU ETS.

For this report, we assume that half of the CO_2-equivalent emissions are excluded from the cost-savings reported above. The EU ETS price currently is about €80 per ton, but it shows an increasing trend in parallel with an ever-stricter EU ceiling on emissions. Here we assume €100/ton during the operation of the plant. €100 translates to 430 PLN.

Combining 750 tons of unaccounted-for emission reductions and 430 PLN per ton we estimate about 0.3 million PLN as the external value of CO_2 emission, that is, the value that is unaccounted for in the cost savings reported above. In a social analysis this figure should be added to the genuine cost savings outlined above.

Besides the impact on CO_2, CH_4 and N_2O emissions the project will contribute to increased energy security and a robust energy system. Reducing negative climate impacts is a value in itself. In the case of public investments, this should also be significant, irrespective of the formal conditions that translate into economic performance of the investment.

6 Conclusions

Based on the analysis we make the following observations:

- The MOFTMO has significant potential for agricultural biogas production, partly realized by already functioning biogas plants. The mapping of the agricultural biogas potential indicates that in almost every municipality at least one 0,5 MW biogas plant could operate. Due to the fact, that the prevailing in the area farms are small with limited animal population, cooperation between stakeholders from the agricultural sector is needed. One of the ways in which the cooperation in agricultural sector could be established is energy cooperative. The cooperatives would enable the exploitation of the economy of scale existing in the biogas production sector. The cooperatives could also use support from the functioning in Poland support system which favours the agricultural sector.
- The biogas potential of the municipal sector is much smaller than that of the agricultural sector. Moreover, biogas production facilities using substrates from the municipal sector (wastewater sludge, organic fraction of municipal waste), due to the required pre-treatment the feedstock requires, tend to incur higher capital and operational costs than other facilities.
- In MOFTMO, the investment in biogas production in a municipal wastewater treatment plant is possible in Tomaszów Mazowiecki where the biggest WWTP in the area is located. Investment in biogas plant could be an important step for WWTP on the path to achieving energy self-sufficiency. Using in the biogas plant the municipal sludge generated in WWTP with the addition of grease trap sludge, wastewater from the agricultural industry, and sludge from neighbouring WWTP, could produce energy to cover ca. 50% of WWTP energy needs. The analysis indicates that without co-fermentation (addition of other substrates besides wastewater sludge), the biogas plants located within WWTPs won't allow the WWTP to become energy self-sufficient. This observation means that available grants/loans for the municipal sector should not reduce the support by limiting the substrates accepted to one stream (eg. only agricultural, only sludge, only organic fraction of municipal waste) as sometimes is the case.
- The results of the economic analysis conducted, although simplified and depending on assumptions made, indicate that also profitability of biogas production at Tomaszow Mazowiecki could increase significantly when municipal waste or industrial waste is included as a substrate. The possibility of charging waste gate fees for treating external waste provides the biogas plant with additional income. There is an investment cost required to pre-treat municipal or industrial waste. However, the additional income from gate fees and higher biogas production resulting in greater energy savings make this option profitable which is also supported by the example of the biogas plant at the wastewater treatment plant in the Regional Water and Sewage Management Center in Tychy.
- In energy management of biogas plants, the possibility of using, and preferably selling, the excess heat produced in cogeneration (CHP) impacts the profitability of the investment. Finding use for the excess heat can improve both profitability and social acceptance of the installation. It may also reduce environmental and climatic impacts as unutilized excess heat just warms the air. One may consider including the full use of heat as a condition in loan/grant agreements. However, in the case of biogas plants in the municipal sector, the

use of excess heat is often impeded by the location of installations – usually in distance from possible points of use.

- The need for cooperation is especially crucial in the municipal sector. The option in which sludge from wastewater treatment is co-digested with other substrates requires cooperation with the possible co-substrate providers. The exploitation of excess heat generated during energy production in cogeneration calls for cooperation with potential heat recipients. It is also necessary to find markets for the digestate making cooperation with, preferably local, digestate utilizers a must. The stakeholders in the municipal sector could possibly cooperate as an energy cluster, exploiting the support offered by the new regulation in this area. The development of a network structure around biogas plant investments could contribute to the growing importance of biogas in the region's energy economy.
- How the digestate is treated, both in legal (as a bio-fertiliser or as a waste) and technological terms (does it need energy-intensive treatment before use) has an impact on the profitability of biogas plants. This is brought out clearly both in Phase 1 and Phase 2 at the Tomaszow Mazowiecki wastewater treatment plant. It is necessary to improve the regulations and conditions for using digestate in agriculture.
- Biogas production in the anaerobic digestion process offers many environmental benefits mitigating the impact of waste management on the environment and climate change. The important benefit – capturing the methane released in the process – is especially relevant for the agricultural sector where livestock manure is a significant source of methane emissions. Processing manure in AD plants reduces emissions from traditional manure management practices such as open lagoons or piles. Another benefit is the offsetting of fossil fuel use. Electricity and heat generated from biogas can replace fossil fuels such as coal, oil, and natural gas, leading to a reduction in carbon dioxide emissions from energy production. The use of digestate as a biofertilizer supports sustainable agricultural practices leading to recycling nutrients back into the soil, reducing the need for synthetic fertilizers, enhancing soil structure and increasing organic matter.

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Appendices

A Methane production potential from selected subtrates

Table A.1 Methane production potential from selected substrates

Data unit	Content of dry mass [%]	Content of dry organic mass [%]	Methane production from dry organic matter [cubic meters/Mg d.o.m]
Wastes from baking industry	87.7	97.1	403.4
Sludge from municipal wastewater treatment plant(*)	4.4	83.4	212.8
Biodegradable municipal waste	60.3	55.0	396.8 75-390(**)
Food and kitchen waste	18.9 15-25(**)	71.9 85-94(**)	530.0 90-305(**)
Plant and grass clippings (urban greenery)	23.2	88.2	489.7 310-408(**)
Straw	87.5	87.0	387.5
Hay	87.8	89.6	417.9
Corn silage	32.6	90.8	317.6
Cattle manure	23.7	76.4	249.4
Cattle slurry	9.5	77.4	225.5
Pig manure	23.8	79.9	228.0
Pig slurry	6.6	76.1	301.0
Poultry manure	30.3	72.7	230.0
Poultry slurry	15.0	75.6	320.0

Source: Curkowski et al, 2009; except (*) AL-PROJEKT, 2023, (**) Krasucka E. Oniszk-Popławska A. (2013).

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