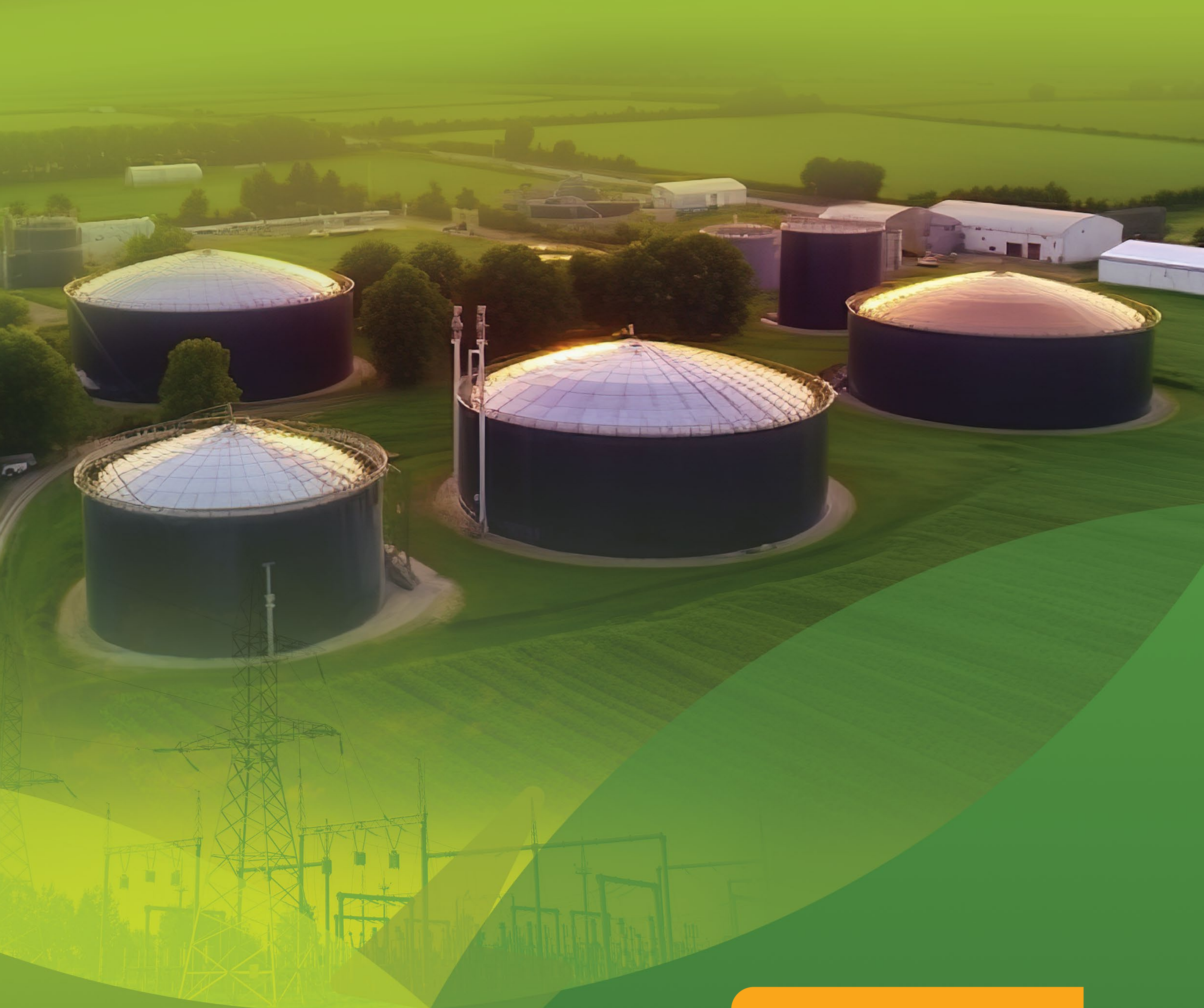

Report 2024

From natural gas to biomethane
Decarbonising the Polish gas industry

DISE ENERGY

Lower Silesian Institute
for Energy Studies
Wrocław, September 2024

From natural gas to biomethane
Decarbonising the Polish gas industry

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WROCŁAW September 2024

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Foreword from Miłosz Motyka, Undersecretary of State, Ministry of Climate and Environment

Ladies and Gentlemen,

To begin with, I would like to express my immense gratitude to all those who have worked for the promotion and development of biomethane production in Poland. In particular, I would like to thank the authors of this report for this study, which brings the issue of biomethane in Poland closer to stakeholders, decision makers and all those who will read it.

As I write these words, there is not yet a single biomethane plant in operation in Poland, which is a kind of illustration of how much work awaits our state and entrepreneurs in terms of developing the capacity to produce this fuel. We cannot afford the present situation to continue, as all of our western and southern neighbours have biomethane installations in place, benefiting from them and strengthening their economies today. Poland cannot continue to remain a biomethane desert, if only because of our country's dormant potential - according to various estimates, the potential for biomethane production in Poland ranges from 5 to 8 billion m^3 per year. Given forecasts of a demand for natural gas of 21-30 billion m3 per year in 2029, the domestic potential for biomethane production could cover as much as one-third of the annual demand for the blue fuel! Harnessing this potential will be another milestone on the road to making the Polish energy sector independent of imported fossil fuels, thereby increasing the security of our entire economy and citizens. The ability to produce a domestic substitute for natural gas will also have an impact on energy prices, guarding against the use of natural gas as a weapon against our economy by countries exporting blue fuel.

However, biomethane is not only one of the keys to the country's energy independence - it is also one of the elements limiting humanity's negative impact on the climate and the environment. Biomethane, being a purified biogas, consists mainly of methane (CH4) and therefore has very low greenhouse gas emissions during combustion. Furthermore, some of the production pathways for biomethane can make it have negative life-cycle greenhouse gas emissions, meaning not neutral, but positive climate impacts. Another desirable aspect of biomethane is that its production fits perfectly into the philosophy of the circular economy by being able to use agricultural substrates such as slurry, which as a digestate can be further used in agriculture as fertiliser, and waste (including municipal and agricultural waste). Thus, by producing biomethane, not only can we gain a renewable energy carrier, but the benefit here is to maximise the use of feedstocks that would otherwise be treated as waste.

In order to use biomethane in the Polish energy mix, there is no need for extensive investment in infrastructure for the transmission and use of this fuel. Thanks to its similarity to natural gas, biomethane can be injected into the existing gas infrastructure and used as required: to fuel gas boilers, to be burned in facilities producing electricity and heat, or to power vehicles with engines adapted to use CNG or LNG. With these characteristics, the development of the biomethane market can be very dynamic, as there is a receptive domestic market for biomethane while the infrastructure for transmission is in place. However, this does not mean that there are no barriers to development - problems such as the insularity that characterises the deployment of biomethane plants (which means that they are far from the gas network) or the high investment costs that need to be incurred for this type of installation need to be addressed.

There is no doubt that the development of biomethane production capacity is in the interest of Poland, and thus of all its inhabitants. In order to implement effective, well-considered and evidence-based measures, reliable and objective analyses are needed. In my opinion, this report is just such an analysis - a kind of compendium of knowledge about biomethane and its conditions in the Polish legal and market reality. Therefore, I would like to encourage all interested parties to familiarise themselves with this study, which is another building block laying the foundations for the effective development of the biomethane market in Poland.

I wish you a successful and fruitful reading!

Miłosz Motyka, Undersecretary of State, Ministry of Climate and Environment

Foreword from Remigiusz Nowakowski, President of the DISE Management Board

Ladies and Gentlemen,

We are handing over to you the next DISE Energy report on the role of gaseous fuels in the energy transition 'From Natural Gas to Biomethane. Decarbonising the Polish gas industry'. This time we have comprehensively analysed the potential for the use of biomethane in Poland as an alternative fuel to natural gas. This study is the result of a project carried out by DISE Energy in cooperation with the European Climate Foundation, and I would like to take this opportunity to thank the ECF team for their support and very good and creative cooperation.

In previous studies, we have focused on analysing the legitimacy of using natural gas as an interim fuel in Poland's energy transition process. Following Russia's attack on Ukraine, and the ensuing energy crisis, significant risks related to Europe's dependence on gas supplies from eastern directions materialised and the issue of security of supply became a priority. In response, the European Commission proposed ambitious targets for the use of renewable fuels, including biomethane, as a local fuel and alternative to natural gas in the REPowerEU package. This approach, based on the diversification of supply and the use of local resources and synergies between the agricultural and energy sectors, is also crucial from the point of view of Poland, which has so far obtained most of its natural gas for energy purposes from Russia. We are convinced, which is also confirmed by the analysis conducted in our study, that Poland has very good conditions for the development and production of biomethane and its use in the process of decarbonisation of many sectors of the economy. Therefore, we have attempted to formulate strategic directions of actions necessary for the development of this RES sub-sector. We sincerely hope that the conclusions of our report will be used by the Polish government in the process of updating strategic documents concerning energy and climate policy and will serve to formulate a sectoral policy aimed at systemic support for the efficient production of energy from biomethane in Poland.

Over the last 20 years, there has been much talk about the potential that agricultural biogas has in Poland, and successive governments have made ambitious plans to use biogas for energy purposes in Poland. Unfortunately, this ended mainly in assumptions and declarations. Meanwhile, in European Union countries such as Germany, Denmark, France and the Czech Republic, the development of biomethane has become a viable economic programme, resulting in the establishment of hundreds of biogas and biomethane plants. The key success factors for the development of this sector in these countries are synthesised in this report.

As a gas produced from renewable raw materials, biomethane meets the taxonomic criteria of "sustainable development" and, in terms of its physical and chemical characteristics, is directly suitable for replacing natural gas. Electricity generation from biomethane, in conjunction with other sources of 'green energy' such as wind and photovoltaic power plants, has a positive effect on increasing the flexibility of RES energy supply due to the possibility of stable production independent of the time of day and year, as well as weather conditions.

Biomethane is a valuable and limited resource that should ultimately be used mainly to generate electricity or heat directly for end-users. In this way, biomethane energy can make a real contribution to the decarbonisation of Poland's energy mix and respond to the new demand that will be generated by the growing trend of electrification of many sectors of the economy. For this to happen, however, concrete solutions are needed to create a regulatory framework and provide effective financial support to stimulate investment in the initial phase of this process. In addition, biomethane production will positively influence the transformation of the agricultural sector and, in the long term, provide additional financial transfers to farmers, who will be able to gain a tangible benefit from the economically optimal use of waste from agricultural production for energy purposes.

I wish you a pleasant reading of our report, and I invite decision-makers to take advantage of the good practices and recommendations presented in the report, the implementation of which will help to create a well-operating biomethane energy subsector in Poland.

Yours sincerely,

Remigiusz Nowakowski, President of the DISE Management Board

Executive summary

As part of the REPowerEU plan, the European Commission has proposed to accelerate the energy transition and increase the share of renewable energy in the energy mix of EU member states. One of the objectives of this plan is the production and use of 35 billion cubic metres (abbreviated as bcm) of biomethane by 2030 and a new biomethane industrial partnership to "support the achievement of the target and create the preconditions for further development by 2050". Given the identified potential for biomethane development, Poland can contribute significantly to this goal.

Biomethane has the potential to replace fossil fuels in many sectors, thereby reducing greenhouse gas (GHG) emissions and directly contributing to the energy transition. Furthermore, the use of fermentate as a fertiliser further reduces GHG emissions by replacing the production of synthetic fertilisers.

Biomethane produced in EU member states will reduce dependence on gas imports, improve Europe's energy security, reduce the cost of CO_2 negatively impacting on fossil fuel energy prices and reduce fuel poverty levels in real terms. There is significant economic potential to be gained by producing a European form of 'green gas' produced using European technology.

The following key conclusions can also be drawn from the analysis carried out in this study:

- The future of the Polish energy sector, including the gas sub-sector, is determined to the greatest extent by the current climate policy of the European Union, expressed in two strategies: European Green Deal and REPowerEU. In the light of the assumptions and goals adopted in these strategies, the traditional gas sector model based solely on fossil fuels will have to undergo a profound transformation leading to the absorption of renewable gases.

- Confidence in natural gas as a secure energy source has been severely undermined as a consequence of the 2021-2022 energy crisis. The dominant supply of imported gaseous fuel to the domestic market, despite the transport infrastructure developed in recent years, will continue to be subject to geopolitical risks. Its reduction will be served by maximising the use of domestic energy resources, including agricultural biogas, from which biomethane can be efficiently produced. The unique characteristics of the biomethane sector make it a valuable source of energy for local energy communities and support the diversification of supply using renewable resources based on local supply chains.

- A matter that requires swift action in the coming years is the need to reduce the carbon footprint of products manufactured by the Polish industry. This is because the European Commission will make it compulsory to label goods with their carbon footprint. Such action is being taken on their own initiative by pan-European retail chains, which are already demanding goods with a low or zero carbon footprint. This puts companies operating in Poland in an extremely difficult position, as the carbon footprint is heavily influenced by the 'greenness' of the electricity and gas used in production. The use of biomethane should help solve this problem.

- Biomethane can therefore significantly help Poland to achieve its decarbonisation targets for the industry and energy sector, including gas, and through it other sectors of the economy. Under Polish conditions, biomethane, due to its physical and chemical characteristics, can replace fossil gas in the fastest way, leading to a reduction in its consumption. Biomethane obtained from domestic biomass resources will also contribute to Poland's energy security by reducing dependence on imported gaseous fuel.

- Poland has an appropriate raw material base for the development of biomethane production in the form of biomass, which is waste from agricultural production in the form of manure, slurry or maize straw, among others. It is on the basis of such a substrate, rather than the cultivation of energy crops, that the production of biomethane in Poland should be developed, and this should be regulated at the initial stage of the development of the market for this raw material. Biomethane can be produced from organic household waste, industrial waste, agricultural residues and sustainable forms of biomass. This not only provides an effective waste management solution, but also promotes a circular economy by converting waste materials into valuable energy sources. A key factor for the large-scale use of biomethane is meeting sustainability criteria.

- In the perspective of several years, achievable biomethane production in Poland may amount to 3.2 bcm per year (approx. 33.7 TWh per year), which corresponds to approx. 10% of the target set in REPowerEU. This figure is a realistic level of biomethane production to be achieved. Poland has one of the highest potentials for biomethane production in Europe. Given its close links with the agricultural sector, biomethane production can foster new employment opportunities and economic development in rural regions. However, the indicated volume of biomethane production will not allow the complete elimination of natural gas in the short term and therefore the full decarbonisation of the gas sector. The development of biomethane production and its introduction into the economic cycle cannot therefore be seen as the only and complete solution for decarbonisation and improved energy security. Renewable hydrogen and the process of reducing the use of gaseous fuel through the electrification of industry and transport must also be included in the gas transition scenario.

- Biomethane production involves the separation of pure biogenic CO_2 from methane. This CO_2 of biogenic origin can replace the CO_2 from fossil fuels needed for various industrial applications and contribute to the removal of greenhouse gases.

- Given the significant, albeit finite, potential for biomethane production in Poland, it is necessary to determine the most rational ways of using it from an ecological and economic point of view. The examples of some EU member states, where the production of biomethane has been developing for several years, indicate that one way of utilising biomethane is to make it available to consumers connected to the existing natural gas distribution and transmission network. In this way, the environmentally friendly fuel will be able to reach power plants and CHP plants that currently use fossil natural gas. In this way, biomethane will also be able to contribute to the decarbonisation of the Polish district heating sector. This approach should be used in the short term (approx. 10 years) when there is still significant use of natural gas both for energy purposes and in transport (e.g. CNG buses).

- In the long term (2035-2050), the use of biomethane as efficiently as possible by energy end-users should dominate. Biomethane is a scarce resource, so any end-use that can be used for electricity generation should be favoured. A possible end-use of biomethane that is not currently used is the production of high-temperature heat for industry, such as process steam. One of the key uses of biomethane in the long term should be direct electricity generation to meet the increased demand for RES energy in local electricity systems generated by:
  - » heat pumps (decarbonisation of individual heat sources);
  - » individual and urban transport sector (electric cars and electric buses).

- Increasing the scale of electricity production from biomethane will also support the development of other (weather-dependent) RES, such as wind power and photovoltaics. Permanent access to biomass feedstock will allow the production of a consistent energy profile, which will have a positive impact on local balancing and better match the energy demand profile of consumers. Biomethane can also be temporarily stored in tanks and thus used as a kind of energy store, which can be generated in gas engines or gas turbines when there is a shortage of energy from other RES. One model for the development of biomethane technology is the use of this technology in local energy clusters and energy cooperatives especially in rural areas. The biomethane production process naturally generates fermentate, i.e. an organic fertiliser that can be used in agriculture as a substitute for synthetic fertilisers.

- The development of the biomethane sector in Poland is still at a very early stage. The biogas plants in operation are not yet being adapted to produce biomethane. Despite the formal possibility of connecting a biomethanation plant to the distribution grid and the strong interest of investors in this possibility, no such event had occurred by the time this Report was published. By the end of 2024, the first pilot biomethanation plant built by the University of Life Sciences in Poznań is expected to be operational and connected to the grid. One of the barriers to the development of the biomethane sector is the complex approval process forming a part of the investment process, which can be accelerated by establishing special zones for the development of biomethanation plants in areas with abundant feedstock and existing gas grid infrastructure for sustainable biomethane production.

- Another major challenge is to ensure an appropriate level of profitability for investment in the development of biomethanation plants, which is related to the level of cost of biomethane production and energy from biomethane. Calculations made in this report show that the cost of electricity from biomethane sources at a biomethane price of EUR 65/MWh (estimated by DNV experts) for 2035 in Poland is comparable to the averaged LCOE of gas sources with a gas price of 50 EUR/MWh and a CO_2 price of 70 EUR/tCO_2, making biomethane an attractive economic alternative to natural gas in view of the assumed increases in the price of CO_2 emission allowances in the EU ETS, well above the assumed level of 70 EUR per tonne of CO_2. Crucial to the competitiveness of biomethane in electricity generation is the future price of natural gas. With relatively low natural gas prices (around EUR 30/MWh), conventional gas plants remain cheaper than biomethanation plants even with high CO_2 prices.

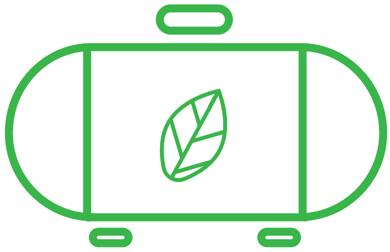
- Biomethane fed into the gas grid can also serve to decarbonise the district heating sector. We assume that system heat generated from biomethane should remain competitive in contrast to generation sources above 20 MW, which are currently covered by the EU ETS. With a CO_2 price of 70 EUR/tonne and 100% natural gas combustion in CHP plants covered by the EU ETS, the heat generated will be burdened with an additional CO_2 cost of approximately 10 EUR/MWh, while with a CO_2 price of 145 EUR/tonne, the CO_2 cost in heat will already be over 20EUR/MWh. The achievement of competitiveness of biomethane heat in sources not covered by the EU ETS will occur when the prices of biomethane and natural gas become equal, alternatively if the installed capacity threshold of installations covered by the EU ETS is lowered.

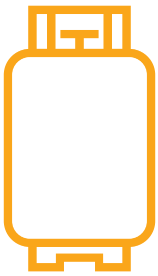
- Bearing in mind the current level of electricity prices in Poland for the fuel mix, in which approx. 60% is made up of energy from fossil fuels, primarily coal, it is necessary to implement an incentive mechanism, in the form of a structured support system, for biomethane, the competitiveness of which will increase over time. An important source of support in the short term should be, among other things, European funds intended to accelerate the energy transition and decarbonisation. Therefore, it seems reasonable to create a dedicated operational programme for the development of biomethanation plants in Poland.

- Given the decarbonisation needs of the Polish economy and the distance in this respect from many European economies, the development of a dedicated biomethane sector strategy should be considered, with specific objectives, time horizons, a list of stakeholders with assigned tasks and funding sources, and its correlation with strategic documents - the Polish Energy Policy and the National Energy and Climate Plan.

List of abbreviations

CAKE	- Centre for Climate and Energy Analysis
CHP	- Combined heat and power
CNG	- Compressed Natural Gas
DISE	- Lower Silesian Institute for Energy Studies
EU ETS	- European Emissions Trading System
ESG	- E - environmental, S - social responsibility, G - corporate governance
EGD	- European Green Deal
FIP	- Feed in Premium
FIT	- Feed in Tariff
GHG	- greenhouse gases
GOs	- Guarantees of Origin
NECP	- National Energy and Climate Plan 2021-2030
EC	- European Commission
KOBIZE	- National Centre for Emissions Management
LCOE	- Levelized Cost of Electricity
LNG	- Liquefied Natural Gas
PEP2040	- Energy Policy of Poland until 2040
PSA	- Pressure Swing Adsorption
PSG	- Polska Spółka Gazownictwa
RRF	- Recovery and Resilience Facility
UN	- United Nations
DSO	- Distribution System Operator
TSO	- Transmission System Operator
RES	- Renewable Energy Sources
NCRD	- National Centre for Research and Development
NEMO	- Nominated Electricity Market Operator
TGE	- Polish Power Exchange





Introduction

Introduction

This report entitled "Decarbonising the Polish Gas Industry. From Natural Gas to Biomethane" is a continuation and development of the analysis and research conducted by the Lower Silesian Institute for Energy Studies (DISE) in 2020-2022 on the role of gaseous fuel in the context of the energy transition and geopolitical conditions[1]. The gas sector in Poland, as well as in the European Union as a whole, currently operates in a political and regulatory environment shaped primarily by pro-climate aspirations and expectations. An expression of this direction is the European Green Deal document announced by the European Commission in 2019, which contains the European Union's current climate policy. Confirmation of the EU climate goals is also found in the 2022 REPowerEU strategy. In light of the aspirations expressed in these strategies, profound changes in the operation of the natural gas sector, leading to its climate neutrality, seem inevitable. An additional element putting pressure on today's gas industry and the gas market as a whole is the persistent risk of supply disruptions, linked to ongoing conflicts in the international environment, led by the Russian-Ukrainian war. Political conflicts, as well as armed conflicts, are phenomena permanently inscribed in the functioning of international relations and therefore permanently generate disruptions in international trade and transport of natural gas and other goods. Meeting these challenges should be aided by an appropriate strategy for the Polish gas industry, which will be able to reconcile the achievement of climate goals with meeting market security needs.

The latest Report prepared by DISE experts should be regarded as a substantive contribution to the public discussion aimed at determining an appropriate transformation path for the Polish gas industry. Thus, the publication proposes a specific course of action, the implementation of which should lead to the change of the homogeneous model of the gas industry, which has been in place for many decades, based solely on fossil fuels, in favour of a decarbonised and multi-fuel sector. Ultimately, non-carbon gases are to play a dominant role in this new model. It is DISE's belief that the vehicle for this desired change will primarily be biomethane produced from domestic resources. The adoption of the above thesis has been based on the findings and rationale developed in previous research work:

1 In 2020-2022, DISE, with the support of the European Climate Foundation, developed and published two reports: Natural *Gas in the Energy Transition in Poland*, Wrocław 2020, *Natural Gas Hostage to Geopolitics*, Wrocław 2022. The first report shows the bridging importance of natural gas fuel in the implementation leading to climate neutrality. In contrast, the second report shows the vulnerability of European gas markets to geopolitical risks, the materialisation of which has led to a sudden EU-wide energy crisis.

a. As a consequence of the implementation of the EU climate policy, the traditional gas industry based on natural gas monoculture will evolve into a multi-fuel sector in which renewable gases, including biomethane, will play an increasing role.

b. The development of biomethane production in Poland is in line with the European Union's current plans for the gas sector. The REPowerEU strategy, which is a response to the energy crisis, has set a production target of 35 bcm of biomethane per year by 2030, which translates into an increase in its production by 18 bcm compared to the volumes forecast in the 'Fit for 55' plan. According to the assumptions adopted in the draft of the so-called EU Gas Package by 2050, biogas, biomethane, renewable and low-carbon hydrogen and synthetic methane are to achieve a 2/3 share in the structure of the EU gas mix.

c. The dissemination of biomethane in the economy, due to its physical and chemical characteristics, can be carried out using the existing gas infrastructure, which should help to speed up the whole process and reduce its costs.

d. Poland has adequate potential to launch and develop large-scale biomethane production. The development of this new field of production will be conducive to the achievement of a state of climate neutrality by the Polish economy and, at the same time, will have a positive impact on strengthening the country's energy security by reducing its dependence on imported natural gas.

This Report is based on a formal analysis (review of EU and Polish strategic documents), a comparative analysis (presentation of strategies and system solutions supporting the production of biomethane in selected EU countries), as well as the output of economic sciences as well as expertise and statistics regarding the functioning of the agricultural economy in Poland. The multifaceted and interdisciplinary analysis contained in this Report, framed in a total of seven chapters, was primarily aimed at a multifaceted evaluation of biomethane as an alternative fuel to natural gas. First of all, the qualitative parameters and physico-chemical properties of biomethane were characterised by comparing and contrasting it with the group E high-methane gas commonly used in the national economy. The comparison carried out serves to support the thesis of biomethane's ability to replace traditional gaseous fuel and make an effective contribution to the decarbonisation of the gas sector. A critical review of available biomethane generation technologies is also carried out, based on the sustainability criterion set out in current legislation, including Commission Implementing Regulation (EU) 2022/996 of 14 June 2022 on rules to verify sustainability and greenhouse gas emissions saving criteria and low indirect land-use change-risk criteria. This section of the report also presents ways to use biomethane as part of the decarbonisation of the Polish economy while attempting to establish an appropriate gradation of the sectors involved in this process.

In the next chapter, the Report refers to the most important EU and Polish strategic documents and legal acts currently in force, which define the role of biomethane in the energy transition process. In this context, particular attention is of course paid to the regulatory framework in place, albeit not yet fully formed, dedicated to the transformation of the gas industry towards climate neutrality in this sector.

An important part of the publication is the third chapter, which describes the state of development of biomethane markets in four selected EU countries: Denmark, Germany, France and the Czech Republic. The aim of this analysis is primarily to present practical solutions (e.g. legislative or financial) to support the development of biomethane production and dissemination in the economy. The choice of these cases was dictated by the considerable advancement in the development of biomethane production in these countries and the different profile of markets, motivations and implementation of biomethane policies.

In chapter four, the analytical effort, again using the sustainability criterion, focused on estimating the domestic generation potential based on available categories and volumes of bio-based substrate, i.e. biomass. At the same time, available estimates of the future possible demand for this fuel in Poland were given, broken down into different market segments. The calculations presented in the Report should not, however, be treated as final, as the determination of achievable biomethane production is and will be in the near future subject to analysis by various research centres or industry organisations. The next key issue considered in this Report relates to the infrastructural aspect of the introduction of biomethane into the gas sector and the overall economy. In this case, the aim of the study was to examine, using the distribution network as an example, the feasibility of using the existing gas infrastructure to receive and transport future volumes of biomethane produced in Poland. This part of the Report also included the identification of potential technical and administrative barriers limiting the availability of the existing gas infrastructure in Poland for biomethane.

The scope of this Report also covers the economic aspect of the production and use of biomethane in Poland, focusing on the competitiveness of this fuel vis-à-vis fossil natural gas in the economic cycle. The study also covers the projected impact of biomethane on electricity prices in the context of changes in carbon dioxide emissions.

The final result of the work on this report is a summary of the benefits associated with the decarbonisation of the gas industry with the use of biomethane and the recommendations relating to the most important issues, in the opinion of the authors, associated with the removal of barriers and the initiation and subsequent development of biomethane production in Poland. They include proposals for organisational, regulatory and economic solutions, the implementation of which should foster the launch of large-scale biomethane production and thus support the energy transition process. The authors of this Report, in making a list of recommendations outlining a specific path forward for the gas sector, were guided primarily by the conviction that it is necessary to consider a number of equivalent values, such as climate neutrality, sustainable economic development and energy security.

1 Biomethane - characteristics

Chapter 1.

Biomethane - characteristics

Biomethane is a gas produced from the purification of biogas (i.e. a mixture of mainly CH_4 and CO_2), although, in addition to the traditional understanding of biogas produced in biogas plants, it can also be produced by gasification processes or power-to-gas technologies (i.e. the conversion of other gases such as H2 and CO_2 into CH_4, especially when using excess electricity from weather-dependent RES). According to the RES Act, biomethane is a gas obtained from biogas, agricultural biogas or renewable hydrogen, subjected to a purification process, fed into the gas grid or transported in compressed or liquefied form by means of transport other than gas grids, or used for refuelling motor vehicles without being transported.

In practice, biomethane hardly differs from typical natural gas, but due to its high purity and the minimal presence of admixtures of other gases, it can be slightly less calorific compared to natural gas containing naturally occurring admixtures of ethane or propane, as well as significantly more calorific than nitrogenated natural gas. BioCH_4 is distinguished above all by its renewable origin: it is a decarbonised gas, for the production of which waste is mostly used, and as a result of the GHG emissions avoided during the storage of bio-waste, biomethane can have a negative carbon footprint. In practice, biomethane can easily be used in existing natural gas infrastructure, making it an extremely valuable gas for low-cost greening of the natural gas sector without the need to replace pipelines and peripherals as is the case with the use of hydrogen being currently the most famous decarbonised gas.

1.1. Quality parameters, physico-chemical characteristics

While the composition of biogas can vary greatly and depends on the substrates used and the digestion technology, BioCH4 is a gas containing mainly methane in concentrations mostly above 97%. Unlike natural gas, which is classed as a fossil fuel, biomethane is a renewable, low-carbon energy source. Traditional natural gas (methane) is extracted from deposits formed from the remains of organic matter from millions of years ago, located in the deep layers of the Earth. Meanwhile, biomethane is produced by fermentation processes from the processing of organic matter (agro biomass and bio-waste), making it a renewable energy source that can be produced virtually worldwide[2]. Natural gas consists mainly of methane (70-98%), ethane, propane, carbon monoxide and dioxide, nitrogen and helium. The biomethane formed after biogas purification accounts for almost all of the gas volume. Table 1. provides information on the types of natural gas and biomethane, together with their characteristics.

TAB. 1. Types of natural gas and biomethane and their characteristics

No.	Characteristics	Common name
Natural gas	> 85% methane	high-methane gas (natural gas E)
	30-80% methane	nitrogenous gas (natural gas Ls)
	methane and ethane content approx. 95%	dry natural gas
	up to about 30% of higher hydrocarbons, such as propane and butane, are present with crude oil	wet gas (condensate)
Biomethane	- 94-99.9% methane, depending on the treatment method used *(biogas upgrading technology)* - 0.1-4% carbon dioxide - < 3% nitrogen - < 1% oxygen - < 10 ppm hydrogen sulphide - 36 MJ/m^3 lower heating value *(LHV)*	biomethane

1.2. Technologies

PRODUCTION

The primary source of biomethane generation in Europe and Asia is biogas purification. The Renewable Energy Sources Act of 20 February 2015 defines biogas as gas derived from biomass, in particular from animal or plant waste processing facilities, sewage treatment plants and landfills. Unlike most countries in the world, in Poland agricultural biogas is still defined, for which the sources of production have been narrowed down to the following agricultural substrates:

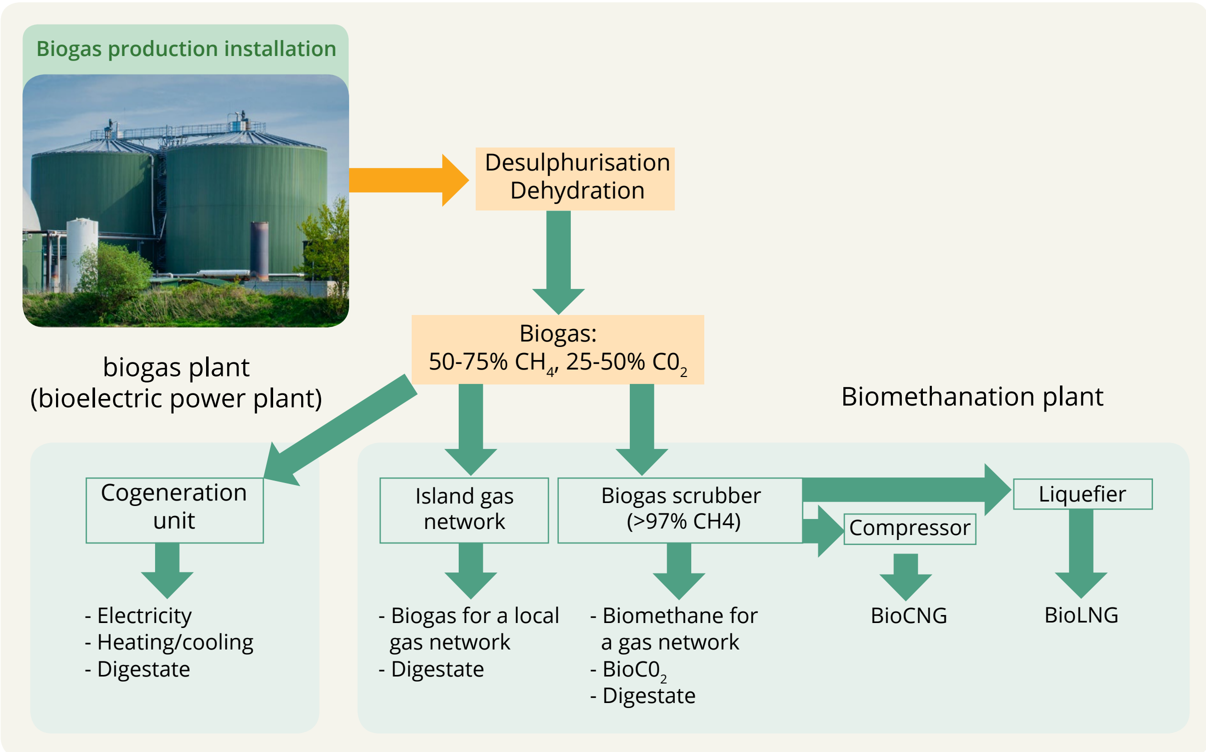
- agricultural products and agricultural by-products, including animal manure,
- products from the processing of products of agricultural origin and by-products, waste or residues from such processing, including food processing and production, from industrial plants, as well as from on-site waste water treatment plants from agri-food processing, where separation of industrial waste water from other types of sludge and waste water is carried out,
- food products that are out of date or unfit for consumption,
- fats and oil mixtures from oil/water separation containing only edible oils and fats,
- plant biomass harvested from land other than that declared as agricultural,
- manure from non-agricultural activities.

2 *Biomethane UK (2019)*: https://www.biomethane.org.uk/; 15.03.2024.

Biogas, generally containing 48-76% methane, is produced most often in installations called biogas plants, operating through a wet mesophilic fermentation process (temperature 36-42°C). Worldwide, in the more than 50 million installations in operation (usually small), the biogas produced is used directly by users, or in the case of larger installations, after drying and desulphurisation, in local biogas networks or, after purification to biomethane, injected into the natural gas network via a direct connection or transported by tanker trucks (so-called virtual gas pipelines).

In Europe, where, due to the harsher climate than in the tropics and equatorial zones, biogas plants have to be heated and thus have the character of large industrial installations, the use of raw biogas is almost non-existent in practice; most often, the biogas produced is combusted in cogeneration engines to produce electricity and heat in cogeneration (or possibly refrigeration, in which case trigeneration occurs), although the production of biomethane (and bioCO_2) is becoming more common and the production of electricity and heat is used exclusively to meet the biomethanation plant's own needs. A diagram of the most common biogas utilisation options, depending on the products obtained, is shown in Figure 1.

FIG. 1. Diagram of the most common biogas utilisation trends



Source: made by Jacek Dach

Biomethane can also be produced by gasification or power-to-gas technology if the electricity used is generated from renewable sources and the hydrogen and carbon dioxide are biologically converted to methane[3]. It is worth noting that a very interesting trend in biomethane production is the use of green hydrogen and carbon dioxide generated during the biogas production process or the purification of biogas into biomethane. Research carried out in many research centres around the world (but also at the University of Life Sciences in Poznań) has shown that introducing hydrogen into the digesters of a biogas plant can increase the CH_4 level in the biogas produced from a typical 55-60% up to 90%, which for a biomethanation plant with a power equivalent of 2 MW can mean an increase in biomethane production from about 4 million m^3 (abbreviated as MCM) per year to even over 6 million m^3 of CH_4 per year. This is potentially a very good way of cheaply and efficiently managing excess green hydrogen produced during surplus electricity from weather-dependent sources, as the extra biomethane can be injected into the natural gas network which is a specific and capacious energy store (in chemical form).

PURIFICATION

Biogas, even after dehydration and desulphurisation, generally cannot be injected directly into gas networks as it contains significant amounts of CO_2, which is not desirable due to its lack of calorific value (it is ballast from the energy point of view). Technologies for the purification of biogas into biomethane make it possible to capture or get rid of carbon dioxide and other gases present in trace amounts in biogas. Among the purification methods, a distinction is made between absorption, adsorption, membrane and cryogenic methods, i.e.:

- Water scrubbing;
- Pressure Swing Adsorption (PSA);
- Vacuum Swing Adsorption (VSA);
- Membrane separation;
- Cryogenic upgrading;
- Amine absorption.

Water scrubber was initially the most common biogas treatment and purification technology due to its low investment costs, moderate operating costs, simplicity of construction and ease of equipment operation[4]. This method separates CO_2 and H_2S from the raw biogas due to the increased solubility of CO_2 compared to CH_4. According to Henry's law, the solubility of CO_2 in water at 25°C is approx. 26 times higher than the solubility of methane[5].

Pressure Swing Adsorption (PSA), involves the separation of CO_2 from CH_4 under high pressure due to differences in the molecular characteristics of the gases being separated and the adsorbent material used, called a molecular sieve. The materials used as PSA adsorbent must have a large surface area, e.g.: alumina, silica gel, activated carbon, zeolite, polymer sorbents and carbon molecular sieves[6]. Vacuum variation adsorption (VSA) is based on the same principle, but with the difference that it operates

3 *EBA (2023): About biogas and biomethane:* https://www.europeanbiogas.eu/about-biogas-and-biomethane/; 15.03.2024.

4 K. Butlewski, *Methods of biogas treatment including the possibility of thermal integration with the biomass fermentation process, Problems of Agricultural Engineering*, Poznań 2016, 2(92), 67-83.

5 O. W. Awe, Zhao, Y., Nzihou, A., Minh, D. P., & Lyczko, N. *A Review of Biogas Utilisation, Purification and Upgrading Technologies. "Waste and Biomass Valorization"*, 2017, 8(2), 267-283. https://doi.org/10.1007/S12649-016-9826-4/METRICS.

6 M. Kabeyi, O. Olanrewaju. *[in] Biomethane Production and Applications. "Anaerobic Digestion - Biotechnology for Environmental Sustainability"* ed. S. Aydin. 2023. https://doi.org/10.5772/INTECHOPEN.112059.

under vacuum during the desorption step. The gas bound to the sieve is released in a process called sieve regeneration and is expanded to vacuum using an additional vacuum pump[7].

One alternative to conventional absorption in biogas treatment is membrane separation, which uses membranes that can be made of different types of polymeric materials. A membrane is a filter with the ability to separate the raw biogas components (methane and carbon dioxide) at the molecular level[8]. The membrane traps large molecules of compounds and allows smaller molecules to pass through a physical barrier, which is a module made of a specially shaped material, which is usually an array of tubular polyamide fibres. Biogas is pumped through the membrane at an increased pressure of 0.2 to 5.5 MPa[9].

The cryogenic separation technology involves gradually lowering the temperature of raw biogas, causing the CO_2 to liquefy and allowing it to be removed from the purified biogas stream. Further cooling of the purified methane means that, CH_4 can reach the form of liquefied natural gas (bioLNG). In one variation of this technology, the raw biogas is initially dried and compressed to 80 bar and then gradually cooled down to -110°C, leading to the gradual removal of impurities such as siloxanes, H_2O, H_2S, halogens, etc. and CO_2, which is the main impurity (ballast) of biogas[10].

Amine absorption involves the capture of carbon dioxide from biogas by an amine solution in an absorption column. In this method, the biogas is pre-cleaned of impurities, primarily hydrogen sulphide, and is then introduced from below into a counter-current column where it contacts an aqueous amine solution introduced into the column from above[11]. Amine absorption results in low methane loss and allows high quality CO_2 to be obtained, although this may involve high energy consumption[12].

Table 2 presents the most common biogas treatment methods along with the methane content after treatment, electricity (or heat) consumption and methane losses during the process.

7 K.Butlewski, op. cit.

8 M. Kabeyi, O. Olanrewaju, op. cit.

9 K. Butlewski, op. cit.

10 M. Kabeyi, O. Olanrewaju, op. cit.

11 K. Butlewski, op. cit.

12 M. Kabeyi, O. Olanrewaju, op. cit.

TAB. 2. Biogas treatment methods with characteristics

No.	Biogas treatment method	Methane content [%]	Electricity consumption [kWh m^{-3}]	Methane losses [%]
1	Water scrubber	96-98%[13] 93-99%[14]	0,2-0,3[15] 0,4-0,5[16]	1%[17] 1-2%[18]
2	Pressure/vacuum variable adsorption	95-98%[19] 98%[20]	0,2-0,3[21] 0,25-0,46[22]	2-12%[23] 1.8-2%[24]
3	Membrane separation	98%[25] > 96%[26]	0,2-0,3[27] 0,15-0,43[28]	0,5%[29] <10%[30]
4	Cryogenic treatment	98-99%[31] 96-99%[32]	0,2-1,54[33]	0,5-1%[34] without loss[35]
5	Amine absorption	99%[36] 97-99,5%[37]	0,12-0,14[38] **additional heat consumption 0.55[39]	<1%[40] <0.1%[41]

13 S. Singhal, Agarwal, S., Arora, S., Sharma, P., & Singhal, N. *Upgrading techniques for transformation of biogas to bio-CNG: a review. "International Journal of Energy Research"*, 2017, 41(12), 1657-1669. https://doi.org/10.1002/ER.3719.

14 Q. Sun, Li, H., Yan, J., Liu, L., Yu, Z., & Yu, X. *Selection of appropriate biogas upgrading technology-a review of biogas cleaning, upgrading and utilisation. "Renewable and Sustainable Energy Reviews"*, 2015 51, 521-532. https://doi.org/10.1016/J.RSER.2015.06.029.

15 S. Singhal et al, op. cit.

16 O. W. Awe, Zhao, Y., Nzihou, A., Minh, D. P., & Lyczko, N. *A Review of Biogas Utilisation, Purification and Upgrading Technologies. "Waste and Biomass Valorization"*, 2017, 8(2), 267-283. https://doi.org/10.1007/S12649-016-9826-4/METRICS.

17 S. Singhal et al, op. cit.

18 Q. Sun, et al, op. cit.

19 O. W. Awe, et al., op. cit.

20 S. Singhal et al, op. cit.

21 Ibid.

22 Q. Sun, et al, op. cit.

23 Ibid.

24 S. Singhal et al, op. cit.

25 Ibid.

26 O. W. Awe, et al., op. cit.

27 S. Singhal et al, op. cit.

28 Q. Sun, et al, op. cit.

29 S. Singhal et al, op. cit.

30 O. W. Awe, et al., op. cit.

31 Ibid.

32 R. Muñoz, Meier, L., Diaz, I., & Jeison, D. *A review on the state-of-the-art of physical/chemical and biological technologies for biogas upgrading. "Reviews in Environmental Science and Biotechnology"*, 14(4), Department of Chemical Engineering and Environmental Technology, University of Valladolid, Valladolid, pp. 727-759

33 Q. Sun, et al, op. cit.

34 Ibid.

35 K. Hoyer, Hulteberg, C., Svensson, M., Jernberg, J., & Nörregård, Ö. *Biogas upgrading - Technical review. "Energiforsk."* 2016. https://portal.research.lu.se/en/publications/biogas-upgrading-technical-review.

36 S. Singhal et al, op. cit.

37 Ibid.

38 Ibid.

39 S. Singhal et al, op. cit.

40 Q. Sun, et al, op. cit.

41 Ibid.

Of the methods mentioned, the membrane method is the most common, although it is not without any drawbacks (such as the methane losses that occur). European companies have been at the forefront of membrane technology in the development of biomethane scrubbers, although at present, especially in the context of the post-2020 EU energy crisis, there is a huge oversupply of scrubbers in excess of demand, resulting in long waits for delivery. It is to be expected, however, that Europe may soon become a market under very strong pressure from Chinese manufacturers of scrubbers, similarly to what is currently happening in the field of PV installations or electromobility. Thanks to the skilful support of manufacturers, the Chinese authorities have led to the creation of Membrane Valley, namely a valley of membrane manufacturers, modelled on California's Silicon Valley, where the result has been a huge increase in the number of companies producing highly sophisticated cleaning equipment based on the membrane technology in applications for the water and wastewater sector, but also for the gas sector. Technologically, their products do not stand out from European products in any way, while being significantly cheaper. In addition, unlike European manufacturers, Chinese suppliers offer state-of-the-art equipment for upgrading biogas to biomethane also on a much smaller scale, even for biomethanation plants with a capacity of only a few tens of m^3 of biogas per hour.

Cryogenic biomethane purification technology is also an interesting, but expensive solution in terms of investment and operation. It is particularly suitable if there are plans to produce bioLNG (liquid biomethane), as cooling biogas to its liquefaction temperature results in liquid CO_2 and highly cooled bioCH4, which can be liquefied with a lower energy input. In view of the increasing demand for bioLNG, increased interest in this technology can be expected. A very interesting solution for cryogenic separation technology is the patented method developed with the participation of experts from AGH University of Science and Technology to separate CO_2 from biogas using liquid nitrogen as a cooling carrier. Due to the relatively low price of this carrier, the operating costs of such an installation can be very low and largely covered by the revenue from the sale of liquid bioCO_2.

1.3. Biomethane applications

The use of biomethane depends on a number of factors: the degree of purification, the location of the generation plant and existing connections, the market situation, the directions and amount of support and the form obtained. Unpurified biomethane (in the form of biogas) is most often used in combined heat and power (CHP) units to generate electricity and heat in cogeneration. On the other hand, purified biomethane, meeting quality standards, including specific physico-chemical parameters, can be injected directly into the grid to replace natural gas, or can take the form of compressed (bioCNG) or liquefied (bioLNG) gas. The possibilities of using biomethane as a substitute for natural gas are enormous. Indeed, it can be used directly virtually anywhere natural gas is currently used, leading directly to a reduction in the carbon footprint of manufactured products. Of course, due to the more limited availability of biomethane compared to natural gas and its higher purchase price, the use of biomethane should be planned accordingly. One of the most effective ways of its application is to use it as a fuel, especially to decarbonise transport in the form of bioLNG and bioCNG. In addition to the use of biomethane as a fuel in vehicles, it can make its way into in air transport, as rocket fuel, or fuel used by trains or ships.

The use of bioCH_4 to produce biohydrogen from it (by reforming) to produce decarbonised fuels or directly to power fuel cells in hydrogen vehicles is debatable. In this case, it seems to make more sense to produce hydrogen through electrolysis, and perhaps also to produce biohydrogen directly at biogas plants through a continuous fermentation process (in 2013, for a few months, an installation near Międzyrzec Podlaski produced bioH_2 using this technology as the first one in the world; however, production was discontinued due to a lack of interest from customers and severe damage to the co-generator burning a mixture of hydrogen and biogas). Instead, it makes sense to use biomethane in industry, especially in chemical industry, although other industrial sectors (e.g. car manufacturers) are also interested in using bioCH_4 instead of natural gas due to the need to reduce the carbon footprint of products. In the agri-food industry, on the other hand, it will not always be worthwhile to purify biogas into biomethane, because if a plant can produce biogas from its own waste and uses natural gas to produce electricity and/or heat, the simplest way is to build an internal gas network and use untreated biomethane (e.g. the Nowalijka plant near Piotrków Trybunalski). In principle, there should also be a high demand for biomethane from the fertiliser production sector, however, due to the huge scale of natural gas currently used for the production of nitrogen fertilisers, cheaper imports of fertilisers from outside the EU and the general trend of reducing the use of mineral fertilisers in agriculture. A large share of biomethane use by the fertiliser sector is rather not expected.

Biomethane can also be used in agriculture, on farms to power agricultural machinery, to heat farm premises, or as a substitute for fossil fuels in other agricultural processes e.g. drying, cooling (trigeneration). It can also be used in district heating to replace traditional fossil fuels. Recently, analyses have been carried out in Poland on the feasibility and cost-effectiveness of using biogas (especially municipal biogas) or biomethane for co-firing with other fuels in medium-sized heating plants. Table 3 shows examples of biomethane applications.

TAB. 3. Possible uses of biomethane depending on its form

No.	Form of biomethane	Use of biomethane
1.	Fuel (bio-CNG)	Highly compressed biomethane used as a substitute for compressed natural gas (CNG), e.g. in vehicles, especially buses, trucks and cars equipped with natural gas engines.
2.	Fuel (bio-LNG)	Liquefied biomethane used as a substitute for liquefied natural gas (LNG), e.g. in vehicles, especially buses, trucks and cars equipped with natural gas engines.
3.	Injection into gas networks	Biomethane meeting quality standards can be injected into existing distribution networks to replace natural gas.
4.	Energy in chemical form	Untreated biomethane (biogas) can serve as an energy carrier and be useful in areas not connected to the gas/electric grid (island grids) where access to traditional energy sources is limited.
5.	Combined heat and power generation	Untreated biomethane (biogas) can be used on site for cogeneration of electricity and heat/cooling.

Since biomethane is energy in chemical form, it can also act as an energy reserve in situations of power shortages in the grid due to, for example, morning or evening peak demand and reduced generation of weather-dependent installations. In this situation, it is expected that there will be an increased demand for biogas for peak electricity generation, which is likely to become significant competition for biomethane production for other uses.

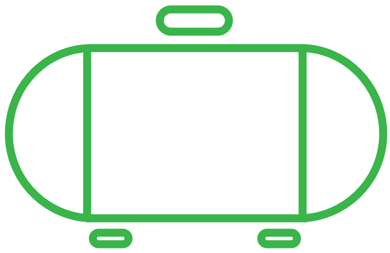
It should also be stressed that the production of biomethane (biogas) is an extremely important element in the recycling of bio-waste and, more broadly, in a circular economy (CE). No other technology for the use of 'wet' bio-waste (kitchen waste, green waste, waste from the agri-food industry or sewage sludge) than methane fermentation is better suited for its management from an economic, energy and environmental point of view.

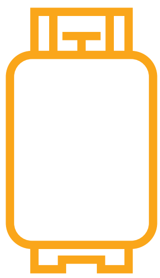
1.3.1. Decarbonisation using biomethane

The above table shows the multitude of options for using biomethane in the economy. However, it is important to be aware that even the advanced state of development of biomethane generation infrastructure, will not be able to meet all needs for renewable fuels. The limited volume of biomethane available in the future will require the development of the most climate-efficient and economically rational model for its use. It seems that the fastest way to spread biomethane while reducing consumption of a fossil fuel such as natural gas is to inject it into the gas system. Indeed, it should be emphasized that, unlike hydrogen, injecting bioCH4 into existing gas networks requires little investment. Biomethane supplied by means of transmission infrastructure should be used first in those segments of the economy where electrification will not be possible or will be introduced in the distant future.

The challenge is to resolve the issue of uneven gas demand at different times of the year and day, and thus solving the problems associated with the possibility of storing biomethane or reverse pumping of gas from lower pressure pipelines to higher pressure pipelines, as well as the development of so-called virtual gas pipelines in areas where there are no gas networks (this system is very common, for example, in China, where biomethane from a significant proportion of biomethanation plants is transported to collection points - gas pipelines or filling stations - by means of tanker trucks). In turn, given that the existing gas grids are *de facto* a giant energy store (in chemical form), it is to be expected that in the face of the need to decarbonise the Polish power sector and the increasing share of weather-dependent RES, biomethane used in rapidly switching on and off gas-fired power plants operating as so-called 'peaking plants' may in future play an increasingly important role in stabilising the national electricity system. Work on the analysis and modelling of such scenarios using biomethane as a fully dispatchable energy carrier has been carried out at the National Centre for Research and Development (NCBR) since 2023.

The decarbonisation of the Polish economy is necessary not only because of the need to move away from fossil fuels and to achieve climate neutrality by 2050. Much more urgent is the need to reduce the carbon footprint of the products of Polish companies. Indeed, the European Commission is working towards making it compulsory for goods to indicate their carbon footprint, but even faster action is being taken by various pan-European retail chains, which are already demanding goods with a low or zero carbon footprint from suppliers. This puts companies operating in our country in an extremely difficult position, as the carbon footprint is heavily influenced by the 'greenness' of the electricity and gas used in production. As Poland still produces about 75% of its electricity from coal, it has the highest (apart from Estonia, which is a small country) emissivity index of electricity at the level of about 770 g $CO_{2\text{-eq}}$ /kWh (by comparison France or Scandinavian countries below 50 g $CO_{2\text{-eq}}$ /kWh), while natural gas used in production has an emissivity of about 450 g $CO_{2\text{ -eq}}$/kWh. Meanwhile, biomethane produced from bio-waste or faeces (especially manure) can have negative emissions due to so-called avoided emissions (bio-waste used immediately in a biomethanation plant does not emit methane or nitrous oxide as it does when stored). This is why biomethane, also as an option in a mixture with natural gas, is of strong interest to companies. UPP's Ecotechnology Laboratory has consulted on the use of biomethane with representatives from industries as diverse as cement, paper, automotive, agri-food processing and district heating. It should be stressed that the growing tendency (both legal at EU level and related to the policies of large retail chains) to label products with carbon footprints could drastically collapse the steadily increasing exports to other EU countries over the past 20 years and cause huge problems for the Polish economy, which is based on high-carbon energy carriers. Rapid and large-scale implementation of RES in the energy sector, as well as a sharp increase in the volume of biomethane produced, will be key ways to radically decarbonise the Polish economy and reduce the carbon footprint of manufactured products.





2 Policy and legislative framework for biomethane production in Poland

Chapter 2.

Policy and legislative framework for biomethane production in Poland

The launch of biomethane production in Poland is part of the implementation of the EU climate policy aimed at achieving climate neutrality through a profound transformation of the economies of the Member States. The rationale for the use of biomethane is also considered from the perspective of ensuring energy security, particularly in the segment of access to gaseous fuels[42]. The first rationale refers to the global consensus in the drive to reduce greenhouse gas emissions pursued both in individual national systems and by international organisations, most notably the United Nations and the European Union. In the case of biomethane use, the potential to reduce carbon dioxide and methane is indicated[43]. The second rationale implies the ability of the energy system to meet current and future energy and fuel needs in a technically and economically viable manner taking into account environmental standards[44]. More broadly, it means the diversification of gas supply by replacing the so-called gas monoculture in terms of source (expansion of the natural gas market to include biomethane and hydrogen) and directions of supply (transmission of gas via large-scale interconnectors)[45] while respecting the well-being of the environment[46], of which the climate is also a part[47].

Objectives expressed in policies (*soft-law*) lack binding force and therefore do not create obligations. Instead, they have a preliminary, 'pre-legislative' role (*pre-law*), guiding the preparation of future legis-

42 Cf. International Energy Agency, *Outlook for biogas and biomethane. Prospects for organic growth*, 2020 p. 33 i 41.

43 Cf. International Energy Agency, *The role of biogas and biomethane in pathway to net zero*, 2022, p. 2 and European Biogas Association, *Biomethane production potentials in the EU*, 2022, pp. 16-20.

44 Article 3(16) of the Act of 10 April 1997. - Energy Law (Journal of Laws 2022, item 1385, as amended), hereinafter referred to as the "EL".

45 Z. Muras [in:] *Commentary to the Act of 22 July 2016 amending the Energy Law and certain other acts* [in:] Energy Law. Volume II. Commentary to Articles 12-72, 2nd edition (ed.) M. Swora, Warsaw 2016, art.

46 I. Przybojewska, *Delivering clean, affordable and secure energy in light of the intentions of the European Green Deal*, EPS 2022, no. 2, pp. 13-22.

47 Art. 3 item 39 of the Act of 27 April 2001. Environmental Protection Law (Journal of Laws of 2024, item 54).

lation (*hard-law*)[48]. Policies program legislative activity, justify and explain the binding legal regulations that follow their issuance[49]. In turn, their objectives are implemented through legislation adopted at EU and national levels and through the regulations contained therein that introduce specific obligations. Together they form the political and legislative framework for the development of biomethane production in Poland.

Although the scope of this chapter covers the policies and regulations shaping the development of biomethane at EU and national levels, it is impossible, in order to structure the analysis, not to include an international perspective. Indeed, the UN's pro-climate actions determine the EU's commitment to biomethane development. It is crucial to refer to the 2030 Agenda for Sustainable Development[50], the main objective of which is to ensure socio-economic prosperity, care for the planet, maintain peace, freedom and eradicate poverty (including energy poverty) by setting specific goals to achieve sustainable development[51]. From the perspective of this analysis, it is important to see the link between the two specific objectives of the above-mentioned Agenda, i.e. Goal 13: Take urgent action to combat climate change and Goal 7: Affordable and clean energy. This primarily means simultaneously increasing climate change adaptation and mitigation capacity and decarbonising the energy sector through the deployment of low- and zero-carbon sources. Importantly, the agenda does not explicitly identify the technologies to be deployed, but the targets that should be achieved. Consequently, individual countries set the actions that, in the socio-economic situation of the country, will best achieve the sustainable development goals[52].

2.1. Biomethane in the European Union's climate strategy

Clean energy for all

From the perspective of the decarbonisation vision for the gas sector set out in EU policies, it is important to point out that the need to develop biomethane was already recognised in the 2018 Clean Planet for All Communication[53], which was an analysis of possible climate and energy transition scenarios. The important role of using liquefied natural gas, hydrogen and biomethane was raised, while increasing RES-based electrification. The use of liquefied natural gas admixed with methane in transport was proposed. The aforementioned policy does not indicate specific plans for the development of biomethane, but plans to issue a long-term strategy for the reduction of greenhouse gas emissions in 2019. Consequently, the European Commission has issued a European Green Deal (EGD).

48 M. Pietrzyk, *Soft law and hard law in European administrative law: the relation of alternative, complement, exclusion and transition* [in:] Administracja publiczna wobec wyzwań i oczekiwań społecznych, Wrocław 2015, pp. 139-140.

49 J. Supernat, *Miejsce i znaczenie soft law w prawie publicznym Unii Europejskiej* [in:] Nowe problemy badawcze w teorii prawa administracyjnego (ed.) J. Boć & A. Chajbowicz, Wrocław 2009, pp. 440-441.

50 Resolution adopted by the General Assembly on 25 September 2015, Transforming our world: the 2030 Agenda for Sustainable Development.

51 The concept of sustainability focuses on reducing greenhouse gas emissions to a level that would prevent dangerous anthropogenic interference with the climate system and ensuring economic development in a sustainable manner.

52 Poland is one of the countries that fulfil the Sustainable Development Goals to the highest degree, cf. https://dashboards.sdgindex.org/map.

53 Communication from the Commission to the European Parliament, the European Council, the Council, the Economic and Social Committee, the Committee of the Regions and the European Investment Bank *A Clean Planet for All A European long-term strategic vision for a prosperous, modern, competitive and climate-neutral economy* (COM/2018/773 final).

European Green Deal

Announced in 2019 by the European Commission, the strategy[54] sets a specific goal for Member States: to achieve climate neutrality by 2050. The EGD can be qualified as a cross-sectoral policy[55] due to the multitude of regulated areas of socio-economic life in which climate neutrality will be pursued. The EGD sets out a vision for developing the economy in a way that is climate-neutral and contributes to economic growth.

In the case of energy, this objective is to be achieved through:
- the creation of a sector based largely on renewable sources,
- moving away from coal at a rapid pace,
- decarbonising the gas sector.

In case of the latter, it is to be achieved through the development of 'low carbon' gas production. In doing so, the European Commission declared the need to develop "(...) a forward-looking concept for a competitive carbon-free gas market and to address energy-related methane emissions".

The EGD does not explicitly state the need to use biomethane. However, the realisation of its objectives, i.e. decarbonising the energy system (including the gas sector), channelling support for development work in the area of low-carbon gases and addressing energy-related methane emissions and diversifying supply, creates space for biomethane as an alternative to fossil natural gas.

EU methane strategy

The strategy announced by the European Commission in 2020[56], indicates that methane is the second gas after carbon dioxide to contribute to the ongoing climate change. It should therefore be an obvious objective of the European Union to reduce emissions of this gas into the atmosphere. The strategy identifies the economic sectors most responsible for methane emissions in the EU in the following order:
- agriculture primarily in the livestock segment: 53%,
- waste management in the area of landfills, sewage sludge and leaks from poorly designed biogas plants: 26%,
- energy in the segment of oil and gas extraction, transport and processing and coal mining: 19%,
- waste management in the area of landfills, sewage sludge and leaks from poorly designed biogas plants.

The strategy identifies the need to build a system to monitor and measure methane emissions in these economic sectors and to implement appropriate solutions to reduce them. The EU objective should be achieved through cross-sectoral cooperation, implementation of a measurement and reporting sys-

54 Communication from the Commission to the European Parliament, the European Council, the Council, the Economic and Social Committee and the Committee of the Regions on the European Green Deal (COM/2019/640 final).

55 A. Bator, A. Borek, K. Łuczak, A. Rybicka, P. Siwior, E. Wróblewski, *Adaptation to climate change in EU and Polish climate policy and climate law*, Warsaw 2021, p. 39.

56 Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions on an EU strategy to reduce methane emissions (COM/2020/663 final).

tem and the adoption and enforcement of appropriate environmental and climate regulations[57]. One of the recommended projects to reduce unwanted emissions is to develop biogas production. The raw material base for such activity should be municipal waste and waste from agricultural activity, mainly manure. According to the EC, biogas production will have many positive effects:

- reduction in emissions resulting from natural anaerobic digestion processes,
- reduction in fossil fuel consumption,
- obtaining a source of sustainable renewable energy,
- obtaining a natural soil improver from the digestate,
- generation of an additional source of income for farms[58].

Regulatory efforts have also been announced to facilitate the market introduction of gases from renewable sources. Efforts are to focus first and foremost on resolving the issue of connection to the appropriate infrastructure to enable these gases to access markets[59].

REPowerEU

In the face of Russia's military aggression against Ukraine and in response to the accompanying energy crisis, the EU adopted a new strategy in May 2022[60], the implementation of which is expected to lead to the parallel achievement of climate goals and objectives related to strengthening energy security. Above all, the document diagnoses a fundamental weakness in the EU energy markets in the form of overdependence on fossil fuel imports from the Russian Federation. The prescription for improving energy security is simple: '... to rapidly reduce our dependence on Russian fossil fuels by accelerating the transition to clean energy and joining forces to achieve a more resilient energy system and a true energy union'. One of the listed actions to achieve this is to "rapidly replace fossil fuels" with clean energy sources[61]. In this case, one of the replacements that the EC points to is biomethane, as its production is a cost-effective way to implement the plan to reduce natural gas imports from Russia. The REPowerEU strategy sets the desired level of biomethane production in the EU at 35 bcm, to be achieved in 2023. Meanwhile, the capital expenditure to develop the production of this gas is valued at EUR 37bn[62]. The document also includes a list of recommended actions that should "(...) remove the main barriers to increasing the sustainable production and use of biomethane (...)":

- establishing an industrial biogas and biomethane partnership to stimulate the renewable gas value chain;
- introducing additional measures to encourage biogas producers to set up energy communities;
- providing incentives for biogas upgrading to biomethane;

57 Ibid, pp. 4-8.

58 Ibid, pp. 8-9.

59 Ibid, p. 10.

60 Communication from the Commission to the European Parliament, the European Council, the Council, the European Economic and Social Committee and the Committee of the Regions REPowerEU: *Towards secure, sustainable and affordable energy together* (COM/2022/108 final), which was further detailed in the Communication from the Commission to the European Parliament, the European Council, the Council, the European Economic and Social Committee and the Committee of the Regions REPowerEU Plan (COM/2022/230 final).

61 Ibid.

62 Ibid, p. 9.

- promoting the adaptation of existing infrastructure and the implementation of new infrastructure to transport more biomethane through the EU gas network;
- closing the gaps in research, development and innovation performance;
- facilitating access to finance and mobilising EU funding under the Connecting Europe Facility, cohesion policy, the RRF and the Common Agricultural Policy[63].

In doing so, the EC emphasises particularly a sustainable approach to biomethane production, the essence of which is to rely on the use of "(...) organic waste and forest and agricultural residues to avoid impacts on land use and food security"[64].

2.2. Biomethane in Poland's energy and climate strategy

National Energy and Climate Plan 2021-2030 (NECP)

The plan is an EU Member State policy of a strategic nature, the development of which follows from an EU regulation - the European Climate Law[65].

The current plan includes a concept for further development of the energy economy in Poland, taking into account the need to achieve the EU's climate goals in terms of reducing greenhouse gases and increasing the share of RES.

The development of RES in Poland is therefore also to include:
- the generation of controllable energy and heat from biomass for households,
- the use of biomass by district heating companies (due to fuel availability and its technical and economic parameters),
- use of biogas in combined heat and power generation.

In the light of the National Energy and Climate Plan (NECP), the biogas plant network under construction in Poland, depending on location and local needs, can be used to produce electricity, cooling and biomethane. The plan also emphasises obtaining additional benefits from such biomass development in the form of:
- better waste management (e.g. animal waste, municipal waste),
- the capacity to store energy in biogas for regulatory purposes,
- rural development[66].

The preliminary version of the NECP update[67] does not significantly change the assumptions for biomethane development. It indicates that:

63 Ibid, p. 10.

64 Ibid.

65 Article 6 of Regulation (EU) 2021/1119 of the European Parliament and of the Council of 30 June 2021 establishing a framework for achieving climate neutrality and amending Regulations (EC) No 401/2009 and (EU) 2018/1999 (European Climate Law) (Official Journal of the EU. L. 2021 No. 243).

66 Ministry of State Assets, National pan for energy and climate for 2021-2030. Assumptions and objectives and action policies, Warsaw, pp. 95-96.

67 Preliminary version of the National Energy and Climate Plan 2030 (2019 update of the NECP) dated 29 February 2024 submitted to the European Commission for assessment.

- Biomethane power plants will complement RES, but these investments, in the opinion of policy makers, require high investments,
- The use of biomethane is determined by the will of the local community,
- transmission and distribution system operators are obliged to adapt their networks to transmit, among other things, biomethane.

The initial update of the NECP does not prioritise biomethane, focusing its objectives around large-scale nuclear and hydrogen. On the other hand, the lack of explicit indication of biomethane's potential does not mean that its importance will not grow in local civic energy, as the use of biomethane represents an opportunity for the transformation of district heating and allows diversification of the gas industry.

Poland's Energy Policy until 2040 (PEP2040)[68]

The role of biomethane and biogas in Poland's energy economy is defined in the current National Energy Policy adopted in 2021[69]. One of the three pillars of PEP2040 is the creation of a zero-emission energy sector in Poland. The general direction of pro-climate changes is to lead to a significant reduction in the consumption of fossil fuels and greenhouse gases. By 2040, the share of RES in the energy economy is to reach 28.5%. The transformation envisaged in PEP2040 is to concern the electricity, gas and transport sectors. A role has been identified for biogas and biomethane in all three segments.

- **Transformation of the electricity sector**: the share of energy production from RES by 2040 was estimated at around 40%. Biogas is to be one of the renewable sources of electricity and heat generation. The generation potential of biogas is to be used primarily in 'combined heat and power generation'. Due to the possibility of storing biogas, it is envisaged that it can also "(...) be used for regulatory purposes and for the self-balancing of energy clusters and energy cooperatives"[70] .

- **Gas transformation**: The aim is for the national pipeline system to be capable of transporting approximately 10 per cent of gases other than natural gas, including primarily biomethane and hydrogen. In doing so, it is pointed out that biomethane can be a suitable substitute for fossil gas especially in situations where the construction of a gas pipeline feeding local island gas networks is not possible. In such cases, the development of biomethanation plants and supplying such infrastructure and consumers with biomethane may be a solution to the problem of access to gaseous fuel[71].

- **Transport transformation**: Poland is obliged by EU regulations to achieve by 2030 14% of renewable energy in road and rail transport. Among other things, this objective is to be

68 The adoption of the update of the NAPE will effectively render the objectives adopted in the PEP2040 obsolete. On the other hand, both policies are in force in parallel and are issued on the basis of separate legal bases, i.e. the adoption of the PEP2040 results from Article 15a of the Act of 10 April 1997. - Energy Law (Journal of Laws 2024, item 266), and the EPC, as indicated above from Article 6 of Regulation 2021/1119.

69 Announcement by the Minister of Climate and Environment of 2 March 2021 on the national energy policy until 2040 (M.P. of 2021, item 264).

70 Ibid, pp. 65, 66.

71 Ibid, p. 50.

achieved through measures leading to "(...) an increase in the use of waste raw materials for the production of biocomponents and biogas (biomethane) used in transport"[72].

The aforementioned policy also highlights additional future benefits achieved through the development of biomethane production. First of all, it was pointed out that this production will contribute to the rational management of waste and by-products from agriculture and agri-food processing. Biogas and biomethane production will also strengthen the development potential of agricultural areas in Poland.

2.3. EU and national legislation

The legal implementation of the EU's planned targets for the development of biomethane and the use of this source to decarbonise the gas industry is the adoption of the so-called gas-hydrogen package[73], as part of the so-called Fit For 55 package[74]. The gas-hydrogen package aims to move away from -a mono-commodity gas market to diversify generation sources by including hydrogen and biomethane. The new regulations allow for the injection of hydrogen and biomethane in a so-called blending formula[75]. However, the definition of natural gas has equalised the importance of the methane it contains with biomethane, due to its physical and chemical properties. The injection of biomethane into the natural gas network has been made possible, provided that technical and safety conditions are met. Ultimately, the EU gas system is to consist of diversified gas networks - pipelines supplied with natural gas blended with hydrogen and biomethane and separate hydrogen pipelines. With regard to sustainability criteria, the production of hydrogen from biomethane remains debatable, given its scarce nature, the demand for biomethane in the economy and, at the same time, the multitude of processes enabling the production of renewable hydrogen.

2.4. Evolution of Polish legislation

In parallel to the adopted policies and pending regulations for biomethane development at the EU level, the Polish energy market is also preparing for the implementation of the EU Gas and Hydrogen Package, including for biomethane. A consequence of the set strategic goals for biomethane development in Poland is the adoption of the first legal regulations for biomethane in 2023. In this regard, it is important to point out the introduction of a statutory definition of biomethane[76], which indicates that it is a gas that can be obtained from biogas, agricultural biogas or renewable hydrogen after purification and can be fed into a gas network or transported in compressed or liquefied form by means

72 Ibid, 54.

73 Regulation (EU) 2024/1789 of the European Parliament and of the Council of 13 June 2024 on the internal markets in renewable gas, natural gas and hydrogen, amending Regulations (EU) No 1227/2011, (EU) 2017/1938, (EU) 2019/942 and (EU) 2022/869 and Decision (EU) 2017/684 and repealing Regulation (EC) No 715/2009 (Recast) Text with EEA relevance (OJ L 2024, p. 1789) adopted on a proposal from the European Commission (COM/2021/804 final) and Directive (EU) 2024/1788 of the European Parliament and of the Council of 13 June 2024 on common rules for the internal markets in renewable gas, natural gas and hydrogen, amending Directive (EU) 2023/1791 and repealing Directive 2009/73/EC (Recast) (OJ EU. L. 2024, item 1788) adopted on a proposal from the European Commission (COM/2021/803 final).

74 See the legislative proposals that form part of the Fitfor55 package, which is designed to allow, among other things, a reduction in the EU's greenhouse gas emissions of at least 55% by 2030, https://www.consilium.europa.eu/pl/policies/green-deal/fit-for-55-the-eu-plan-for-a-green-transition/.

75 Cf. European Biogas Association, *Decarbonising Europe's hydrogen production with biohydrogen. The role of sustainable biohydrogen in the total energy mix*, 2023, p. 10.

76 Article 2(3c) of the Act of 20 February 2015 on Renewable Energy Sources (Journal of Laws 2023, item 1436, as amended).

of transport other than gas networks or used to refuel motor vehicles. The legislator has significantly expanded the catalogue of substrates from which agricultural biogas can be produced. Observing the experience of other countries[77], the legislator should also introduce regulations preventing rapid cultivation of energy crops, which would not contribute to the production of biomethane from waste, but would constitute gas production contrary to the principle of sustainable development with regard to biomethane production as well as agricultural and food policy.

Biomethane has been covered by a system of guarantees of origin, which confirms that an adequate amount of biomethane has been produced in a RES installation and fed into (i) the gas grid, (ii) another means of transport or (iii) a facility for refuelling motor vehicles with biomethane[78]. This solution significantly supports the reduction of emissions and the fulfilment of ESG standards by companies pursuing corporate sustainability strategies. The operation of a biomethane generation business is a regulated activity and the generator is subject to registration in the relevant register[79]. The production of biomethane in RES installations with an installed capacity of 1 MW or less has been subject to a feed-in-premium support scheme[80]. This means that biomethane injected into the gas grid can be sold to a selected entity. The reference price for the sale of 1 MWh of biomethane is determined by means of a regulation by the minister responsible for climate, separately for RES installations for the production of biomethane from biogas and biomethane from agricultural biogas[81].

On the other hand, the full exploitation of Poland's potential for large-scale biomethane production requires the support system to be extended to units of higher capacity. Another important solution is the introduction of an obligation for the gas distribution system operator (DSOg) to indicate an alternative closest location to the location indicated by the applicant for the connection of a biomethane generation facility in the event of a refusal to issue connection conditions at the location indicated by the applicant, resulting from technical or economic reasons[82]. At this point, it is also necessary to point out the adopted special law[83], by means of which solutions facilitating the realisation of investments in agricultural biogas plants have been introduced, which is of key importance for biomethane production. Among others, a possibility to build an agricultural biogas plant regardless of the provisions of the local spatial development plan was introduced, provided that it does not contradict the study of spatial development conditions and directions of the municipality[84] and the resolution on the creation of a cultural park, and the municipality council adopts a resolution on determining the location of the agricultural biogas plant. A maximum deadline for issuing conditions for connecting an agricultural

77 *Z. Szymanska, Corn, soy are not the only way for Germany to cut CO_2 emissions from fuels -ministry*, https://www.reuters.com/business/environment/corn-soy-are-not-only-way-germany-cut-co2-emissions-fuels-ministry-2022-05-03/, 14.08.2024.

78 Article 120(1)(2) of the aforementioned Act.

79 Cf. J. Kozikowski, A. Pinkas, W. Wrochna, *New law for biomethane. Will it accelerate large-scale biomethane investments in Poland?* [in:] Magazyn Polska Chemia, 3/2023, pp. 15-17, https://pipc.org.pl/wp-content/uploads/2023/09/Polska-Chemia-3.2023-online.pdf.

80 Article 83l of the aforementioned Act.

81 According to the regulation of the Minister of Climate and Environment of 13 November 2023 on the reference price of biomethane (Journal of Laws 2023, item 2477), the reference price of biomethane for RES installations for the production of: (i) biomethane from biogas is PLN 538/1 MWh and (ii) biomethane from agricultural biogas is PLN 545/1 MWh.

82 Article 7(1e) EL

83 Act of 13 July 2023 on facilitating the preparation and realisation of investments in agricultural biogas plants and their operation (Journal of Laws 2023, item 1597).

84 With the proviso that the municipality's land use study will be replaced by a master plan by the end of 2025 at the latest.

biogas plant with a capacity of no more than 2 MW to the power grid has also been set (up to 90 days).

An obligation is also introduced for DSOg to adopt, in the case of introduction of biomethane into the network, a methodology for determining the combustion heat of gaseous fuels for a given area in such a way that the determined average combustion heat of gaseous fuels for a given day does not differ by more than ±4% from the combustion heat of gaseous fuels determined at any point in the given area (as a deviation from the average combustion heat of gaseous fuels of up to ±3%)[85]. A regulation is also under procedure[86], which will detail the methodology for the calculation of, inter alia, biomethane produced by a RES installation and transported by means other than a gas network. Biomethane is to be measured on the basis of measurement and billing devices, continuously during the period of biomethane transport and at a location immediately upstream of the point of further use or processing of biomethane.

It should also be mentioned that, at the level of Polish domestic law, legal regulations are being processed with regard to the extension of the gas market to include the so-called decarbonised gases[87], the assumptions of which are not yet known, but in connection with the adoption of the aforementioned EU gas and hydrogen package, the implementation of EU regulations will be required.

Also important for the development of biomethane are the regulations currently under way as part of the draft amendment to the RES Act[88]. With regard to biomethane, it is worth pointing out that it is planned to extend the construction and modernisation of RES installations to activities of overriding public interest and to qualify such activities as serving health or safety[89]. In order to sell biomethane to the gas grid, the generator will also be obliged to indicate in the declaration submitted to the President of the Energy Regulatory Office that no biogas or agricultural biogas or renewable hydrogen which does not meet sustainability criteria will be used to produce biomethane[90]. In addition, the entitlement period for biomethane producers to obtain the right to cover the negative balance is to be extended from 30 June 2048 to 30 June 2051[91].

85 §40(3a) of the Ordinance of the Minister of Economy of 2 July 2010 on detailed conditions for the operation of the gas system (Journal of Laws 2018, item 1158, as amended).

86 Draft Ordinance of the Minister of Climate and Environment on requirements for measurement, registration and calculation of quantities of biogas, agricultural biogas and biomethane produced by renewable energy source installations from renewable energy sources and transported by means of transport other than gas networks [List no. 1098].

87 Draft Law on Amendments to the Energy Law and Certain Other Laws [List No. UD36].

88 Draft Law on Amendments to the Law on Renewable Energy Sources and Certain Other Laws [UD List No. 41].

89 the planned addition of Article 3b to the l.r.e.s.

90 the planned addition of points 5 and 6 to paragraph 1(4) in Article 83m l.r.e.s with regard to the conditions for submitting a statement

91 planned amendment to Article 83p l.r.e.s.

Conclusions:

- The development of biomethane as a renewable energy source is key to meeting climate commitments and increasing energy security by diversifying supply sources.

- The targets set at policy level for biomethane development, although lacking binding force, represent an important pre-legislative role, setting the desired legislative direction.

- There is an urgent need to update national energy policies taking into account the changing dynamics of an increasingly distributed energy system. Energy policies should indicate not only targets for biomethane capacity in the energy system, but also the extent of involvement in biomethane development by business, public administration, science and NGOs, including planned support instruments. Including this, the draft update of the NECP should indicate a much higher potential for biomethane.

- The adoption of the EU gas and hydrogen package will enable the creation of an EU market for so-called decarbonised gases, including biomethane and hydrogen. Feed-in of gas networks, largely with biomethane, will enable the development and stabilisation of the biomethane sector and allow diversification of gas fuel sources towards decarbonisation.-

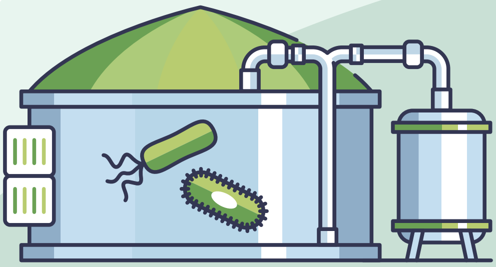
- Gas transformation should include not only the use of hydrogen, but also the wider use of biomethane due to the large-scale domestic potential for biomethane production. It is not beneficial to promote the use of biomethane only as a feedstock for hydrogen production.

- The first regulations for biomethane have been introduced into the Polish legal system, including: (i) a legal definition, (ii) the inclusion of biomethane in the system of guarantees of origin, (iii) the extension of the support system on the basis of subsidies to the market price (FIP) to RES installations producing biomethane, (iv) the obligation for gas distribution system operators to indicate an alternative location for the connection of biomethane installations in the event of a refusal to connect. A special law for the realisation of investments in agricultural biogas plants was also adopted, which introduces simplifications in the location of agricultural biogas plants.

- An important regulation for the so-called greening of gas networks is the introduction of a derogation from the average combustion heat value of gaseous fuels for biomethane injected into gas networks. It will also be crucial to define a methodology for the calculation of, among other things, biomethane produced in a RES installation and transported by means other than the gas network.

- By way of a *de lege ferenda* postulate, an extension of the biomethane support system to units with a capacity greater than 1 MW could be indicated, taking into account the economic viability of such investments, and the introduction of regulations that will define acceptable substrate categories. The use of substrates derived from organic waste, municipal waste and production by-products should be promoted and the use of unsustainable substrate such as energy crops should be restricted.

- Undoubtedly, the development of biomethane requires the adoption of targets for the projected share of biomethane in the energy mix, which will allow investors to see the Polish market as promising for the development of biomethane projects.



3 The development of biomethane production in the European Union – a case study

Chapter 3.

The development of biomethane production in the European Union - a case study

3.1. European biomethane sector

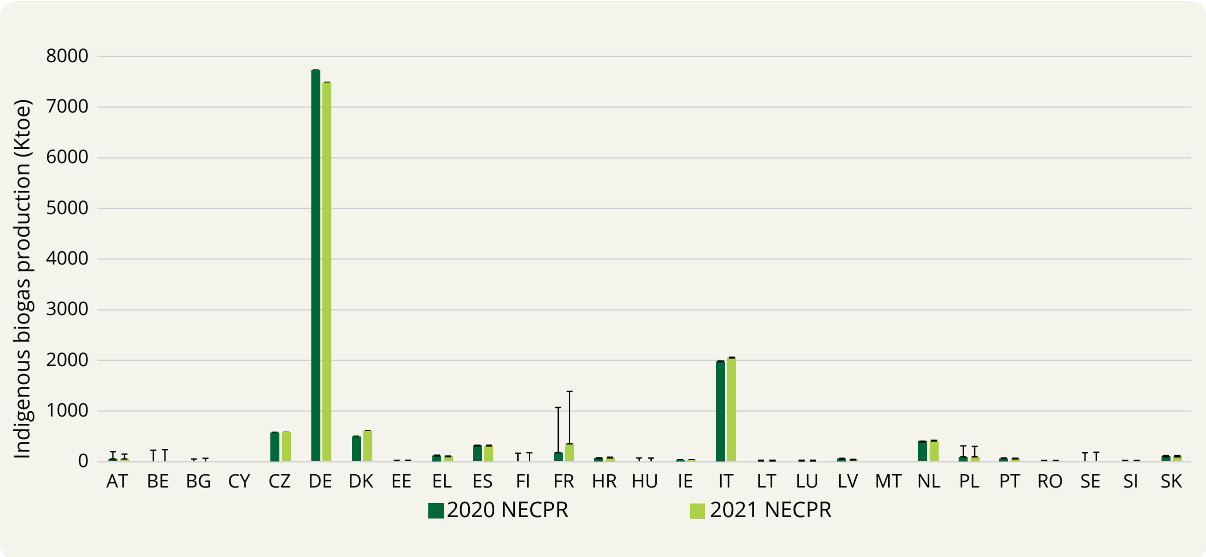
Biomethane production in the European Union is closely linked to the development of the biogas sector that preceded it. Biogas production was, and still is, intended for the local generation of zero-emission electricity. Indeed, obtaining energy from biogas is one of the directions for the transformation of the energy economy in the EU climate policy[92]. According to data made available in 2022 by the International Energy Agency (hereafter IEA), biogas production in the European Union was expected to reach 170 TWh (approx. 16.1 billion m^3)[93]. The gas volumes reported in the statistics were produced by approximately 20,000 biogas plants operating in EU member states (data for 2021)[94].

92 U. Brémond, A. Bertrandias, J-P Steyer, N. Bernet, H. Carrere, *A vision of European biogas sector development towards 2030: Trends and challenges*, https://www.sciencedirect.com/science/article/abs/pii/S095965262035109X, 10.03.2021.

93 M. Torrijos, State of Development of Biogas Production in Europe, "Procedia Environmental Sciences "35 (2016) 881 - 889.

94 Z. Nowak, M. Zaniewicz, *Biogas - an element of EU energy security*, PISM "Bulletin", No. 108 (2527), 6 JULY 2022, p. 1.

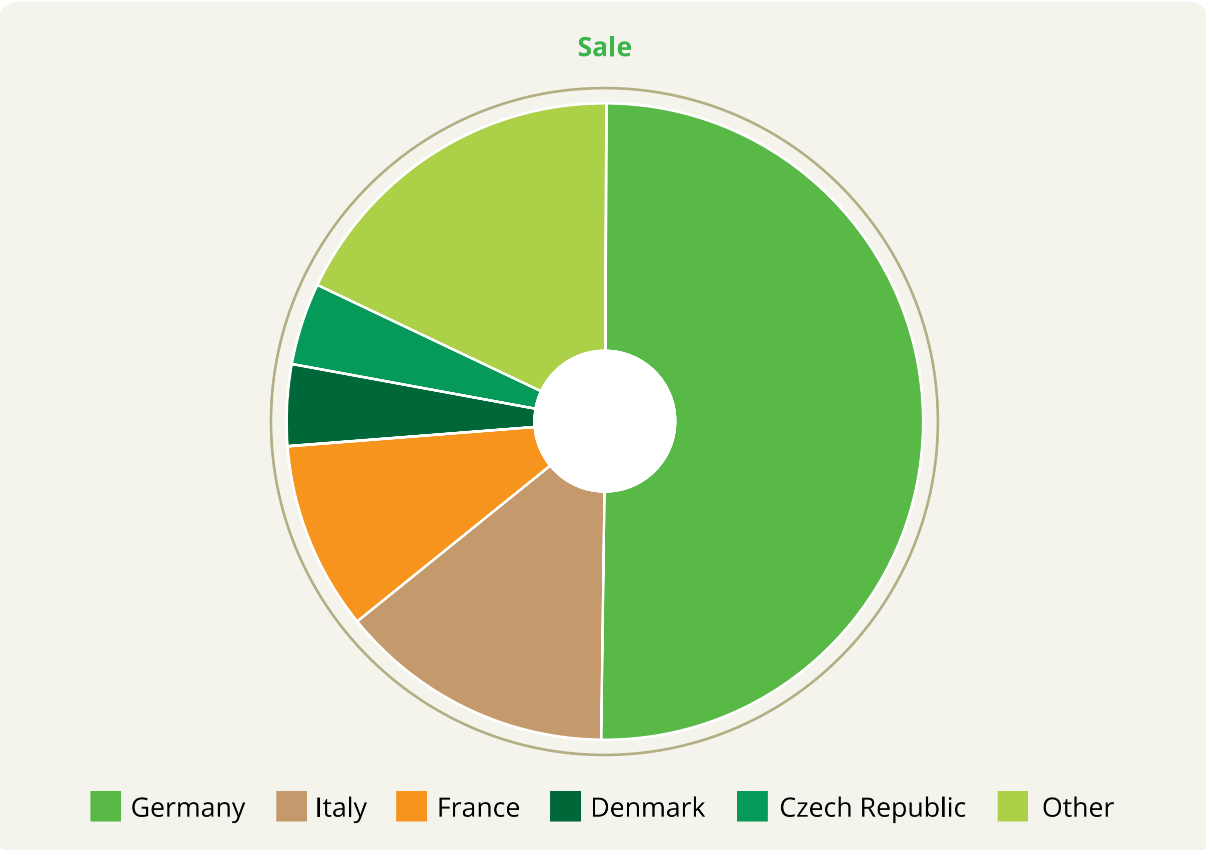
FIG. 2. Biogas production in EU member states in 2020-2021*.



*Biogas production reported in 2020. - left-hand bar and 2021 - right bar in each Member State.

Source: European Commission

FIG. 3. Share of individual Member States in total biomethane production in the European Union.

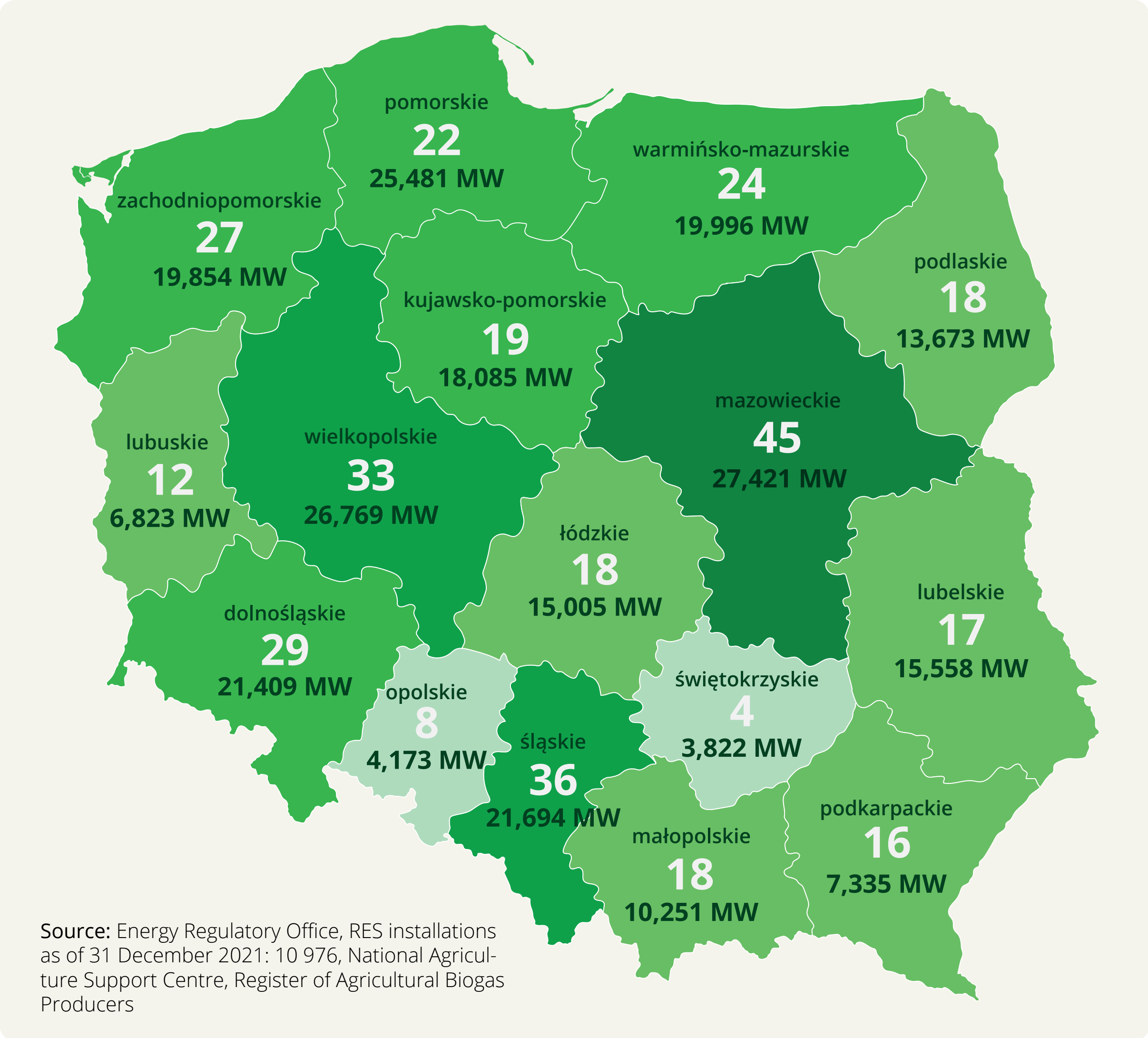


Source: Own compilation based on the European Commission data.

The long-standing leader in biogas production in the EU is Germany, which in 2021 accounted for 50.4% of total production with 11 269 biogas plants[95]. Other major producers of this gas include: Italy (13.9%), France (9.4%), Denmark (4.2%) and the Czech Republic (4%). The total biogas production recorded in the EU in 2021 was 14 929 ktoe, up 1.7% from 14 687 ktoe in 2020[96].

At the end of 2021, there were 346 biogas installations in Poland with a total installed capacity of 257 MW[97].

FIG. 4. Map of locations of biogas plants in Poland by voivodship, as at the end of 2021.



Source: https://magazynbiomasa.pl/biogazownie-w-polsce-gdzie-jest-ich-najwiecej-sprawdz/

95 Now Environment, *Biogas in Poland. A new opening*, https://www.teraz-srodowisko.pl/publikacje/biogaz-w-polsce-2023/teraz-srodowisko-publikacja-biogaz-w-polsce-2023.pdf, 3.04.2023.

96 European Commission, State of the Energy Union 2023 report, Brussels, 24.10.2023,

97 *Biogas in Poland. New* ...[op. cit.], p. 11., https://www.teraz-srodowisko.pl/publikacje/biogaz-w-polsce-2023/teraz-srodowisko-publikacja-biogaz-w-polsce-2023.pdf, 3.04.2023.

Biomethane, as already mentioned in Chapter 2, is obtained through a biogas upgrading process. The formation of the biogas sector has created a basis for the start-up and production of biomethane in Europe. However, the biomethane production capacity achieved to date is still a considerable distance away from the existing biogas production capacity.

According to IEA data, biomethane production in the European Union in 2021 was expected to be 35 TWh (approx. 3.3 billion m^3)[98]. Meanwhile, according to the European Biogas Association (hereafter EBA), biomethane production capacity located in Europe totaled 6.4 billion m^3 (about 67.5 TWh). 81% of this capacity is located within the borders of the 19 countries belonging to the European Union. Between 2021 and 2024, production capacity in the EU increased steadily, reaching the following values:

- 2021 r. - 3.5 bcm (about 37 TWh)
- 2022 r. - 3.8 bcm (about 40 TWh)
- 2023 r. - 4.2 bcm (approx. 44 TWh)
- 2024 r. - 5.2 bcm (approx. 54 TWh)

The EBA also tracks the number of biomethane plants in each European country, with a total of 1,548 as of June 2024, 80% of which were connected to the existing gas grid. The data made available shows that their number has been growing steadily over the past 2-3 years, but the scale of this growth is not similar from country to country. The vast majority of biomethane installations, as many as 1,366, are located within the borders of the 19 countries belonging to the European Union. Among the EU countries, the undoubted leader in this field is France, which records the largest year-on-year increases. The number of installations is also clearly increasing in Italy and the Netherlands. Countries such as Lithuania, Portugal and Slovakia have joined the ranks of biomethane producers in the last 2 years. Stagnation in the development of the biomethane industry, on the other hand, can be noted in Germany and Austria (see Table 4).

TAB. 4. Biomethane production capacity by EU member states.

No.	Country	2022	20223	2024
1.	Austria	16	16	16
2.	Belgium	6	8	9
3.	Czech Republic	2	2	9
4.	Denmark	49	50	58
5.	Estonia	5	6	8
6.	Ireland	2	2	2
7.	Finland	22	23	24
8.	France	337	477	675
9.	Spain	3	5	9
10.	Netherlands	61	70	79
11.	Lithuania	0	0	2

98 IEA, *Scaling up biomethane in the European Union: Background paper* https://iea.blob.core.windows.net/assets/9c38de0b-b710-487f-9f60 f19d0bf5152a/IEAWorkshop_Scalingupbiomethane_backgroundpaper.pdf, 28.09.2022.

12.	Luksemburg	3	3	3
13.	Latvia	1	1	4
14.	Portugal	0	0	3
15.	Germany	242	254	254
16.	Slovakia	0	1	1
17.	Sweden	70	72	74
18.	Hungary	2	2	3
19.	Italy	33	106	133
	Total	**849**	**1 098**	**1 366**

Source: European Biogas Association, EBA Statistical Report 2023, 2024

EBA predicts the continuation of an upward trend in the EU, which should result in the development of biomethane production to a level of about 20.2 bcm per year (about 213 TWh) in 2030[99]. The feasibility of such a scenario is to be indicated by planned investments in new generation capacity, estimated at €27 billion by 2030[100]. Looking ahead to 2030, according to the Institute for Energy and Environmental Research (ifeu), with reference to ICCT estimates, a realistic and sustainable scenario envisions 17 bcm of biomethane[101].

Outside the EU, the EBA noted 182 more biomethane plants in 5 countries: Iceland, Norway, Switzerland, Ukraine and the UK[102].

TAB. 5. Number of biomethanation plants in non-EU European countries, as of April 2023.

Country	Number of biomethanation plants
Iceland	2
Norway	14
Switzerland	42
Ukraine	5
United Kingdom	119
Razem	**182**

Source: EBA

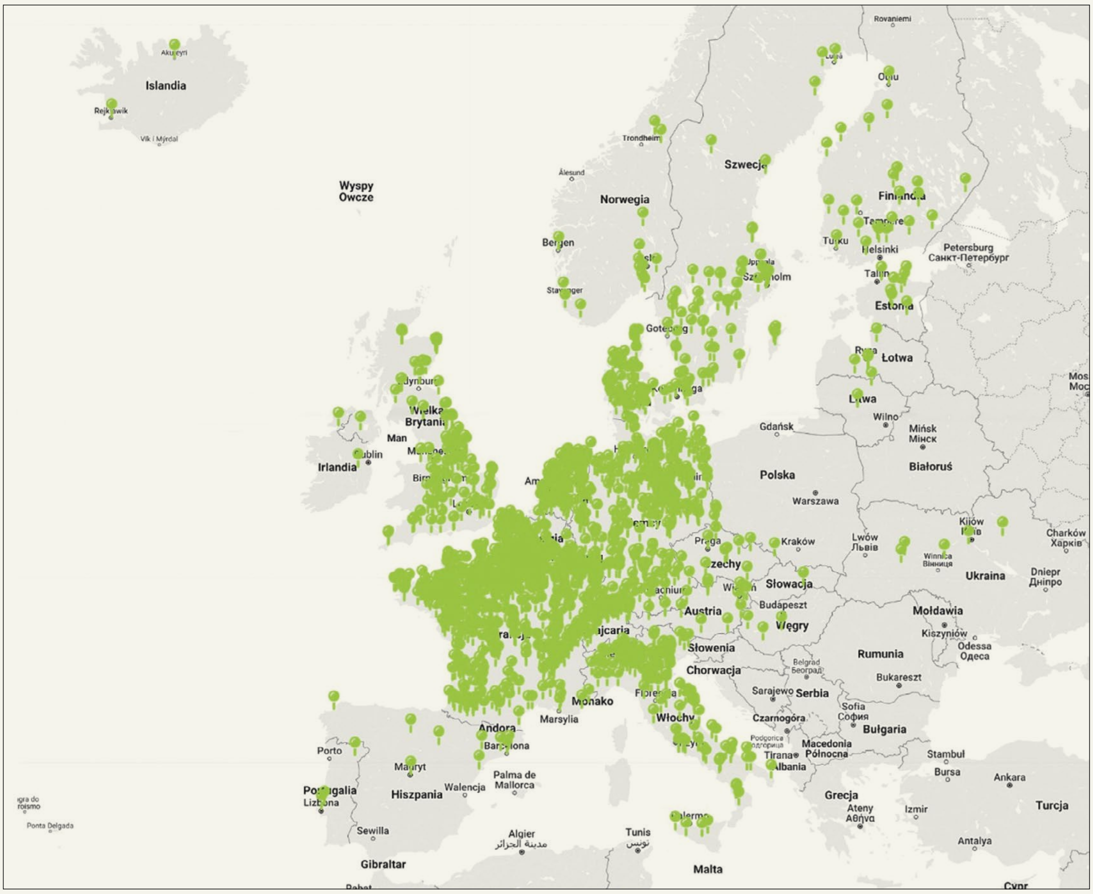
99 European Biogas Association, *EBA Statistical Report 2023*, https://www.europeanbiogas.eu/eba-statistical-report-2023/, 5.12.2023 r.

100 EBA, https://www.europeanbiogas.eu/wp-content/uploads/2024/07/EBA-Dig-Deep-Webinar_-Biomethane-scale-up-in-figures.pdf

101 ifeu, Biomethane in Europe, 2022, https://www.ifeu.de/fileadmin/uploads/ifeu_ECF_biomethane_EU_final_01.pdf

102 EBA, *European Biomethane Map. Infrastructure for biomethane production 2024*, https://www.europeanbiogas.eu/european-biomethane-map-2024/

FIG. 5. Map of the distribution of biomethanation plants in Europe, as of June 2024.



Source: https://www.europeanbiogas.eu/european-biomethane-map-2024/

The European Union remains the leader in biomethane production, but competition is growing rapidly from the Chinese and US markets[103], where the advantage lies, among other things, in simplified and relatively fast investment processes and a negligible licensing or certification regime. Despite impressive growth rates, it is estimated that Europe uses only 4% of its anaerobic digestion potential and biomethane still accounts for less than 1% of gas consumption on the old continent[104].

Support systems for biomethane production

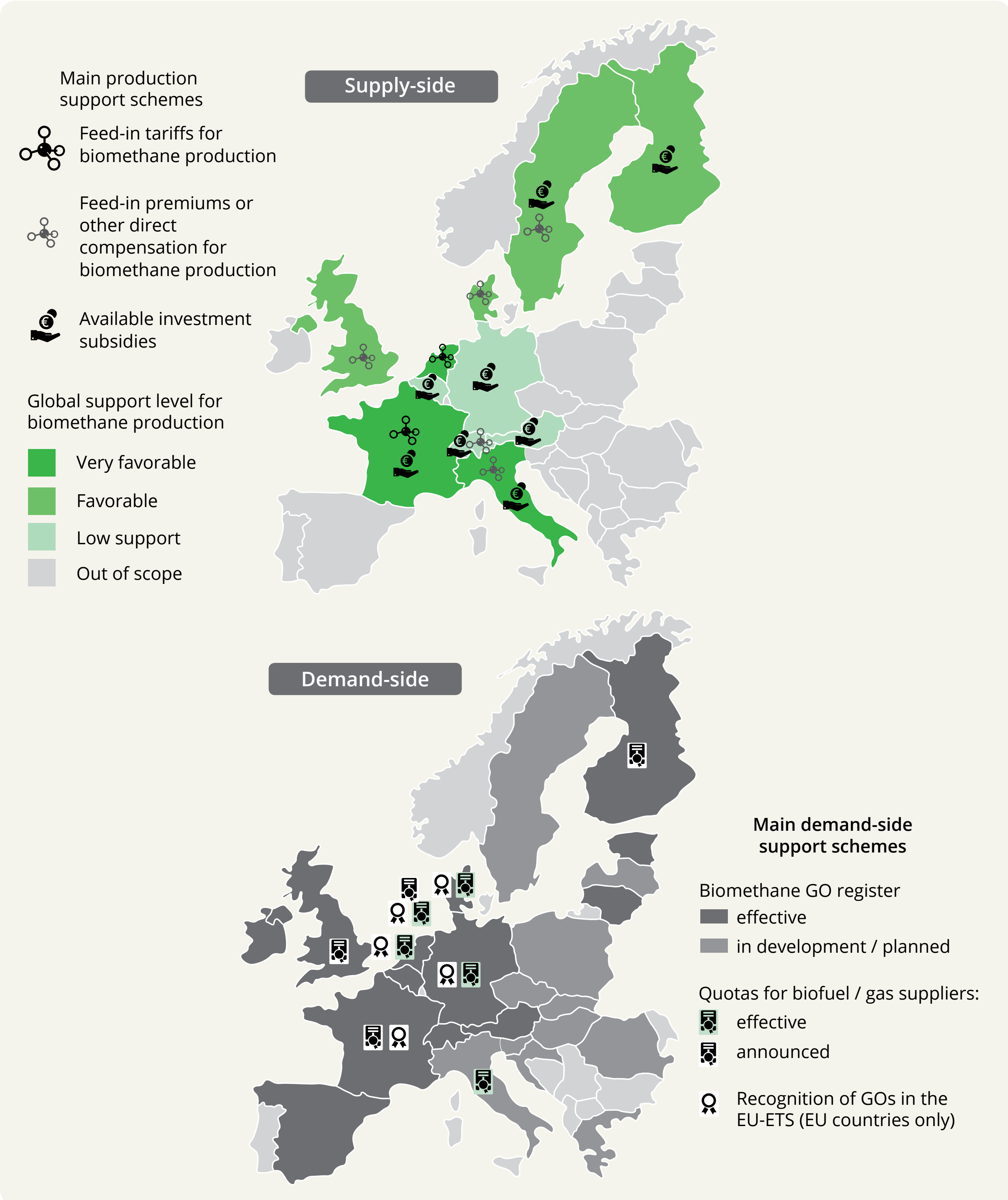
There is no doubt that the development of biomethane production in the European Union would not be possible without the use of investment support mechanisms and the operation of the market for this raw material. This is because biomethane production under market conditions is still not profitable

103 Lukáš Výlupek et al, The future of biomethane, Arthur D. Little, https://www.adlittle.com/en/insights/viewpoints/future-biomethane, 14.06.2023.

104 EBA Report 2022.

due to the relatively high investment and logistical costs associated with, among other things, the process of obtaining substrate. In Europe, programmes to support biomethane production have been in place for more than a decade in countries such as the UK, Denmark, Sweden and France. These are the result of political decisions stemming from a belief in the need to develop renewable energy sources.

FIG. 6. Regulatory support systems in 11 major European countries



Source: https://www.sia-partners.com/system/files/document_download/file/2023 12/Sia%20Partners_Benchmark_Europe_Biomethane.pdf

The most commonly used support mechanisms in European countries are as follows:[105], [106], [107]

- **Feed-in tariff (FIT)**: a state-policy incentive to invest in renewable energy by providing long-term contracts to RES producers in line with the production costs of individual technologies - adequate remuneration per unit of renewable energy produced, long-term contracts, guaranteed access to the grid, prices based on the costs of individual technologies;

- **Market price subsidy/feed-in premium (FIP) scheme**: a support mechanism for investments in renewable energy, consisting of the premium payment for the sale of a unit of renewable energy on the market (market price subsidy);

- **Quota and green certificates**: a system whereby renewable energy is sold at the market price and an additional income for the producer in the form of the sale of green certificates (issued for each unit of RES energy produced);

- **Investment grants**: the amount of financial support received for an investment in the form of the construction of a power plant or energy facility, which must meet certain requirements depending on the type of support;

- **Fiscal incentives**: an incentive in the form of tax exemptions or tax reductions to compensate for the lower competitiveness of a technology in the market or to encourage the development of a technology in market circulation.

Community legislation empowers EU member states to support producers of renewable energy sources in support of overarching climate and energy policy goals. In the case of biogas production, there is no defined or imposed framework of support mechanisms and each country introduces them within the range of possible financial inputs as well as legal and operational solutions[108]. While some countries have chosen to focus on supply-side support through the establishment of feed-in tariffs or investment subsidies, most countries generalise demand-side incentives, in particular through quotas and GO market organisation. Multiplicity, diversity and variability in mechanisms are repeatedly cited as one of the barriers to the development of the European biomethane market[109]. This chapter provides an overview of support mechanisms for biomethane production and looks at the experience of Germany, France and Denmark as the countries with the highest production and most diverse cross-section of biomethane generation capacity in Europe.

105 W. Ignaciuk, M. Szymańska, A. Wąs, *Development of the Biomethane Market in Europe*, 'Energies', https://www.mdpi.com/1996-1073/16/4/2001, 17.02.2023.

106 SIA Partners, 2023, 7th European Biomethane Benchmark. https://www.sia-partners.com/system/files/document_download/file/2023-12/Sia%20Partners_Benchmark_Europe_Biomethane.pdf

107 Yuxia, Y.; Ryssel, M.; Scholwin, F.; Grope, J.; Clinkscales, A.; Bowe, S. *Biomethane Production and Grid Injection: German Experiences, Policies, Business Models and Standards*; National Energy Administration: Beijing; Berlin, 2020.

108 M. Decorte et al, *Mapping the state of play of renewable gases in Europe*, https://www.regatrace.eu/wp-content/uploads/2020/02/REGATRACE-D6.1.pdf, 4.02.2020.

109 G. Freedman, *Can biomethane decarbonise Europe's gas market?* WoodMackenzie 2020, https://www.woodmac.com/news/opinion/can-biomethane-decarbonise-europes-gas-market/, 23.09.2020.

3.2. Germany

The beginning of biomethane production in Germany was preceded by the development of a biogas facilities network. The impetus for the development of biogas production capacity in Germany was provided by an amendment adopted in 2000 to the Renewable Energy Sources Act, Erneuerbare Energien Gesetz (EEG)[110], which, among other things, introduced guaranteed rates for electricity produced from biogas in the form of feed-in tariffs (FiTs). In 2008, a financial bonus was introduced for the use of manure and other bio-waste as raw materials, the refining bonus[111]. As a consequence of the above support mechanisms, the biogas sector in Germany grew rapidly between 2009 and 2011, with 1,000 biogas plants per year. In 2014, both the substrate premium and the refining premium were abolished[112]. Since 2017, there has been a change in the support system - moving from 'feed-in tariffs' (FiTs) to an auction model (pay-as-bid[113]), with the aim of introducing an element of competition between different generation technologies. Two such auctions were held in 2017 and 2018, but neither the targeted volumes were allocated nor significant cost reductions achieved. As a consequence of these measures, an eight-year period of elimination of government support for biogas began. After the transition from the German FiT to an auction system, biogas production began to decline, reaching 71 TWh in 2020[114].

According to the figures published by the European Commission, 8.35 billion m^3 of biogas was produced in Germany in 2021 and used to produce electricity and heat[115]. The evolution of the biogas sector shows that, in the case of Germany, the above model of biogas utilisation is gradually being exhausted. In light of the current regulations in the aforementioned EEG Act, older biogas plants can no longer benefit from high feed-in tariffs. The sector has prospered thanks to a government policy that established an initial 20-year incentive period for new installations. In the absence of continued support, producers are beginning to find it difficult to continue operations due to high running costs, including debt service. For new producers, on the other hand, these are high-risk investments. The market is now 'forcing' biogas producers to look for other uses for biogas by upgrading it to biomethane. This gas is then injected into the existing grid as a gaseous fuel.

Since 2006, when the first three biomethanation plants were commissioned[116], the business of upgrading biogas to the biomethane standard has been expanding. In 2022, the 252 biomethanation plants operating in Germany produced approximately 1.2 billion m^3 of biomethane (approximately 13 TWh).

110 It was enacted on 29 March 2000 on the initiative of the ruling coalition of the SPD and the Alliance90/Greens

111 B. Kupiec, *Biomethane in Germany's energy strategy*, Green Economy 2023 Portal, https://zielonagospodarka.pl/biometan-w-strategii-energetycznej-niemiec-9900, 23.03.2023.

112 Marc-Antoine Eyl-Mazzega and Carole Mathieu (eds.), *"Biogas and Biomethane in Europe: Lessons from Denmark, Germany and Italy"*, Études de l'Ifri, Ifri, 2019

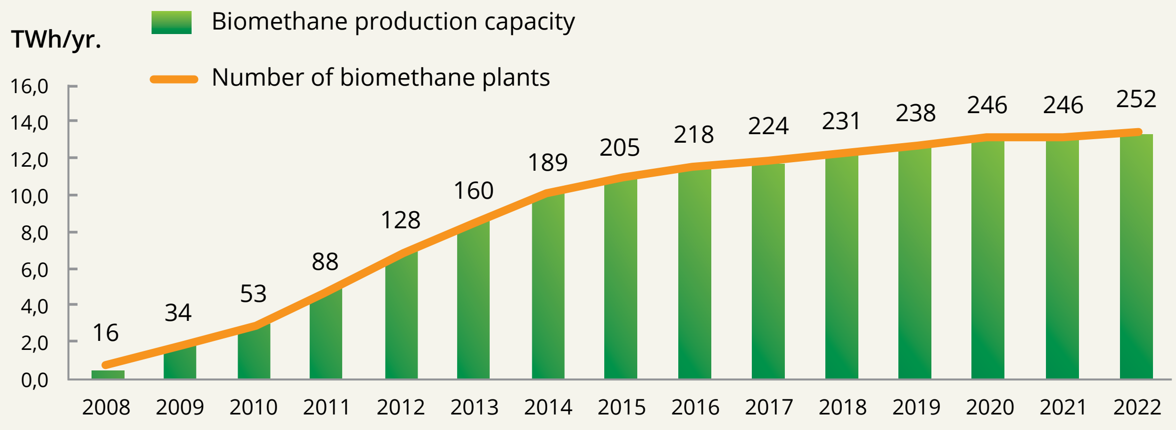
113 All entities interested in installing a biogas plant enter the auction - the auction is won by each successive bidder who has offered the lowest price until the bid amount is reached. In the event of bids for the same amount, the system with the lower value is auctioned again.

114 Yuxia, Y.; Ryssel, M.; Scholwin, F.; Grope, J.; Clinkscales, A.; Bowe, S. *Biomethane Production and Grid Injection: German Experiences, Policies, Business Models and Standards*; National Energy Administration: Beijing, Berlin, 2020.

115 *BIOMETHANE FICHE - Germany (2021)*, https://energy.ec.europa.eu/system/files/2023-09/Biomethane_fiche_DE_web.pdf, 14.08.2024.

116 Fachagentur Nachwachsende Rohstoffe, Biomethan, https://biogas.fnr.de/biogas-nutzung/biomethan, 14.08.2024.

FIG. 7. Biomethane production in Germany from 2008 to 2022**.**



Source: https://www.sia-partners.com/en/insights/publications/7th-european-biomethane-benchmark

At present, the German federal government also seems to favour hydrogen as the leading renewable gas, which has the effect of, among other things, restricting access to biomethanation plant connections to the gas grid[117]. German support programmes currently include neither preferential tariffs for biomethane at the entrance to the gas grid nor direct funding for biomethane production itself. Indirectly, biomethane production is supported by programmes dedicated to increasing the share of renewable energy in electricity, heat and mobility generation. The most important support programmes include the production of biomethane energy in CHP units, as fuel for natural gas-powered vehicles and for the heating and cooling of buildings - under strict conditions. The Federal Emission Control Act (BImSchG) prescribes quotas based on greenhouse gas emissions for fuel suppliers, targeting reductions of between 8 per cent in 2023 and 25 per cent in 2030[118]. Biomethane, on the other hand, is regarded as the biofuel that contributes to the largest CO_2 reduction at present, so tax credits are provided for bioLNG production.

In Germany, the cost-effectiveness of new biogas installations is too low to be market-justified. Alternative plant concepts are now being sought that would be most suitable, taking into account economic and technical constraints while maximising environmental and agricultural benefits. The only viable alternatives are the expansion of existing plants, the adaptation of plants for more flexible operation and the slight expansion of small-scale biogas plants based on manure and bio-waste digestion plants, in line with the requirements for 'sustainability' of the substrate. Sensible options include combining plants to achieve higher capacities while reducing costs. Increasingly, there is also a focus on combining technologies, with biomethane production also being linked to hydrogen technologies and the liquefaction of CO_2, in order to produce liquid bio-CO_2 as a desirable end product in the food industry sector, among others.

117 Dirk Bonse, *German biogas market, or the whole industry with one voice*, 'Biomass Magazine', https://magazynbiomasa.pl/niemiecki-rynek-biogazowy-czyli-cala-branza-jednym-glosem/, 01.04.2023.

118 ePURE ASBL, *Overview of biofuels policies and markets across the EU*, https://www.epure.org/wp-content/uploads/2023/02/230227-DEF-REP-Overview-of-biofuels-policies-and-markets-across-the-EU-February-2023-1.pdf, 15.02.2023.

Cost containment is also sought in stable substrate supplies, pointing to large-scale agricultural and industrial waste. An additional revenue stream is now also seen in the sale of digestate as biosolids. The criteria for sustainable biomass limit the share of cereals and maize to 40% due to the collision with food policy.

It is also pointed out that there is a need to determine the most cost-effective way of connecting and injecting biomethane into the grid in cooperation with operators (concerning, for example, gas quality requirements, grid upgrades and adaptations, or compression needs and power allocation). For example, limits have been set on connection costs for biomethanation plant operators, allowing for a balanced distribution of costs. Plant operators pay up to a maximum of EUR 250,000 to connect a biomethanation plant located less than 1 km from the gas grid, with the rest being paid by the system operator[119]. Systems tailored to the distributed nature of biomethane sources are also being developed, if only through a reverse flow mechanism allowing bi-directional distribution and transmission flows[120]. Another aspect is the trading of greenhouse gas emission reduction certificates. Certificates of guarantee of origin can be used by biomethane producers in EU-ETS schemes and the national nEHS, which includes the transport sector[121].

Regardless of the evolution and complexity of the support systems, Germany has achieved a leading status in biomethane production on an EU-wide scale. It is also noteworthy that the German biogas market is somewhat unified, through the activities of a single leading organisation, the German Biogas Association (Fachverband BIOGAS), which has virtually no competition there (in contrast to the Polish market, where there are four main associations).

3.3. France

France is currently leading in the development of production infrastructure for biomethane in the EU, with still a lot of growth potential in this area. This is primarily due to its very well-developed agriculture, giving the country first place in EU agricultural production (18% share of production in 2021)[122] and its long-standing national energy and climate policy. France has more than 40% of biomethane production units in Europe, which produced 7 TWh of feedstock in 2022[123]. At the end of 2022, biomethane production for grid injection accounted for 30% of the total installations and the number of biomethane installations doubled compared to 2020. These were mainly agricultural units (441 units) and wastewater treatment plants (35 units)[124].

119 SIA Partners, 2023, op. cit.

120 Gas for Climate, *Guidehouse Manual for National Biomethane Strategies*, https://www.europeanbiogas.eu/wp-content/uploads/2022/09/2022-Manual-for-National-Biomethane-Strategies_Gas-for-Climate.pdf, 1.09.2022.

121 Sustainable Agribusiness Forum 2021, *Biomethane market development in Germany: status and prospects* https://saf.org.ua/en/news/1473/ 23.11.2023.

122 A. Dziubinska, *Strategic dimension of French agricultural policy*, https://pism.pl/publikacje/strategiczny-wymiar-francuskiej-polityki-rolnej, 10.03.2022.

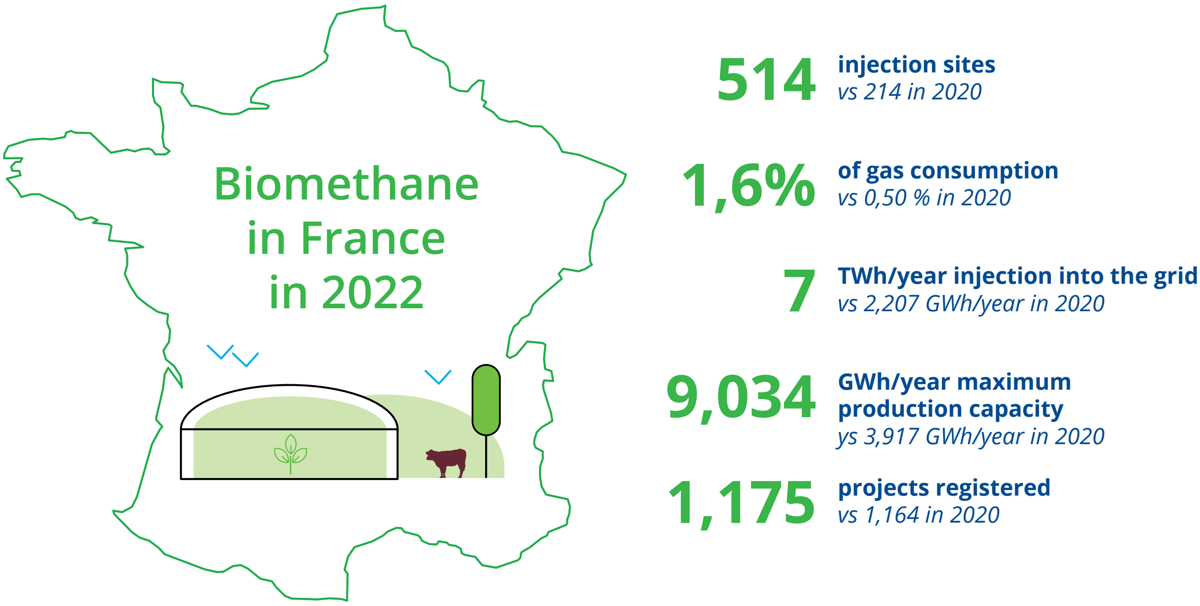
123 Metha France Portail National de la Methanisation, 2022, *En chiffres*, https://www.methafrance.fr/en-chiffres, 15.08.2024.

124 Teréga, GRDF, GRTgaz, SPEGNN, SER, *Panorama des Gaz Renouvelables en France*, https://assets.ctfassets.net/ztehsn2qe34u/4gcWxemhrEy3i7Z8bRiq4n/96dc9c38742c373a3e2892279819c7e6/PanoramaGazRenouvelables2022.PDF , 31.12.2022.

The beginning of the development of the biogas sector is inextricably linked to the introduction of state support mechanisms in the form of financial tools. Feed-in tariffs for biogas as a fuel for electricity, heat and cogeneration were implemented in France as early as 2001. In 2009, a national "methanation of agriculture" program was launched, including a collection of instruments to improve energy efficiency and reduce greenhouse gases in the sector[125]. The main objective of the programme was to install a number of on-farm biomethane production units and to pursue additional income for farmers through the economic use of digestate and bioenergy. At the same time, there was a strong emphasis on reducing the share of energy and food crops in the process, also to limit massive land use changes. These measures were also aimed at increasing the competitiveness of French agriculture. The main goal of the program was to install a large number of on-farm biomethane production units and to pursue additional income for farmers through the economic use of digestate and bioenergy. At the same time, great emphasis was placed on reducing the share of energy and food crops in the process, also to limit massive land use changes. These measures were also aimed at increasing the competitiveness of French agriculture. Then, around 2010, a national renewable energy action plan and the country's first multi-year energy program were presented. The plan laid out the basis for setting a feed-in tariff for biomethane injected into the natural gas grid, and regulations were subsequently enacted to enable public support for the biomethane injection sector.

Since 2011, a state-guaranteed tariff has been in operation in France, providing producers with a minimum price for a period of 15 years. The amount of support depends on the size of the installation and the raw material (minus landfilled waste) and compensates wastewater treatment and municipal waste management services with premiums. A GO guarantee of origin register has been in place since 2012, allowing the supplier to make a 'green offer' to customers. Distribution and transmission network operators contribute to the connection costs of biomethane installations.

FIG. 8. Biomethane statistics in France in 2022



Source: https://www.terega.fr/en/newsroom/editorial/what-are-the-perspects-for-biomethane-in-france-in-2023/

125 Farm Energy Efficiency Plan 2009-2013: https://agriculture.gouv.fr/environnement-sobriete-energetique-et-efficacite-energetique-des-entreprises-et-des-exploitations, 9.01.2015.

Although the French energy mix is one of the cleanest in Europe, the country is taking further steps to reduce greenhouse gas emissions due to the predominance of nuclear power. The transport and agricultural sectors are responsible for the highest emissions. However, the French agricultural sector is not free from a number of problems such as loss of profitability, loss of competitiveness vis-à-vis imported food and a decline in the number of farms. French agriculture, which generates 19% of national greenhouse gas emissions, will also have to face up to the decarbonisation policy of the sector as laid down in the European Green Deal in the coming years.

The country's ambitious energy and climate goals favour biomethane production and involve a robust producer support scheme. France has committed to increasing the share of renewable gases in its natural gas consumption[126] and a biomethane injection target of 7-10% by 2030[127]. French climate and agricultural policy allows for subsidising local research and equipment investments, and applies price guarantees to bioenergy products, allowing for effective emission reductions in many subsectors. In contrast to the German Energiewende approach, which replaces fossil and nuclear power with RES, France has managed to develop the low-carbon energy sector as a strategy for waste management and agricultural development through, among other things, methanisation[128]. This policy is based on two policies and two main support instruments. These are:

The 'nitrogen' plan for energy methanisation autonomy (Le plan Énergie Methanisation Autonomie Azote EMAA),

- the Agricultural Competitiveness and Adaptation Plan 2014-2020 (Plan pour la compétitivité et l'adaptation des exploitations agricoles 2014-2020 PCAE),
- FIP subsidy for biogas for electricity and heat production,
- feed-in tariff (FIT) for the injection of biomethane into the gas network[129].

The rapid growth of the industry, coupled with the recent inflationary crisis, has resulted in top-down steps tightening access to the feed-in tariff. In 2020, the state authorities reduced the purchase price of biomethane by around 10% for suppliers, and many plants subsequently struggled with electricity price increases. In 2023, a new tariff decree was published, raising the purchase price of biomethane by up to 15% and announcing indexation of the price in line with energy prices[130].

The energy crisis, which culminated in 2022, was followed by a series of reforms, including:

- taking into account the inflation factor, a reindexing of the regulated FIT purchasing tariff for small projects, which also accounts for the hourly labour cost and the 2022 production price index,
- the planned tendering system for larger installations,
- certification, involving plans to require French energy suppliers to supply some customers with biomethane, providing them with certificates,

126 Energy Transformation for Green Growth Act (LTECV 2019)

127 Long-term Energy Schedule (PPE)

128 BEACON, Bio-Methane Support Policy in France Study, https://www.euki.de/wp-content/uploads/2019/09/20180827_FR_Biomethane-Support_Study.pdf, 3.09.2018.

129 Ibid.

130 Dametis, *Biogas and Biomethane: Highly Favorable Prospects Again in France*, https://www.dametis.com/en/biogas-and-biomethane-once-again-very-favorable-prospects-in-France/, 14.11.2023.

- simplifying the transaction process through so-called biomethane purchase contracts, negotiated between the producer and the consumer.

It is also envisaged to guarantee the right to inject biomethane into the grid to any producer located sufficiently close to the grid. This is intended to balance the technical, economic aspects in biomethane production and access to infrastructure[131].

As a purely mitigation instrument, 'biomethanisation' of agriculture may not seem particularly cost-effective, given the current potential emission reduction opportunities under the EU ETS of EUR 15 per tonne CO_2 or less. However, cost-effectiveness clearly increases with scale and there is potential for costs to fall as the scale of investment increases[132]. In addition to GHG reductions, the effects of such a broad policy are reflected in an increase in the share of RES in the energy mix, a reduction in the use of mineral fertilisers in agriculture, a reduction in unmanaged waste, or an increase in employment in the agricultural sector and rural areas.

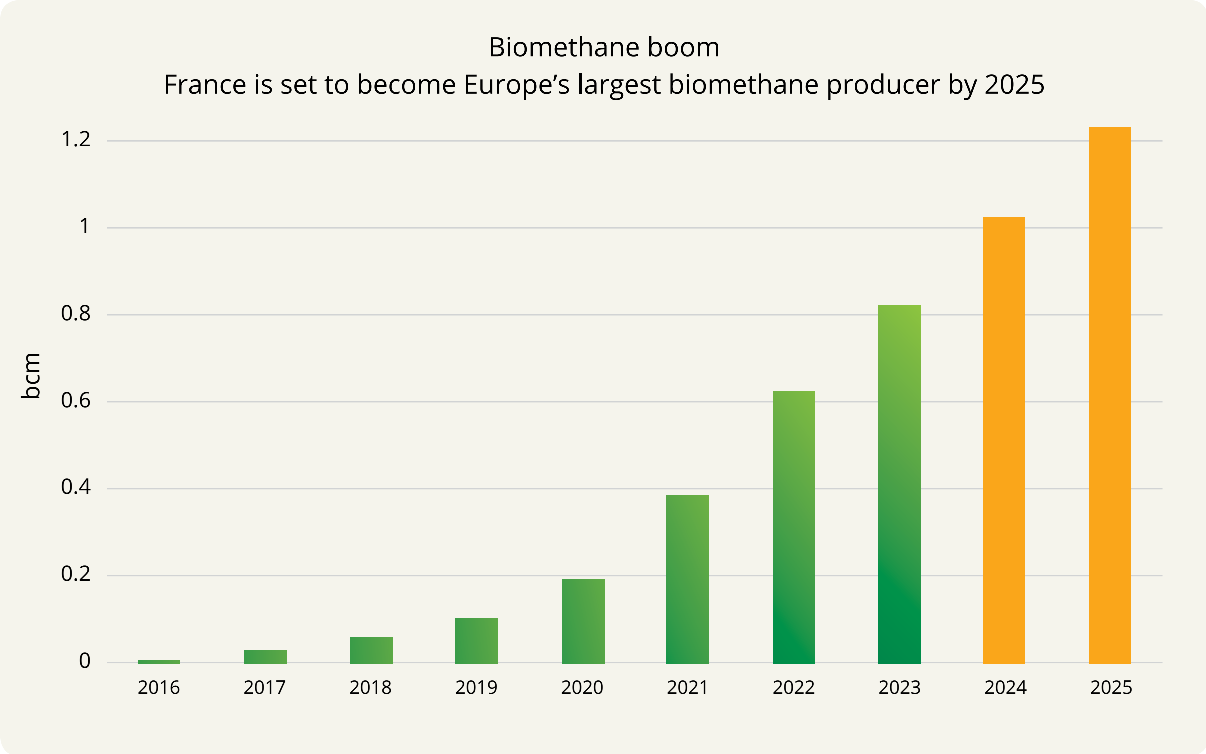
A long-term policy regime for the support of biomethane production poses a number of challenges, depending on the duration of the programme in question, the number of investments and the associated implications. Among the biggest of these is maintaining a balance between the level of tariff schemes over time to encourage investment, but at the same time maintain market competitiveness and align costs with the development of sectoral innovations. Public awareness and the need to maintain public support for biomethane investment is also an important issue, as the costs of incentives are borne by society as a whole - so it is necessary to keep communicating the benefits of 'biomethanisation' of the country. The economic outcome of climate policy, with an assumed increase in carbon prices, will be an increasing market competitiveness of biogas and biomethane against fossil fuels. Over time, it is anticipated that CO_2 prices will have to be increased2 in many other sectors, e.g. residential heating and transport[133].

131 Terega, What are the prospects for biomethane in France in 2023? https://www.terega.fr/en/newsroom/editorial/what-are-the-perspects-for-biomethane-in-france-in-2023, 15.08.2024.

132 French Ministry of the Environment, Energy and the Sea, *Rapport De La France: En application de l'article 13.1 du règlement n° 525/2013 relatif à un mécanisme pour la surveillance et la déclaration des émissions de gaz à effet de serre*, 15.03.2017.

133 Marc-Antoine Eyl-Mazzega, Carole Mathieu (eds.), *Biogas and Biomethane in Europe: Lessons from Denmark, Germany and Italy*, https://www.ifri.org/sites/default/files/atoms/files/mathieu_eyl-mazzega_biomethane_2019.pdf, 15.04.2019.

FIG. 9. Projected growth in biomethane production in France.



Source: https://www.linkedin.com/posts/greg-moln%C3%A1r-38601171_gas-lng-biogas-activity-7209451665098194944-5j91/

The extensive policy dedicated to biomethane is yielding high results, as France is poised to become the European leader in its production as early as 2025, according to the latest data. In 2023, biomethane production increased by as much as 30% (Fig. 9.). As factors for the success of the French biomethane sector, analysts point to the continued development of agriculture, well-designed subsidy programmes, the proactive approach of network operators and attention to social acceptance.

3.4. Denmark

The construction of the biomethane sector in Denmark is linked to the country's ambitious national climate goals, including achieving climate neutrality by 2050 and the prospect of running out of gas fields in the North Sea. The origins of Denmark's 'green gas' policy can be traced to the Energy Agreement adopted by parliament in 2012, which set out the direction of climate and energy policy until 2020. Among other things, it provided for support for the production of upgraded biogas, i.e. biomethane[134]. The support was mainly based on price subsidies of three types: indexed annually, adjusted for the price of natural gas and reduced successively each year from 2016 onwards[135]. Thanks to this support, the first biomethanation plant was commissioned in 2013. In the government's 2021 Green Gas Strategy document, it was assumed that the existing gas system would be primarily dedicated to the distribution of biomethane. This system consists of approximately 900 km of transmission pipelines and 18,000 km of distribution pipelines. It supplies gaseous fuel to approximately 430,000 households, 20,000 businesses, and 250 electricity and heat producing utilities. These are potential customers for the biomethane produced in Denmark. Indeed, the Danish authorities' goal is to completely eliminate fossil gas from the national economy by 2035 and replace it with 'clean gases' led by biomethane, the production of which is to be based on the country's own substrate resources[136].

Assumptions:

- the estimated available domestic biomass resource for biogas production is expected to be around 55 PJ by 2030,
- total biogas production is expected to increase to around 50 PJ by 2030,
- 80% of this biogas will be upgraded and fed into the gas system,
- 20% is to be used directly for industrial purposes and for the generation of electricity and heat,
- domestic biomass resources will be sufficient to produce additional quantities of biogas and biomethane to cover the increased demand in 2040,
- slurry and straw are the main substrate categories whose efficiency of use is expected to improve steadily.

134 IEA, Danish Energy *Agreement for 2012-2020 - ban on fossil-fuel based heating*, https://www.iea.org/policies/606-danish-energy-agreement-for-2012-2020-ban-on-fossil-fuel-based-heating, 27.02.2024.

135 Marc-Antoine Eyl-Mazzega, Carole Mathieu (eds.), *Biogas and Biomethane in Europe: Lessons from Denmark, Germany and Italy*, https://www.ifri.org/sites/default/files/atoms/files/mathieu_eyl-mazzega_biomethane_2019.pdf, 15.04.2019.

136 Danish Ministry of Energy, Environment and Utilities, 'Green Gas Strategy', https://ens.dk/sites/ens.dk/files/OlieGas/green_gas_strategy.pdf, 2021.

FIG.10. Steps in the implementation of the Danish biomethane strategy[137]:

STAGE 1: Development of small-scale agricultural biogas plants based on ‚wet' agricultural waste, combining production and consumption. Support in the form of subsidies for the use of biogas in cogeneration.

STAGE 2: Conversion of existing biogas plants into biomethane plants. Introduce biomethane into the existing gas grid once formal and technical issues have been settled. Cooperation with gas grid operators is necessary at this stage. Establishing rules for sharing the costs of connecting biomethane plants to the grid. Setting up a national register of certificates. A system for subsidising the use of biomethane.

STAGE 3: Close cooperation between distribution network operators (DSO) and transmission network operators (TSO) to achieve reverse flow from the DSO network to the TSO network. Expected cost reduction for biomethane plants. Maximising the gas yield per tonne of biomass processed. Extinguishing the subsidy scheme by introducing a cut-off date. New biomethane plants commissioned after this date will not be eligible for subsidies. Existing plants remain eligible for subsidies after the cut-off date.

STAGE 4: Create the technical conditions for the cross-border flow of biomethane. Expected increase in ecological value and market price, optimisation of production and streamlining of the biomethane value chain. Significant increase in biomethane production on a commercial basis.

STAGE 5: Development of cross-border biomethane trade. Biomethane transactions concluded at market-determined prices. Creation of a continental standard for guarantees of origin to document the environmental value of biomethane. European oversight and harmonisation of national subsidy schemes to avoid „double subsidisation"....

Source: https://en.energinet.dk/media/bsjijbgd/danish-biomethane-experiences.pdf

A Danish scheme to support the production of 'green' gas was launched in 2012. It consisted of subsidising biogas production through a fixed level of subsidies for eligible biogas producers, who could receive financial support for, among other things, upgrading the gas they obtained to the biomethane standard. The subsidy sceme was closed in 2018, but as the subsidies were granted for a period of 20 years, much of the biogas currently produced in Denmark is still subsidised[138.]

Currently, the sale of biomethane in Denmark is done on a market basis. Biomethane is sold on the natural gas market after being fed into the gas network. Biomethane producers enter into buy-sell transactions with wholesale trading companies, which inject it further into the gas system along with the other gas in the system. The price of biomethane is market-based and follows wholesale natural gas prices. The environmental value of the gas is documented by guarantees of origin.

137 Energinet, *Danish biomethane experinse*, https://en.energinet.dk/media/bsjijbgd/danish-biomethane-experiences.pdf, 21.09.2022.

138 Table of Danish biomethane subsidy levels: https://ens.dk/sites/ens.dk/files/OlieGas/biogas_subsidy_levels.pdf

Biomethane production in Denmark is covered by a guarantee of origin system. The registration and issuing of guarantees of origin for biomethane injected into gas networks (distribution and transmission) is handled by the Danish gas transmission system operator Energinet.

Guarantees of Origin (GOs) for biomethane can be traded by holders of the relevant accounts. A biomethane producer can sell its GOs to a consumer or do so through an energy trading company. The guarantee of origin is proof of the origin of the green value of the energy purchased by the consumer. After the transaction, the sellers of the guarantee of origin are obliged to delete the guarantee of origin from the register of guarantees of origin kept by Energinet[139]. Transfers of GOs take place within the national register or via electronic trading platforms such as ExtraVert[140] to other European registers. Guarantees of origin can be transferred independently of the energy transfer to which they relate. This ensures an uninterrupted transfer from producer to consumer of the green value of energy produced from a renewable energy source - even though the quality of the final product received by the consumer is indistinguishable from conventional gas[141].

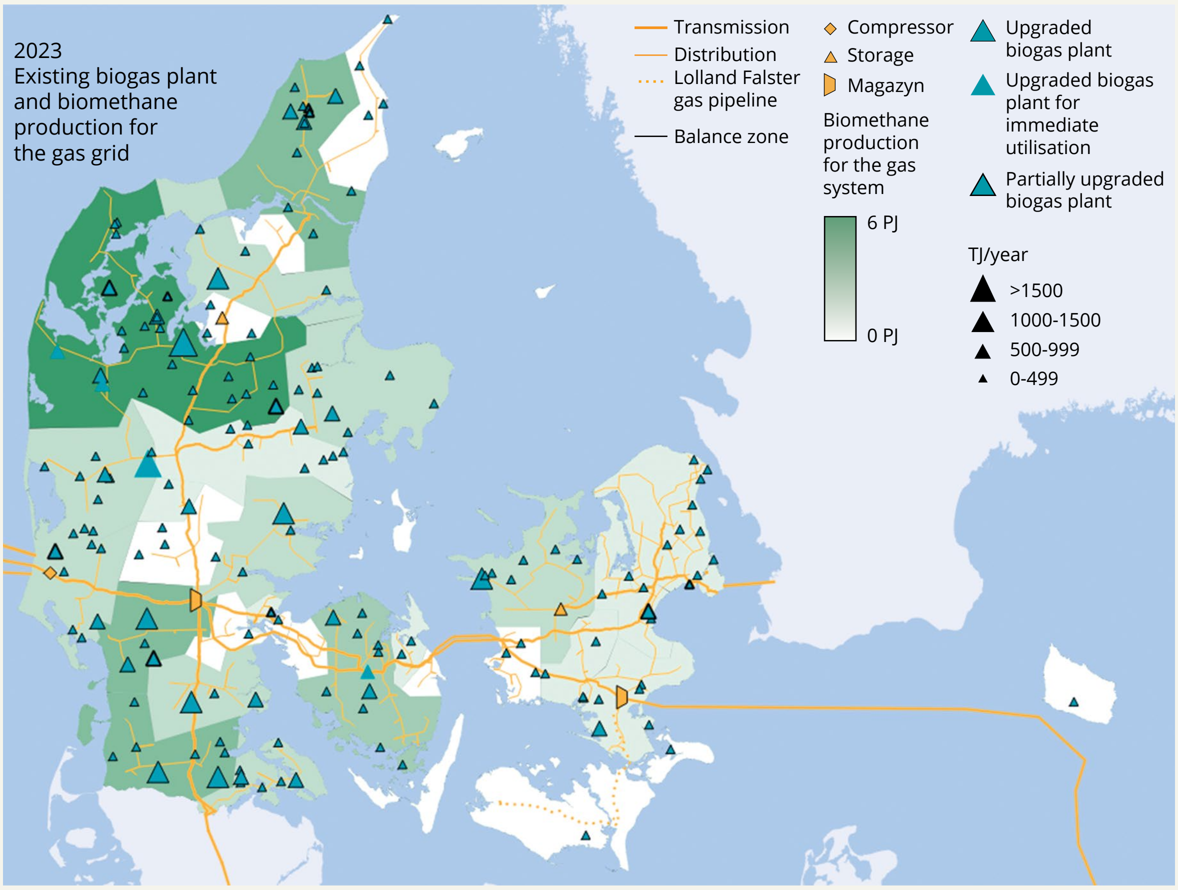
Depending on the type of substrate, Danish biogas plants can be divided into four different types: agricultural plants, wastewater treatment plants, industrial plants and landfills. Approximately 85% of the installations are agricultural plants with animal waste as the main feedstock. Most biogas plants are located in the western part of Denmark, where the density of animal husbandry is highest.

139 Energinet, *Guarantees of origin for renewable gas*, https://en.energinet.dk/gas/biomethane/go-gas/, 1.03.2024

140 ExtraVert platform - established in 2021 by the European Renewable Gas Registry (ERGaR) to enable cross-border trading of guarantees of origin for biomethane, https://www.ergar.org/renewable-gas-certification/

141 Energinet, *Guarantees of* ..., op. cit., , https://en.energinet.dk/gas/biomethane/go-gas/

FIG. 11. Map of the distribution of biogas/biomethanation plants in Denmark



Source: https://ens.dk/sites/ens.dk/files/OlieGas/kort_over_biogasproducenter_i_danmark_2023.pdf

Currently, around 80% of the biogas produced is upgraded and fed into the national gas grid as biomethane. In 2023, the share of biomethane in the Danish gas system will reach approximately 40%[142.]

3.5. Czech Republic

The Czech Republic is not among Europe's leading producers of biomethane, but the country has been making intensive efforts to develop its production in recent years. The first biomethanation plant with a production capacity of 1.2 million m^3 gas was only commissioned in Rapotine in 2019[143]. By the beginning of 2024, seven biomethanation plants were already in operation with a total production capacity of up to almost 10 million m^3 of biomethane[144]. The business model developed in the Czech Republic is

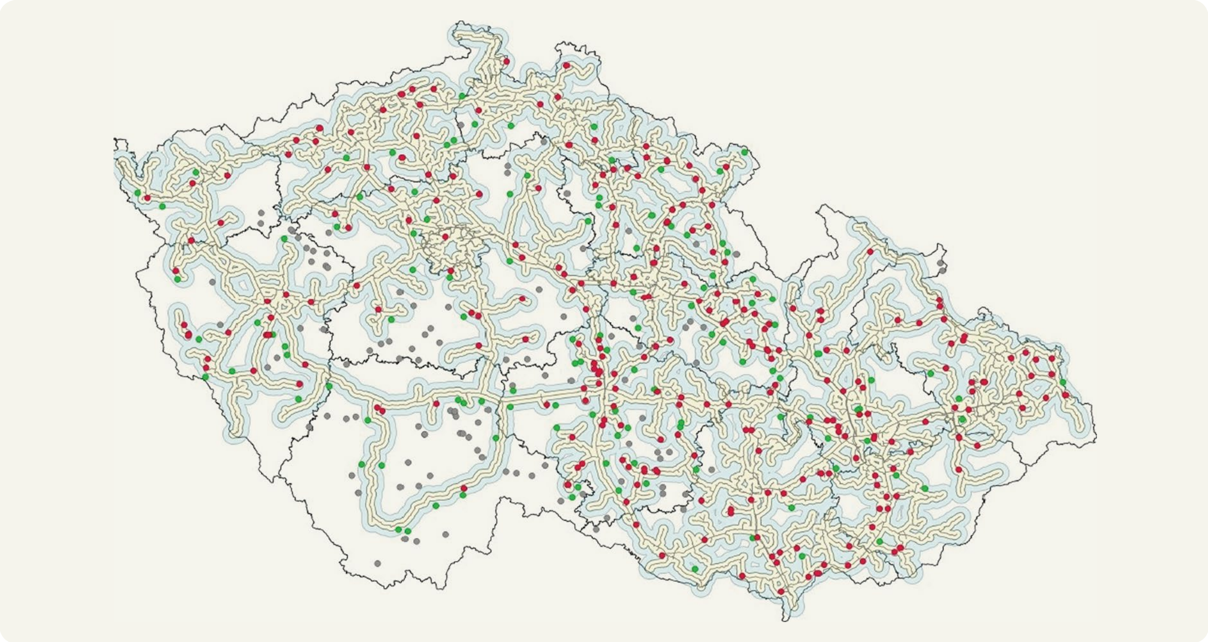
142 Danish Energy Agency, *Biogas in Denmark*, https://ens.dk/en/our-responsibilities/bioenergy/biogas-denmark,

143 Svaz moderni energetiky, *Česká produce biometanu daleko zaostává za plánem, kapacity je potřeba urychleně zvýšit*, https://www.modernienergetika.cz/aktuality/ceska-produkce-biometanu-daleko-zaostava-za-planem-kapacity-je-potreba-urychlene-zvysit/, 16.10.2023,

144 O energetice, *V ČR loni vznikly čtyři nové výrobny biometanu, rozvoj zaostává*, https://oenergetice.cz/obnovitelne-zdroje/v-cr-loni-vznikly-ctyri-nove-vyrobny-biometanu-rozvoj-zaostava, 12.03.2024.

to convert existing biogas plants into biomethane production facilities and then to introduce biomethane into the economic cycle by connecting to the existing distribution network for natural gas[145]. The Czech potential for biomethane production can therefore be launched based on biogas plants operating throughout the country. According to calculations carried out by GasNet s.r.o., the gas distribution system operator, there are 266 biogas plants in the Czech Republic within a 2 km radius of the gas grid and another 117 within a 5 km radius[146].

FIG. 12. Distribution of biogas plants located within 2 km of the gas distribution network (red dots) and those located within 5 km (green dots)



Source: https://vytapeni.tzb-info.cz/vytapime-plynem/20293-biometan-jako-nahrada-zemniho-plynu-pro-vytapeni-v-cr

The above-mentioned operator has a transparent policy for connecting further biomethane installations to the distribution network it manages. The possibility of connecting a biomethanation plant to the distribution system and the subsequent connection process for such a project are individually assessed and analysed with the interested investor. The operator publishes all stages of the connection procedure thus navigating interested parties. The quality requirements for biomethane fed into the gas network are defined in the operator's operating instructions based on Regulation No. 459/2012 Dz. on requirements for biomethane, how to measure biomethane supplied to the transmission system, distribution system or underground gas storage reservoirs[147].

145 Ibid.

146 J. Hodboď, H. Šťovíčková, *Biometan jako náhrada zemního plynu pro vytápění v ČR*, https://vytapeni.tzb-info.cz/vytapime-plynem/20293-biometan-jako-nahrada-zemniho-plynu-pro-vytapeni-v-cr, 28.02.2020,

147 GasNet, *Řád provozovatele distribuční soustavy GasNet, s.r.o.*, https://www.gasnet.cz/-/media/GasNet/Files/Gasnet/obchodni-podminky-a-rady/rad-pds/rad-pds-aktualni/GN_Kodex_2023_od_06012023.pdf, 6.01.2023.

Despite the significant increase in the number of biomethane installations and the regulation of their connection to the gas grid, biomethane production itself has not increased in recent years. The main barrier in this case is the economic uncompetitiveness of this raw material vis-à-vis traditional natural gas. According to the Czech Biogas Association, the negative impact on the economics of biomethanation plants is the cost of connecting such plants to the gas grid, which is fully covered by their owners[148.] These problems are to be solved as a consequence of the Czech state implementing appropriate solutions to support biomethane production. Measures in this regard have been declared by, among others, the Minister of the Environment, Petr Hladík, while pointing out that the conversion of more than 570 existing biogas plants to biomethane is an ideal solution for reducing natural gas consumption in the Czech Republic[149].

The Czech state in its 2023 updated "The Czech Republic's National Energy and Climate Plan" envisages that biomethane can replace 10-15% of natural gas consumption used for heating and road transport by 2030. In the first case, increased amounts of biomethane must be fed into the existing gas network. In the latter case, the use of biomethane is envisaged both in the form of bioCNG and bioLNG[150.] The aforementioned document predicts that total biomethane production in the country will reach about 0.8 billion m^3 gas in 2030[151]. The implementation of these plans has already received support from the European Union. In November 2023 the European Commission approved a EUR 2.4 billion programme for the Czech Republic to support the construction and operation of new or converted facilities for sustainable biomethane production. Financial support will be available for:

- producers of sustainable biomethane to be fed into the gas grid,
- sustainable biomethane producers to supply petrol stations for transport or distribution stations for heating,
- investors converting biogas facilities to biomethane.

The programme will run until 31 December 2025 and is expected to support primarily small and medium-sized enterprises or community-based projects with an installed capacity of up to 6 MW. It is assumed that facilities with a total production of approximately 337 million m^3 of biomethane will benefit from the programme. In order to qualify for support under this programme, it is necessary to meet the requirements set out in the EU Renewable Energy Directive. Under the scheme, support will take the form of a green bonus for biomethane producers for each MWh of biomethane produced over a 20-year period. The amount of the bonus will be set annually by the Czech Energy Regulatory Office and will be limited to the funding gap[152].

148 *Česká bioplynová asociace, Náklady na dodávky biometanu v Česku nesou jen výrobci, změnu může přinést plynárenský balíček,* https://www.czba.cz/aktuality/naklady-na-dodavky-biometanu-v-cesku-nesou-jen-vyrobci-zmenu-muze-prinest-plynarensky-balicek.html, 11.04.2024,

149 Ministerstvo životního prostředí, *V Rakvicích yla spuštěna první biometanová stanice v Jihomoravském kraji*, https://www.mzp.cz/cz/news_20240307_V-Rakvicich-byla-spustena-prvni-biometanova-stanice-v-Jihomoravskem-kraji, 7.03.2024.

150 Aktualizace Vnitrostátního plánu České republiky v oblasti energetiky a klimat, říjen 2023, Prague, p. 98.

151 Ibid.

152 Úřad pro ochranu hospodářské soutěže, *EVROPSKÁ KOMISE SCHVÁLILA ČESKÝ PROGRAM NA PODPORU VÝROBY BIOMETANU*, https://uohs.gov.cz/cs/informacni-centrum/tiskove-zpravy/verejna-podpora/3711-evropska-komise-schvalila-cesky-program-na-podporu-vyroby-biometanu.html, 1.11.2023.

Another source of funding for the energy transition in the Czech Republic is the State Modernisation Fund, which provides support programmes for, among others:

- infrastructure for international and domestic transport, distribution and storage of biomethane,
- biogas-to-biomethanation plants,
- waste biomethane installations (provided the biomethane produced in these installations meets the conditions for advanced biomethane),
- installation of control and measurement equipment to optimise and save on the distribution and transport of biomethane,
- bioLNG installations[153.]

On 1 January 2024, the issuing of guarantees of origin for biomethane produced began in the Czech Republic. The guarantee of origin registration system is operated by OTE a.s., a company that operates exchange-based trading platforms for electricity and gas. OTE also holds the status of Nominated Electricity Market Operator (NEMO). Pursuant to Act No. 165/2012 Dz. on the promotion of renewable sources, the Market Operator issues guarantees of origin for biomethane at the request of its generator. The market operator maintains the Guarantees of Origin Register. This is an information system in which the guarantee of origin is recorded in the accounts of its holder throughout its life cycle (i.e. from its issuance to its application)[154]. A Guarantee of Origin for biomethane is issued for the quantity of biomethane that was produced by a biomethane producer in the Czech Republic and supplied to the transmission or distribution system of the Czech Republic within a period of one calendar month, thereby proving to end users the origin of the fuel they consume.

3.6. Observed trends

Countries with developed biomethane production are moving away from investment subsidies and feed-in tariffs towards tendering schemes, with the aim of encouraging the industry to lower costs and reduce dependence on government support mechanisms. In parallel, the introduction of biomethane quotas applied to energy suppliers, particularly in France, is an effective measure to increase the inclusion of biomethane in the gas-fuel mix. Some countries are also increasing quotas for renewable fuels, aligning with the mandates set out in the RED II Directive. In addition, some countries are encouraging the use of biomethane as a fuel by offering exemptions from consumption tax and carbon tax.

A notable trend among biomethane producers is the diversification of business models through the use of captured carbon dioxide in production processes. CO_2 is being used in a variety of industries, including the agri-food and medical sectors. In addition, some manufacturers are switching to bio-LNG production, decarbonising the transport sector. In addition, the use of biomethane under the ETS significantly encourages the development of this sector. The economic incentives provided by the ETS create a favourable environment for the formation of contracts between biomethane producers and industrial consumers.

153 *Státní fond životního prostředí ČR, podpory programmes*, https://www.sfzp.cz/dotace-a-pujcky/modernizacni-fond/programy/.

154 OTE, Záruky *původu a povolenky*, https://www.ote-cr.cz/cs/zaruky-puvodu-a-povolenky/zaruky-puvodu/zakladni-informace.

"Advanced" biomethane

Before 2016, the structure of biomethane installations was dominated by facilities for which the primary feedstock was energy crops, which farmers were encouraged to grow. The popularity of these feedstocks was also influenced by the soaring price of biomass[155]. This was most influenced by the large-scale production model prevalent in Germany and the UK. Changes in this area can be linked, in turn, to the RED II Directive, according to which biomass for sustainable biogas production should not create competition for agricultural land, considered to be for food and feed production.

Today, increasingly stringent regulations and growing public awareness of the criteria for sustainable biomass and biomethane (so-called advanced biomethane) are resulting in less availability and dimension of public financial support for unsustainable biomethane installations. The share of new installations using energy crops as a primary feedstock is falling dramatically. There is now an increasing share of sustainable feedstocks as substrate for biogas units, which mainly include agricultural and crop residues, manure and catch crops[156]. The accumulation of agricultural residues in biomethanation plants is also one method to reduce methane emissions into the atmosphere, of which agriculture is still a significant source.

Climate norms and measures leading to conscious decarbonisation have also influenced the nature of biomethane production. Reducing greenhouse gas emissions for biomethane means both concern for methane leakage and the renewability of the gas obtained. To ensure quality in the biomethane market, a certification system has been introduced.

Although the economic calculus of biomethane production does not account for its market advantage, other key issues related to its development are still often overlooked. Among the greatest advantages must be its versatility of use, its ability to store and control the energy system with stored resources. This is valuable especially in energy systems relying on renewable sources and looking for smart solutions to supplement the energy mix. Many economic sectors can be decarbonised using biomethane. The examples of the countries analysed show that biomethane needs to be thought of decisively in the long term and responded to market developments with the support and incentive tools already known. Biomethane should also be considered multi-sectorally, not only in the context of energy and climate protection, but also in the development of agriculture, transport, improving the efficiency of waste management and the appropriate management of local resources.

These requirements mean that the effective and profitable development of the biomethane industry requires efficient coordination between different sectoral policies covering, among others, energy, agriculture, industry and environmental protection. Actions to be taken, on the other hand, should include, inter alia, conducting a thorough analysis and identification of the needs of the domestic market in terms of missing regulatory solutions and financing tools for biomethane investments. Building public awareness and countering the resistance faced by the biogas industry also remains an important issue.

155 A. Górna, et al. *Predicting Post-Production Biomass Prices. Energies* 2023, Poznań, p. 16

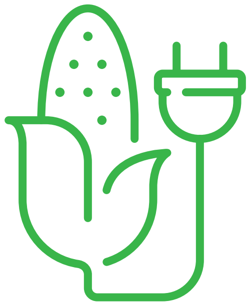
156 SIA Partners, 2023, op. cit.

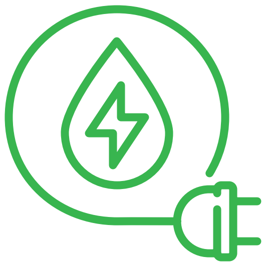
The main reason for the still modest production of biomethane in the EU is considered to be the lack of specific policies to encourage its development[157]. The economic barriers are the relatively high costs and the still low competitiveness with natural gas. Non-economic factors include low awareness and lack of information on biomethane and the 'capture' of greenhouse gases, as well as technological and engineering shortcomings. The lack of support systems is evident in the spatial distribution of investment locations associated with biomethane.

Conclusions

- The production and dissemination of biomethane have not yet been priorities in the development of renewable energy sources in the European Union and in the member states described.
- The production of biomethane was preceded by the creation of generation infrastructure for biogas, which is used locally to generate electricity and heat.
- Under existing market conditions, the development of biomethane production and its contribution to gas decarbonisation is not possible without public support schemes. For national economies, the development of biomethane production is the result of a conscious, long-term policy, the benefits of which go deep beyond the immediate economic aspects, building on the management of waste from multiple industries, decarbonisation and the exploitation of local potential.
- The main concern of the financial tools used in biomethane production at the moment is to avoid subsidy costs getting out of control and to take care of competition in the market.
- The development of biomethane production in Poland requires the creation of comprehensive legal and financial solutions to encourage and enable investments in biomethane installations.
- Attention to public education and sustainable production (both in terms of substrate categories and avoiding leaks from production facilities) from the very beginning of market development will help accelerate the achievement of climate targets and make Polish biomethane more competitive.
- Stimulation of biomethane production should go hand in hand with the country's agricultural and energy policies, as well as with cooperation with gas infrastructure operators.

157 IEA 2020 Report, *Outlook for biogas and biomethane, Prospects for organic growth*, https://www.iea.org/reports/outlook-for-biogas-and-biomethane-prospects-for-organic-growth/sustainable-supply-potential-and-costs, 18.03.2020.





4 Production potential and demand for biomethane in Poland

Chapter 4.

Production potential and demand for biomethane in Poland

In Q1 2024, the volume of biomethane production in Poland was 0 m^3. This puts the country in an extremely unfavourable light, as according to data published in April 2023 by the European Biogas Association (EBA), Poland was in a small group of EU member states without operating biomethanation plants, together with Romania, Bulgaria, Slovenia, Croatia, Greece, Lithuania, Cyprus and Malta[158]. Lithuania, however, has already emerged from this 'group of shame', as it launched its first biomethanol plant in September 2023. Biomethanation plants are developing in all Central (except Poland) and Western European countries. Paradoxically, the biomethane market does not yet exist in Poland - a country with a production potential among the largest in Europe. At the same time, it is worth emphasising that the demand for natural gas in Poland has increased significantly in the last decade (to approximately 17 billion m^3 in 2023), which, as a non-renewable resource, is treated in the EU as a transitional fuel and must be replaced by decarbonised gases, primarily biomethane. In view of, on the one hand, the strong demand for biomethane for the rapid decarbonisation of the Polish economy and, on the other hand, the huge production potential for $bioCH_4$, especially in the agri-food sector, the Polish biogas market (including both biogas plants with CHP units and biomethanation plants) is the largest investment market in the EU with a value of approximately EUR 40-45 billion in the 2035 perspective. It is therefore worth taking a closer look at both the production potential of this sector and the demand for biomethane from other sectors of the economy.

4.1. Substrate categories

In Poland, there is a division into three types of biogas plants: agricultural, municipal (waste including the sewage treatment sector) and landfill ones using landfill gas. In the case of biomethanation plants, a similar division will be applied with regard to the type of investment (a so-called agricultural biomethanation plant will have greater facilitations in the administrative procedure for obtaining the necessary permits than a municipal one), and this division is determined primarily by the types of substrates

158 EBA, *Biomethane Map 2022-2023*, https://www.europeanbiogas.eu/biomethane-map-2022-2023/, 04.2023.

used. At the same time, it should be emphasised that the biomethane produced should be certified according to criteria other than "agricultural" or "waste"; in this case, the type of substrate in particular is taken into account (agricultural biomass from the main crop has a lower ecological value, while waste material is preferred, especially that which generates strong greenhouse gas emissions when stored as manure).

For this reason, the substrate categories have been divided according to the type of biogas plant (and in the near future biomethanation plant) in which they are used. It is likely that the first biomethanation plant in Poland (under construction at the Brody experimental facility belonging to the University of Life Sciences in Poznań), which is scheduled to be commissioned in 2025, will obtain the necessary permits as an agricultural biogas plant with a power equivalent of less than 500 kW (i.e. a production of less than 1.055 million m^3 $bioCH_4$ /year) - according to the same legislative path as if it were a classic biogas plant with a cogeneration unit.

4.1.1. Agricultural biogas

Agricultural biogas (but also biomethane) has by far the greatest potential compared to the municipal or landfill sector. In Q1 2016, specialists from the Ecotechnology Laboratory at the University of Life Sciences in Poznań (UPP) carried out an analysis of Poland's biogas and biomethane potential, taking into account the agricultural and agri-food processing sectors. For this, the theoretically available volumes of agricultural by-product biomass and bio-waste were taken, reducing them (after discussions with agri-food experts) to realistically available substrate volumes. These volumes were then multiplied by the biogas yields of these substrates obtained in studies carried out in the Ecotechnology Laboratory. The following materials recognised as potential substrates for biogas plants were used in this analysis:

- A total of 90 million tonnes of manure, slurry and poultry manure (an approximate figure, the amount of manure and slurry fluctuates with changes in animal populations) out of a generally available mass produced of over 125 million tonnes;
- 8 million tonnes of cereal and rape straw out of a total of more than 35 million tonnes - as part of this straw must also be used for livestock production (bedding), for pellets/briquettes and as a substrate for mushroom production, while some farmers plough the straw for fertilising purposes;
- 4 million tonnes of maize straw out of the nearly 6 million tonnes available in the country;
- waste plant biomass (e.g. beet leaves, non-feed hay, including from protected areas, nature reserves, etc.);
- waste from food processing, sugar factories, abattoirs, slaughterhouses, dairies, distilleries;
- refood, i.e. out-of-date and spoiled food (before it is sold to individual customers - after that it is included in Group 20, or municipal, waste).

A summary of available biomass and biogas/biomethane potential on a national scale for 2015 is presented in Table 6.

TAB. 6. Agricultural biogas and biomethane production potential in Poland in 2015 (own study)

Type of substrate	Mass	Biogas efficiency	Concentration of CH_4	Amount of biogas	Amount of methane
	million Mg	m^3 /Mg fresh weight	%	million m^3	million m^3
manure	70	80	62	5600.0	3472.0
slurry	20	18	64	360.0	230.4
maize straw	4	420	52	1680.0	873.6
beetroot leaves	4,5	70	54	315.0	170.1
beet pulp	4,5	42	52	189.0	98.3
cereal and other straw	8	520	54	4160.0	2246.4
non-feed hay	1.6	420	54	672.0	362.9
animal waste tissue	0.4	300	66	120.0	79.2
processing plant sludge	0.14	80	65	11.2	7.3
pomace and processing waste	0.95	150	56	142.5	79.8
waste from dairying	0.15	40	56	6.0	3.4
decoctions and musts	1.32	45	60	59.4	35.6
cellulose waste	1.08	140	56	151.2	84.7
refood	0.36	160	64	57.6	36.9
				13523.9	**7780.5**

On the basis of the calculated values, it can be concluded that the total potential of the agricultural biogas sector reached 7.78 billion m^3 bioCH_4 / year (13.5 billion m^3 biogas), and in terms of electrical power it is nearly 3.7 GW in continuous operation (24 h/day) and nearly 11 GW in peak operation (8 h/day). It should be mentioned that in the eight years since this compilation was made, the production volume of some substrates has changed, so a new study would be advisable. Currently, work on determining the biomethane potential is being carried out by specialists from NCRD, as part of its 'Innovative Biogas Plant' programme. In a study published by NCRD in May 2024, the raw material base necessary for the production of biogas and subsequently biomethane is organic matter: biomass, estimated at around 112 million tonnes per year[159]. It consists primarily of agricultural waste and residues such as animal manure, surplus cereal straw, maize straw, bio-waste from agri-food processing, municipal bio-waste selectively collected. Based on the analysis of biomass availability and technical accessibility to the gas grid, 3 types of biomethane production potentials in Poland were identified: technical, implementation and investment ones. The characteristics of the identified production potentials and the estimated biomethane volumes for them are presented in Table 7.

159 NCRD, *Real potential for biomethane production in Poland*. Study for the Polish Energy System Simulator. Version of 20.05.2024, p. 2.

TAB. 7. Potential supply of biomethane in Poland[160]

Types of potentials	Description	Volume in billion m³	Volume in TWh
Technical capacity	This is the amount of biomethane that can be produced nationwide from physically available resources processed through methane digestion and biogas conditioning to biomethane.	8.0	84.4
Implementation capacity	It takes into account the possibility of mobilising and supplying available resources for biomethane installations nationally. In practice, not all resources will be able to be supplied to biomethane installations.	4.7	49.5
Investment potential	It determines the amount of biomethane that can be produced in the country bearing in mind the concentration of feedstock in the amount necessary for a certain size of installation. It only takes into account locations where installations with a capacity of more than 2 million³/year of net biomethane can be built.	**3.2**	**33.7**

Source: National Centre for Research and Development (NCRD), *Realistic potential for biomethane production in Poland.* 20.05.2024, p. 4.

Another attempt to calculate the national biomethane production potential was made by the Polish Biomethane Organisation (PBO). The summary of the report, published in July 2024 entitled "Biomethane Production Potential in Poland", identifies waste from the agri-food sector as the main source of biomethane (e.g. straw, manure, slurry, bird manure). By using these resources, the technical capacity is expected to allow as much as 8.5 bcm to be captured[161]. This is a far more optimistic estimate than

160 Ibid, pp. 6-8.

161 Polish Biomethane Organisation, *Potential of biomethane production in Poland. Executive summary*, Warsaw 2024, p. 9

the figures given by the NCRD. Following a cautious approach to forecasting, the investment potential for biomethane production of 3.2 bcm (approx. 33.7 TWh) per year as quoted by NCRD will remain the reference point for further analysis in the Report. This volume is also very close to that given by the European Biogas Association, which forecasts production in Poland at 3.3 bcm per year.

The potential calculations presented earlier do not include all types of agricultural biomass that can be used for biogas production. In particular, there is huge potential in the cultivation of energy crops, especially on wasteland and on set-aside or degraded soils. The RED II Directive generally denies the use of maize silage (the most popular substrate for biogas plants in the EU in recent years) for biomethane production. We estimate that the use of up to 5% of land available in Poland for growing energy crops (maize, sorghum, etc.) could result in the production of an additional 4.5 billion m^3 of biomethane. Biomethane derived from such a substrate would be a significant source of additional profit for farmers and would significantly reduce Poland's natural gas import needs. However, the authors of this Report realise that the implementation of the above scenario would collide with the principles of sustainable development, inter alia, by competing with agricultural production for food needs of the population. Therefore, this issue will not be developed further.

4.1.2. Municipal biogas

The municipal sector currently generates less than 200 MW of power from biogas sources and, until recently, surpassed the agricultural sector in biogas production. Its production potential is difficult to calculate due to the lack of reliable data and the very different composition/energy value of municipal bio-waste. UPP's Ecotechnology Laboratory has unique data for studying the composition (morphology) and energy (biogas) value of bio-waste from the largest cities in Poland. On this basis, it can be assumed that biodegradable kitchen waste (code 20 01 08) collected in an appropriate manner has an average efficiency of 60 m^3 bioCH$_4$/Mg fresh mass, while green waste (20 02 01) has an average efficiency of 45 m^3 bioCH$_4$/Mg fresh mass. It is estimated that the amount of biodegradable organic fraction in the municipal waste stream in Poland is about 5 million tonnes. Research carried out at the Ecotechnology Laboratory shows that of this, about 75% is kitchen fraction and about 25% is green waste. On this basis, it was possible to calculate the potential for biogas/biomethane production in the municipal sector, which is presented in Table 8. It should also be added that the biomass stream going to the Municipal Selective Waste Collection Points (MSWPCs) was also taken into account, where out of approx. 1.5 million tonnes per year, approx. 0.4 million tonnes can be used as substrate in biogas plants.

TAB. 8. Biogas and biomethane production potential in Poland in 2015. (own study)

Type of substrate	Mass	Biogas efficiency	Concentration of CH_4	Amount of biogas	Amount of methane
	Mg	m^3/Mg fresh weight	%	million m^3	million m^3
sewage sludge	0.58*	192.2**	62	111.5	69.1
kitchen waste	3.75	103.5	58	388.1	225.1
grass leaves	1.25	88	52	110.0	57.2
green waste from MSWPCs	0.4	80	50	32.0	16.0
				641.6	**367.4**

* mass given in Mg dry matter (data according to CSO); ** dry matter yield

Based on the above analysis, it can be concluded that the municipal sector has many times less potential for biomethane production than the agri-food sector. However, it should be emphasised that bio-waste from the agri-food sector can also be used in municipal installations and this is already the case for some biogas plants operating at sewage treatment plants.

4.1.3. Landfill biogas

Landfill facilities will disappear in the coming years due to the fact that it is compulsory to separate waste and collect the so-called kitchen waste as a separate stream. Therefore, the mixed municipal waste stream currently sent to landfill is very poor in organic matter compared to the situation a few or a dozen years ago. As the anaerobic decomposition time for the organic fraction present in landfills is estimated to be around 15 years, the landfill gas facilities currently in operation will therefore become increasingly irrelevant due to the significant reduction in the organic load entering landfill sites in recent years.

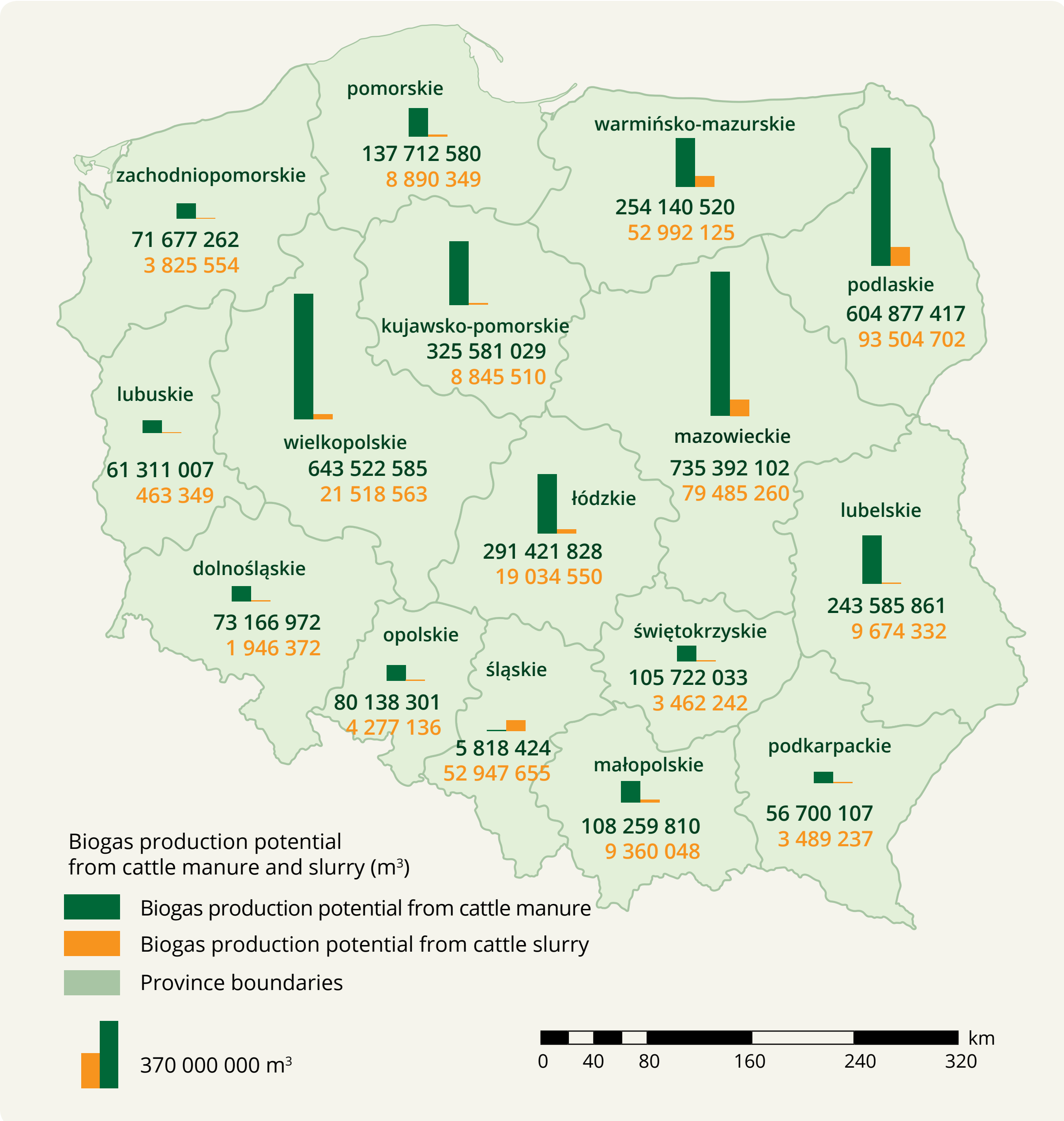
4.2. Polish substrate volumes by geographic areas

As stated in the previous chapter, the greatest substrate potential concerns the agricultural biogas/biomethane sector, and in particular livestock manure, whose potential, estimated at around 70 million tonnes per year in real terms (out of a total of around 125 million tonnes produced), is by far the most dominant among the materials analysed. Manure is a particularly favourable substrate from the point of view of the RED II Directive, as the biomethane produced from it has negative emissions (-162 g CO_{2eq} /MWh) due to the reduction of greenhouse gas emissions (methane and nitrous oxide) during traditional storage of this manure.

In an article from 2021[162], a team of authors from several scientific institutions presented a graphical distribution of the manure and slurry produced in cattle and pig production, calculating the biogas potential for individual provinces. As can be seen in Figures 13 and 14, the areas with the highest production potential are the provinces of central Poland (Wielkopolskie, Mazowieckie, Łódzkie and Kujawsko-Pomorskie) and the provinces of northern and eastern Poland. The smallest production potential in the area of livestock manure extends in the belt of provinces along the borders with Germany, the Czech Republic and Slovakia.

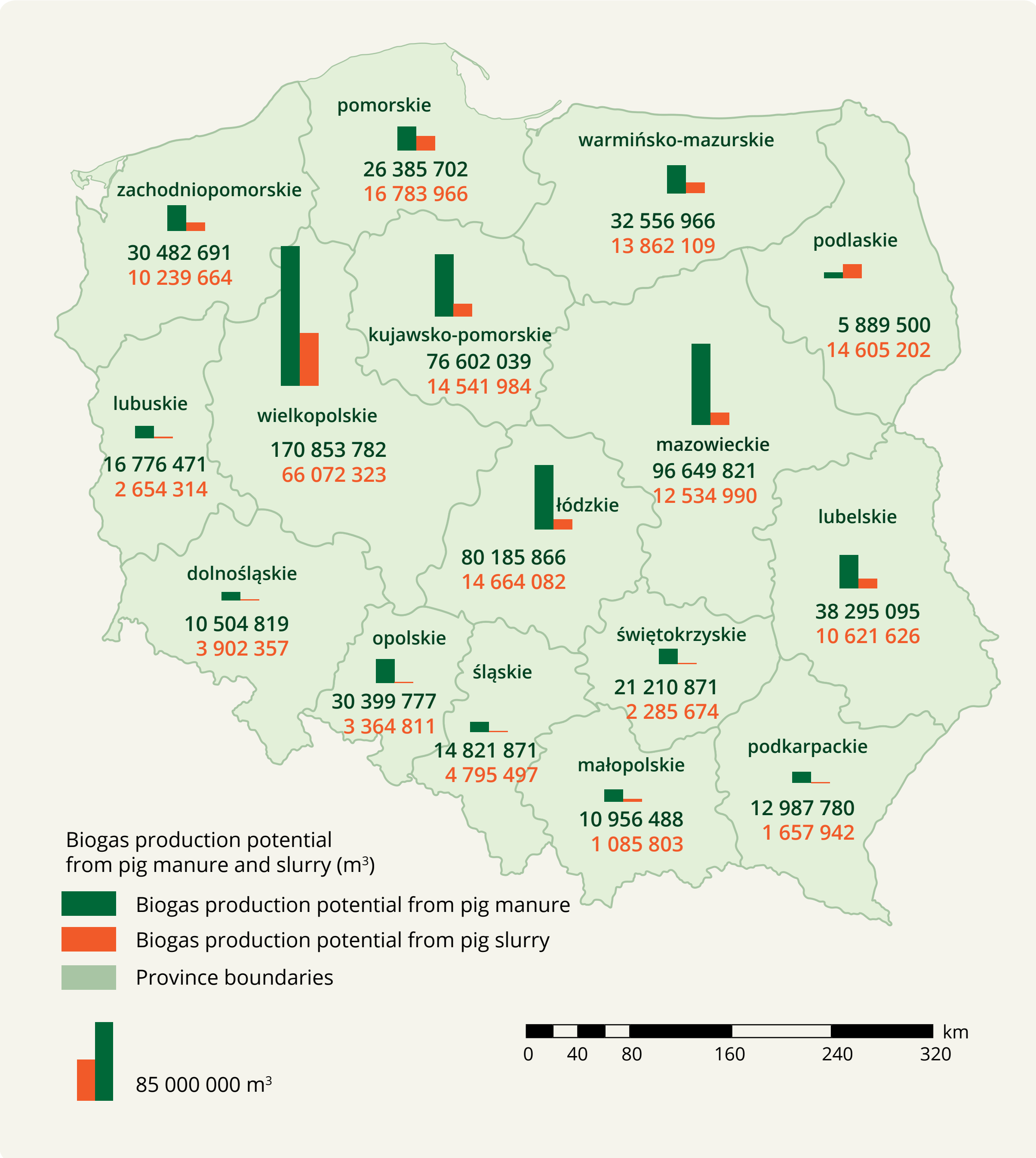
162 A. Wawrzyniak, A. Lewicki, P. Pochwatka, P. Sołowiej, W. Czekała, *Database system for estimating the biogas potential of cattle and swine faeces in Poland, Journal of Ecological Engineering*, 22 (3), 111-120, 2021.

FIG. 13. Biogas production potential from cattle manure and slurry in Poland



Source: Wawrzyniak et al., 2021

FIG. 14. Biogas production potential from pig manure and slurry in Poland



Source: Wawrzyniak et al., 2021

It should be noted, however, that straw, the second most available material in terms of biomethane potential in Poland, is much more available in provinces with lower livestock production intensity, as it is much less used there for animal bedding. It is worth adding that the lack of available livestock manure in a given area does not necessarily mean that the construction of a biomethanation plant should be abandoned, as the fermentation process can take place without its involvement. In Germany, for example, until a few years ago, more than 6,000 agricultural biogas plants were powered only by plant feedstock, primarily maize silage. Of course, the monosubstrate feedstock in biogas plants causes some biotechnological problems in the fermentation process, but experienced teams of experts help effectively to solve these problems. Objectively, however, it has to be admitted that most investors do not consider feeding biogas plants with substrates containing lignocellulosic materials (straw, manure) because of problems related to effective fragmentation, clogging of pipes or a strong tendency to form dross. Hence the frequent complaints about the lack of substrates. Indeed, if one removes manure and all types of straw from Table 6, the mass of available substrates will decrease several times (from 117 million Mg to only 19 million). However, modern biogas plants equipped with suitable mechanical and cavitation destructors and an effective mixing system to break up the dross can successfully use substrates with a predominance of lignocellulosic materials. In doing so, however, it is important to be aware of the risk of the phenomenon known as 'nitrogen starvation' and appropriate countermeasures.

4.3. Estimating the size and structure of potential demand

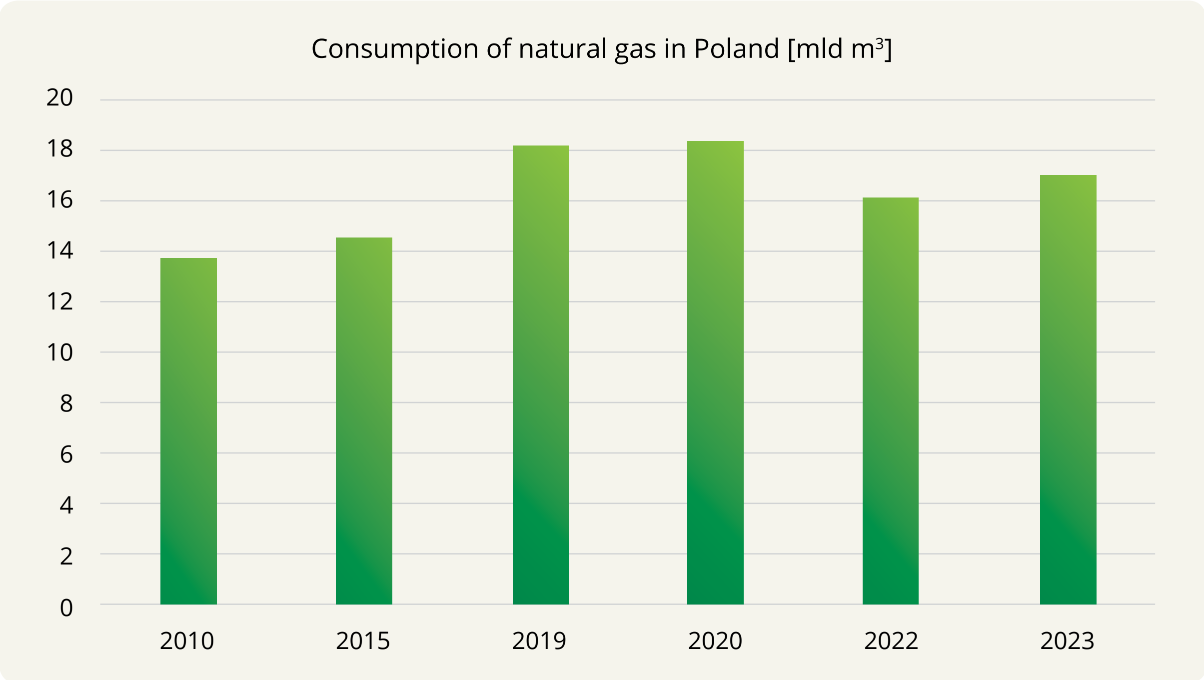
In the economic conditions of Poland in the summer of 2024, it is difficult to estimate the potential demand for biomethane due to very low natural gas prices, which have fallen to the level before the EU energy crisis triggered by Russian gas blackmail and then Russian aggression against Ukraine. Declaratively, demand for biomethane appears to be very high in the coming years. According to NCRD estimates, real demand for biomethane in Poland could reach around 4 billion m^3 per year[163]. The demand for this renewable gas will be generated mainly by the electric power and district heating industry - up to 2 billion m^3 per year, and by industry - about 2 billion m^3 per year.

It should be concluded that it is in Poland's economic and political interest to increase the production of biomethane and replace some of the natural gas consumed with it. As can be seen in Figure 15, natural gas consumption in Poland has been increasing over the last 15 years despite the European Commission's intentions to reduce its use as a transitional fuel in the Green Deal assumptions. After a decline in gas consumption in the crisis year of 2022, its level increased again in 2023, reaching 17 billion m^3[164].

163 NCRD, Real potential for biomethane production in Poland Developed for the Polish Energy System Simulator. Version of 20.05.2024.

164 Polskie Górnictwo Naftowe i Gazownictwo, *ORLEN fully secures gas supply for Polish consumers*, https://pgnig.pl/aktualnosci/-/news-list/id/orlen-w-pelni-zabezpiecza-dostawy-gazu-dla-polskich-odbiorcow/newsGroupId/10184?changeYear=2024&currentPage=1, 1.03.2024.

FIG. 15. Consumption of natural gas in Poland



Source: CSO data, for 2023. - estimates

As biomethane is a much more expensive (and scarcer) energy carrier than natural gas, its use is limited for the time being. One potential opportunity for the economic use of biomethane is the use of this gas as a clean fuel for public transport. The Electromobility Act[165] stipulates that, as of 1 January 2025, public transport must be provided using zero-emission buses or biomethane-powered buses in the fleet of vehicles in use in the area of that local authority of at least 20% (Article 68, paragraph 4). It is worth pointing out that many Polish local authorities have fleets of buses powered by CNG installation which, in the transitional period with the development of electrification and domestic RES resources, could use biomethane. Moreover, a bus with a CNG installation is free of most of the current limitations of electric buses: it has a much longer range regardless of the season, refuelling times are shorter, or it is easier to operate in winter or difficult terrain conditions. In addition, municipalities can invest in municipal biomethanation plants and produce bioCH_4 to power their own fleet, based on their own bio-waste. The latter aspect is also of social importance: as it is easier to convince residents to better segregate their waste if they are aware that selectively collected bio-waste will be used to produce fuel for local public transport. As highlighted above, biomethane fuel for transport is one possible option for the economic use of this gas. However, it is important to realise that its limited future volume will not allow the full decarbonisation of the public transport sector.

4.4. Investments in biomethane production

The Ecotechnology Laboratory team, as a representative of the University of Life Sciences in Poznań (UPP), is responsible for the implementation of the NCRD programme 'Innovative Biogas Plant', under which the first Polish biomethanation plant is being built at UPP's experimental farm in Brody. How-

165 Act of 11 Jan. 2018 on electromobility and alternative fuels, Journal of Laws 2018, item 317.

ever, due to the time constraints of the competition, this biomethanation plant will have a production capacity equivalent to a biogas plant with an electrical capacity of 499 kW. This avoids the lengthy procedure of obtaining a so-called environmental decision, as agricultural biogas plants below 500 kW el. capacity are exempt from having to obtain a decision on the environmental conditions of the project. However, such a solution is an exception, as due to the need to optimise investment costs and reduce operating costs per cubic metre of biomethane produced; the most common sizes of biomethanation plants in Europe are much larger than the one being built at Brody, usually with an electrical power equivalent of 2-4 MW.

When realising a biomethanation plant of this capacity, one of the most important steps is to select the location and to perform a so-called substrate inventory of the site. A plot of land for a typical biomethanation plant with a capacity of 4 million m^3 bioCH_4 per year should have an area of about 2-2.5 ha for technologies based on classic NaWaRo technology, in the case of modern solutions it is less than 1.5 ha, or even less than 1 ha in the case of only short-term substrate storage. For example, the plot of land at the UPP-owned Przybroda Experimental Farm, which houses a biogas plant operating under such a feed-in regime with a production potential of 2.1 million m^3 biomethane per year, is only 0.35 ha (Fig. 16.). Obviously, if long-term substrates are to be stored in the immediate vicinity of the biomethanation plant to feed it, the plot should be accordingly larger.

FIG. 16. View of the biogas plant (biomethane production potential of 2.1 million m^3/year) at the UPP farm in Przybroda; A - biotechnology accelerator (250 m^3 volume), F1, F2 - fermenters (2 times 870 m^3), ZnP - digestate tank (3600 m^3)

Source: Photo by Jacek Dach

When planning a biomethanation plant, it is necessary to analyse a number of location factors, including:

- Size of the registered plot, its shape, denivelations, development status;
- Zoning of the land in the local spatial development plan (LSDP) or, in the absence of an LSDP, in the spatial development study (future general plan);
- Land use class of the plot according to the land and building register (LBR) - in practice, only land of classes IV-VI not made of organic soils is taken into account, "better" agricultural land requires a decision to exclude it from agricultural production (if it is located in an area covered by an LSDP);
- Possibility, technical condition and distance of connection to the gas grid to enable (or not) the transfer of biomethane to the grid (in the case of a mixed biomethane and biogas plant project, also the possibility and distance to a main power supply point to obtain a power connection and to connect to the district heating grid or build own grid to transfer heat to neighbouring houses);
- Adequate distance of the investment, as well as transport of (odorous) substrates away from human settlements to avoid possible public protests (although this makes heat transfer more difficult);
- Road network prepared for substrate delivery.

A second important element in the planning of a biomethanation plant is the completion of a so-called substrate inventory. Without this step, there is a high risk that the biomethanation plant will not operate efficiently due to a lack or shortage of substrates to feed the digestion process, or that substrates will be delivered from further away generating unforeseen costs, which may strongly reduce the profitability of the plant, even leading to its bankruptcy. In practice, the availability of different types of substrates, especially agricultural and agri-food processing substrates, should be checked and the main substrates should be tested in a specialised laboratory for their methane efficiency (Figure 17.). It is worth noting that the range of substrates that can be used in a biomethanation plant is huge, for example, the UPP Ecotechnology Laboratory, as Poland's largest biogas laboratory, has data on the methane yield of nearly 3,500 different substrates. At the substrate inventory stage, it is worthwhile to consult specialists in fermentation processes, as there are many substrates with a potentially very high biomethane potential which are not taken into account by investors, while on the other hand, many business plans contain significantly overestimated capacities which, after verification, may reduce the production potential to a real level of even only 40-50% of the planned one.

FIG. 17. Biogas/methane efficiency test reactors according to DIN 38 414/S8

Source: www.ekolab.up.poznan.pl

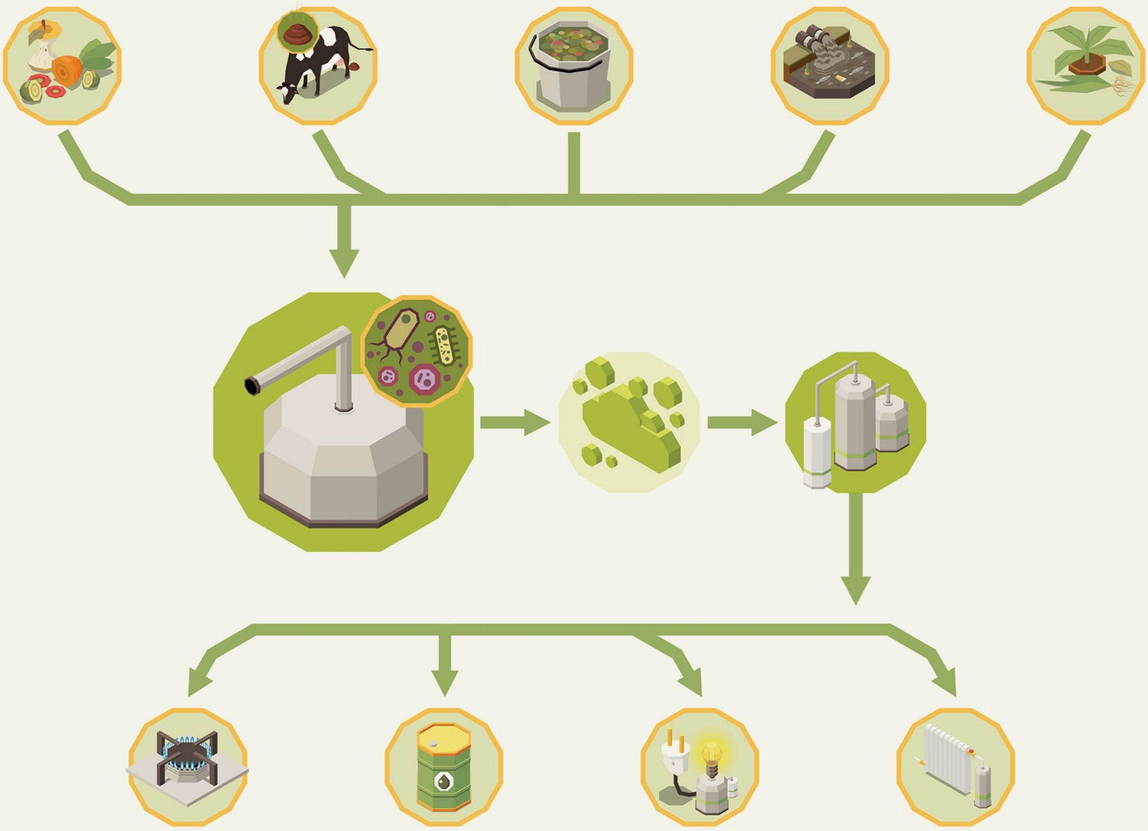
Once the location has been selected and the type and quantity of substrate available (and thus the size of the planned biomethanation plant) have been determined, an application for an environmental decision should be submitted, accompanied by a previously completed environmental impact report. At the same time, an application can also be made for conditions for connection to the local gas network to the PSG or other Distribution System Operator (DSO). If the business plan assumes the sale of surplus electricity from own cogenerator to the grid, one should also apply for the conditions for connection to the electricity grid operator operating in the area. At this stage, it is already worthwhile to start negotiations with suppliers of biomethane scrubbers and a CHP unit to run the biomethanation plant - as the waiting time for scrubbers in Europe is significant, and the waiting time for CHP units has also lengthened since 2022.

The next step is to apply for a permit to treat the bio-waste in an R3 recovery process, which will enable the biomethanation plant to produce the greenest biomethane from the waste, and to apply for permits for the storage of bio-waste (if planned at the location). If the waste is to be stored, then an opinion on the non-combustibility of the stored bio-waste issued by the local representative of the National Fire Service is necessary. If, however, there is a risk of fire, then a fire safety report (by a fire engineer or a certified expert) must be carried out, which is then agreed with the local State Fire Marshal.

Since the vast majority of biomethanation plants will be operating with zoonotic substrates in the future, it is necessary to apply to the district veterinarian for the possibility of accepting ABP (animal by-products) waste at the plant, even if the biomethanation plant only plans to use slurry or manure.

In addition, if the use of slaughterhouse waste (which is a very energy-intensive substrate) is planned, then this possibility and the sanitation of this waste, according to EU standards, must also be requested in the application. Once constructed, the finished plant must undergo technical acceptance (building supervision) and approval by UDT (Technical Inspection Authority) for pressure equipment (if any). The start-up of the biomethane production itself must be preceded by arrangements with the gas grid operator as well as the power grid (if the biomethanation plant cogeneration unit is connected to the grid).

The final stage is the certification of the biomethane produced, which, prior to commissioning, is based primarily on declarations of the substrates to be used, which will, of course, be verified by an auditing company in the course of the plant's operation.



5 Infrastructure considerations for biomethane production in Poland

Chapter 5.

Infrastructure considerations for biomethane production in Poland

The origins of the Polish gas industry go back to the period after the Second World War, initially based on the production and use of town gas without the construction of a transmission system. These activities were only carried out locally through 'island' solutions. It was not until the turn of the 1940s and 1950s that the sector was revolutionised, as natural gas production began in the area of the Carpathian Foothills. In southern Poland, the gasification stage began, culminating in the late 1970s and early 1980s. During this period, larger quantities of high-methane natural gas from the Soviet Union also began to be supplied to the country. The gas distribution network currently in operation, managed by the largest distribution system operator, Polska Spółka Gazownictwa (PSG), was designed for several central sources of gas fuel including mines, imports and based on the transmission system. The energy transformation is also linked to the transformation of the gas sector. This in turn involves decentralising the system and adapting it to accept fuel from small local biomethane sources.

Currently, the model of the Polish gas market is based on five business pillars: gas exploration and production, storage, trading - sales, distribution of gaseous fuel through high, medium and low pressure networks and transmission of gaseous fuel through high pressure networks. These activities are regulated and require the granting of an operating licence and the approval of a tariff for the prices of the services provided by the President of the Energy Regulatory Office. At the end of 2022, there were 51 distribution system operators (DSOs) in Poland, there were more than 7 million connected end-users and the distribution network of medium-pressure pipelines was approximately 165.7 thousand km.

FIG. 18. The transmission network for Group E high-methane natural gas (red) and Lw nitrogenous natural gas (blue)

Legend

Branch operation boundaries

- Branch Office in Rembelszczyzna
- Branch Office in Tarnów
- Branch Office in Świerklany
- Branch Office in Wrocław
- Branch Office in Poznań
- Branch Office in Gdańsk

Province boundaries

- GIS_WOJEWODZTWA_PNG

E system gas pipelines

- 100
- 300
- 500
- 700
- 1000

L system gas pipelines

- 100
- 300
- 500

Source: Gaz-System

FIG. 19. Transmission system in Poland

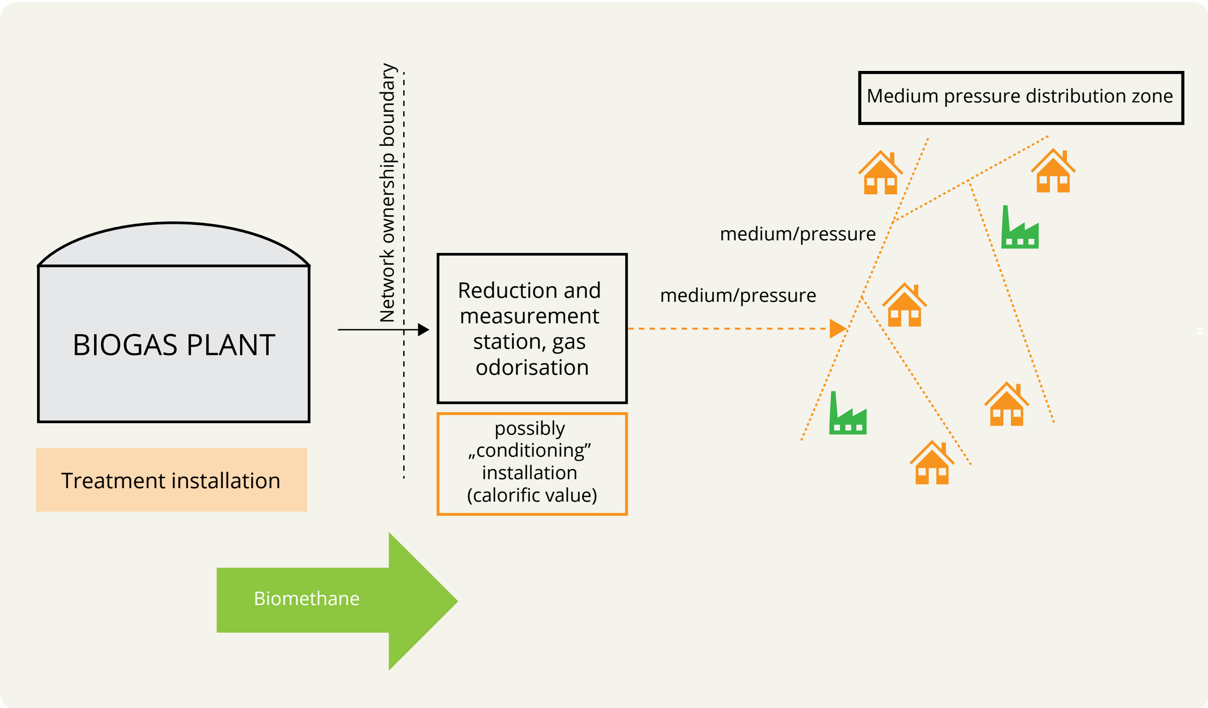
Source: J. Kawula, D. Staśko *Potencjalny portfel dystrybucji niskoemisyjnych paliw gazowych [Potential distribution portfolio of low carbon gaseous fuels]* MBA S&CI DIPLOMA THESIS, Scientific supervision: dr hab. inż. Piotr Janusz, dr hab. Aneta Nowakowska-Krystman, prof. ASzWoj, War Studies University, Warsaw 2022, p. 11.

5.1. Current status of distribution networks in Poland

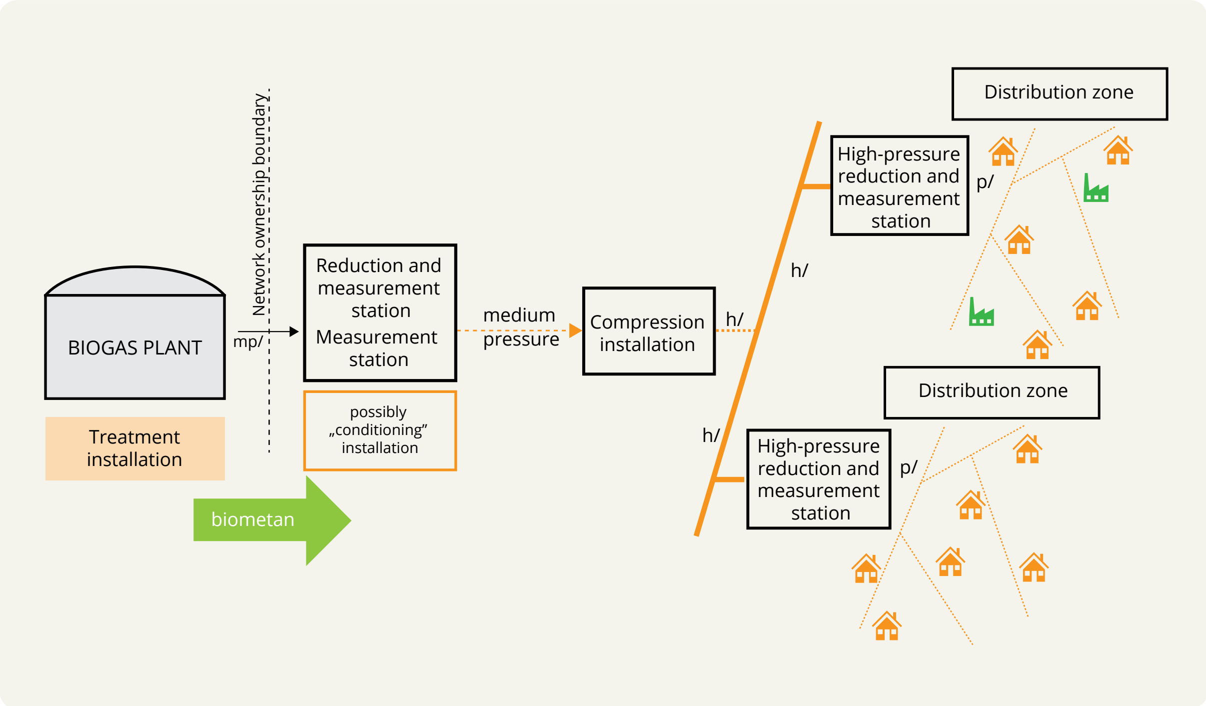
The ongoing energy transition aims to reduce the environmental impact of the energy sector and, above all, to increase the use of own renewable energy resources, selected individually for each location. There should be a shift from large, centralised sources to local, small-scale and almost self-sufficient energy enclaves. Such 'energy enclaves' should be based on a mix of all available renewable energy sources and fuel or technical solutions to stabilise the system. Such an approach allows for increased energy security and independence from fuels and energy imported into Poland. Local sources of biomethane will play an important, if not the main role in this process, but for this to happen, this fuel must be injected into local gas distribution systems.

Proposed options for connecting the biogas plant to the distribution network, with 100% absorption of the biomethane produced:

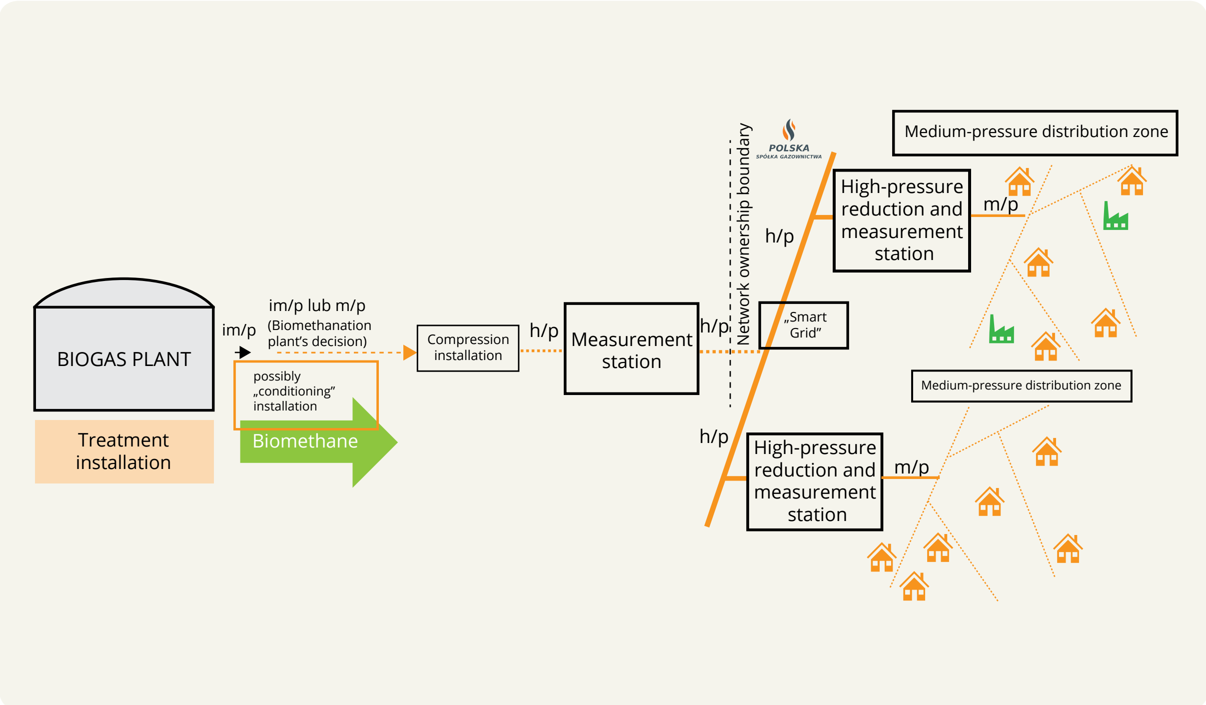
Option 1: Connection to the medium pressure network



Option 2: Connection of the biogas plant to the high-pressure network via a medium-pressure or increased medium pressure gas pipeline and compressor and connection to the high-pressure network



Option 3: Connection to the high-pressure network



5.2. Technical characteristics of the natural gas distribution network in Poland in the context of its availability for biomethane

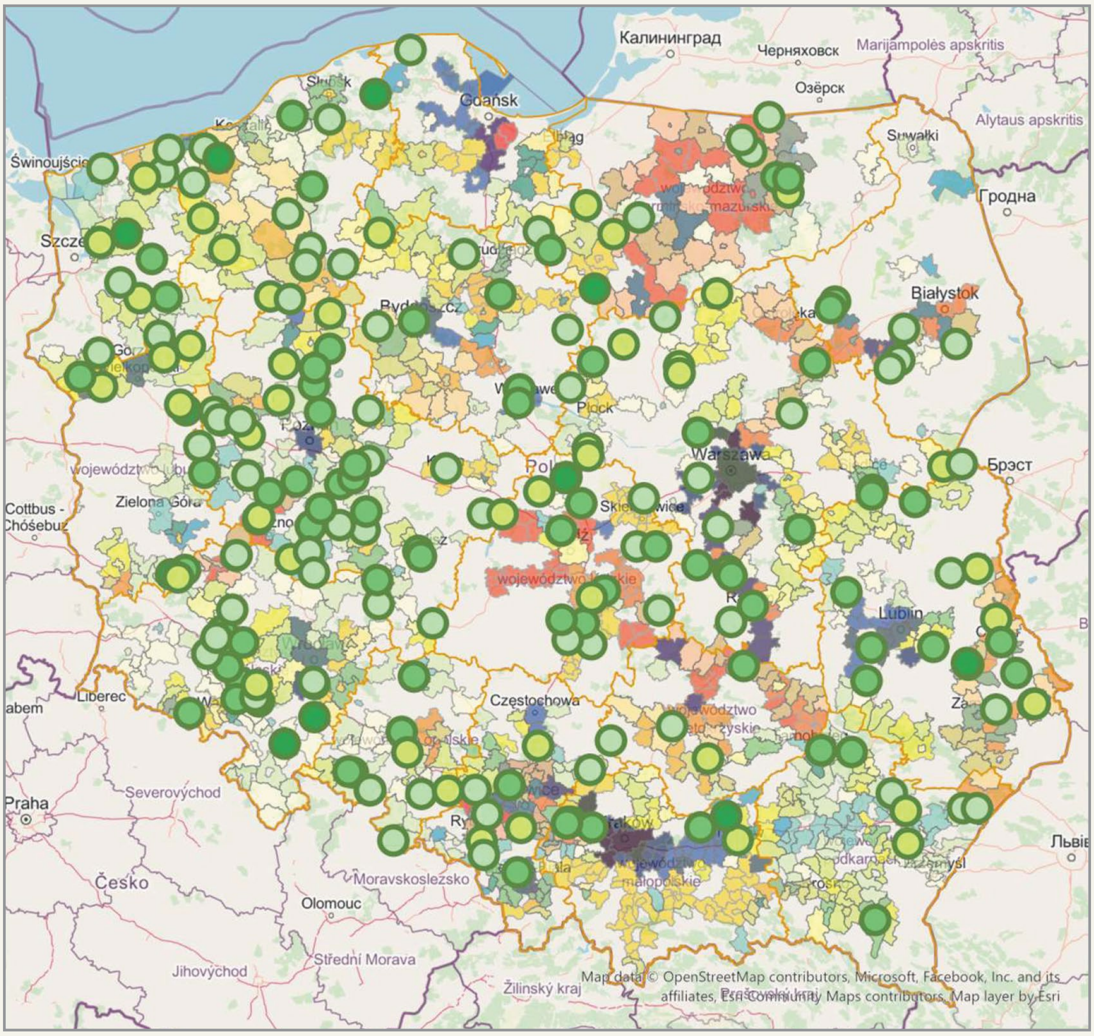
From a technical point of view, the distribution networks managed by PSG are suitable for transporting biomethane, the quality parameters of which comply with current legislation. However, the distribution system has limitations on the amount of biomethane that can be accepted, referred to as the absorption capacity of the zone, and resulting from the historical conditions of network development.

Zone absorbency - the amount of gaseous fuel that can be taken by the DSO in one hour within a Distribution Zone, corresponding to the minimum hourly volume of gaseous fuel that can be taken by all end customers supplied from that Distribution Zone. PSG, Instruction of the Transmission System Operation and Maintenance, p. 6.

The exact parameters can only be determined once the connection point has been identified. In order to increase the absorption capacity of the low- and medium-pressure networks, investments in so-called "system couplers" are necessary to connect several areas, thereby increasing the number of consumers. Only in the case of gas pipelines with an operating pressure of more than 5 bar, i.e. the high-pressure network, this problem does not occur. However, due to their "transmission" nature, these pipelines are few in number and, moreover, the connection to such a pipeline is associated with higher costs for the investor, including for the compression of the biomethane to an appropriate pressure. This is because at present, in accordance with the system and tariff regulation, all costs resulting from the connection of a biomethanation plant to the gas network are passed on to the biomethanation plant.

The figure below shows an analysis of the applications submitted for the connection of biomethanation plants, together with the total connection capacity. These figures are juxtaposed with the existing absorption capacity of the network at medium pressure - the municipalities are marked in blue shades according to the level of absorption. It can be clearly seen here that the highest absorption capacity is in the vicinity of Gdańsk, Poznań, Warsaw, Lublin and the Upper Silesian area, which is due, among other things, to the large number of gas fuel consumers. In the areas with the greatest biogas/biomethane potential, which is reflected in the number of applications submitted, i.e. the North and Mid-West areas, the absorptive capacity of the network at low and medium pressure is not satisfactory. The distribution is different in the areas where absorption was studied, but on high-pressure networks. Here, the greatest absorption potential is located in the areas of north-eastern and central Poland.

FIG. 20. Analysis of the existing absorption capacity of the gas network in terms of the potential of submitted applications for connection of biomethanation plants.



Legend

Biomethanation plant, applications submitted

Connection power [m³/h]

- 97 - 400
- 401 - 670
- 671 - 1 250
- 1 251 - 3 140
- 3 141 - 10 000
- Gas plant branch

Medium-pressure network capacity in municipalities

[m³/h]

- 0
- 1 - 100
- 101 - 500
- 501 - 1 000
- 1 001 - 5 000
- 5 001 - 11 000

High-pressure network capacity in municipalities

Minimum flow (****)

(area capacity)

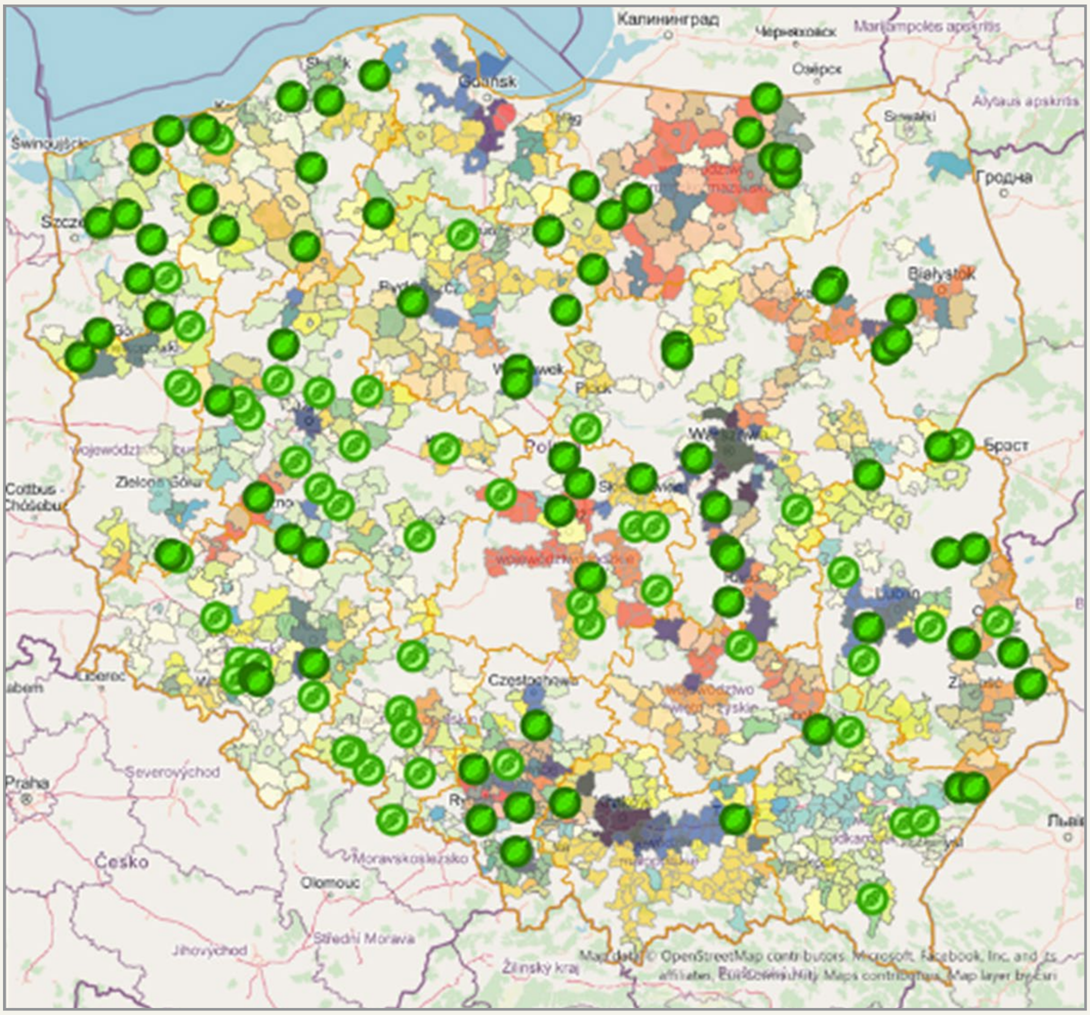
[m³/h]

- 0 - 612
- 613 - 1 689
- 1 690 - 3 220
- 3 221 - 4 922
- 4 923 - 9 334
- 9 335 - 16 287
- 16 288 - 27 435

Source: Own material of Polska Spółka Gazownictwa Sp. z o.o., author: Urszula Zając (collective work - Department of Energy Transformation).

Below is an analysis based on the conditions issued for the connection of the biomethanation plant, indicating whether the area has conditions for continuous (100%), uninterrupted offtake and areas where the conditions issued have variable offtake, i.e. the grid will not be able to accommodate the full production of the biogas plant in terms of months with less potential for customer uptake. This means that during summer periods the network will not have sufficient absorption capacity.

FIG. 21. Analysis of conditions issued for the connection of a biomethanation plant in terms of the existing absorption capacity of the gas network



Legend

- Biogas plants - fixed offtake
- Biogas plants - variable offtake
- Gas plant branch

Medium-pressure network capacity in municipalities [m³/h]

- 0
- 1 - 100
- 101 - 500
- 501 - 1 000
- 1 001 - 5 000
- 5 001 - 11 000

High-pressure network capacity in municipalities Minimum flow (****) (area capacity) [m³/h]

- 0 - 612
- 613 - 1 689
- 1 690 - 3 220
- 3 221 - 4 922
- 4 923 - 9 334
- 9 335 - 16 287
- 16 288 - 27 435

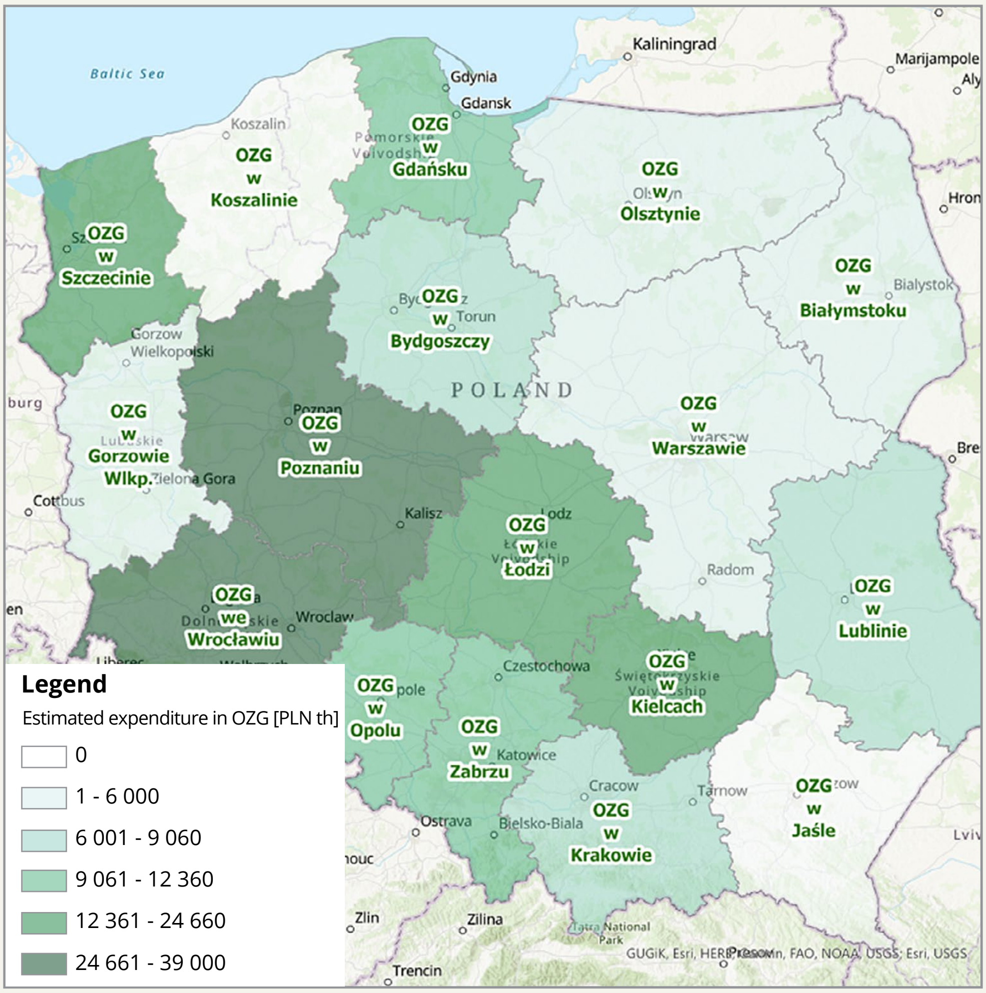
Source: Own material of Polska Spółka Gazownictwa Sp. z o.o., author; Urszula Zając (collective work - Department of Energy Transformation)

5.3. Distribution System Operator's activities to increase the absorption capacity of the low and medium pressure network

The Distribution System Operator's primary obligation is to supply gaseous fuel in a continuous, safe manner with respect for the environment and to ensure (maintain) appropriate quality parameters of the transported gaseous fuel. By the same token, the quality parameters of this fuel during transport through the distribution networks must not deteriorate. Therefore, PSG is planning a number of investments to meet the needs of the biogas sector. These include measures by means of "system couplers". The analysis covers 17 Gas Works Branches. A total of 68 system couplers have been identified to improve the absorption capacity for potential biomethanation plants, and are estimated to be between 0.4 km and 20 km long. Investment outlays were estimated at around PLN 250 million.

In the process of selecting areas for increased absorption, the issued refusals of profiled conditions for the connection of biomethanation plants in correlation with the location of the substrate were taken into account.

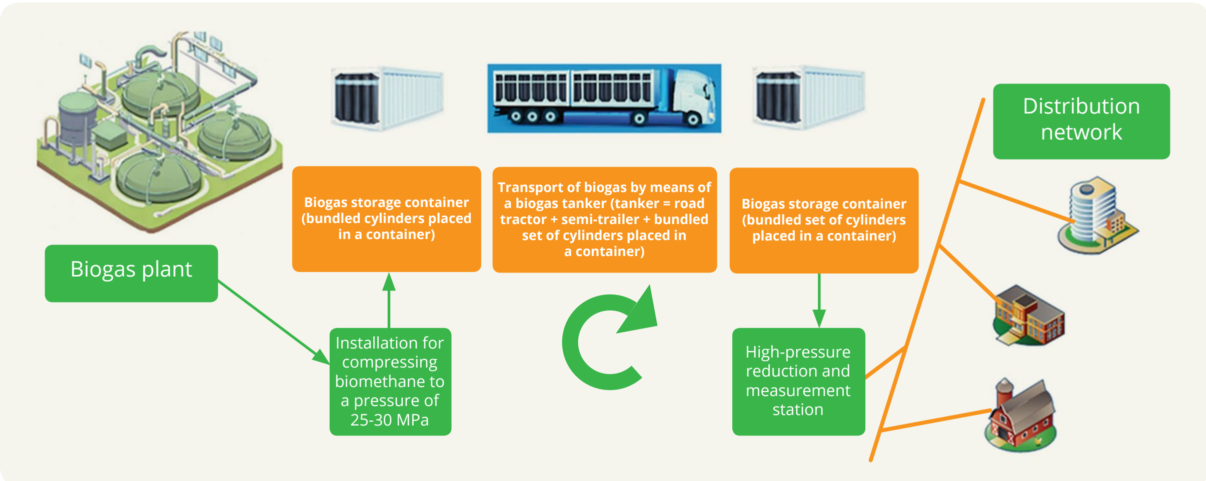
FIG. 22. Network capacity - capital expenditure



Source: Own material of Polska Spółka Gazownictwa Sp. z o.o., author; Urszula Zając (collective work - Department of Energy Transformation)

Another issue relating to connecting a biogas plant to the gas network is the complicated and lengthy formal and legal procedure - obtaining approvals, permits and designing the project takes approximately 24-36 months. Having in mind a comprehensive approach to the issue of connecting a biogas plant and wishing to meet the expectations of biogas producers, PSG has started to work on a solution complementing the above-mentioned options, i.e. 'virtual gas pipelines', i.e. the transport of biomethane in the form of CNG from the producer to the gas network. The main objective of this solution is to collect the biomethane obtained as quickly as possible and inject it into the gas network. The biomethane at the exit from the generation facility would be compressed to a pressure of about 250-300 bar and then transported to the injection points into the distribution network. The location of these points would eliminate the current challenges faced by PSG which exist in certain areas, i.e. lack of network absorption capacity and the need to condition the injected biomethane. Due to the current legal conditions, the construction period for the connection from the biogas plant to the gas grid ranges from a dozen to even several dozen months. With virtual gas pipelines, the off-take time can be reduced to the necessary minimum, and at the same time we can carry out the investment process to build the connection. Once this is completed, the entire 'virtual gas pipeline' system is transferred to another biogas plant. According to preliminary estimates by PSG, the application of this solution will entail an expenditure of approximately PLN 250 million.

FIG. 23. Schematic diagram of 'virtual gas pipelines'



Source: Own material of Polska Spółka Gazownictwa Sp. z o.o., author; Urszula Zając (collective work of the Department of Energy Transformation)

5.4. Potential users of biomethane

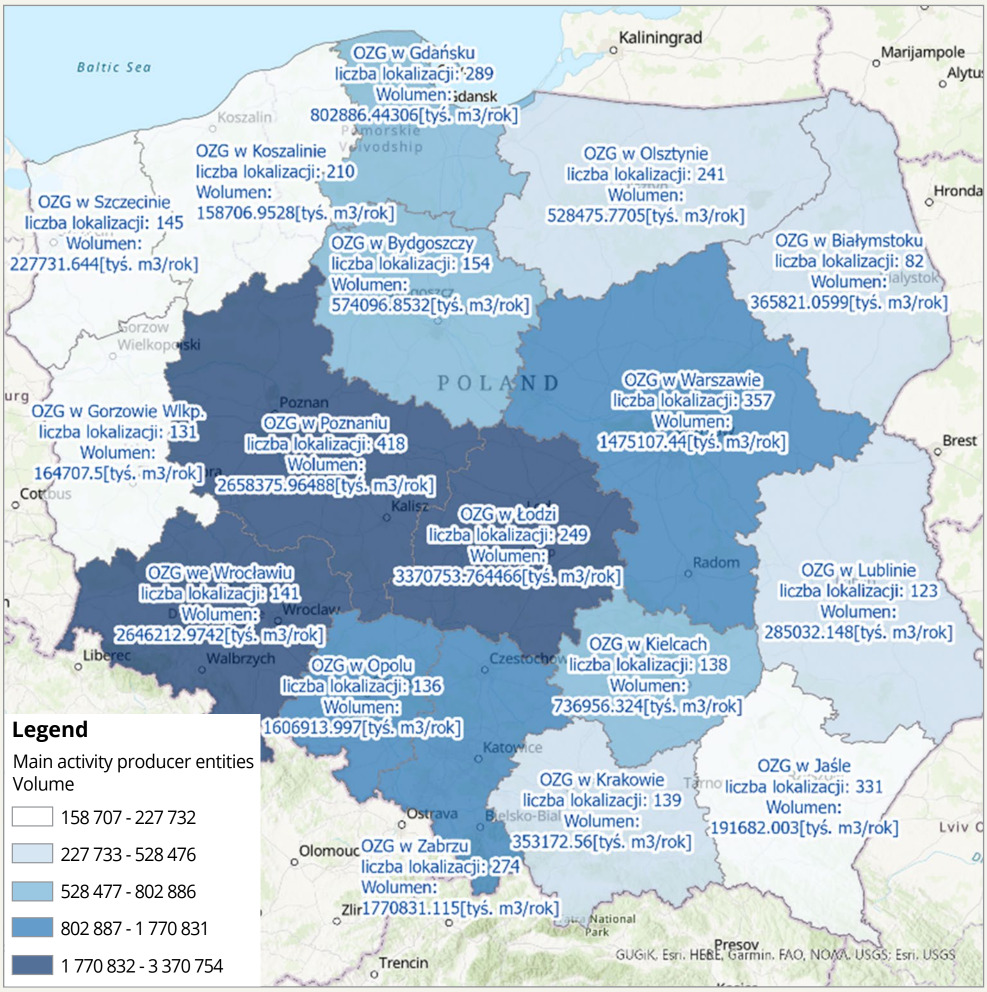
The energy transition has meant that demand for gaseous fuels has increased enormously over the past few years. It is estimated that the number of professional entities interested in consuming gaseous fuel wishing to connect to the PSG distribution network or wishing to increase the volume of consumption will be around 3,300, and the possible additional volume of gaseous fuel is more than 12 billion m^3/year.

As part of the analyses carried out by PSG, the connection potential for heat and CHP plants across Poland was estimated at approximately 540 locations, while the volume of fuel these entities would like to consume was estimated at an additional over 5 billion m^3 per year. From the point of view of the strategy of Orlen, and thus of PSG, the aim is to connect entities from the broadly understood energy sector to the distribution network, with particular emphasis on heat and CHP.

The predictions of the country's largest DSO regarding the growth of demand for gaseous fuel in Poland are confirmed by the assessment of this issue made by the Transmission System Operator Gaz System. The transmission service demand forecast for 2024-2040, updated in 2024, adopts two scenarios:

- Optimal Growth, which projects demand to increase from 18.4 bcm of gas in 2024 to 27.2 bcm per year in 2030,
- Moderate Growth, which predicts demand growth from 18.2 bcm of gas in 2024 to 24.8 bcm per year in 2030[166].

FIG. 24. Estimated potential for connection of professional entities-all professional entities not connected.

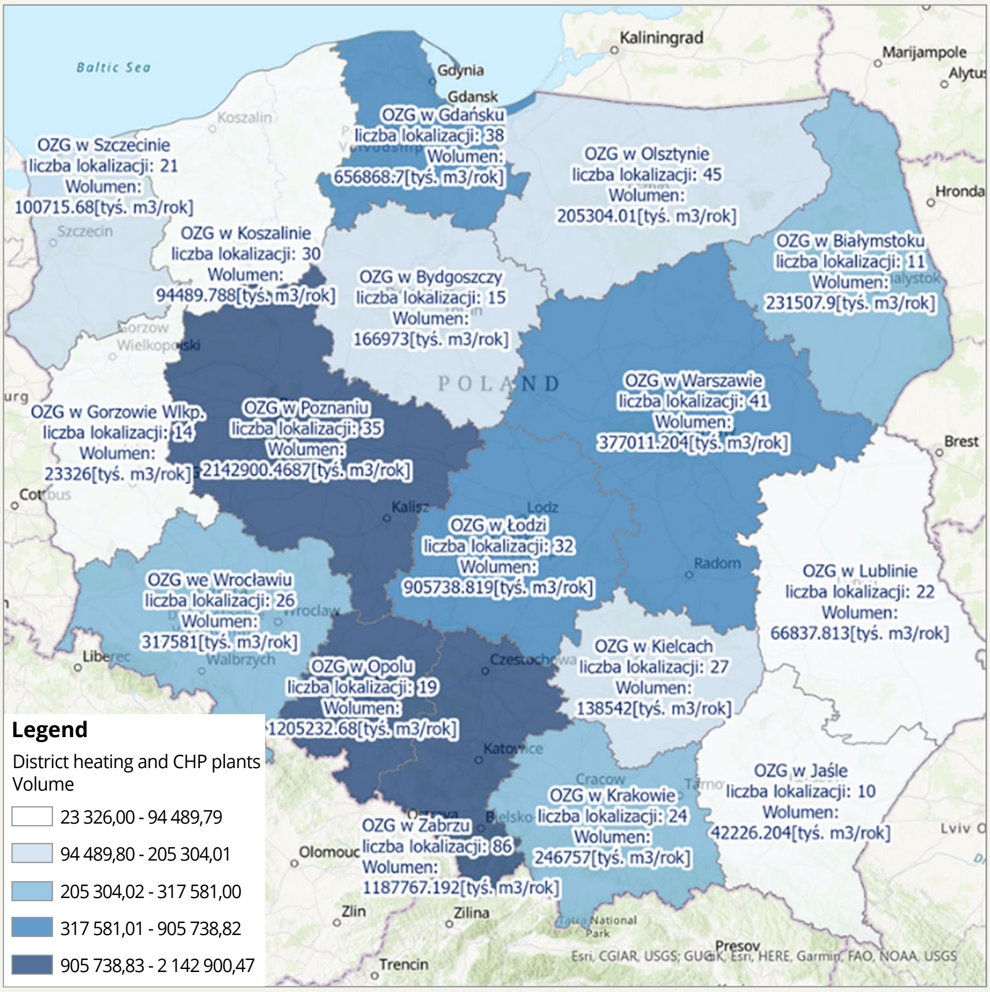


Source: Own material of Polska Spółka Gazownictwa Sp. z o.o., author: Urszula Zając (collective work by the Department of Energy Transformation)

The figure above shows the potential for additional distribution of gaseous fuel in terms of utility entities.

166 Gaz-System, Transmission service demand forecast update for 2024-2045.

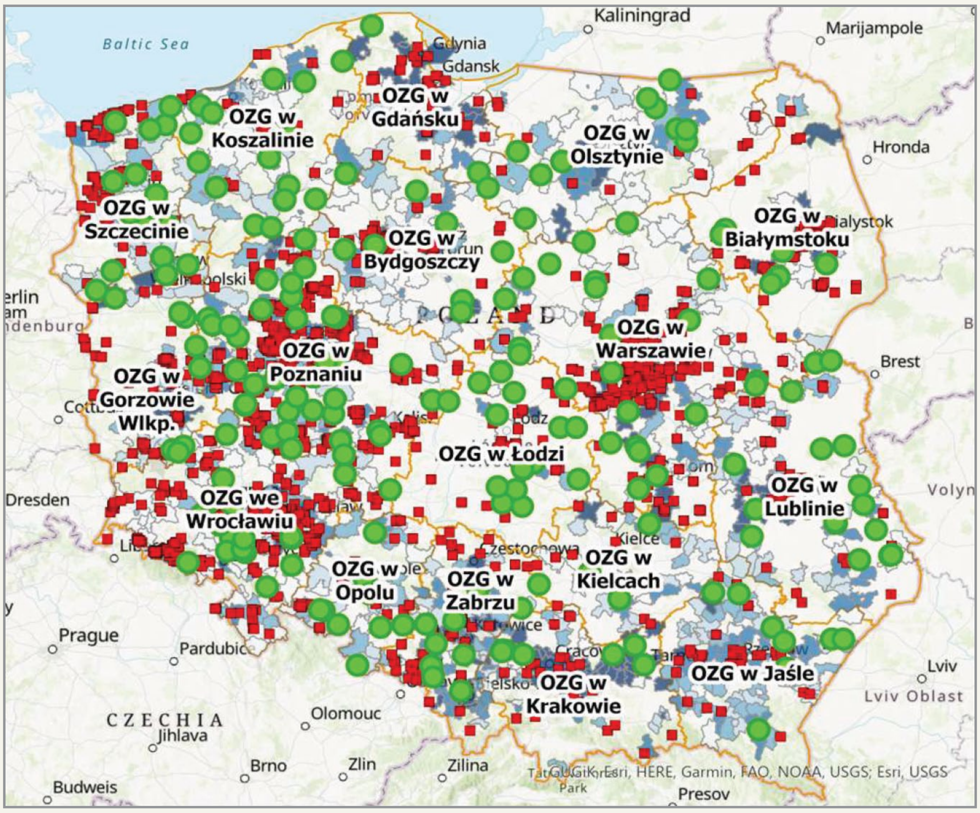
FIG. 25. Estimated potential for connection of unconnected heat and power plants (PAC: 35.11, 35.30)



Source: Own material of Polska Spółka Gazownictwa Sp. z o.o., author: Urszula Zając (collective work by the Department of Energy Transformation)

The figure above shows the potential for additional gaseous fuel distribution in terms of district heating and CHP plants. This analysis indicates how much additional gaseous fuel needs to be supplied in a given region. From the point of view of the obligations imposed on district heating, the ideal solution would be to introduce biomethane into the distribution system.

FIG. 26. Utility entities expressing a desire to consume gaseous fuel - technical refusals



Legend

Biogas plants, applications submitted

Main activity producer entities – refusal for technical reasons

Medium-pressure network capacity

Values

0

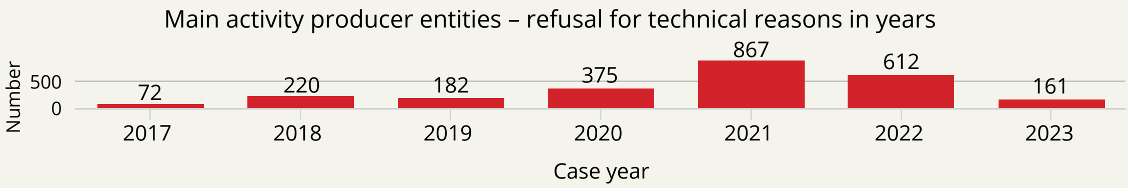
1 - 12

13 - 72

73 - 459

460 - 10 796

OZG boundaries



Source: Own material of Polska Spółka Gazownictwa Sp. z o.o., author: Urszula Zając (collective work by the Department of Energy Transformation)

Above is a visualisation of the analysis of the potential for off-take of produced biomethane based on the applications submitted to PSG and the estimated needs for decentralisation of the distribution system to date. All refusals to connect to the grid, issued to utility entities wishing to off-take gaseous fuel to decarbonise their operations, have been analysed. These data were overlaid with the applications submitted for the connection of the biomethanation plant. The connection of a biomethanation plant could meet the needs of these entities.

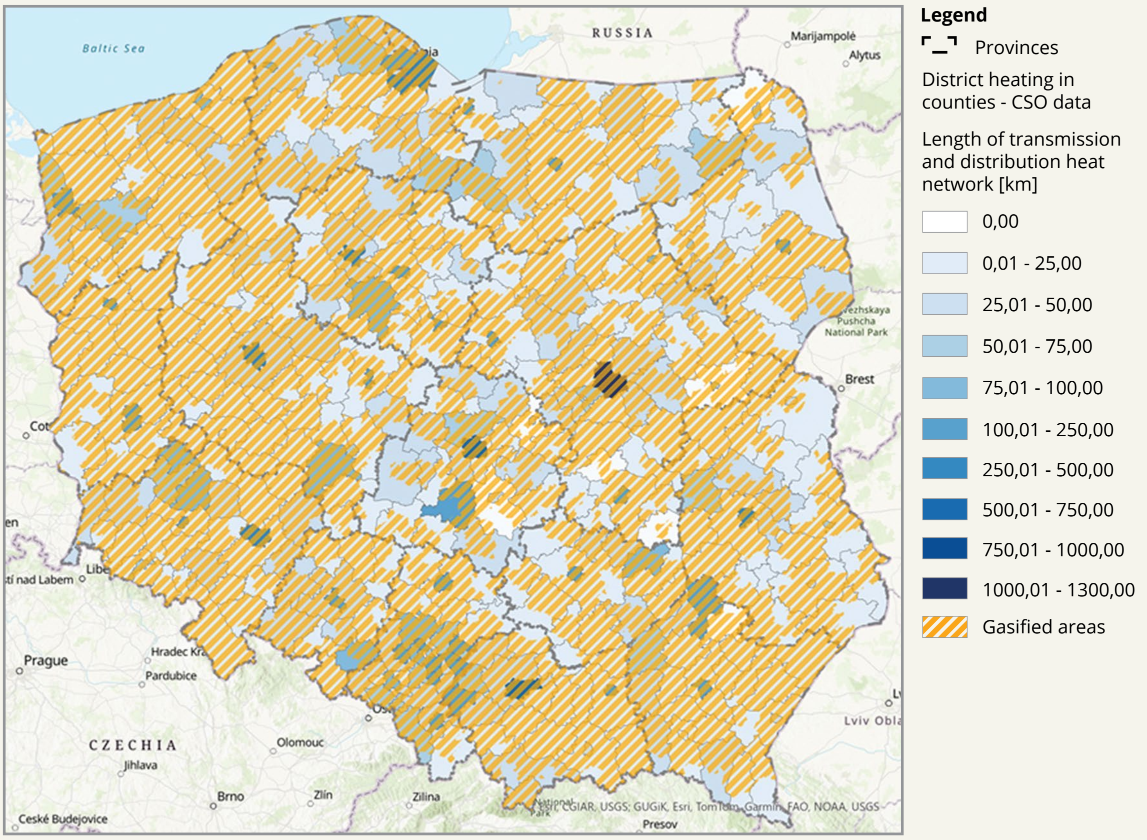
5.5. Importance of high-efficiency cogeneration in a district heating system based on renewable gaseous fuel or its mix with fossil fuel

Demand generation for biomethane should be facilitated by the regulations contained in the Directive of the European Parliament and of the Council on energy efficiency and Regulation (EU) 2023/955 of 13 September 2023. The said directive emphasises that one of the factors for decarbonisation is energy efficiency, i.e. measures to reduce energy needs (energy efficiency per unit of product) as well as high-efficiency generation. "High-efficiency cogeneration and the use of efficient district heating and cooling systems have significant potential for saving primary energy in the EU. (...)". The Directive indicates an obligation to use "high-efficiency cogeneration units", where thermal energy is a "waste" from electricity generation, which is heat recovery. The EU indicates that Member States should encourage the introduction of measures and procedures to support cogeneration installations with a total rated output of less than 5 MW, so as to encourage distributed generation. The DEE Directive also directs Member States to facilitate access to the grid system for electricity produced from high-efficiency cogeneration, especially for small-scale cogeneration units. At the same time, the Directive does not eliminate sources of high-efficiency cogeneration after 1 January 2024. Furthermore, it indicates its appropriateness but in terms of the RES fuel, biomethane. It is currently not clear whether it has to be 100% biomethane or whether it can be a mix of fossil and renewable fuel.

The analysis of the above regulations clearly indicates that the preferred solution is to develop district heating in as large an area as possible to meet the energy needs of local residents from local district heating sources, especially in the area of Poland, as most energy consumers are burdened with "energy poverty". What we consider to be "fuel poverty" is not well defined, but "informal analyses" indicate a situation in which the cost of energy for a household exceeds 10% of the family income.

Figure 28 shows the need to gradually replace the fuels currently in use, but abandoning high-efficiency CHP from 1 January 2045 does not mean abandoning high-efficiency CHP systems, in fact quite the opposite. Indeed, it is enough to switch from natural gas to renewable gaseous fuels. Let us remember that both biomethane and biogas are RES fuels. Based on the above, both gas grids and cogeneration based on gaseous fuels will be part of the energy transition. All that needs to be done is to ensure that there is a sufficient supply of clean, emission-free fuels. This does, however, point to the huge potential of biomethane and biogas in the decarbonisation of industry, including the broadly understood district heating. The characteristics of this approach are also evidenced by the analysis of demographic movements in terms of urban analysis. The following visualisation indicates the potential of existing district heating systems to participate in the biomethane trading market.

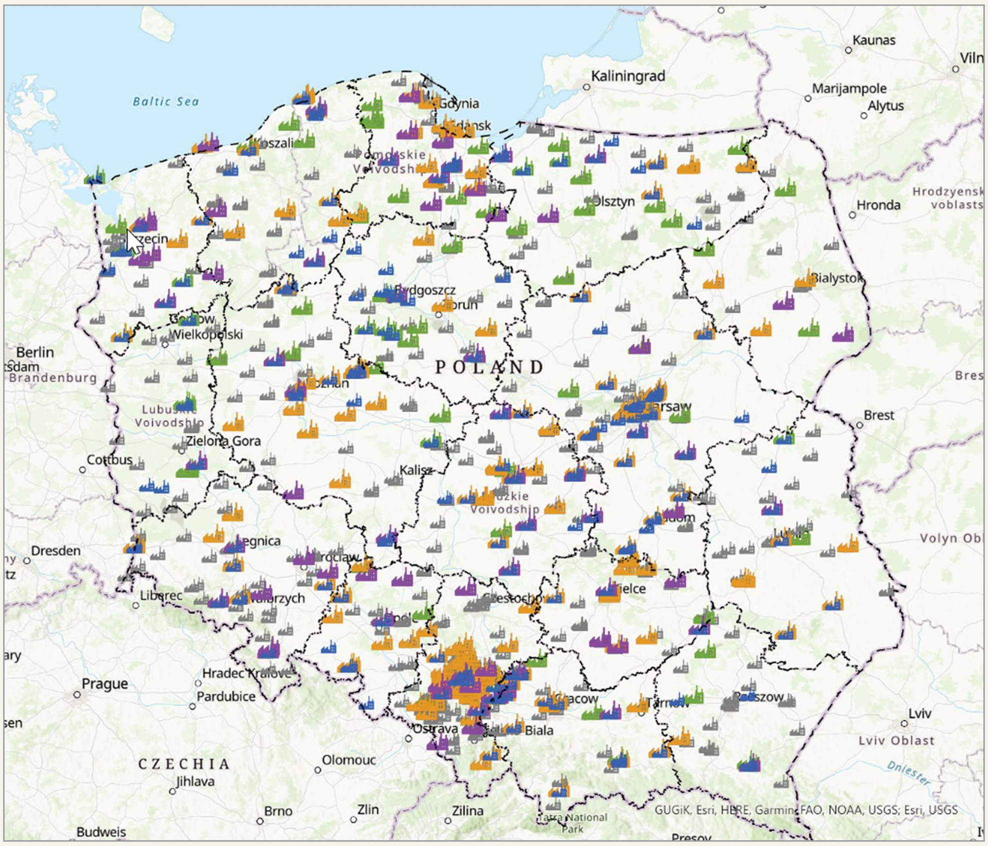
FIG. 27. Length of heat and transmission network in individual areas of Poland.



Source: https://bdl.stat.gov.pl/bdl/metadane/metryka/3542

5.6. Analysis of existing and planned cogeneration units in the Polish heat and power system.

FIG. 28. Utility entities with PKD 35.11.Z and 35.30.Z in their activity classification



Legend

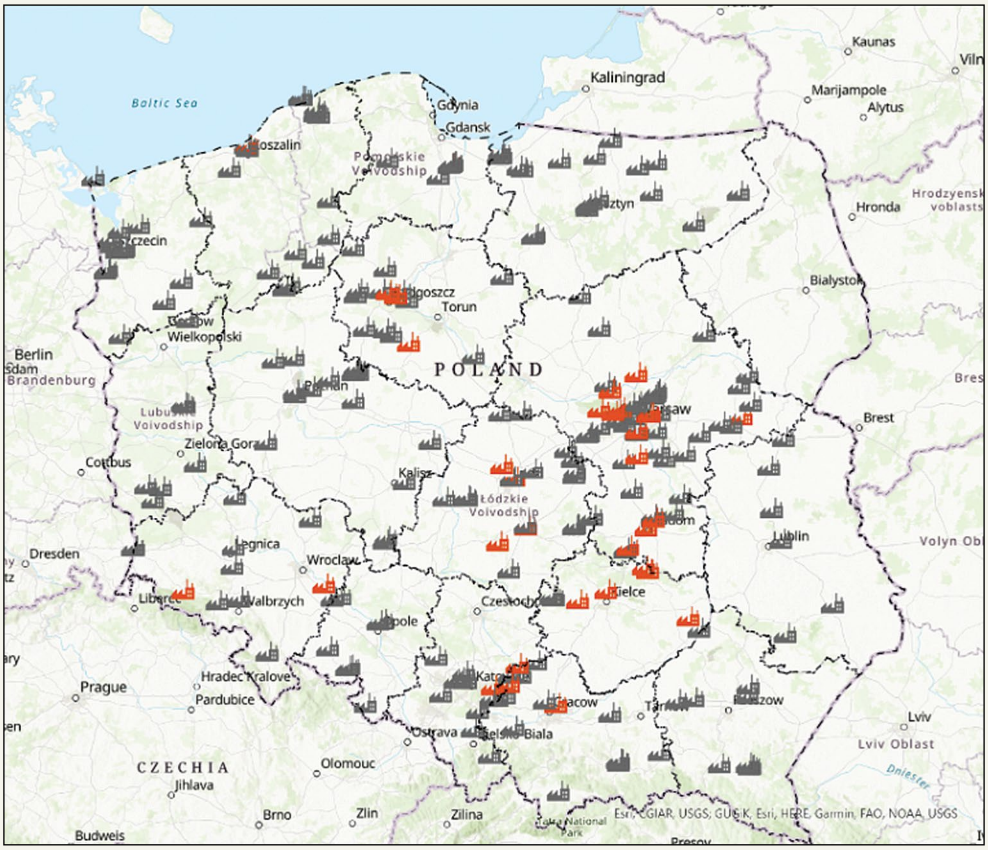
- Main activity producer entities
- Main activity producer entities - CHP
- Main activity producer entities not connected, interested in connection
- Main activity producer entities – applications submitted
- Main activity producer entities – contracts signed
- OZG/ZG boundaries

Source: Own material of Polska Spółka Gazownictwa Sp. z o.o., author: Urszula Zając (collective work by the Department of Energy Transformation)

The PSG identified 854 entities involved in district heating in the broad sense, of which 171 already have CHP installed. At the same time, 306 locations of entities interested in connecting to the gas grid have been identified, of which 260 have applied for connection to the gas grid and 73 have signed a connection agreement (as of November 2023).

The following analysis shows the existing CHP units in the district heating and electricity system.

FIG. 29. Analysis of utility entities with their own energy sources in terms of cogeneration technologies.



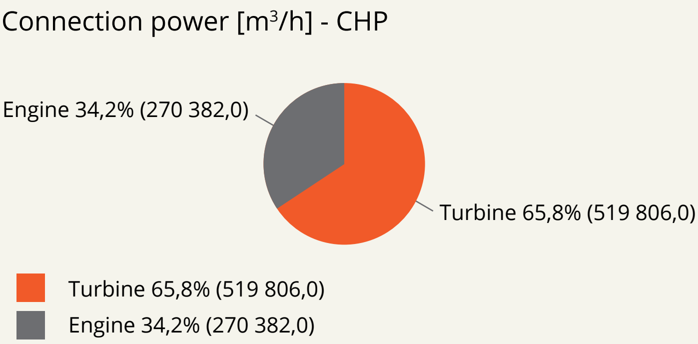
Legend

Main activity producer entities - CHP

Turbine

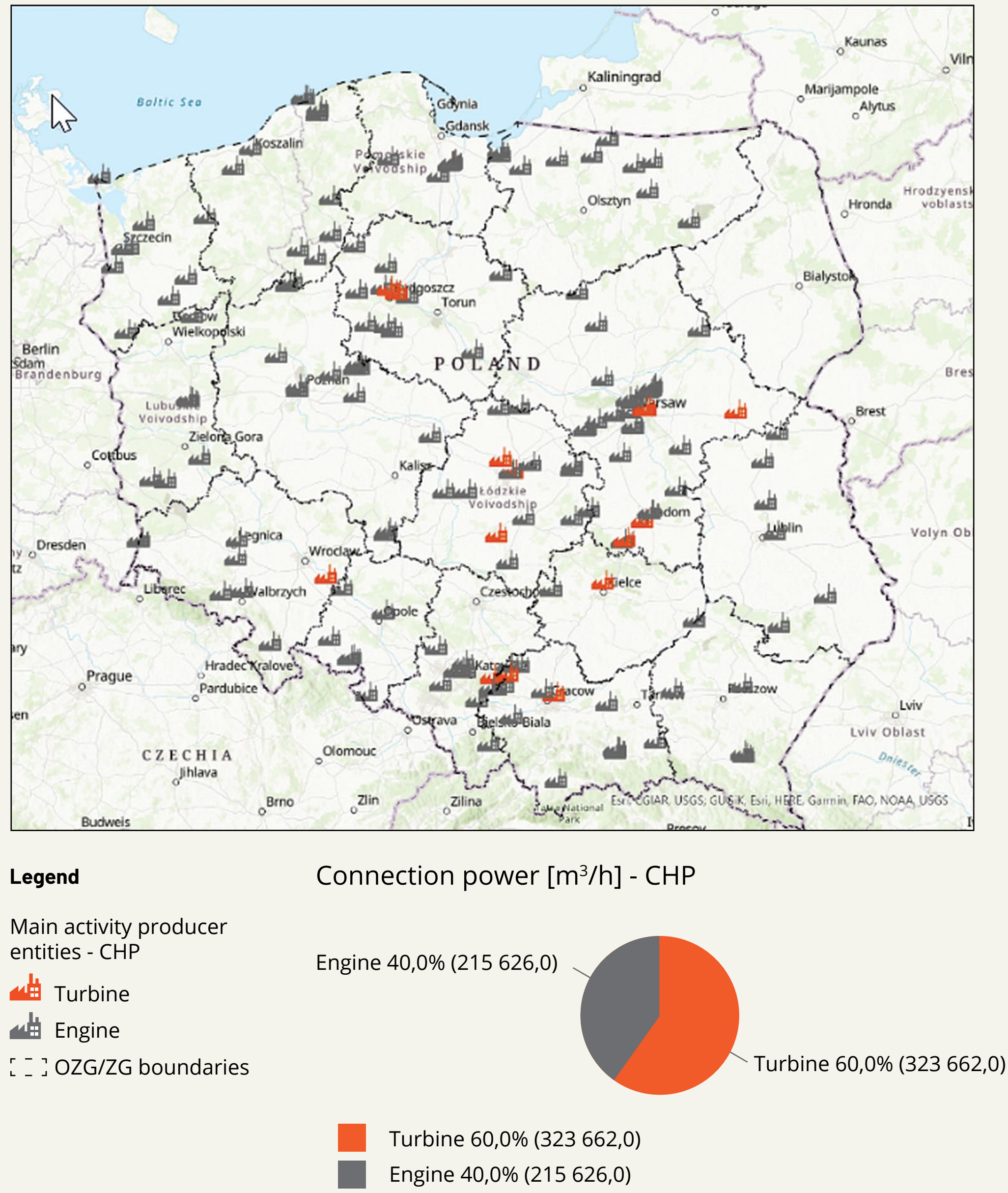
Engine

OZG/ZG boundaries



Source: Own material of Polska Spółka Gazownictwa Sp. z o.o., author: Urszula Zając (collective work by the Department of Energy Transformation)

FIG. 30. Analysis of district heating and CHP plants with their own energy sources in terms of CHP technologies



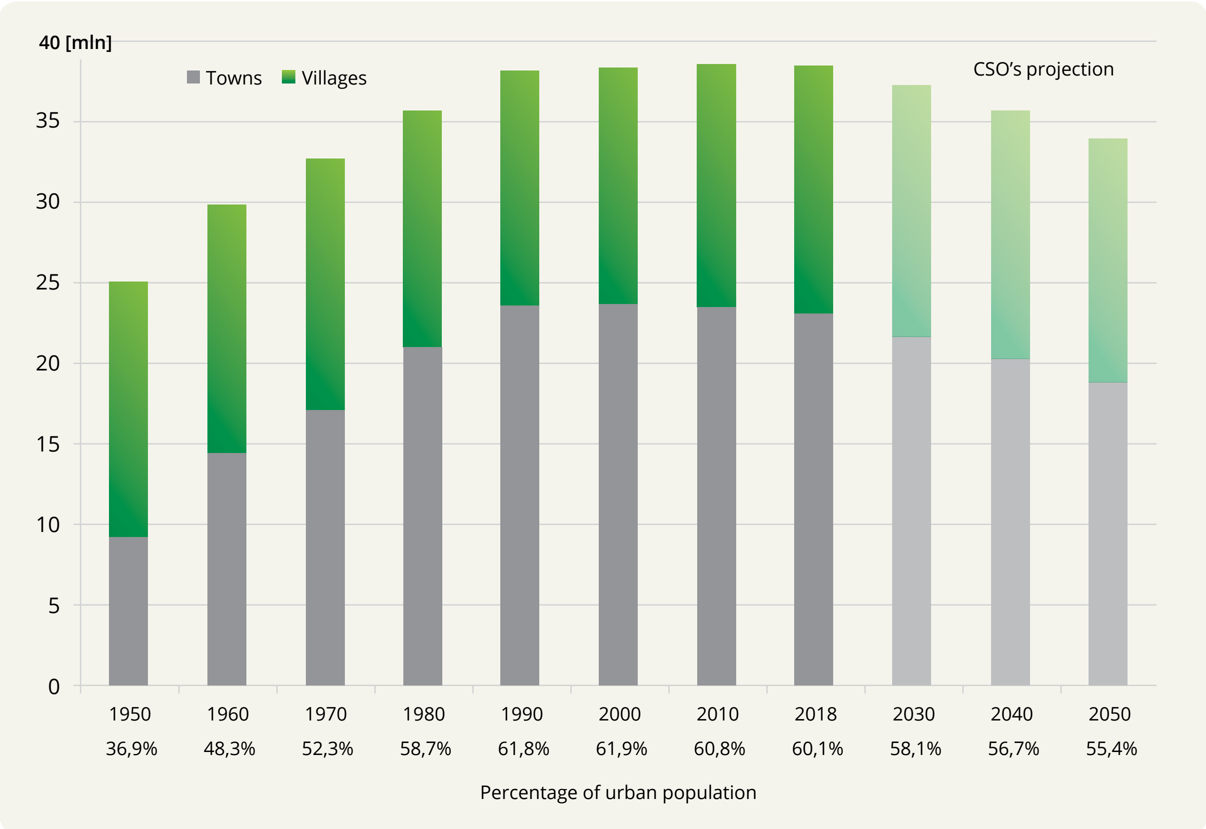
Source: Own material of Polska Spółka Gazownictwa Sp. z o.o., author; Urszula Zając (collective work - Department of Energy Transformation)

The results of the above analyses are very important in terms of carrying out energy balances for a specific area in terms of, among other things, the expansion of the gas network, the need for fuel quantities and fuel flow. It is estimated that the amount of energy generated in turbine units ranges from 0.001 MW to 800 MWe, and in the case of cogeneration engines from approx. 0.5 kW to 8 MWe.

5.7. Analysis of demographic trends in terms of urbanisation of anthropogenic areas in the next 30 years

One of the determinants influencing the perspective level of fuel and energy consumption are demographic processes related to, *inter alia*, changes in the structure of residence of a given population. This issue is particularly important in the aspect of further functioning and implementation of decarbonisation strategies of district heating networks in Poland.

FIG. 31. Percentage of population living in areas of the urban tissue and in rural areas in terms of the directions of urban change in Poland.



Source: http://geografia24.pl/liczba-i-rozmieszczenie-ludnosci-polski

The chart above illustrates the actual changes and trends in the movement of Poland's population in terms of the choice of specific areas of residence. Precisely at the turn of the 20th and 21st century, there was a very large increase in the migration of the population of urban areas to suburban areas. This phenomenon most strongly affected three Polish metropolitan areas: Warsaw, Wrocław and the Tri-City. However, this trend is gradually changing direction due to the existing obstacles caused by the distances people have to travel every day, for example to work, the lack of infrastructure, crèches, schools, etc. The Central Statistical Office (CSO) forecasts that in 2050, we will reach the percentage level of urban population that we had in the late 1970s and early 1980s. The demographic trends described above will be accompanied by regulatory changes aimed at banning the use of fossil fuels in the heating of single-family houses, which together will lead to an increase in the demand for district heating. It should be noted, however, that a reduction in the population living in rural areas may lead to a dilution of the settlement tissue, which may contribute to limiting the possibility of building district heating systems in these areas. In summary, dedicated biomethane transmission lines supplying gaseous fuel to newly built district heating plants may be constructed where this is possible. However, it should be borne in mind that an alternative solution to biomethane for heating purposes is the installation of heat pumps.

The emergence of such infrastructure will also be conditioned by the historically shaped structure of spatial development in various regions of Poland, manifested, inter alia, in the number and size of farms (differences e.g. between Wielkopolska and Podkarpacie). District heating systems can also not be used in the case of high fragmentation of individual consumers as well as high variability of terrain levels. This means that in mountainous areas (e.g. Beskids, Karkonosze) such a solution will not be feasible. The district heating system must therefore correlate with the gas system, as this will allow the energy needs of those living outside the district heating network area (most often also in energy poverty) to be met; moreover, the gas pipeline system will allow fuel to be supplied to utility sources in need of RES fuel, which further confirms the view that biomethane can play a very important role in the energy transition, especially for the district heating sector, which through such fuel will be able to showcase high-efficiency cogeneration in the energy mix as a source of RES and as a component of a decarbonised energy balance.

Conclusions:

- The existing national gas network was not designed and built with a view to developing local sources of gaseous fuel (biogas plants). In order for it to properly serve the development of biomethane in Poland, measures must be taken to invest in the decentralisation of grid entry points.
- The use and production of biomethane depends on regional conditions, in particular with regard to the connectivity and absorption capacity of the distribution network.
- The largest substrate resources that could be used for biogas production are located in the Wielkopolska, Silesia and Lublin regions.
- From a technical point of view, i.e. the materials used, construction technology, etc., the gas networks managed by PSG, are suitable for the transport of biomethane, the quality parameters of which comply with the applicable legislation.
- Biomethane as a RES fuel, should support the energy mix of district heating and electro-heating.
- Biomethane should systematically replace natural gas in existing gas units.
- District heating systems with biomethane/biogas in the power generation base should be developed.
- Local cogeneration systems for gaseous RES fuel, supplemented by other unstable RES sources, is a solution for balancing Poland's energy needs.
- Administrative requirements in terms of the construction of biomethanation plants as well as the development of the distribution network (special act) should be minimised.
- The fuel quality requirements of the distribution system in the area where the biomethanation plant is being built should be relaxed.
- The lack of biomethane offtake and injection into the gas grid will have a negative impact on Poland's energy balance.
- From a technical point of view, i.e. the materials used, construction technology, etc., the gas networks managed by PSG, are suitable for the transport of biomethane, the quality parameters of which comply with current legislation.
- The network should be redeveloped with a view to decentralising it by increasing its absorptive capacity.
- Virtual Gas Pipelines - the off-take of biomethane in the form of LNG - is one of the solutions for transporting biofuels until a gas network is built.

6 Economic issues

Chapter 6.

Economic issues

6.1. Assumptions for economic analysis

For the purposes of this analysis, a hypothetical rounded biomethane production value of 3 bcm in 2030 has been assumed, which is similar to the NCRD estimates of up to 3.2 bcm per annum already given above and the European Biogas Association, which forecasts production in Poland at 3.3 bcm per annum. Assuming a nominal heat of combustion for biomethane equivalent to the heat of combustion of E-gas (high methane gas) of 39.5 MJ/m³ and a projected biomethane production of 3 bcm³ - this will yield approximately 33 TWh of primary energy from biomethane in 2030.

“Poland’s Energy Policy until 2040” as well as the “National Energy and Climate Plan 2021-2030” provide projected capacities and production volumes for biogas. Neither document distinguishes between biogas and biomethane production due to the lack of currently operating biomethanation plants in Poland and thus the lack of specific data for this gas. In addition, biogas consumption is dedicated only to local CHP plants, which is justified for biogas plants that are not connected to the gas grid. The development of biomethane production will also result in other end solutions than those foreseen in the strategic documents, i.e. the development of local, small-scale CHP systems and the expansion of gas networks. Table 9 and Table 10 show the capacities and productions from biogas resulting from the projections in PEP2040.

TAB. 9. Net installed capacity of biogas CHP plants [MW].

Power	2020	2025	2030	2035	2040
biogas CHP plant	305	517	741	945	1 094

Source: PEP2040.

TAB. 10. Production from biogas CHP plants [TWh].

Production	2020	2025	2030	2035	2040
biogas CHP plant	1.5	2.7	3.9	5.0	5.8

Source: PEP2040.

In the case of a biomethanation plant, where methane accounts for about 98% of the gas produced, connected to the gas grid, part of the biomethane production will be consumed in gas-fired power plants and CHP plants fed with natural gas from the grid. Table 11 and Table 12 show the capacity and production of electricity from natural gas.

TAB. 11. Installed capacity of natural gas-fired sources [MW].

Power	2020	2025	2030	2035	2040
natural gas-fired power plant	0	1 900	1 900	3 039	3 260
CHP plant for natural gas	2 688	3 807	4 371	4 100	5 261

Source: PEP2040.

TAB. 12. Electricity production from natural gas-fired sources [TWh].

Production	2020	2025	2030	2035	2040
Natural gas	12.0	15.3	20.7	31.3	38.4

Source: PEP2040.

In order to estimate the impact of biomethane injected into the gas grid for electricity generation, a biomethane factor in grid gas of 1% was expertly assumed. The cumulative (i.e. biogas production as shown in PEP2040 and % of the volume of electricity production from natural gas according to PEP2040) electricity production from biogas/biomethane produced by biogas/biomethane facilities and gas facilities fed into the gas grid into which gas from biogas/biomethane facilities has been injected is shown in Table 13.

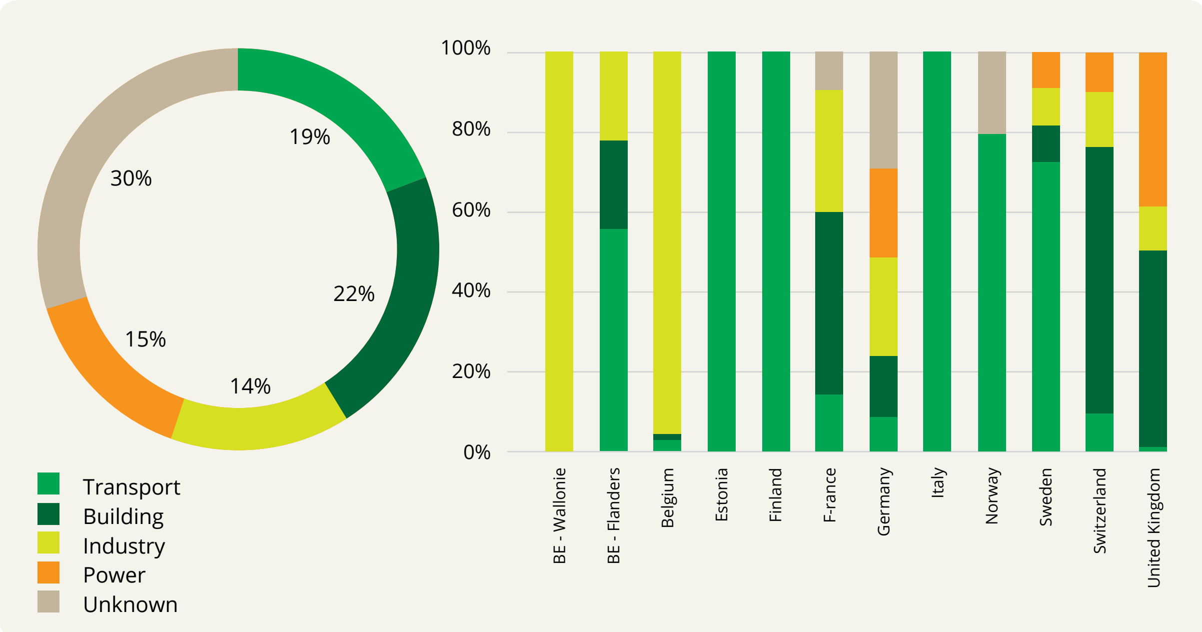
TAB. 13. Electricity production from biogas/biomethane [TWh].

Production	2020	2025	2030	2035	2040
from biogas / biomethane	1.5	2.7	3.9	5	5.8
of 1% biogas/biomethane in network gas at natural gas sources	0.1	0.2	0.2	0.3	0.4
Total production from biogas / biomethane	**1.6**	**2.9**	**4.1**	**5.3**	**6.2**

Source: own study based on PEP2040.

Biomethane consumption for electricity generation according to the 'EBA Statistical Report 2023'[167] in Europe is estimated at 15% of consumption across all sectors in 2022. The highest consumption of biomethane for electricity generation reaching 40%[168] is in the UK.

FIG. 32. Biomethane consumption by sector and selected countries.



Source: EBA Statistical Report 2023.

The estimated electricity production from biogas/biomethane of about 4.1 TWh in 2030 in Poland against a biomethane production potential of 33 TWh - taking into account the efficiency of gas-fired power and CHP plants estimated at an expert level of 45% - represents about 27% of biomethane consumption for electricity production. Given the current biomethane consumption for electricity generation in Europe of 15% and the projected increase in biomethane production by 2030, it can be concluded that the level of electricity production estimated in PEP2040 is ambitious, but realistic[169].

167 European Biogas Association, *EBA Statistical Report 2023*, https://www.europeanbiogas.eu/wp-content/uploads/2023/12/PR_EBA-Statistical-Report-2023.pdf, 5.12.2023.

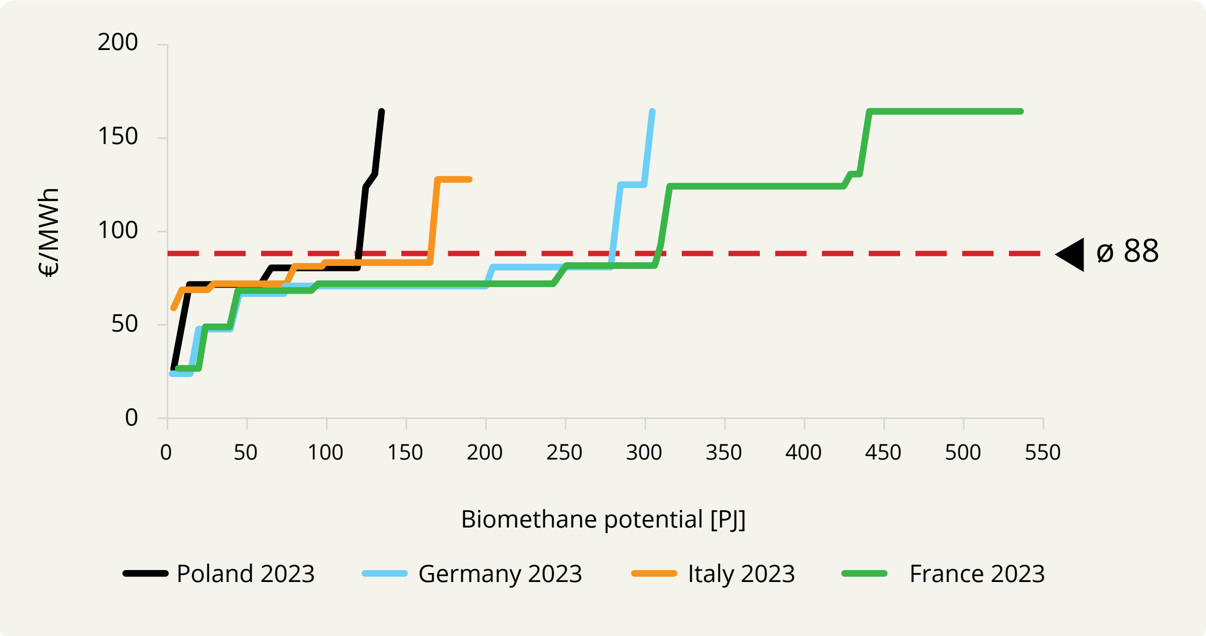
168 Ibid

169 The production of 4.1 TWh also includes biogas.

6.2. Economics of electricity production from biogas/biomethane

The dynamics of the biomethane market in Poland are mainly influenced by the availability of the raw material from which it will be produced. According to Det Norske Veritas (hereafter: DNV) data from January 2024[170], the average production costs for biomethane in four countries (Italy, France, Germany and Poland) are currently around 88 EUR/MWh. The range of production costs is between EUR 20 and 160/MWh. The large range in biomethane costs is due to differences in substrate costs. According to DNV, there is a limited supply of cheap substrate in the form of straw and crop residues in Poland. Other substrates required to realise the full potential of biomethane in Poland are, in turn, much more expensive.

FIG. 33. Biomethane potential in selected countries in 2023.

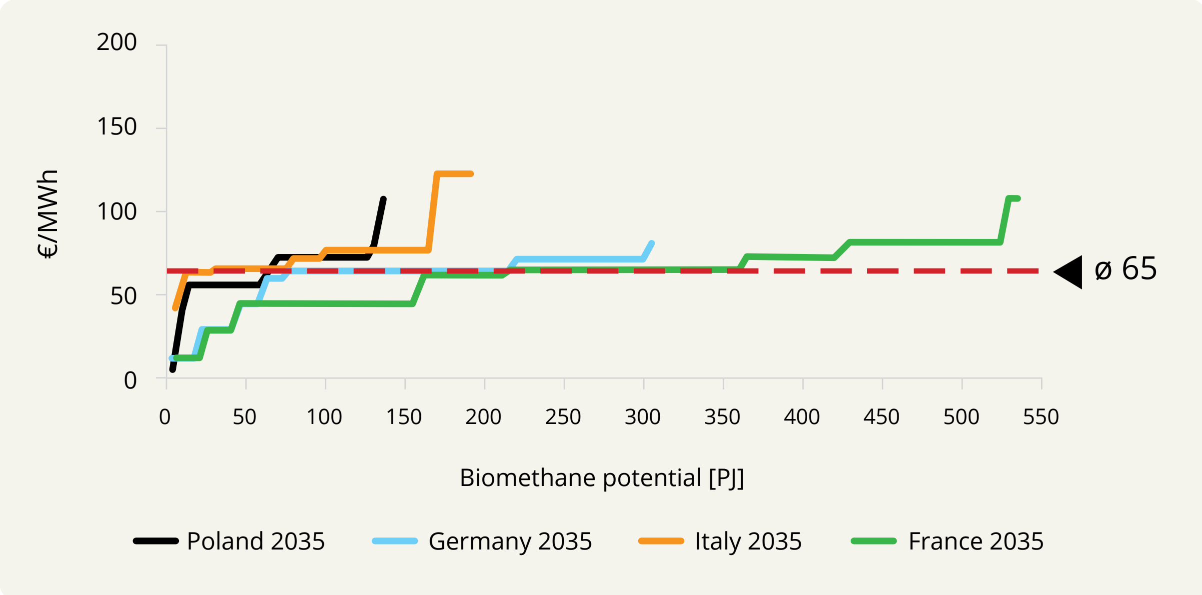


Source: DNV, Biomethane in the heating system of Italy, Germany, Poland, and France by 2030 - A cost comparison, Webinar DNV I European Climate Foundation 24.01.2024.

DNV predicts that these costs will fall to 65 EUR/MWh by 2035. A large potential, according to the organisation, lies in agricultural waste and products. The cost of producing agricultural biomethane is in the range of 60-75 EUR/MWh. It is worth noting that both the current and future (2035) potential for cheap biomethane in Poland is estimated to be relatively low compared to the other EU countries analysed, which, as DNV experts point out, is related to the relatively low supply in our country of the most economically attractive substrate in the form of agricultural waste.

170 DNV, *Biomethane in the heating system of Italy, Germany, Poland, and France by 2030 - A cost comparison*, Webinar DNV I European Climate Foundation 24.01.2024.

FIG. 34. Biomethane potential in selected countries in 2035.



Source: DNV - Biomethane in the heating system of Italy, Germany, Poland, and France by 2030 - A cost comparison, 24.01.2024.

PEP2040 assumes an increase in domestic electricity consumption from around 160 TWh in 2020 to more than 204 TWh in 2040 and an increase in peak power demand from around 25 GW in 2020, to more than 31 GW in 2040.

TAB. 14. Electricity and peak demand forecast.

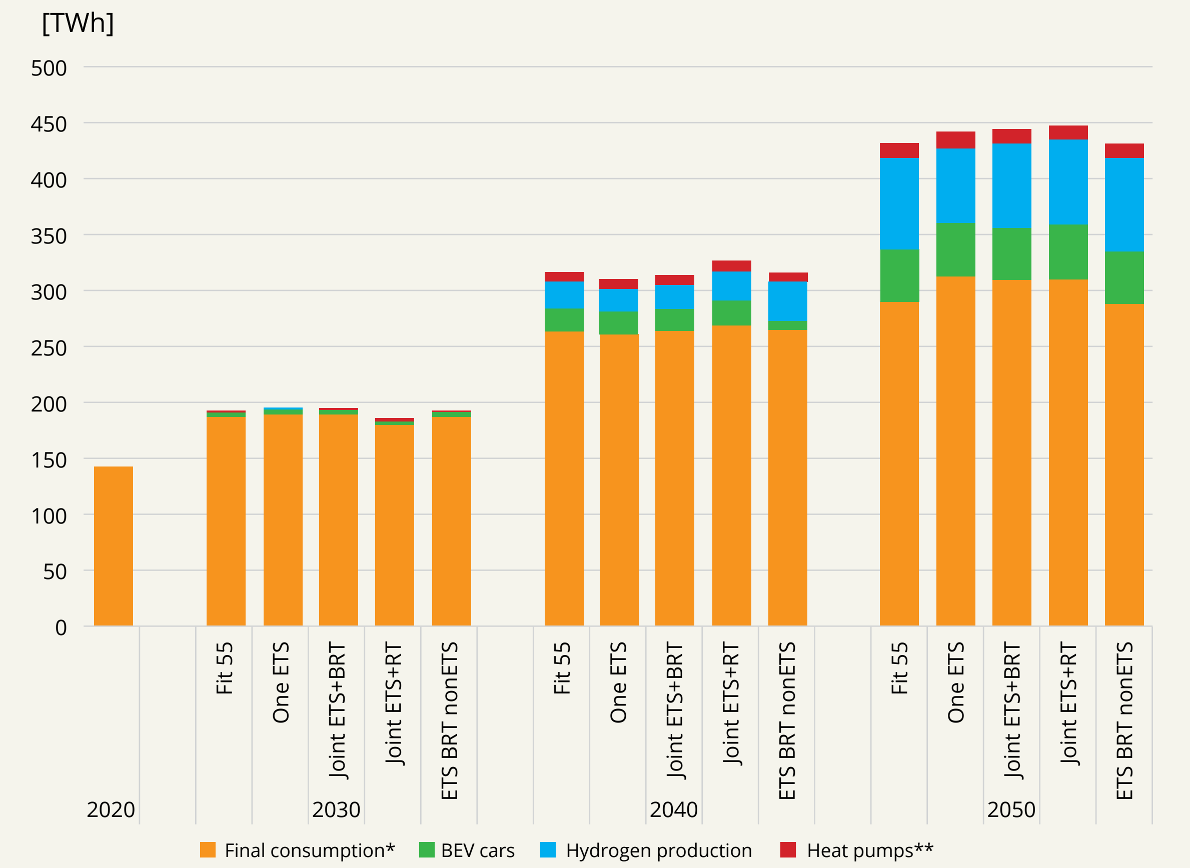
	2020	2025	2030	2035	2040
net electricity demand [TWh]	159.9	170.1	181.1	191.9	204.2
net power demand at annual peak [GW]	24.5	25.9	27.7	29.5	31.3

Source: PEP2040.

In contrast, the KOBIZE Centre for Climate and Energy Analysis[171] (hereafter CAKE) forecasts electricity consumption at a higher level than PEP2040. CAKE estimates that final energy demand in 2030 will reach about 200 TWh in each scenario, i.e. higher by about 10% than PEP2040 assumptions, and more than 300 TWh in 2040, i.e. approximately 50% higher than in the government document.

171 CAKE/KOBiZE, *View 2050. new sectors in the EU ETS in the context of EU climate neutrality in 2050*, https://climatecake.ios.edu.pl/wp-content/uploads/2023/06/CAKE_VIIEW-on-EU-ETS-2050_Nowe-sektory-w-EU-ETS-w-kontekscie-neutralnosci-klimatycznej-UE-w-2050-Skutki-dla-Polski..pdf, 7.04.2023.

FIG. 35. Electricity demand forecast for Poland



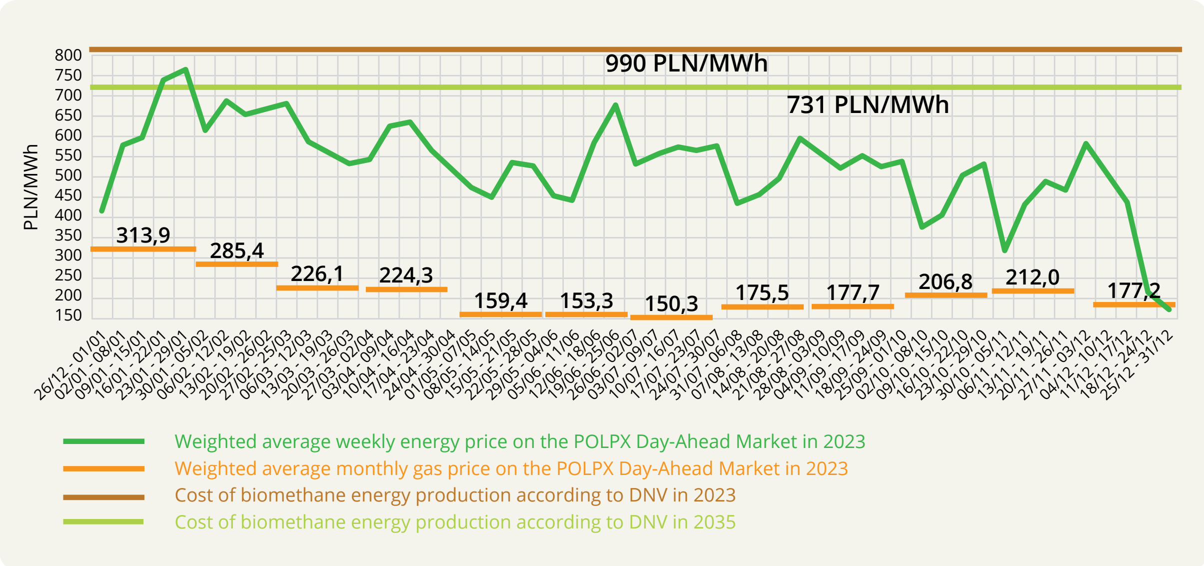
* Final consumption (taking into account a part of the energy sector)
** only in part replacing district heating

Source: CAKE/KOBIZE - 'VIEW on EU ETS 2050: New sectors in the EU ETS', Warsaw 2023, p. 20.

The electricity production from biogas/biomethane estimated in section 1 of 4.1 TWh in 2030 and 6.2 TWh in 2040 correspond to 2-3% of Poland's electricity demand.

Taking into account also the average efficiency of CHP plants of 35% and approx. 60% of gas-fired power plants and the fact that biomethane will be used mainly in local CHP plants located close to the substrate sources, the expert assumed an efficiency of biomethane conversion to electricity of 40% (higher efficiency of biogas CHP plants resulting from the use of new generation units with a higher efficiency factor and the partial inclusion of biogas in the operation of gas-fired power plants with biogas admixture). The costs of producing energy from biomethane estimated by DNV will translate into an electricity price of approx. 490 PLN/MWh and approx. 660 PLN/MWh, respectively.

FIG. 36. Weighted average weekly electricity prices (PLN/MWh) in 2023 and cost of biomethane production



Source: own study based on TGE and DNV.

The above graph of weighted average weekly electricity prices and weighted average monthly gas prices on the POLPX Day-Ahead Market in 2023 shows that biomethane costs of 65 EUR/MWh in 2035 and 88 EUR/MWh in 2023 (at 40% CHP generation efficiency) - as estimated by DNV - at 2023 energy prices, would not allow for economically viable electricity production from biomethane.

In order to compare the levelised cost of electricity (LCOE) from biomethane to the LCOE from natural gas in 2030, six scenarios were estimated for the purpose of this study, i.e. for three gas price scenarios, i.e. EUR 30/MWh; EUR 50/MWh; EUR 70/MWh and two CO_2 price scenarios , i.e. 70 EUR/tCO_2 and 145 EUR/tCO_2.

Fuel and emissions costs have been included in the LCOE of the gas-fired power plant and gas-fired CHP presented in Lazard's Levelised Cost of Energy Analysis-Version 16 report of 2023 presented in Tables 15 and 16. For the purpose of this study, the average LCOE from Lazard's report for power plants and CHP plants was used, from which the LCOE for the six scenarios described above was estimated, and the LCOE for biomethane was calculated in two biomethane price scenarios, i.e. for 65 EUR/MWh and 88 EUR/MWh. The capital expenditure (CAPEX) and variable (non-fuel and emission) and fixed costs for biomethane sources were estimated at the same level as for natural gas sources due to the use of the same technology.

TAB. 15. LCOE of a natural gas-fired peaking power plant.

		LAZARD LCOE			CO price$_2$ 70 EUR/tonne			CO price$_2$ 145 EUR/tonne			Biomethane	
		min	max	average	Gas price 30 EUR/MWh	Gas price 50 EUR/MWh	Gas price 70 EUR/MWh	Gas price 30 EUR/MWh	Gas price 50 EUR/MWh	Gas price 70 EUR/MWh	Biomethane price 65 EUR/MWh	Biomethane price 88 EUR/MWh
Power plant	**EUR/MWh**	**126.5**	**243.1**	**184.8**	**260.9**	**312.6**	**364.2**	**296.1**	**347.7**	**399.4**	**318.5**	**377.9**
CAPEX	EUR/MWh	79.2	185.9	132.6	132.6	132.6	132.6	132.6	132.6	132.6	132.6	132.6
Variable costs	EUR/MWh	5.5	20.9	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2
Fixed costs	EUR/MWh	4.4	5.5	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
Fuel costs	EUR/MWh	37.4	30.8	34.1	77.4	129.1	180.7	77.4	129.1	180.7	167.8	227.2
Issue costs	EUR/MWh	0.0	0.0	0.0	32.8	32.8	32.8	68.0	68.0	68.0	0.0	0.0

Source: Own study based on Lazard - Levelised Cost of Energy Analysis-Version 16.

TAB. 16. LCOE of a natural gas-fired CHP plant.

		LAZARD LCOE			CO price$_2$ 70 EUR/tonne			CO price$_2$ 145 EUR/tonne			Biomethane	
		min	max	average	Gas price 30 EUR/MWh	Gas price 50 EUR/MWh	Gas price 70 EUR/MWh	Gas price 30 EUR/MWh	Gas price 50 EUR/MWh	Gas price 70 EUR/MWh	Biomethane price 65 EUR/MWh	Biomethane price 88 EUR/MWh
CHP plant	**EUR/MWh**	**42.9**	**111.1**	**77.0**	**132.8**	**170.4**	**208.1**	**158.6**	**196.2**	**233.9**	**174.6**	**217.9**
CAPEX	EUR/MWh	15.4	72.6	44.0	44.0	44.0	44.0	44.0	44.0	44.0	44.0	44.0
Variable costs	EUR/MWh	1.1	6.6	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9
Fixed costs	EUR/MWh	3.3	5.5	4.4	4.4	4.4	4.4	4.4	4.4	4.4	4.4	4.4
Fuel costs	EUR/MWh	23.1	26.4	24.8	56.5	94.1	131.8	56.5	94.1	131.8	122.4	165.7
Issue costs	EUR/MWh	0.0	0.0	0.0	24.1	24.1	24.1	49.8	49.8	49.8	0.0	0.0

Source: Own study based on Lazard - Levelised Cost of Energy Analysis-Version 16.

The above calculations show that the LCOE of biomethane sources with a biomethane price of 65 EUR/MWh estimated by DNV for 2035 in Poland is comparable to the averaged LCOE of gas sources with a gas price of 50 EUR/MWh and a CO_2 price of 70 EUR/tCO_2, **making biomethane an attractive economic alternative to natural gas in view of the assumed increases in CO_2 emission allowance prices in the EU ETS**.

6.3. Economics of heat production from biogas/biomethane

Biomethane fed into the gas grid can also serve to decarbonise the district heating sector. We assume that system heat generated from biomethane should remain competitive in contrast to generation sources above 20 MW, which are currently covered by the EU ETS.

Compared to heat obtained at current gas prices quoted on the Polish Power Exchange (TGE) at a level of 160-206 PLN/MWh reflected in Table 17 and with no heat charge imposed on sources below 20 MW (in installations outside the EU ETS). (POLPX) at 160-206 PLN/MWh reflected in Table 17 and with no CO_2 charge on heat from sources below 20 MW (in installations outside the EU ETS), heat from biomethane at 300-400 PLN/MWh (cost of biomethane: 65-88 EUR/MWh) is currently not competitive with heat produced from natural gas.

TAB. 17. Monthly statistics for natural gas supply contracts.

Products	W Avg Price	W Avg Price	W Avg Price Change	Low Price	High Price	Volume	Vol. Change	Traded Contr.	No. of Trades
	PLN/MWh	EUR/MWh	%	PLN/MWh	PLN/MWh	MWh	MWh		
GAS_BASE_W-49-23	**201,00**	**46,40**	↓ -5,93	201,00	201,00	**67 200**	↓ -767 760	400	14
GAS_BASE_W-50-23	**191,15**	**44,12**	↓ -7,45	187,00	201,00	**148 848**	↓ -38 640	886	29
GAS_BASE_W-51-23	**174,79**	**40,35**	-	172,00	190,00	**44 520**	↑ 44 520	265	26
GAS_BASE_W-52-23	**161,75**	**37,34**	-	155,00	164,00	**3 360**	↑ 3 360	20	2
GAS_BASE_W-01-24	**167,99**	**38,78**	-	161,00	177,00	**29 568**	-	176	25
GAS_BASE_W-02-24	**170,87**	**39,44**	-	162,90	183,00	**61 152**	-	364	39
GAS_BASE_W-03-24	**168,88**	**38,98**	-	165,00	183,00	**28 728**	-	171	24
GAS_BASE_W-04-24	**165,57**	**38,22**	-	164,00	167,00	**11 760**	-	70	9
GAS_BASE_M-01-24	**179,06**	**41,33**	↓ -20,07	159,00	211,50	**1 569 840**	↓ -571 392	2 110	546
GAS_BASE_M-02-24	**183,79**	**42,43**	↓ -18,99	163,05	214,00	**913 848**	↓ -391 152	1 313	364
GAS_BASE_M-03-24	**176,07**	**40,64**	-	164,50	212,50	**88 417**	88 417	119	59
GAS_BASE_Q-1-24	**188,20**	**43,44**	↓ -16,45	164,00	212,00	**1 128 611**	↓ -2 324 895	517	223
GAS_BASE_Q-2-24	**169,95**	**39,23**	↓ -22,03	160,00	205,50	**554 736**	↑ 314 496	254	107
GAS_BASE_Q-3-24	**169,30**	**39,08**	↓ -26,31	162,00	202,99	**128 064**	↑ 99 360	58	27
GAS_BASE_Q-4-24	**199,51**	**46,05**	↓ -17,97	187,00	229,50	**991 841**	↑ 397 620	449	186
GAS_BASE_S-S-24	**-**	**-**	-	-	-	**0**	→ 0	0	0
GAS_BASE_S-W-24	**206,46**	**47,66**	↓ -17,35	192,49	234,00	**899 808**	↑ 183 456	206	100
GAS_BASE_S-S-25	**-**	**-**	-	-	-	**0**	→ 0	0	0
GAS_BASE_ Y-24	**182,33**	**42,09**	↓ -20,19	169,50	214,00	**2 090 592**	↑ 852 048	238	119
GAS_BASE_ Y-25	**193,04**	**44,56**	↓ -13,29	182,00	215,00	**1 314 000**	↑ 157 680	150	102

Source: TGE - Monthly report, December 2023.

The achievement of competitiveness of biomethane heat in non-EU ETS sources will occur when biomethane and natural gas prices equalise, alternatively if the installed capacity threshold of EU ETS installations is lowered.

The heat sources covered by the EU ETS are medium- and large-capacity sources, which mostly operate as CHP plants and have different technical characteristics. For the purpose of this report, a CHP plant was assumed to have an average electricity generation efficiency of 55%, a heat generation efficiency of 25% and a total efficiency of 80%.

For the purposes of the report, gas-fired peak load boilers, which have an efficiency of around 95% and CO_2 costs will not overburden the heat generation process, are not considered.

The table below shows the impact of the CO_2 price for heat generation in EU ETS gas-fired CHP plants for a CO_2 price of 70 EUR/tonne (current prices) and 145 EUR/tonne (CAKE/KOBIZE projections for 2030). The admixture of biomethane in the fuel used by CHP plants at levels of 5%, 10% and 20% was also taken into account.

TAB. 17. Impact of CO_2 prices on heat production (in EUR/MWh).

CHP heat	CO_2 70 EUR/tonne	CO_2 145 EUR/tonne
Emission costs - 100% natural gas	10,5 EUR/MWh	21,8 EUR/MWh
Emission costs - 95% natural gas	10,0 EUR/MWh	20,7 EUR/MWh
Emission costs - 90% natural gas	9,5 EUR/MWh	19,6 EUR/MWh
Emission costs - 80% natural gas	8,4 EUR/MWh	17,4 EUR/MWh

Source: own study.

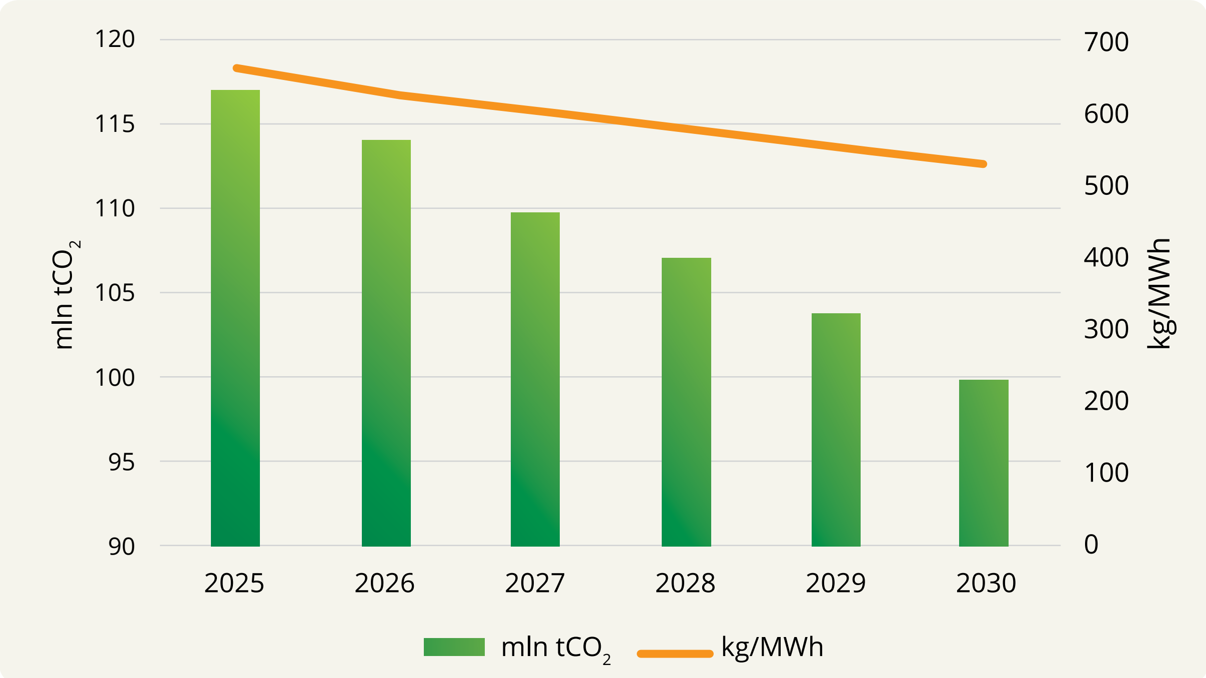
With a CO_2 price of 70 EUR/tonne and the combustion of 100% natural gas in thermal power plants covered by EU ETS, the heat produced will be burdened with an additional CO_2 cost of approx. 10 EUR/MWh, while with a CO_2 price of 145 EUR/tonne the CO_2 cost in heat will already be over 20 EUR/MWh.

With a biomethane admixture of 20% in network gas, the CO_2 costs in the price of heat will fall by more than 2 EUR/MWh at an emission price of 70 EUR/tonne and by more than 3 EUR/MWh at an emission price of 145 EUR/tonne.

6.4. Impact of biomethane on CO_2 reduction of the electricity sector in Poland in the 2030 perspective

The emissivity of power plants and combined heat and power plants is presented below, based on the Energy Policy of Poland until 2040 for the period 2025-2030.

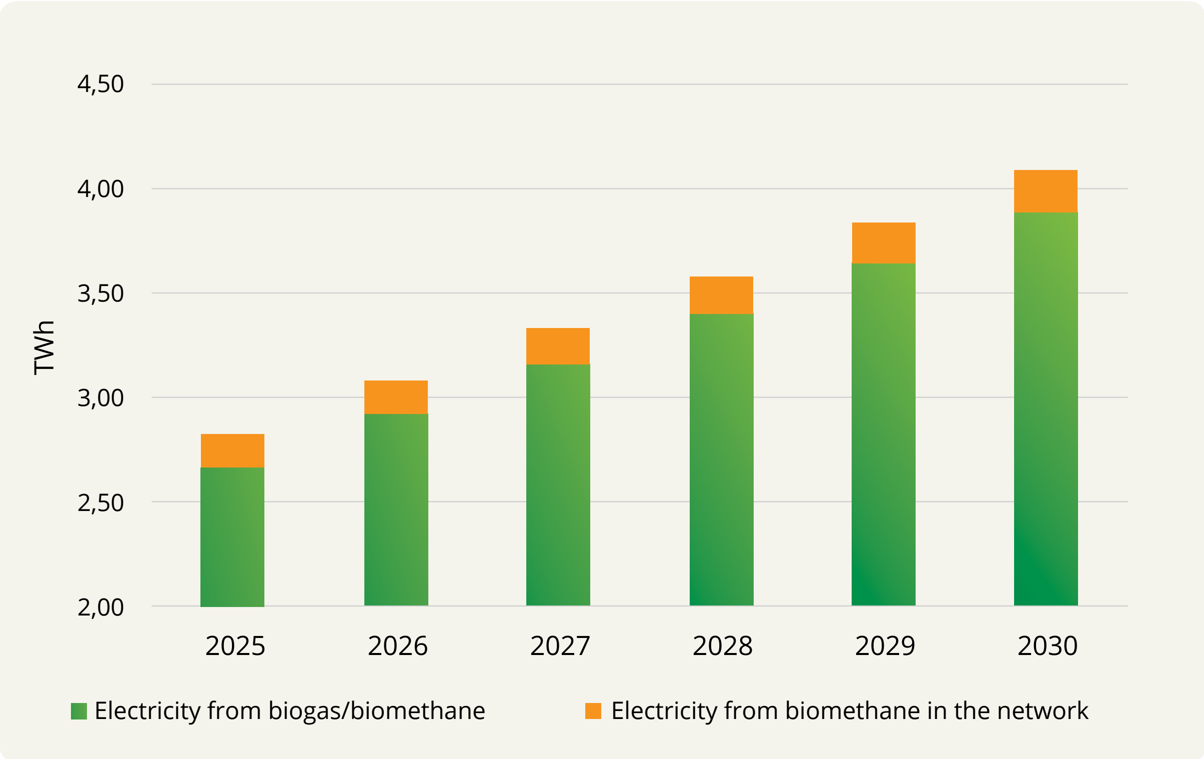
FIG. 37. Emission performance of power and CHP plants according to PEP2040.



Source: PEP2040.

For the purpose of estimating the CO_2 emission reductions in the 2030 timeframe associated with the development of biomethane-based electricity generation in Poland in the current absence of biomethane facilities, the period 2025-2030 was adopted for analysis. The volume of electricity generation from biogas/biomethane in this period was estimated at approximately 21 TWh, as illustrated in Figure 39 below.

FIG. 38. Electricity production in the period 2025-2030 [TWh].



Source: own study based on PEP2040.

In order to determine the total CO_2 reductions between 2025 and 2030 relative to the biogas/biomass plant development baseline included in PEP2040, two options have been analysed in which biogas/biomass electricity generation is replaced by conventional sources.

In option (a), 100% of electricity production from biogas/biomethane by 2030 from the baseline scenario is replaced by electricity production from coal-fired sources.

In option (b), electricity generation from biogas/biomethane by 2030 from the baseline scenario is replaced by 50% electricity generation from coal-fired sources and 50% from gas-fired sources.

Option (a)

Given that by 2030 PEP2040 does not envisage any changes in installed capacity in lignite sources and the development of new hard coal sources, for the purpose of this study the expert carbon intensity of the coal sources that will produce electricity as a substitute for biogas/biomethane sources was assumed to be 1.0 tonnes per CO_2/MWh. The table below shows the additional over baseline electricity production from coal sources and the additional emissions associated with this.

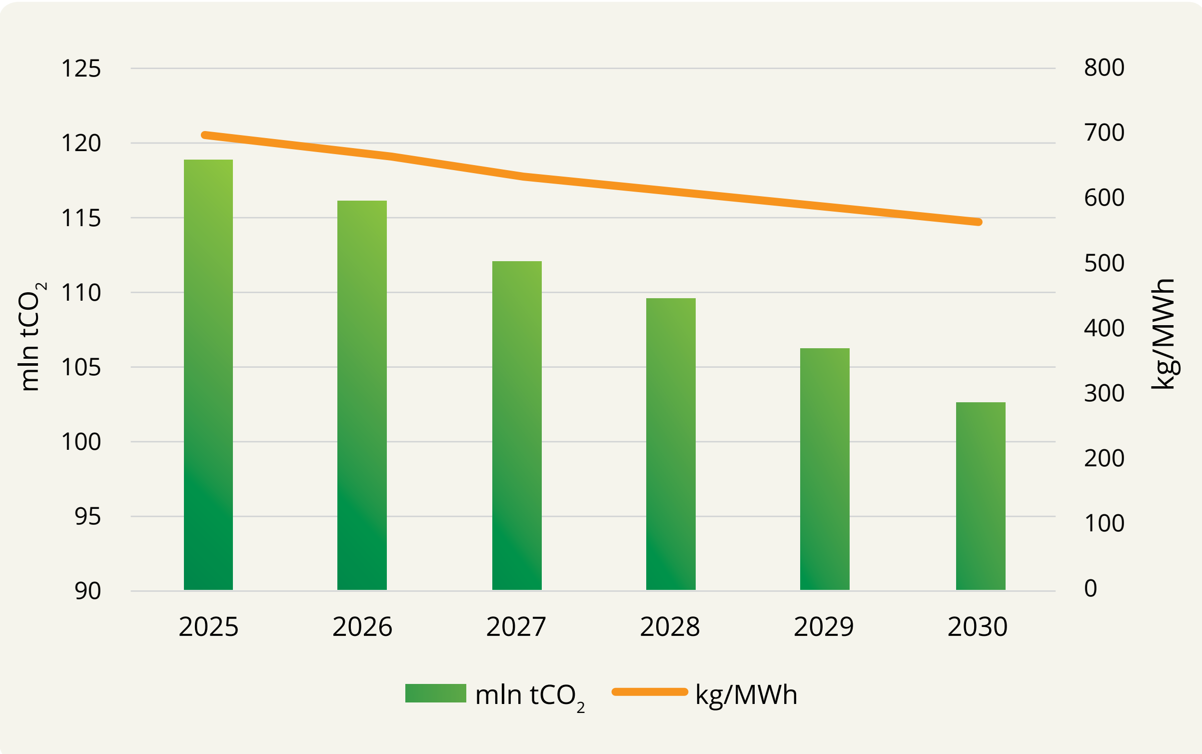
TAB. 19. CO_2 reduction - option (a).

	2025	2026	2027	2028	2029	2030	SUMA
Additional electricity production [TWh]	2.83	3.08	3.33	3.59	3.84	4.09	20.77
Additional emissions [million tCO_2]	2.83	3.08	3.33	3.59	3.84	4.09	20.77

Source: own study.

In this option, the avoided emissions associated with the development of biomethane in Poland have been estimated at around 21 million tonnes CO_2, with an average annual reduction over the study period of around 3.5 million tonnes CO_2 per year.

FIG. 39. Emissivity of variant (a)



Source: own study.

Option (b)

In this variant, the emission factor for gas sources due to the development of gas-fired CHP plants was expertly assumed at 0.32 tonnes CO_2 /MWh and the emission factor for coal sources at 1.0 tonnes CO_2. The results of the additional emissions and production volumes are shown in Table 20.

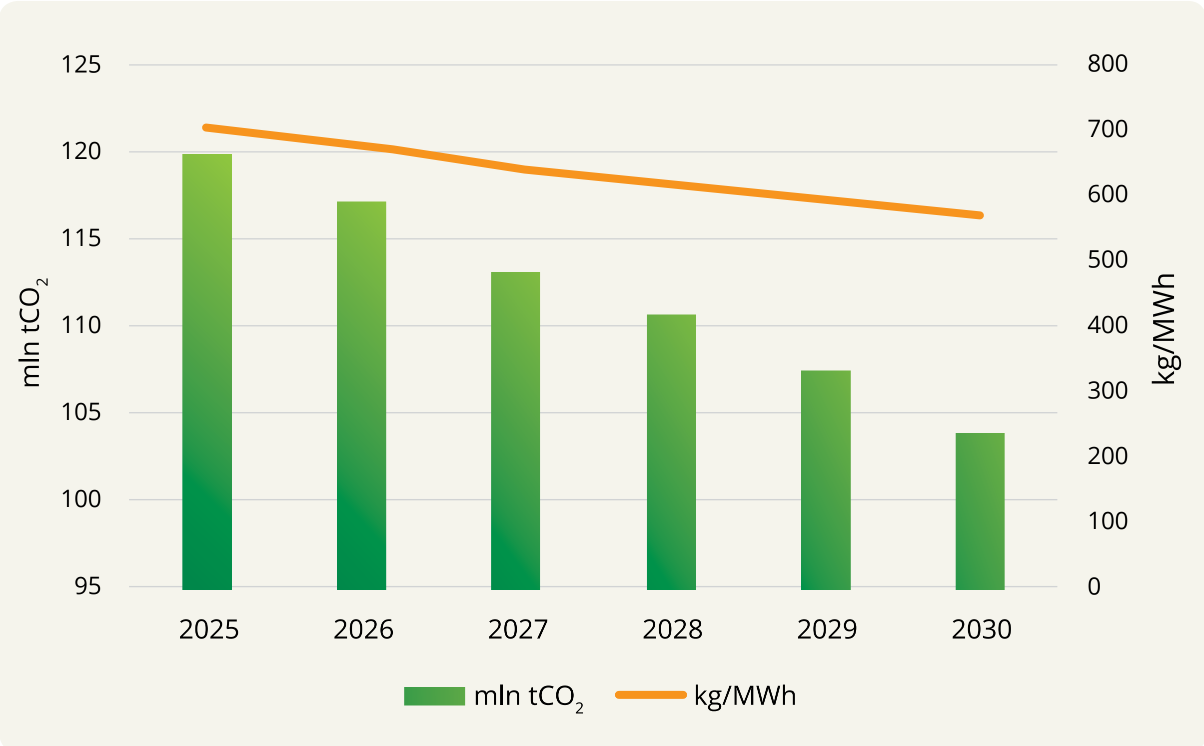
TAB. 20. CO_2 reduction - variant (b)

	2025	2026	2027	2028	2029	2030	SUMA
Additional electricity production - coal [TWh]	1.41	1.54	1.67	1.79	1.92	2.05	10.38
Additional electricity production - gas [TWh]	1.41	1.54	1.67	1.79	1.92	2.05	10.38
Additional emissions [million tCO_2]	1.87	2.03	2.20	2.37	2.54	2.70	13.71

Source: own study.

In option (b), the avoided CO_2 emissions associated with the development of biomethane in Poland have been estimated at approximately 14 million tonnes CO_2, with an average annual reduction over the study period of approximately 2.3 million tonnes CO_2 per year.

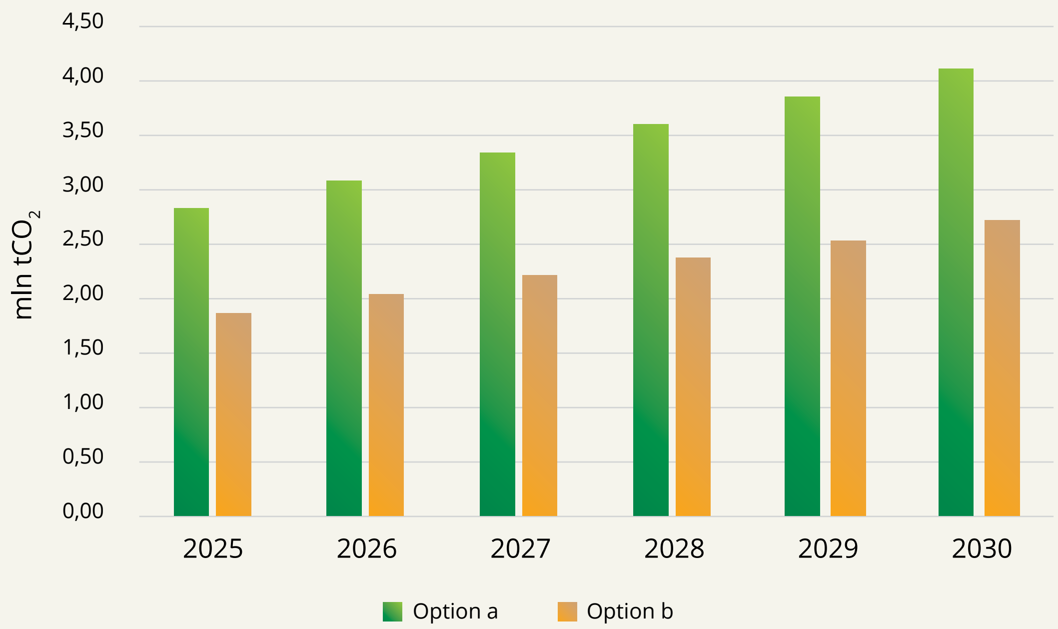
FIG. 40. Emissivity of option (b)



Source: own study.

The emission reductions for each option by year are shown in the graph below.

FIG. 41. Avoided CO_2 emissions over the period 2025-2030.



Source: own study.

To compare the total reduction of CO_2 in the analysed variants, the emissions of the electricity and heat sector in Poland in 2022 amounted to a total of approximately 136.9 million tonnes CO_2[172]. **In variant (a), the emission yield would therefore account for about 15% of the annual emissions of the entire energy sector in Poland, and in variant (b) it would be about 10%.**

172 KOBIZE, *CO_2 Market Report* - December 2022, Warsaw 2023.

TAB. 21. Summary of Poland's emissions under the EU ETS in 2021 and 2022 by sector.

Industry	CO_2 emissions (Mg)		Difference %
	2021	2022	
Main activity producer power plants	104 965 331	104 914 418	-0,05%
Main activity producer CHP plants	24 200 820	21 152 789	-12,59%
District heating plants	6 210 186	5 152 430	47,03%
Industrial CHP plants	6 372 520	5 663 296	-11,13%
Iron and steel industry	5 813 034	4 839 076	-16,75%
Non-ferrous metallurgy	2 004 405	1 838 187	8,29%
Cement industry	10 597 955	11 156 795	527%
Sugar industry	1 133 573	1 124 163	-0,83%
Chemical industry	9 787 938	8 293 445	-1527%
Wood-based industry	298 034	226 859	-23,88%
Coke industry	2 025 507	1 814 275	40,43%
Mineral industry	35 830	34 110	-480%
Other industries	2 106 693	1 538 495	-26,97%
Refinery industry	9 968 433	10 386 590	4,19%
Glass industry	2 283 326	2 212 759	-3,09%
Lime industry	1 797 803	1 598 056	41,11%
Ceramic industry	1 102 688	1 000 248	-9,29%
Paper industry	1 328 832	1 199 857	-9,71%
Total	**192 032 908**	**184 145 848**	**-4,11%**
Aircraft operators	487 570	795 207	63,10%
Total (incl. aviation)	**192 520 478**	**184 941 055**	**-3,94%**

Source: KOBIZE study.

CO_2 emissions of Polish industries covered by the EU ETS fell by more than 7.5 million tonnes between 2021 and 2022. Poland's total CO_2 emissions, which were covered by the EU Emissions Trading Scheme (EU ETS), amounted to nearly 185 million tonnes of CO_2 in 2022 and decreased by approximately 4% compared to emissions in 2021.

6.5. Conclusions

The economic analyses carried out in Chapter 6 indicate that the LCOE of biomethane sources at a biomethane price of 65 EUR/MWh estimated by DNV for 2035 in Poland is comparable to the averaged LCOE of gas sources with a gas price of 50 EUR/MWh and a CO_2 price of 70 EUR per tonne CO_2,

making biomethane an attractive economic alternative to natural gas especially in view of the assumed increases in the price of CO_2 emission allowances in the EU ETS well above the assumed level of 70 EUR per tonne CO_2. Crucial to the competitiveness of biomethane in electricity generation is the future price of natural gas. With relatively low natural gas prices (around 30 EUR/MWh), conventional gas plants remain cheaper than biomethanation plants even with high CO_2 prices.

Biomethane fed into the gas grid can also be competitive in district heating and serve to decarbonise the district heating sector. **Biomethane-generated district heating should remain competitive in contrast to conventional fuel-based generation sources above 20 MW, which are currently covered by the EU ETS**. With a CO_2 price of EUR 70/tonne and 100% natural gas combustion in EU ETS CHP plants, the heat produced will be burdened with an additional CO_2 cost of about EUR 10/MWh, while with a CO_2 price of EUR 145/tonne, the CO_2 cost in heat will already be more than EUR 20/MWh.

In contrast, the achievement of competitiveness of biomethane heat in non-EU ETS sources will occur when biomethane and natural gas prices equalise, alternatively if the installed capacity threshold of EU ETS installations is lowered, as the EU institutions are considering in the next revision of the EU ETS directive after 2030.

In order to determine the total CO_2 reductions between 2025 and 2030 compared to the biogas/biomethanation plant development baseline included in PEP2040, two variants have been analysed in which electricity production from biogas/biomethane is replaced by conventional sources. In option (a), 100% of biogas/biomethane electricity production by 2030 from the baseline scenario is replaced by electricity production from coal-fired sources. Under option (b), 50% of electricity production from biogas/biomethane by 2030 from the baseline is replaced by 50% from coal-fired sources and 50% from gas-fired sources.

In variant (a), the avoided emission associated with the development of biomethane in Poland has been estimated at about 21 million tonnes CO_2, and the average annual reduction over the studied period is about 3.5 million tonnes CO_2 per year. In variant (b), the avoided CO_2 emissions associated with biomethane development in Poland have been estimated at about 14 million tonnes CO_2, and the average annual reduction over the period studied is about 2.3 million tonnes CO_2 per year.

To compare the total CO_2 reduction in the analysed variants, the emissions of the electricity and heat sector in Poland in 2022 amounted to a total of approximately 136.9 million tonnes of CO_2[173]. **Thus, in variant (a), the emission yield in 2025-2030 would be about 15% of the annual emissions of the entire energy sector in Poland, while in variant (b) it would be about 10%.**

173 Ibid.

Summary

Summary

FIG. 42. Balance of benefits associated with biomethane uptake

CO_2 emission reduction

- Maximum achievable CO_2 emission reduction in the Polish electricity sector for the period 2025-2030 would be approximately 21 million tonnes.
- Through the gas infrastructure, biomethane will be able to contribute to the decarbonisation of Poland's electricity and heating sectors.

Strengthening energy security

- Reducing dependence on natural gas imports, thereby reducing exposure to geopolitical risks.
- By fully utilising the biomethane production potential of approximately 33.7 TWh combined with domestic production of approximately 40.7 TWh, the share of imports in supplying the domestic market could decrease from the current 80.97% (2023) to approximately 65%.*

Development impetus for agriculture

- Additional source of income for farms.
- Reducing methane emissions from agricultural production.
- Organic fertilisers as a by-product of biomethane production.

Source: Ministry of Industry, Reports on the results of monitoring the security of gas fuel supply for the period from 1 January 2023 to 31 December 2023, Warsaw 2024, p. 17.

Given Poland's production potential, biomethane should serve as one of the main means of decarbonising the country's gas industry, and thus the national economy. Because of its quality parameters, biomethane is an optimal substitute for the fossil natural gas currently in use. On the other hand, the use of the Poland's existing gas network for the dissemination of biomethane offers an opportunity to introduce this renewable gas into the economic cycle relatively quickly. Thanks to the decarbonisation of the gas industry through biomethane, it will also be possible to decarbonise the electricity and district heating sectors in Poland. Economic analysis has shown that, for example, system heat generated from biomethane should remain competitive in contrast to conventional fuel-based generation sources above 20 MW, which are currently covered by the EU ETS. In DISE's assessment, the implementation of such an outlined concept for the use of biomethane in Poland will require the following measures:

a. Update national energy policies taking into account the changing dynamics of an increasingly distributed energy system. Energy policies should indicate not only targets for biomethane capacity in the energy system, but also the extent of involvement in biomethane development by business, public administration, science and NGOs, including planned support instruments. Including this, the draft update of the NECP should indicate a much higher potential for biomethane.

b. Develop a National Biomethane Plan (consistent with the updated PEP2040 and NECP), including, inter alia, clearly defined targets for its production volumes, locations for its use, a target market model, the roles and tasks of the various stakeholders, and milestones for its implementation. The substantive work developed to date within the framework of the "Cooperation Agreement for the Development of the Biogas and Biomethane Sector" can be used here.

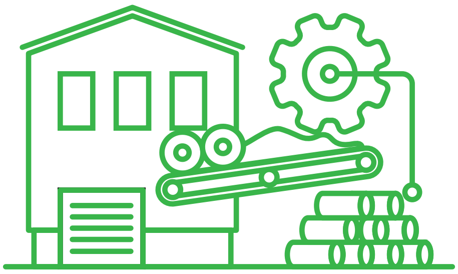
c. The experience of European countries clearly shows that the development of biomethane production on a wider scale requires the introduction of a support system by the state. In our view, such a system should include:
   » A system of guarantee of origin for this gas - an essential element to enable the development of biomethane production. Work on such a system is already underway in Poland and should not be extended.
   » Financial tools to directly support investors converting biogas plants to biomethanation plants or deciding to build a biomethanation plant from scratch.
   » A financial mechanism to compensate biomethane producers for the insufficient revenue generated from the market sale of biomethane. Such a mechanism has already been introduced.

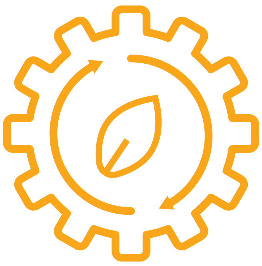
d. By way of a *de lege ferenda* postulate, an extension of the biomethane support scheme to units with a capacity of more than 1 MW could be indicated, taking into account the economic viability of such investments and the introduction of regulations that would prevent the use of energy crops instead of waste for the production of biogas and, consequently, biomethane, which would be contrary to the principle of sustainability with regard to gas production and agricultural cultivation.

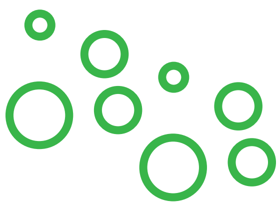
e. Administrative requirements in terms of the construction of biomethanation plants as well as the development of the distribution network (special acts) should be minimised.

f. The grid should be redeveloped with a view to decentralising it by increasing its absorption capacity and coordinating this with the development of district heating systems with biomethane/biogas in the power generation base.

g. Invest in increasing the absorption capacity of the gas distribution network and, where economically viable, develop alternatives in the form of "Virtual Gas Pipelines".







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The Lower Silesian Institute for Energy Studies (DISE), based in Wrocław, is a think-tank actively involved in energy security and energy transition issues in the strategic dimension, as well as concepts for the operation of energy markets, business models for energy companies and industrial energy consumers, and also the effectiveness of infrastructure projects.

DISE is made up of an interdisciplinary group of academics and active managers occupying managerial positions in key companies in the energy sector. Our experts are characterised by a combination of theoretical knowledge and practical experience in managing the largest economic entities in Poland, which allows us to identify barriers and challenges in the Polish energy sector on the pages of numerous popular-scientific publications, analyses and expert opinions. DISE experts critically analyse the current situation in the energy market and formulate strategic recommendations in the form of analytical studies and comprehensive reports. The DISE team focuses, in particular, on renewable energy, low-carbon energy, especially nuclear technology, the use of natural gas and renewable gases, as reflected in four reports published to date, carried out in cooperation with important climate and energy organisations and major Polish oil and energy companies.

We also provide substantive support to Polish and EU parliamentarians. We organise the annual Energy Congresses in Wrocław, an international highly respected forum of debates among policy makers, politicians and energy industry practitioners, aimed at jointly developing solutions for the security and transformation of the Polish energy sector. An important area of DISE's activity is education, i.e. activities aimed primarily at raising the competence of energy industry managers. Combining the expertise and long-term experience of DISE experts with best practices of leading foreign energy sector entities, we organise study tours to learn about the latest technical solutions in energy infrastructure facilities around the world (e.g. offshore wind farms, gas terminals or hydrogen facilities). The value of the study tours organised is the transfer of knowledge during seminars and learning about the cutting edge technologies and experiences in infrastructure operation. We also provide workshops and training for young people to raise public awareness of renewable energy, prosumerism and responsible energy management (e.g. classes in energy clusters). We firmly believe that our activities are changing the face of the Polish energy sector for the better and are initiating desirable legal changes for energy investments with future generations in mind.

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