TECHNISCHE UNIVERSITÄT WIEN
Vienna University of Technology

CHARLES UNIVERSITY

Biomethane production: current state, perspectives, feedstock, and economic evaluation in Austria and the Czech Republic

Camila Rodríguez M., Tomáš Moudrý

Cooperating universities

PRAGUE UNIVERSITY OF ECONOMICS AND BUSINESS

CZECH TECHNICAL UNIVERSITY IN PRAGUE

Funding agencies

AKTION

In cooperation with

CZ-AT EEG
CZECH-AUSTRIAN ENERGY EXPERT GROUP

Prague and Vienna, 01.06.2023

Abstract

In light of the recent events in the energy field and the urgent necessity for achieving low–carbon targets, EU countries have been forced to establish new policies and actions that promote further development of renewable energies. In this sense, biomethane has gained significant attention since it is a promising carbon-neutral renewable energy source because it utilizes organic waste as a feedstock, removing fossil fuel dependence. Biomethane is included in the REPowerEU initiative and has the potential to play a vital role in achieving the objections set in the initiative. Biomethane industrial partnership is another example of the EU's energy orientation for a future ramp-up. Therefore, it is essential to evaluate the evolution and limitations of production technologies and their economics, competitiveness, and perspectives. The first part of this paper intends to provide an overview of the biogas production and upgrading technologies, types of available feedstock, and its limitations and future solutions. The second part gives a technical and economic evaluation of the biomethane potential to be integrated into the Austrian and the Czech Republic's energy mix. The results of this study provide a better outlook on the possibility of implementing this type of energy and its competitiveness with other energy sources.

Contents

1. INTRODUCTION 3
2. LITERATURE REVIEW 5
   - 2.1. Types of available feedstocks 6
   - 2.2. Biogas production technologies 8
     - *2.2.1. Basics of Anaerobic Digestion (AD)* 8
     - *2.2.2. Anaerobic Digestion Technologies* 9
   - 2.3. Biomethane production: biogas upgrading technologies 13
3. METHODOLOGY 15
4. RESULTS 16
   - 4.1. Support schemes within the EU 16
   - 4.2. Consumption of Biomethane within the EU 18
   - 4.3. Biomethane in Austria 21
   - 4.4. Biomethane in the Czech Republic 23
   - 4.5. Long–term visions for Austria and the Czech Republic 24
5. Conclusions 26

REFERENCES 27

1. INTRODUCTION

Overview in Europe and Perceptions of Biomethane in EU Institutions

Biomethane plays a vital role in European Commissions' plans for the future as one of the critical renewable gases of tomorrow. Russian invasion accelerated the need to diversify the gas suppliers within the EU. Two main objectives are the fast reduction of Russian gas dependency and the diversification of gas importers. Both have their advantages and disadvantages. On the one hand, it implies the need for considerable investments to boost energy efficiency, raise the percentage of renewables in countries' energy mixes, and build infrastructure. In terms of potential, biomethane has a vast potential. The EU is aware of that, and the mission is more evident for now – the EU has to unlock this potential. Afterward, biomethane can help to achieve ambitious targets set in the REPowerEU plan, released by European Commission (EC) on March 8, 2022. [1.1] For the smoother implementation of the REPowerEU, the EC released a Staff Working Document which summarises the stances of the EU and what and how it should be done.[2.1]

Annual biomethane production has been set to 35 BMC by 2030. The goal is to support production to a sustainable maximum with its future transformation and upgrade from biogas to biomethane. To upscale biogas production, waste collection systems within the EU member states must improve and strengthen to attract and create new opportunities for potential stakeholders. Perception of avoiding food and feedstocks is more than evident from the EC views because it could cause problems in the countryside, especially on the land, that could further sluggish the transition. [2.1]

Biogas and biomethane industrial partnerships can be very useful in promoting sustainable production. This initiative's primary goal is to support biomethane's growth and create conditions for further years. A platform for strategic discussions of the stakeholders is well needed because it could lead to further engagement and, more importantly, to public acknowledgment and acceptance of the entire switch towards renewables. Other vital actions are developing national strategies, increasing the amount of biomethane and biogas in countries' energy mixes, and, more importantly, forming the public debate and providing a public space to implement national energy and climate plans. This development should be based on sustainable ways with an accent on waste base products such as agricultural, forest, and food industry wastes. That could also contribute to reaching the Methane Strategy of 2020. Another critical harmonization and standardization in the field and of the market. Speaking of that, EC, besides the EU member states, could be the leading actor in addressing the issue. [2.1]

Biogas transition into biomethane is one of the essential things of the plans. One obstacle that discourages stakeholders from investing or strengthening their engagement in the field is money. Now it is too expensive to upgrade biogas to biomethane. That is just one factor that leads to the main problem – the low profitability of biomethane. The aim is apparent. To reduce the costs which are currently sluggish the development. Significantly, the entry of individual economic operators into the production of biomethane.

The most significant prices are for upgrading, connecting, and injecting the grid. The most possible scenario for reducing the costs is to share them. Cost sharing between grid operators and biomethane providers is one of the few examples of cost–sharing.[2.1] These are a few suggested actions and suggestions that could open the deadlock and unlock the full potential of biogas and biomethane within the EU, and the Biomethane Industrial Partnership (BIP) is one of them. It was established to help implement the biomethane targets set in the REPowerEU plan. BIP is a collaborative initiative among stakeholders in the business. It should encourage them to collaborate and work together to achieve the climate targets for 2030; therefore, creating a prerequisite for the 2050s targets.

In 2021 biomethane production was just 3,5 BMC compared to total European gas consumption of 412 BMC. [3.1]The speed and amount of investment in the development and structure are vital and must be as effective and precise as possible. According to European Biomethane Association (EBA), the sector needs more than €83 billion inflow to reach the targets, hand in hand with the construction of more than 5,000 new plants by 2030.[4.1] Of course, it depends on many factors, but gas for climate shows that the price for one MWh by 2050 should be between 57–66€.[4.1] Furthermore, it is estimated that biomethane has the potential to cover up to 35–62 % of gas demand by 2050. Potential can be fulfilled using waste from farms and food sectors, crops, and municipal and industrial streams. Such development in the industry will also require about 420 000 new job positions by 2030 and more than double by 2050. [4.1]

2. LITERATURE REVIEW

The development and introduction of clean gases in the energy system are crucial to the “net-zero emissions 2050 roadmap” set by the International Energy Agency (IEA). [1] These gases are produced by Renewable Energy Sources (RES); therefore, decarbonizing natural gas by displacing fossil fuels usage. One of the main routes for this is creating a high-methane-content gas from biomass or organic waste, or the so-called biogas.

Biogas is conformed mainly from methane (CH_4, up to 75%) and carbon dioxide (CO_2, up to 50%), from which their composition depends on the feedstock and type of process. Additionally, it contains small amounts of nitrogen (N_2, 0-3%), water vapor (H_2O, 5-10%), oxygen (O_2, 0-1%), hydrogen sulfide (H_2S, 0-10000ppm), ammonia (NH_3, up to 200 mg/m^3), and siloxanes (up to 40 mg/m^3) which can affect the quality of the gas. [2], [3] Although this seems to be a great alternative to fossil natural gas, the presence of hydrogen sulfide provokes corrosion on the transporting pipelines, and the high concentrations of CO_2 reduce the Wobbe index and heating value of the gas; therefore, it must be removed in any case. In addition, the gas grids require a minimum methane purity of 95% and low or no impurities. Therefore, the biogas must be treated or upgraded to biomethane by different methods, such as adsorption, membrane separation, or cryogenic separation, before being injected into the grid and utilized by the end users. [3]

Biogas and biomethane technologies are expected to be rapidly developed, increasing 2020 production six times by 2025 (Figure 1). Almost 20% of the global final energy in 2050 will be supplied by biofuels such as biogas, biomethane, and hydrogen. Biogas and biomethane will also be included in cooking and electricity generation applications in this scenario. [1]

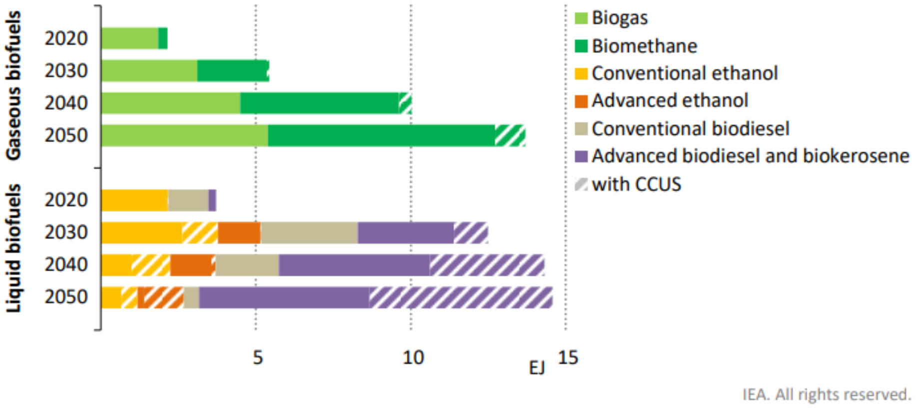


Figure 1. Liquid and Gaseous biofuels production in the Net-Zero Emissions scenario. Source: [1]

2.1. Types of available feedstocks

Many different organic feedstocks can be used to produce biogas by anaerobic digestion. These materials are required to yield high concentrations of methane, which is evaluated by estimating the Biochemical Methane Potential (BMP) through chemical characterization or computational simulations [4]. This value determines the biodegradability and decomposition capacity of the raw material [5]. Generally, agricultural residues, energy crops, and organic wastes are the most used; however, as their compositions and properties differ greatly, the biogas quality also varies. The suitability of the raw material to be processed by anaerobic digestion strongly depends on the water content and inorganic compounds. *Figure 2* shows the relevance of these parameters. It can be observed that significant water content and low bulky/fibrous material, and inorganic matter are preferred for anaerobic digestion. [6]

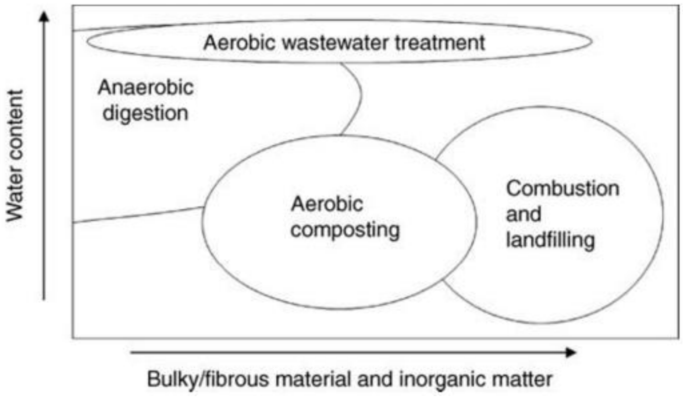


*Figure 2. Feedstocks' inorganic matter and water content variability for different processes** Source:* [6]

Additionally, factors such as the seasonal availability of the feedstock and its temperature (*Figure 3*) must be considered. For example, food crops and municipal waste vary depending on the time of the year; therefore, storing in deposits or sillages is crucial for the biogas plants to operate throughout the year. Furthermore, the temperature to which the material is exposed highly influences the microorganisms of the digestor. In this sense, elevated temperatures must be controlled and avoided [6]. In the same vein, the degradation process also depends on the particle size of the raw material, hence, the surface area from which the enzyme's adsorption takes place. This fine matter must be compacted and isolated from the surrounding environment by an impermeable surface such as a special film. This way, the system's deterioration and declination due to particle's conglomeration can be avoided. [7].

The intrinsic characteristics play an essential role in the process yield. First, the micro- and macronutrients are fundamental for the microorganisms functioning, and their composition determines the interactions within the digestor. The macronutrients include carbon (supplied from the feedstock), nitrogen, phosphor, and sulfur. These elements are required to stabilize the cells, synthesize proteins, transfer energy, and grow necessary components such as amino acids. Micronutrients, such as magnesium, iron, cobalt, nickel, and zinc, facilitate the reproduction of microorganisms by reacting with different components and synthesizing substances needed in anaerobic digestion.

On the other hand, the presence of high concentrations of metal elements can inhibit the process since they tend to accumulate and interfere with the enzyme's functionality. These heavy metals are minor in food crops. [7]

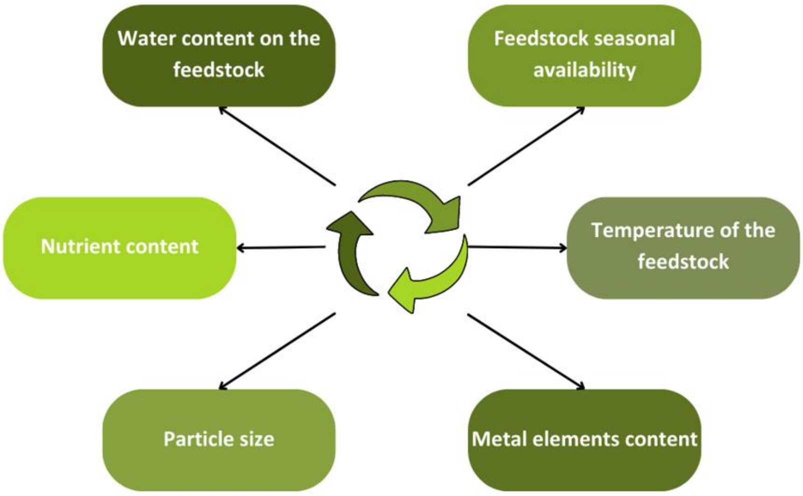
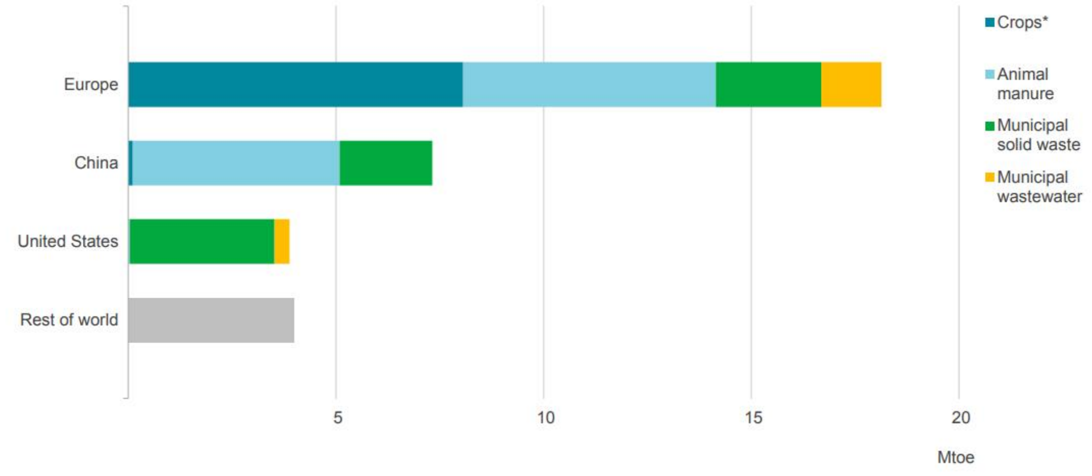


Figure 3. Factors affecting the feedstock properties and suitability for biogas production by the anaerobic digestion process. Information obtained from: [6], [7]

According to the International Energy Agency (IEA), residues from food crops such as maize, rice, sugar cane, wheat, and soybean are used for biogas production. Animal manure, organic matter from municipal waste, and wastewater sludge are suitable for this process. However, woody biomass is preferred for biomethane obtention [13]. This process is carried out by thermochemical conversion of the lignocellulosic biomass by gasification and pyrolysis processes [8].

Figure 4 shows the *biogas or biomethane production* in 2018 by feedstock source and region. In Europe (the largest biogas producer), crops and animal manure are preferred over municipal waste. These animal and energy crops should not compete with the feed industry; therefore, materials with no economic viability or application, such as roots or lignocellulosic material from animals are prioritized [5]. Meanwhile, the most significant production in China comes from animal manure and municipal waste due to the high number of installed household digesters (around 70% of biogas capacity). In the USA, landfill gas collection is the main route to obtain biogas, from which municipal solid waste (MSW) is the primary source.



* Crops include energy crops, crop residues and sequential crops.
Note: 1 Mtoe = 11.63 terawatt-hours (TWh) = 41.9 petajoules (PJ).

Figure 4. Biogas or biomethane production by feedstock source, 2018. Source: [9]

2.2. Biogas production technologies

Anaerobic Digestion (AD) is the most common and widely used process for biogas production. The present chapter intends to overview the process and the existing technologies.

2.2.1. Basics of Anaerobic Digestion (AD)

The overproduction to meet the population's demand has created a great concern over solid waste management for centuries. These residues require a controlled disposal to avoid odor and lixiviation. It was not until the 18th century that the production and collection of biogases from a natural anaerobic process were discovered. Over the following centuries, anaerobic digestion was purposely developed using municipal solid waste, wastewater, and sewage. [10]

Anaerobic digestion consists of degrading organic matter by utilizing microbial organisms in an anoxic environment. The products are mainly a gas mixture (biogas) and a semisolid compound. Different reactions between the bacteria and organic substrate occur during the decomposition. [10] These reactions are displayed in Figure 5.

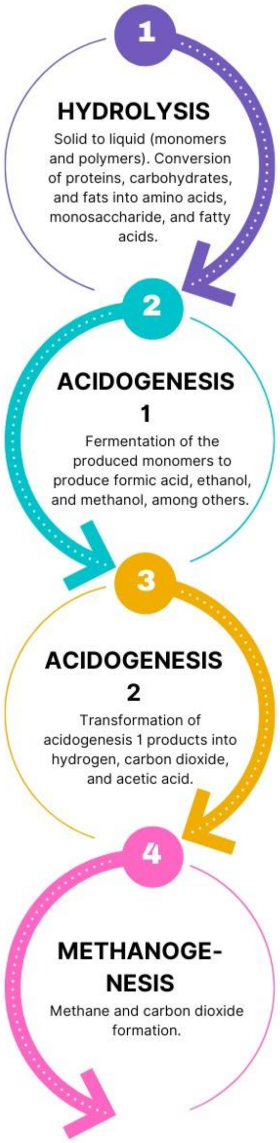


Figure 5. Anaerobic Digestion conversion reactions. Information obtained from [10]

The digestion can be produced by batch, continuous or single- and multiple-stage, and differ by operating parameters, efficiency, and costs. It is the latest, the most efficient, but the most expensive one as it requires several digestion tanks. In addition, the process also varies depending on the feedstock type; therefore, many technologies have been developed with individual characteristics and operating conditions. [10]

2.2.2. Anaerobic Digestion Technologies

Anaerobic digesters differ on the operational parameters such as residence time (RT), hydraulic retention times (HRT), feedstock loading and nature (water content), and from operating expenses and appliances. It is stated that wet digestion (dry matter content ≤ 15%) is more stable as it requires lower

RT compared to dry digestion (dry matter content > 15%) systems. In addition, the necessity of larger dimensions of a single-stage digester reduces its efficiency compared to a two-stage process. [11] These technologies are shown in Figure 6.

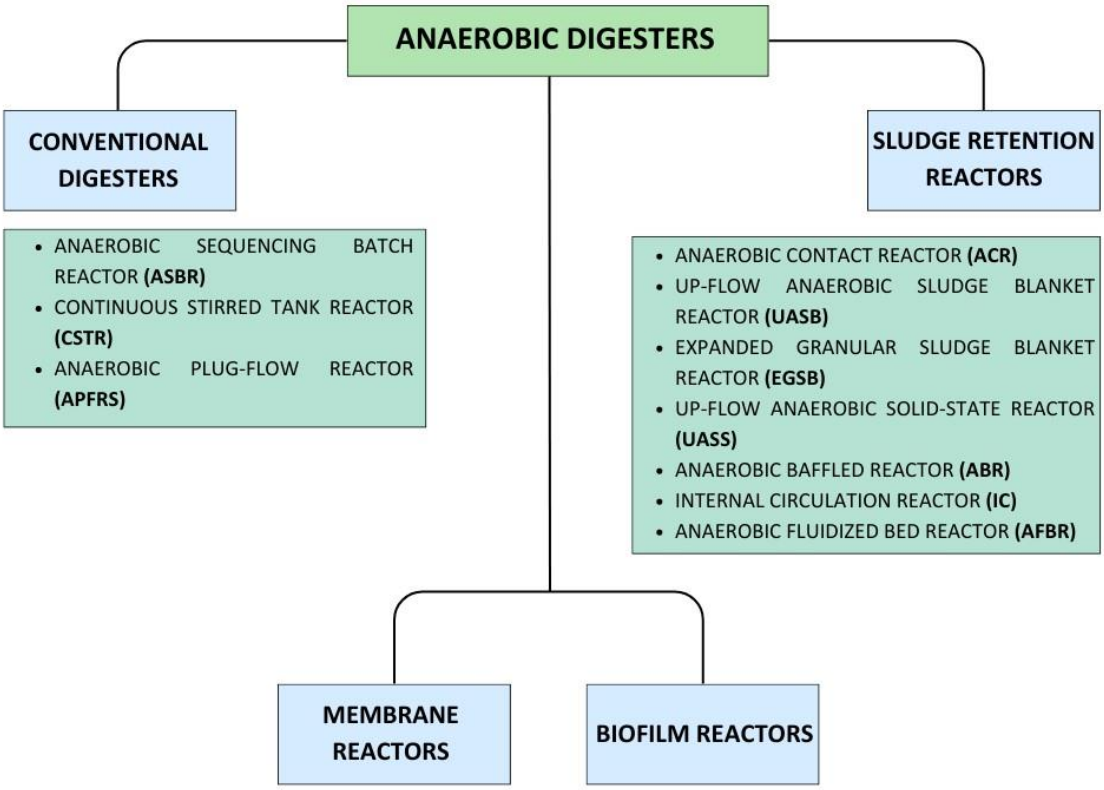


Figure 6. Anaerobic digesters. Information obtained from [11]

The conventional technologies include the Anaerobic Sequencing Batch Reactor (ASBR), the Continuous Stirred Tank Reactor (CSTR), and the Anaerobic Plug-Flow Reactor.

ASBR is the simplest system, requiring a single tank and no stirring. In this reactor, digestion occurs after injecting the wastewater (feedstock) with the existing sludge. After that, the sludge is left to settle and left in the tank for the next batch after the water is drained. This system is generally used for low-volume flows. [11]

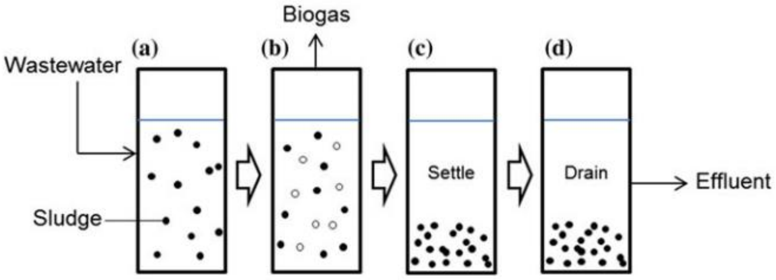


Figure 7. Anaerobic Sequencing Batch Reactor (ASBR) scheme. Source: [11]

The CSTR allows the continuous insertion of the substrate, which gets in contact with the microorganisms by constant mixing. Its configuration has excellent advantages, such as parameter uniformity and system simplicity. [12] However, it also requires high residence times and energy. These aspects can be improved by recycling the microbial matter to the tank after sedimentation on an additional tank. [11]

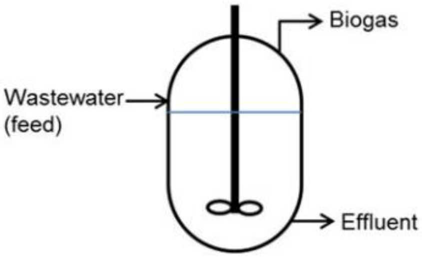


Figure 8. Continuous Stirred Tank Reactor scheme. Source: [11]

Finally, the APFR has a higher biogas conversion efficiency than CSTR. They consist of an inclined reactor with long channels where the organic matter (e.g., wastewater, slurries from organic compounds, and municipal solid waste) is injected from the bottom, and the effluent and biogas are collected from the top. The microbial sludge increases activity along the reactor providing excellent stability and efficiency. [11]

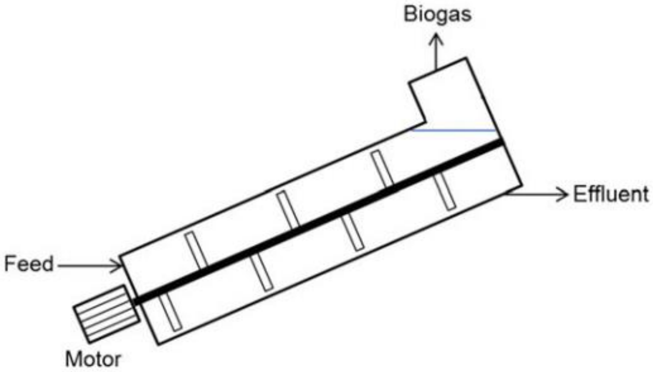


Figure 9. Anaerobic Plug-Flow Reactor scheme. Source: [11]

Although conventional technologies have been proven to be sufficient for biogas production, the efficiency and stability of the reactor can be enhanced by the retention of the sludge. For example, the up-flow anaerobic sludge blanket reactor (UASB) differentiates by suspending the granular sludge on the lower zone of the reactor and retaining it by gravity, increasing the dimensions of the upper area of the reactor. [11]

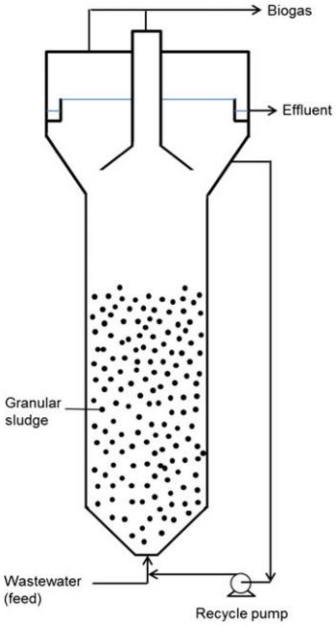


Figure 10. Up-flow anaerobic sludge blanket reactor (UASB) scheme. Source: [11]

Alternatively, membrane-base digestors use an additional ceramic or polymeric membrane which can retain the biomass and recycle it back to the reactor. This system greatly increases the efficiency since the membrane rentate contains higher concentrations of biomass than the granular sludge blanket reactor. On the other hand, it increases the costs since the membranes need regular replacement.

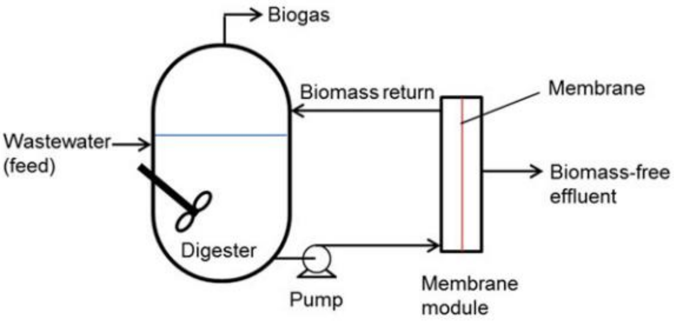


Figure 11. Membrane-based digestor. Source: [11]

2.3. Biomethane production: biogas upgrading technologies

As previously mentioned, the biogas from digesters contains significant amounts of carbon dioxide (CO_2) and trace gases such as hydrogen sulfide (H_2S), siloxanes, and nitrogen (N_2). These gases are considered contaminants as they decrease the biogas quality. For this reason, purification and upgrading are essential to enhance gas versatility. This chapter reviews the available technologies for contaminant removal.

Physical or chemical CO_2 removal consists of the contaminant separation under certain operational conditions by utilizing another gas, liquid, or solid with an affinity to it. As shown in Figure 12, the most common processes for it are water scrubbing, chemical scrubbing, Pressure Swing Adsorption (PSA), and membrane technology. [11]

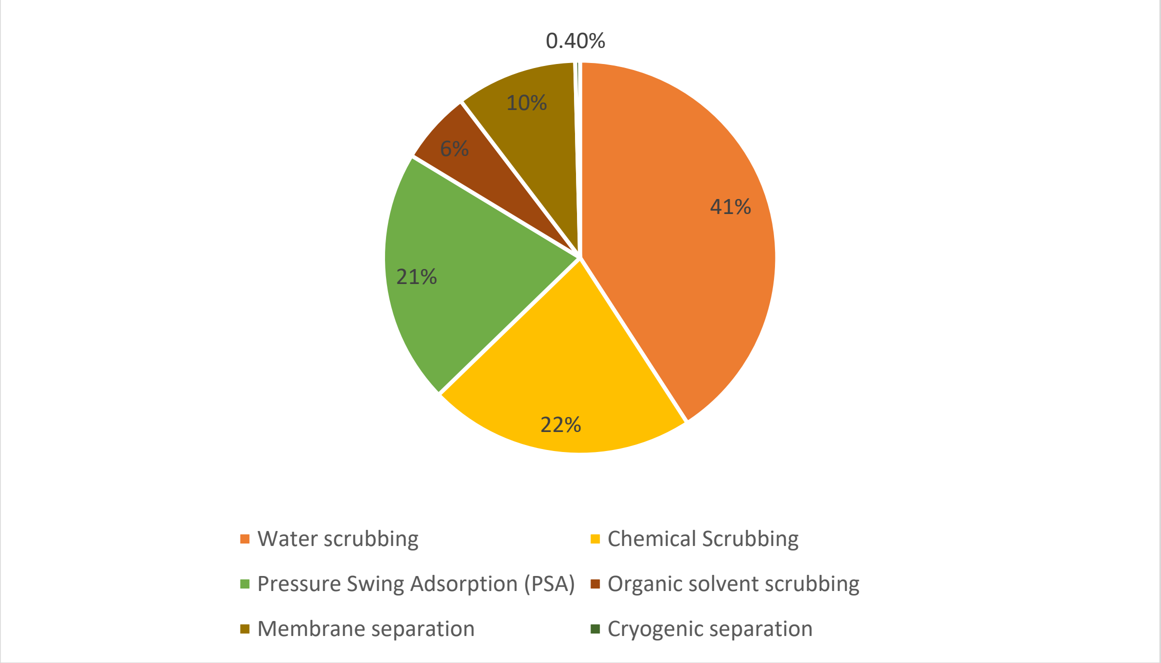


Figure 12. CO_2 removal technologies. Information obtained from [11]

Water scrubbing uses water as a reactive agent as it has higher solvent properties towards CO_2 than CH_4 at standard conditions. The process occurs at relatively high pressures of around 6 to 10 bar, where the water adsorbs the carbon dioxide, and it's later regenerated on a stripping column for further utilization. [11] Additionally, this technology has the advantage of H_2S removal on an initial step and requires a low-cost adsorbent. [13]

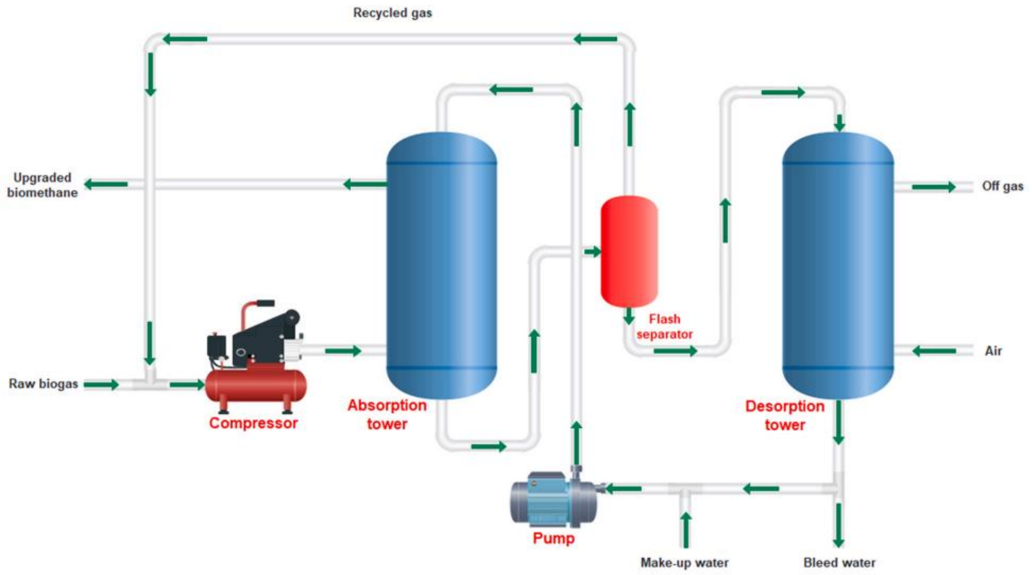


Figure 13. Water Scrubbing scheme. Source: [13]

Furthermore, chemical scrubbing has a similar configuration than water scrubbing; however, it requires a chemical (e.g., KOH, NaOH, or K_2CO_3) that reacts with the CO_2 in reverse mode, allowing the regeneration of the solvent in a second step. Examples of the possible reactions are presented in Equation 1 and Equation 2. [11]

$$CO_2 + 2OH^- \rightarrow CO_3^{2-} + H_2O \qquad \text{Equation 1}$$

$$CO_2 + CO_3^{2-} + H_2O \rightarrow 2HCO_3^- \qquad \text{Equation 2}$$

Lastly, solid adsorption is performed by Pressure Swing Adsorption (PSA). Standard materials are activated carbon, silica, or zeolite, which provide a porous surface with active sites for adsorption. This technology requires that the inlet gas is pre-treated, eliminating any H_2S trace from the stream.

The process consists of four vertical columns which contain the adsorbent material in a bed. The contaminant is removed by alternating adsorption and desorption steps. In the second one, the component is released by reducing the pressure allowing the adsorbent to regenerate. Compared to other technologies, the PSA has significant advantages at medium capacities since it produces a highly pure biomethane with high efficiencies and cost-effectiveness.

3. METHODOLOGY

This paper is a result of a literature review. The information withdrawn was obtained from research papers, official websites, and reports and is intended to give a broad technical and economic vision of biogas and biomethane status in Europe. The search was performed using search engines such as Google Scholar, Science Direct, Scopus, JSTOR, the European Commission, European Biomethane Association (EBA), and International Energy Agency (IEA) official webpages. The following keywords were utilized: “biogas,” “biomethane,” “feedstock,” “anaerobic digestion,” “European Union,” “energy,” “policies,” “renewable energy sources,” “biogas upgrading,” “technologies,” “Austria,” “Czech Republic. ”

Special attention was given to the Renewable Gas Trade Centre in Europe (Regatrace) project. Report from this project assesses remarks such as policy recommendations for the uptake of biomethane production and cross-border trade, results, and impacts of the REGATRACE project on the biomethane industry and state-of-the-art systems for documenting cross-border biomethane transfer.

4. RESULTS

4.1. Support schemes within the EU

Besides many differences within EU member states in biomethane, the support schemes are no exception. There are a few types of support listed below:

Investment support

A fixed amount of money is obtained before, during, and after the building phase of the project/plan.

Fiscal incentives

Such as tax reductions or even exemptions. This type of support is usually just additional or minor in some cases to the support systems. Moreover, the effectiveness of those depends on the applicable tax rate.

Quota /green certificates schemes (TGC)

There is a target or specific percentage of renewable energy in the system's mix of producers, consumers, or distributors. Additional revenue to electricity sales is provided through the certificates. One can benefit from sell of electricity hand in hand with the certificate sell both respective markets.

Feed in Tariffs (FIPs)

This specific support scheme provides technologically specific remuneration per unit of renewable energy. The tariff is guaranteed and defined by public or local authorities and disposes of a few advantages, such as long–term contracts with producers, grid access, which is guaranteed, and payment levels based on the energy generation costs.

Feed in Premium/Green bonus (FIP)

This system contains, apart mentioned above in Feed in Tarif, a bonus through which one can access pre-specified benchmark market prices. It can be designed to avoid externalities in the market price or to help cover the energy generation price by total payment. As of now the FIT combined with FIP are the most widely used support schemes of biogas in Europe. [14.1.]

These are primary subsidiary or supportive schemes in Europe right now. To examine the differences, see the attached overview below. [5.5.]

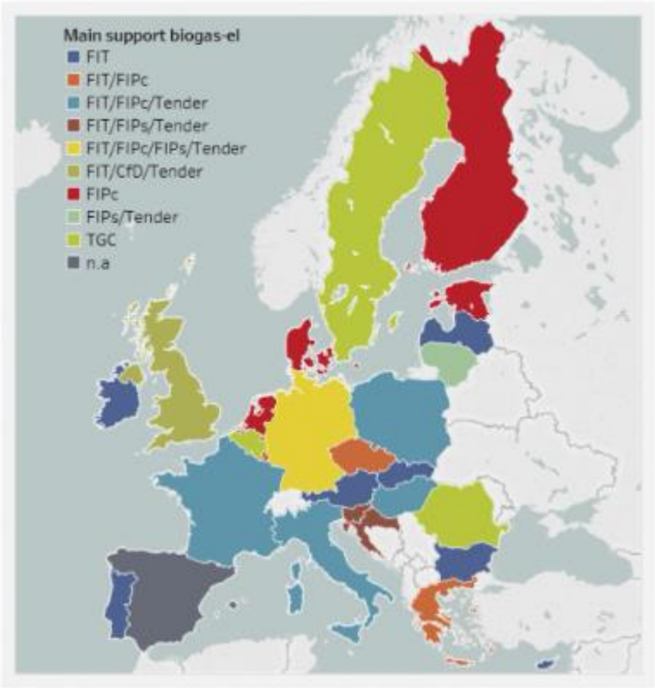


Figure 14. Support schemes of biogas in Europe. Source: 14.1.

Regatrace Initiative

There is one particular project from the Horizon 2020 Initiative related to the topic and assesses the current state of art and long–term views. The Project is called REGATRACE – Renewable Gas Trade Centre in Europe – the duration was over three years, starting on June 1, 2019, ending on November 30, 2022. The primary objective according to EU Commission, is as follows: *The Eu funded REGATRACE project will create an efficient trade system based on issuing and trading biomethane/renewable gases Guarantees of Origin (GoO) along with cost-effective logistics. According to the project, a Europe-wide trade center for biomethane (and other renewable gases) is necessary for enabling investments and promoting cross-border biomethane trade. This is part of broader efforts to decouple Europe's energy systems from fossil fuels.* [8.1] The outcomes were presented in November in Brussels at The Regatrace Conference. [7.1] Two of the report papers made by researchers from across the EU, presented at the conference, are used as primary sources in the following paragraphs. [5.1],[6.1]

Significant differences exist in the implementation level of biomethane across the EU. REGATRCE reflects the fact and aims to deepen the cooperation among EU member states. According to the paper, there are four central pillars through which the objectives should be achieved.

- *European biomethane/renewable gases GO system.*
- *Set – up national GO issuing bodies*

- *Integration of GO from different renewable gas technologies with electric and hydrogen GO systems.*
- *Integrated assessment and sustainable feedstock mobilization strategies and technology synergies*
- *Support for biomethane market uptake Transferability of results beyond the project's countries* [5.1]

European countries are divided into three main categories in the Regatrace project. The target countries are Belgium, Poland, Ireland, Italy, Lithuania, Spain, and Romania. Countries with already existing systems of registries are Austria, Germany, the United Kingdom, Netherlands, Switzerland, Denmark, France, Estonia, and Finland. Supporting countries of the Initiative with either low levels of the development of registries or scarcely any are the Czech Republic, Croatia, Greece, Latvia, Ukraine, Sweden, and Slovakia, as you can see in the overview listed below.

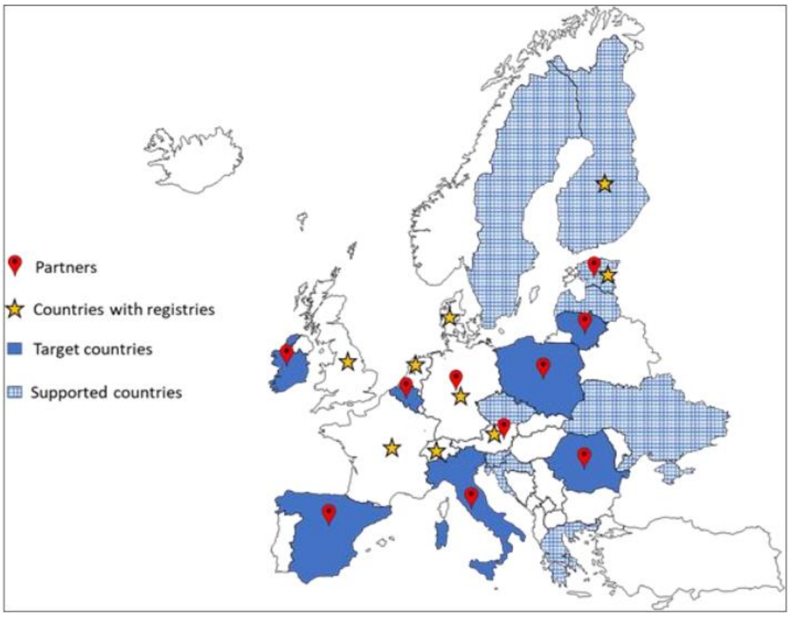


Figure 15. REGATRACE countries and partners. Source: 5.5

4.2. Consumption of Biomethane within the EU

As stated above, EU countries still have many differences in renewable gas production. Germany was a top producer in 2018 with over 10,000 GWh, followed by the UK with approximately 3,000. Nederland’s production was 2,200 in the same year. Meanwhile, Denmark, Sweden, and France had similar numbers, around 1,300 GWh. Besides Germany and Sweden, there was not any other country in Europe that used gasification in the production of renewable gases. Overall, the vast majority of renewable gases are produced through the anaerobic digestion process. [5.1]

The table below shows that consumption and production are well balanced, but a few exceptions exist. Denmark produces more than three times more than the Danish power grid consumes. Meanwhile, in Sweden, there is precisely the opposite situation. It is related to the orientation of the state on consumption or production. Sweden is focused on the consumption side, which subsidizes, or more importantly, has a tax exception. In other European states, the situation is vice versa. Many states support the production or injection of biomethane side rather than consumption via subsidies. Furthermore, Germany produced roughly 1,500 GWh more than it consumed; part of this overproduction was sold to Netherlands and Switzerland, but the vast majority of this overproduction was stored in feedstocks for future use.

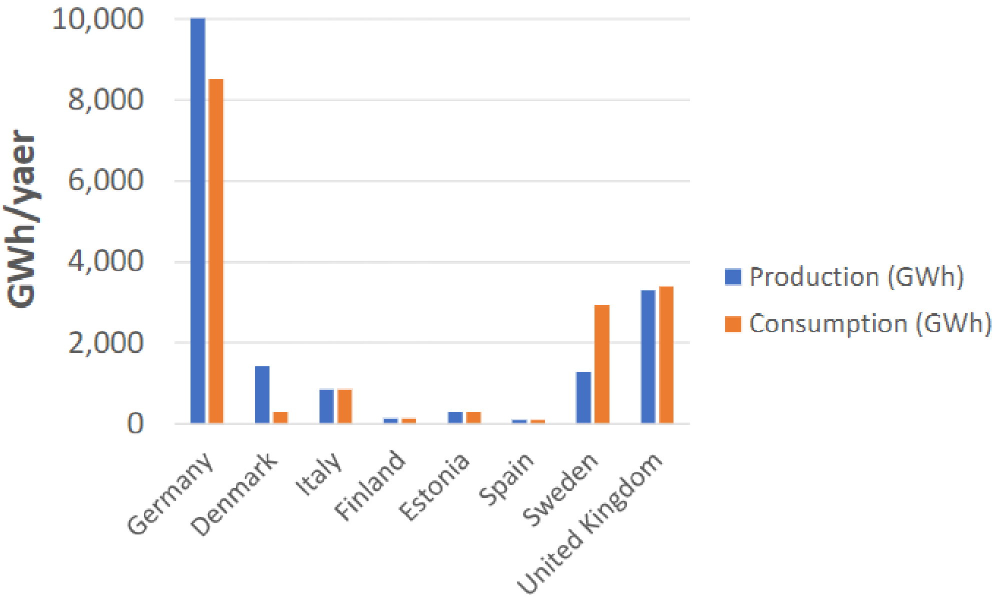


Figure 16. Total biomethane production compared to total biomethane consumption per country in 2018. Source: 5.5

The table below gives an overview of the end–use application, which is different in each EU member state. The graph below differs between use in electricity production, industry and transport, heating and cooling, and other applications. It must be clarified that the counting methods vary in every country.

Biomethane consumption in different sectors varies across the EU. This reflects the fact that there are different starting points for its use in each sector in each country. For example, due to the high infrastructure level and large fleet of public transport vehicles in Italy, most of the consumption goes into the transport category. A similar situation is in Estonia. Sweden uses more than half of the biomethane consumption in transport as well since there is a beneficial support system. On the other hand, heating and cooling applications are dominant in the UK. Most of the German production is used for electricity production in CHP plants. This kind of production is favourable through Feed-in Tariff, a policy mechanism implemented to accelerate the investment in renewables and bring more attention to them through such favourable actions. It is one of the support schemes in Europe. [5.1]

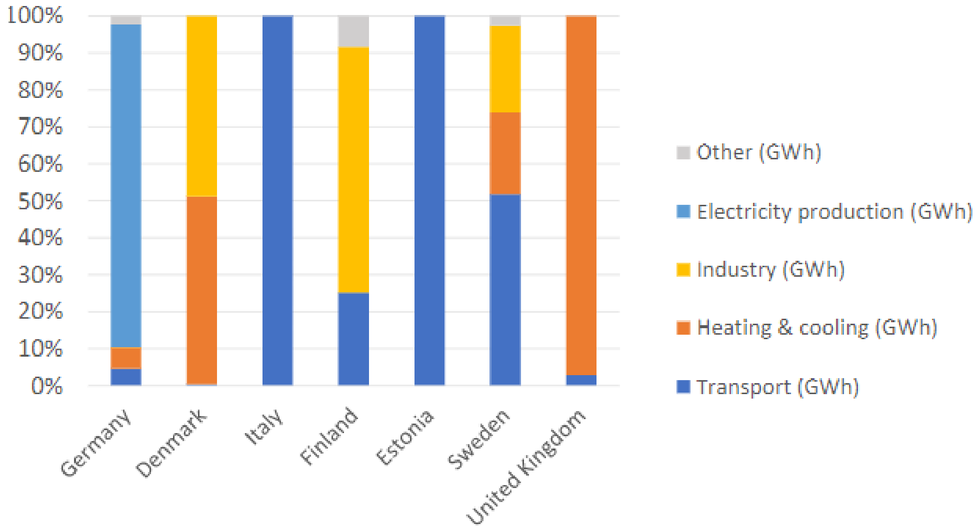


Figure 17. Consumption of biomethane per sector and per country (for countries where data is available) in 2018. Source: 5.5

4.3. Biomethane in Austria

These paragraphs focus on mapping the current situation in the states mentioned above, the Czech Republic and Austria. The current state in Austria and the Czech Republic featuring general overviews, regulatory frameworks, subsidiary schemes, grid connections, investment costs, and biomethane as a biofuel, will be further discussed in the paragraphs below.

The first country is Austria. In 2005, the first biomethane power plant was installed, followed by the others, and the total number today is 15 power plants delivering renewable gas into the grid. The last power plant was set to go in 2017, and there has yet to be much progress in building more. Because the sector is currently in stagnation, on the other hand, Austrian stakeholders and producers perform actively on the market to establish a European market from which Austria and their consumers can benefit. Many biogas plants installed in Austria, almost 400, rely on the Feed-in subsidy scheme (see Chapter 4.1.). Those subsidy schemes are currently running, but operators are keen to either extend their current subsidy schemes or switch to a new one that will lead to biomethane upgrading and grid injection. There is no direct national inducement for biomethane production besides Feed-in Tariffs, but those are for renewable electricity from biogas, not directly aimed at biomethane. Although there is indirect support for biomethane, first implemented in 2012, the framework still has some obstacles, such as better subsidy schemes monitoring, implementation of quality criteria, and tax remuneration. Those must be overcome to strengthen and improve the system.

Gas Cleaning and Settlement AG (AGCS) has been a major group coordinator for the Austrian gas market since 2012. Their goal, besides many others, is to create a system of certificates that the Austrian Renewable Power Settlement Agency will accept. This organization manages the Austrian scheme of subsidies for biomethane. There are 42 account holders within Austria's AGCS Biomethane Registry system, including 14 biomethane plants, traders, auditors, and ten electrification plants. Austria can be an example of a country with several different counting authorities interacting on the market and covering other end uses of biomethane. Aside from AGCS, there are UBA (the Environmental Agency and E-Control, the energy regulator. Each of them disposes of separated high-tech IT systems, which are interconnected to prevent double counting. [5.1]

Speaking of the regulatory framework, there is no direct initiative as mentioned above; there are only Feed-in tariffs, implemented firstly in 2012 due to the Green Electricity Act after approval by the Austrian government and sanctification by European Commission. “*The European Commission has found an Austrian scheme to support the production of energy from renewable sources in line with EU state aid rules, in particular, because it creates incentives for an increased use of renewable energy while containing safeguards to limit distortions of competition. The Commission's aim was to ensure* *that the aid does not lead to an overcompensation of the additional costs linked to the use of renewable sources."* [9.1] Moreover, there are no exemption mechanism for energy intensive undertakings in this initiative. In addition, the additional energy costs will be shared by all players in the process. Meanwhile the Austrian authorities made a commitment of renotify it in 10 years. (From implementation in 2012). That happened in 2017 and 2019. Recent revision implements the prolongation of Feed-in Tariffs until the new legislative will be develop in Austrian Parliament or lawmakers and claims that Renewable Energy Expansion Act (EAG, Erneuerbare Ausbau Gesetz) will be enacted. This particular law is described as a cornerstone of Austrian will to reach 2030 energy and climate targets and has already been passed through the Austrian parliament.

From trading point of view, there have been barely any imports of biomethane into Austria. The export to Germany is based on bilateral treaty agreements with German Energy Agency. This occasion enables Austrian producers to sell their product on German market or buy/purchase renewable gas from Germany. According to Regatrace report the market with biomethane in Austrian is not yet fully developed due to the fact of limited number of plants. In addition, the volume of gas that is produced is used for various purposes not just for one. Furthermore, companies in the field are aware of biomethane and its advantages, but the beneficial side of producing biomethane in Austrian has not yet been widely established. Use of biomethane as a fuel alludes to the fact that there are no counted volumes in transport sector in Austria, according to Regatrace report. However, a few fuel stations for gas exists, but only next to biomethane plants, meanwhile the volume from those is sold only for marketing purpose without the need to count them as biofuel into the country's quota. Another barrier in Austria is the sharing of investment costs for grid access. As of now, operators have to pay e.g., grid access fee and system usage fees. Local subsidies could help in order to overcome these obstacles, but they can differ from region to region. [5.1, 12.1]

4.4. Biomethane in the Czech Republic

This paragraph is focused on the situation with biomethane in the Czech Republic. Compared to Austria, the situation with biomethane in the Czech Republic is different. It reflects the fact that biomethane market is not yet fully developed. Fair to say, biomethane is on the start line. Biomethane is seen as a potential tool to meet the 2030 energy targets. On the other hand, there is no particular government strategy for biomethane. The newly elected government of the Czech republic stated on January 6, 2022, that the Government will support the use of biofuels, production of biomethane and the development of helium technologies. [10.1] However, there is a legislative framework supporting biomethane, which is described in paragraph 27a–27f of the Act 165/2012. The level of regulatory and support frameworks at the level of the Czech Republic is low. This reflects the fact that the market is developing from the beginning compared to Austria. [11.1] Producers of biomethane in Czech Republic can obtain subsidies through Feed in Premium/Green bonus. (See chapter 4.1. and Paragraph 27a–27f of the Act 165/2012) [15.1] Biomethane as a biofuel could be use in order to fulfil the 2030 Climate and energy targets but, with current situation on the Czech market this scenario is a long run. Czech biomethane operators and producers have to also cover all of the costs of grid connection. [5.1] The feasibility of biomethane projects is highly dependent on market opportunities abroad since the market with biomethane is at the started line in the Czech Republic. Meanwhile, the government speaking about the strong development energy sector, especially in the nuclear area. According to the government’s program statement from January 6, 2022, the government sees the future in the combination of nuclear energy and renewables with an emphasis on sufficiency and money savings. [10.1]

The development of the biomethane market differs widely in the EU and each member state has a different view on it as well as on subsidiary schemes and use of renewable gases. Comparation of state of development of biomethane in Austria and the Czech Republic alludes to its disparities and the fact that these two particular countries are incomparable in this point of view because the level of development in all aspects from the market development through subsidiary schemes to cross–border trade and use as biofuels are on different levels in both countries. [5.1] To conclude the situation in the Austrian market is satisfactory, although there is space for development in many areas. On the other hand, the Czech Republic is on the baseline compared to Austria. In addition, Czech officials recognize the potential of biomethane overall, but the absence of particular development strategy trips the will on the path towards further development in the future.

4.5. Long–term visions for Austria and the Czech Republic

The long–term visions and future roadmaps for Austria and the Czech Republic are further discussed in the paragraphs below. From the methodological point of view the data of main source consists of two main documents. First one is again REGATRACE Report and its part D6.3. Originally published in Brussels on in 2019. Reader should bear in mind the fact of when the data were published. On the other hand, the additional sources are EBA reports Support Schemes for Biogas and Biomethane. Those papers apply only on future terms and goals of the Czech Republic and Austria and was published in April 2022.

The Czech Republic currently has roughly 575 biogas plants in operation. Biomethane production started in 2020 and up today there are two biomethane plants in operation. As mentioned above the production is not huge or massive. Nevertheless, the Czech Republic is keen to increase the production of biomethane. The market is developing with support from new act for renewables called RES. It is expected that biomethane production will increase, especially in the transport sector. Nowadays, the Czech Republic’s biogas production raising fast, meanwhile biomethane production stays at small number or compare to other EU countries at non–existent level. Overall, the support is in the beginning in all areas. [13.1]

According to the researchers, the main obstacle why is the Czech Republic so behind in biomethane production are legislative obstacles and barriers. Basically until 2021 the legislative for biomethane did not exist in the country and the concepts either did not include biomethane at all or just in vague wording. Obsolete regulations in gas industry did not help the situation either. The fact that could spart the development in the Czech Republic is according to researchers the demand from petroleum producers. Meanwhile the technical barriers remain to be huge obstacle, maybe the biggest one in the country´s path towards biomethane future. The Act on RES enacted in 2020 conduct obligations especially in transport sector. It is estimated and projected that from January 1, 2025, approx. 2 % and from January 1, 2030 roughly 40 % should be the minimum amount of advanced biomethane in natural gas use as fuel in the transport sector. [5.1]

From a short–term perspective creation of a stable regulatory framework is vital in order to bring the attention of investors and stakeholders toward biomethane. The absence of fully developed infrastructure is also a setback and brings another obstacle from technical and financial point of view. After the settlement of clear legislation in the sector, development of biomethane is expected. Then comes the medium–term objectives. Here we are speaking about more effective way of separate waste collection from households, restaurants, and canteens. Crucial factor is that the food will not end in landfills but will be used in biomethane production process. Long–term perspective is highly dependent on the situation in the future, especially in country´s market and on the EU legislation.

Nevertheless, the production of biomethane from waste production should play key role in the long–term visions. [6.1]

The situation is a bit different in Austria as it is viewed as an advanced country in biogas and biomethane. Austrian government announced #mission2030 initiative which highlights the vision of climate neutral Austria by 2030. The main goal are as follows: to have 100 % renewable electricity by 2030 and a renewable gas target of 5 TWh from hydrogen, biomethane, and syngas. Renewable Expansion Act was enacted in 2021 and provides investment support to convert biogas CHP plants into biomethane. This new act should also change the subsidiary scheme from Feed-in Tariffs towards a market premium system.

Overall, the Austrian government perceives the momentum brought to the sector, and many sector representatives are constantly trying not even to raise awareness about the topic but also to provide information and evidence about the advantages of renewable gas technologies. The sector representatives also highlight that today is the right time to develop the Austrian green gas strategy and biomethane. The analysis for tomorrow considers more effective uses of municipal and industrial organic waste, waste from the wood industry, and agriculture. Furthermore, researchers estimate that Austrian gas consumption could be covered by locally sourced renewable gas by up to 50 % by 2030. [12.1]

To conclude, the Czech Republic tackles obstacles that have been overcome in Austria, such as specific barriers, administrative constraints, subsidiary schemes, and infrastructure for transport. Meanwhile, there are still some common problems that slow down the development of biomethane in both countries, regardless of the market's maturity. Such as the availability of low–cost fossil fuels and the low profitability of biomethane. [6.1] Regatrace report recalls the importance of the involvement of possible stakeholders, besides the usual ones, such as government, local, energetic authorities, producers, and operators. There are also universities, NGOs, media, researchers and experts, consultancy firms, consumer associations, and others.[6.1]

To meet the ambitious targets of Fit for 55, the REPowerEU plan, and Green Deal initiative, biomethane production could be a massive helper in this case if the barriers mentioned above are removed, and the future development will go as planned hand in hand with subsidiary schemes support. Common obstacles that have to be solved are as follows: low profitability of biomethane, technical and administrative obstacles, availability of low–cost fossil fuels, lack of long–term stable initiatives, and lack of waste management policies.

5. Conclusions

Biomethane has the potential to cover part of the future gas demand while solving significant challenges: finding low-emission routes for energy production and valorizing the organic waste generated by our modern society. The wide range of feedstocks that can be utilized combined with the well-developed technologies allows us to get further away from fossil fuels.

Animal manure, organic matter from municipal waste, and wastewater sludge have been demonstrated to be suitable feedstocks for biogas production; therefore, promoting the reutilization of residues and avoiding dedicated food crops. The conventional technologies ASBR, CSTR, and APFRS are the simplest and most cost-effective for biogas production as they require a single-stage system; however, APFRS has been stated to be the most effective. Retaining the sludge can significantly enhance the production rates of the reactor. In this vein, several technologies have been developed which vary their design and recycling system; in this paper, the UASB was reviewed and compared to the membrane-based digestors, being the last one significantly more expensive but the most efficient.

The current state of the art of biomethane differs widely within the EU. To conclude, the situation in Austria and the Czech Republic is different. Biomethane as an energy source is well-established in the Austrian market. On the other hand, biomethane is slowly gaining ground in the Czech Republic. From a long-term point of view, biomethane has the potential to play a vital role in the future, and Eu member states, as well as EU Institutions such as the European Commission and European Parliament, are aware of that. Each state has its supportive mechanisms and schemes, and so has the European Commission. Nevertheless, there are still some common obstacles that have to be overcome.

REFERENCES

[1] I. Energy Agency, “Net Zero by 2050 - A Roadmap for the Global Energy Sector,” 2050. [Online]. Available: www.iea.org/t&c/

[2] J. Pavičić, K. N. Mavar, V. Brkić, and K. Simon, “Biogas and Biomethane Production and Usage: Technology Development, Advantages and Challenges in Europe,” *Energies*, vol. 15, no. 8. MDPI, Apr. 01, 2022. doi: 10.3390/en15082940.

[3] M. U. Khan *et al.*, “Current status of biogas upgrading for direct biomethane use: A review,” *Renewable and Sustainable Energy Reviews*, vol. 149. Elsevier Ltd, Oct. 01, 2021. doi: 10.1016/j.rser.2021.111343.

[4] D. Krishna and A. S. Kalamdhad, “Pre-treatment and anaerobic digestion of food waste for high rate methane production - A review,” *Journal of Environmental Chemical Engineering*, vol. 2, no. 3. pp. 1821–1830, 2014. doi: 10.1016/j.jece.2014.07.024.

[5] C. Bumharter, D. Bolonio, I. Amez, M. J. García Martínez, and M. F. Ortega, “New opportunities for the European Biogas industry: A review on current installation development, production potentials and yield improvements for manure and agricultural waste mixtures,” *Journal of Cleaner Production*, vol. 388. Elsevier Ltd, Feb. 15, 2023. doi: 10.1016/j.jclepro.2023.135867.

[6] B. Drosg, R. Braun, G. Bochmann, and T. Al Saedi, “Analysis and characterisation of biogas feedstocks,” in *The Biogas Handbook: Science, Production and Applications*, Elsevier Inc., 2013, pp. 52–84. doi: 10.1533/9780857097415.1.52.

[7] S. Mirmohamadsadeghi, K. Karimi, M. Tabatabaei, and M. Aghbashlo, “Biogas production from food wastes: A review on recent developments and future perspectives,” *Bioresour Technol Rep*, vol. 7, Sep. 2019, doi: 10.1016/j.biteb.2019.100202.

[8] A. Eftaxias, E. A. Passa, C. Michailidis, C. Daoutis, A. Kantartzis, and V. Diamantis, “Residual Forest Biomass in Pinus Stands: Accumulation and Biogas Production Potential,” *Energies (Basel)*, vol. 15, no. 14, Jul. 2022, doi: 10.3390/en15145233.

[9] International Energy Agency (IEA), “Outlook for biogas biomethane. Prospects for organic growth,” 2020.

[10] H. Negi, R. Agrawal, A. Verma, and R. Goel, “Municipal solid waste to bioenergy: Current status, opportunities, and challenges in indian context,” in *New and Future Developments in Microbial Biotechnology and Bioengineering: Microbial Biotechnology in Agro-environmental Sustainability*, Elsevier, 2019, pp. 191–203. doi: 10.1016/B978-0-444-64191-5.00014-6.

[11] V. Kumar Gupta and M. G. Tuohy, “Biofuel and Biorefinery Technologies Volume 6 Series editors.” [Online]. Available: http://www.springer.com/series/11833

[12] J. G. Usack, C. M. Spirito, and L. T. Angenent, “Continuously-stirred anaerobic digester to convert organic wastes into biogas: System setup and basic operation,” *Journal of Visualized Experiments*, no. 65, 2012, doi: 10.3791/3978.

[13] M. H. V. Bahrun, A. Bono, N. Othman, and M. A. A. Zaini, “Carbon dioxide removal from biogas through pressure swing adsorption – A review,” *Chemical Engineering Research and Design*, vol. 183. Institution of Chemical Engineers, pp. 285–306, Jul. 01, 2022. doi: 10.1016/j.cherd.2022.05.012.