Ref. Ares(2024)1207501 - 16/02/2024

A comprehensive overview of the feedstock supply developments

Deliverable n 1.3

GREENMEUP

Funded by
the European Union

Project	GreenMeUp - Green biomethane market uptake
Call identifier	HORIZON-CL5-2021-D3-02: Sustainability and educational aspects for renewable energy and renewable fuel technologies
Grant Agreement n°	101075676
Coordinator	CRES - Centre for renewable energy sources and saving foundation
Work package n°	1
Work package title	Market dynamics & framework conditions in advanced European and MI countries
Work package Leader	CRES
Document title	A comprehensive overview of the feedstock supply developments
Author	Christos Zafiris, Loukas Gavriil, Myrsini Christou / CRES Carlo Pieroni / CIB
Reference period	01/08/2022 - 31/01/2023
Due date	31/01/2023 (M18)

This project has received funding from the European Union’s Horizon Europe Research and Innovation Programme under Grant Agreement No. 101075676.

Summary of the GreenMeUp project

GreenMeUp – Green Biomethane Market Uptake is a Horizon Europe project that aims at providing a basis for policy-makers and stakeholders to develop more informed renewable energy policies and country-tailored market uptake measures, in order to improve and complement existing biomethane policy in Europe.

The core activity of GreenMeUp is to reduce the gap between countries with higher rates of biomethane production and countries with lower development rates, by analyzing and comparing their framework conditions and market dynamics and promote enabling policies and measures at country level. The project aims at providing societal acceptance of the biomethane value chain through science-based evidence and tools.

This project has received funding from the European Union's Horizon Europe Research and Innovation Programme under Grant Agreement No. 101075676.

Index

This project has received funding from the European Union's Horizon Europe Research and Innovation Programme under Grant Agreement No. 101075676.

Figures

This project has received funding from the European Union's Horizon Europe Research and Innovation Programme under Grant Agreement No. 101075676.

Tables

This project has received funding from the European Union’s Horizon Europe Research and Innovation Programme under Grant Agreement No. 101075676.

1. Introduction

The Energy Roadmap 2050[1] (COM(2011) 112 final) [6] investigated possible pathways for a transition towards a decarbonisation of the energy system and the associated impacts, challenges and opportunities. In addition, it established long term goals to create a competitive low carbon economy and to reach 80–95% GHG emission reduction by 2050. As a consequence, the share of renewable energy could increase substantially in the EU between 55% and 75% of gross final energy consumption in this period. Based on the ambition of the European Commission to strive for climate-neutrality towards 2050, renewable gases with low greenhouse gas (GHG) emission values are being supported in order to substitute fossil gases in the gas grids

Biomethane offers the outstanding opportunity to substitute fossil natural gas as well as other fossil energy carriers in an extremely flexible way. Biomethane is interchangeable with natural gas – having equal physical and burning characteristics. It is produced from biogas by upgrading the gas to natural gas quality. Thus, any natural gas application can be served and the natural gas grid can be used without any technical risk or challenge. Biomethane – in close conjunction with other renewable gases, such as hydrogen – is the basis for a long-term future use of the natural gas grids all over the world. In addition, biomethane is – compared to other renewable gases – a technology, which is available today and has been tried and proven for more than 20 years. Moreover, gas transport in the grid has much lower energy losses when compared with electric power transmission. This reflects the fact that energy transportation will be an increasing challenge in a 100% renewable energy system of the future, e.g. when wind energy must be transported from the coast into industrial areas.

The biogas and biomethane industries are significant and growing contributors to achieving climate-neutrality by 2050. As calculated by the World Biogas Association, the sector has the potential to reduce worldwide GHG emissions by 10-13%, which accounts to 3,290 to 4,360 Mt CO2 eq, based on the biogas production from the anaerobic digestion of wastes and landfill gas[2]. The biogas and biomethane industries reduce emissions via many different pathways, such as avoided emissions with the replacement of fossil fuels, avoided methane slips from manure storage, replacement of carbon-intensive chemical fertilizers with green fertilizers, carbon storage in soils and carbon capture and storage.

Knowledge of the feedstock availability is essential in order to verify that those energy policy targets are feasible. Also, a proper assessment of the biogas potential is the first step for finally assessing the biomethane potential. For the production of biogas several types of organic material can be used as feedstock. The most common type of waste used for this purpose is the livestock manure, food waste and the waste from the dairy industry. It is also important to estimate the potential of biogas production from certain agricultural residues, since they are abundant in almost all the EU States. This deliverable will present comprehensive overlook feedstock availability in EU and therefore realistic estimates for biogas and biomethane production.

[1] COM(2011) 885 final Energy Roadmap 2050
[2] World Biogas Association, 2019. Global Potential of Biogas

This project has received funding from the European Union's Horizon Europe Research and Innovation Programme under Grant Agreement No. 101075676.

2. The biomethane technology

Biomethane typically starts out as biogas. Biogas is one of the outputs of anaerobic digestion of biomass and contains around 55 to 60% methane (CH_4) and 40 to 45% carbon dioxide (CO_2) along with other trace gases (including water vapour and sulphur dioxide, SO_2). Biogas upgrading is the process of removing the CO_2 from the gas mixture resulting in a final product with a CH_4 content of at least 90%. Depending on the quality of the biomethane, it can be used in natural gas applications and/or fed to the public gas grid, which today mainly serves for transporting natural gas. Biogas can be produced at a biogas plant from a wide range of different organic substrates. Those substrates are generally in one of the following categories:

- Energy crops
- Manure
- Municipal organic waste
- Industrial and commercial organic waste
- Vegetable residues from agriculture
- Wastewater with high organic content, such as sewage sludge or residues from industrial processes

As can be seen in Figure 1, biomethane can be used in several applications. A combined heat and power (CHP) unit can be used for the production of electricity and heat. This is especially beneficial and efficient in areas with a high heat demand – ideally throughout the year, e.g. heating of buildings or process heat in industries. Biomethane can also be used as a fuel in vehicles, which run on compressed natural gas (CNG) or in heat-only applications, such as boilers for delivering heat to buildings or industrial processes. A relatively new pathway of using biomethane is its application for material use, e.g. in the chemical industry, where products, based on natural gas can be replaced by biomethane.

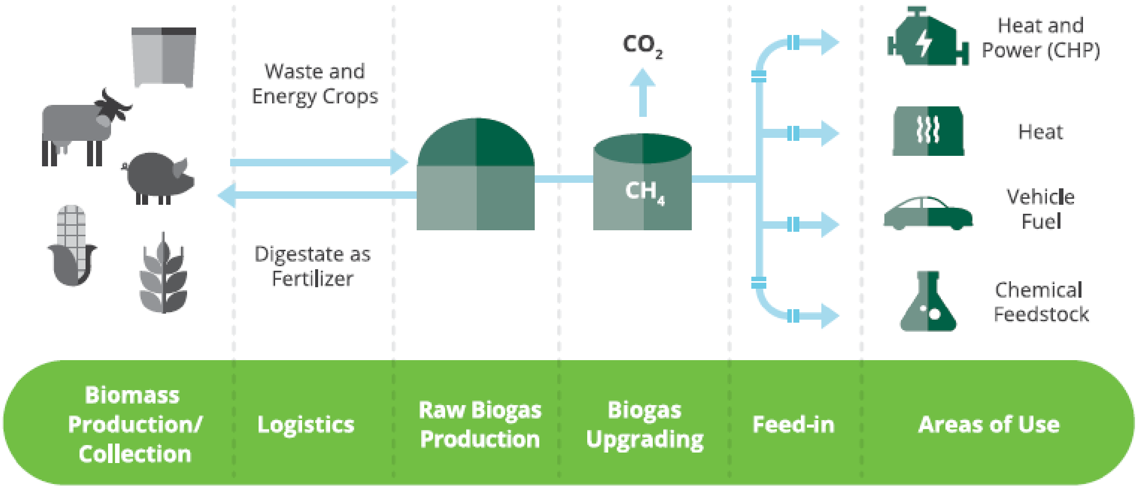


Figure 1. Value supply chain for a biogas plant[3]

[3] Biomethane Production and Grid Injection: German Experiences, Policies, Business Models and Standards, Sino-German Energy Partnership)

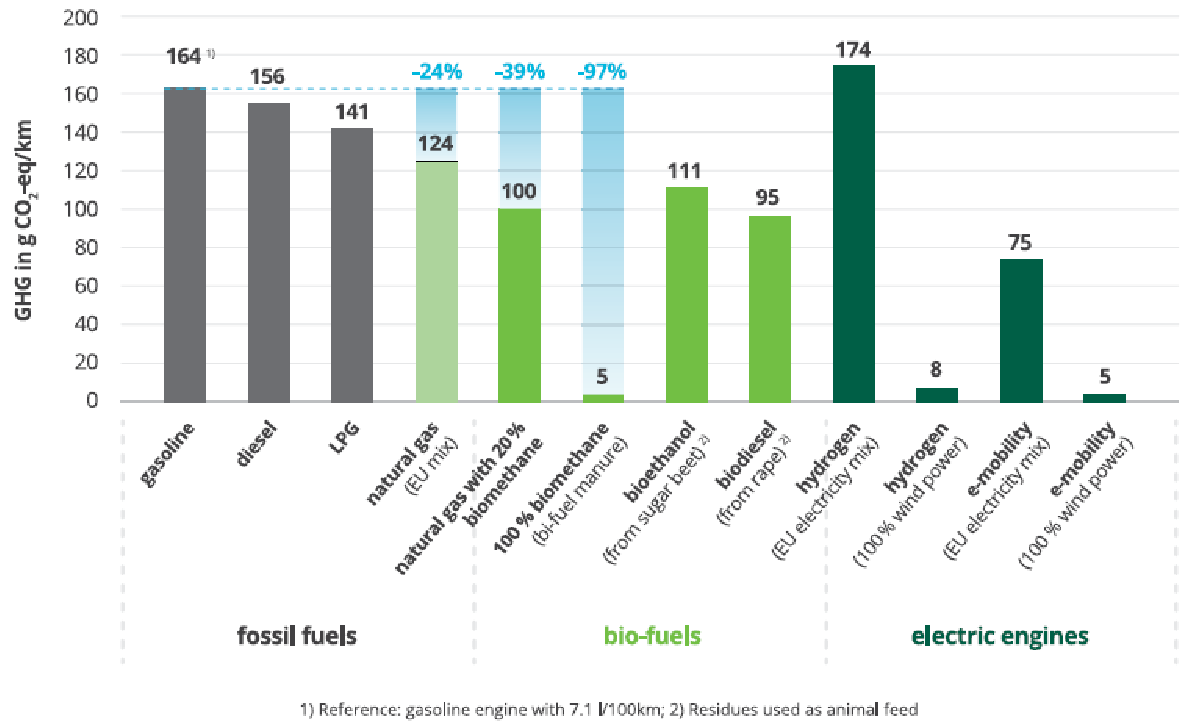
This project has received funding from the European Union's Horizon Europe Research and Innovation Programme under Grant Agreement No. 101075676.

After the biomass has been digested in the biogas plant it leaves as a product called digestate. The digestate can be used in agriculture as a substitute for mineral fertilizers, since the nutrients are retained throughout the biogas production process. Moreover, they contribute to buildup humus and structure in the soil. The use of the digestate closes the nutrient cycle.

Biomethane has many economic and ecological advantages. Not only is it a perfect example of a circular economy, but it also strengthens local and regional economical networks by providing local value chains. Biomethane is flexible and versatile; it can be generated out of a wide range of organic materials and easily stored over long periods of time. Unlike most other renewables, the production of biomethane through biogas is suitable for base loads or even flexible energy supply since it can be planned and controlled, especially by storing the biomethane in the gas grid or gas storage.

Infrastructure and equipment suitable for biomethane is readily available and finding knowledgeable personnel should be relatively easy, especially compared to other new energy fields. Due to the interchangeability with natural gas, it is often easy to have a backup gas grid connection.

Biomethane is deemed as one of the most carbon-saving fuels for transportation or heating. In addition, up to 90% of particulate matter, up to 80% of nitrogen oxide (NOx) and up to 50% of noise emissions can be cut in comparison to using diesel or gasoline as a vehicle fuel. The NOx and particulate matter emission reduction also applies for substitution in processes such as oil or coalfired heat boilers or power supply plants. Moreover, sulphide oxide (SO_2) emissions are cut down close to zero. Thus, the use of biogas and biomethane contributes significantly to local air quality improvement (Figure 2).



Source: (IRENA, 2018)

Figure 2. Greenhouse gas reduction comparison.

This project has received funding from the European Union's Horizon Europe Research and Innovation Programme under Grant Agreement No. 101075676.

3. The feedstock

A wide range of feedstocks with different methane yields can be used for biogas production: livestock manure, energy crops, food wastes, industrial and sewage sludge and MSW, agricultural residues, etc.

Feedstock type choices highly depend on the local availabilities as well as on the applied technologies. According to the European Biogas Association[4], In several countries, there is one dominant feedstock type for biogas production, i.e. industrial waste (industrial wastewater and/or industrial solid waste in Belgium (Wallonia), Sweden and Ukraine, manure in Cyprus, Denmark, Greece, Luxembourg and Poland, whereas in Germany, energy crops (energy Maize) and manure together make up the vast majority of the feedstocks used (Figure 3).

Co-digestion of various substrates improves the methane production of the anaerobic digestion.

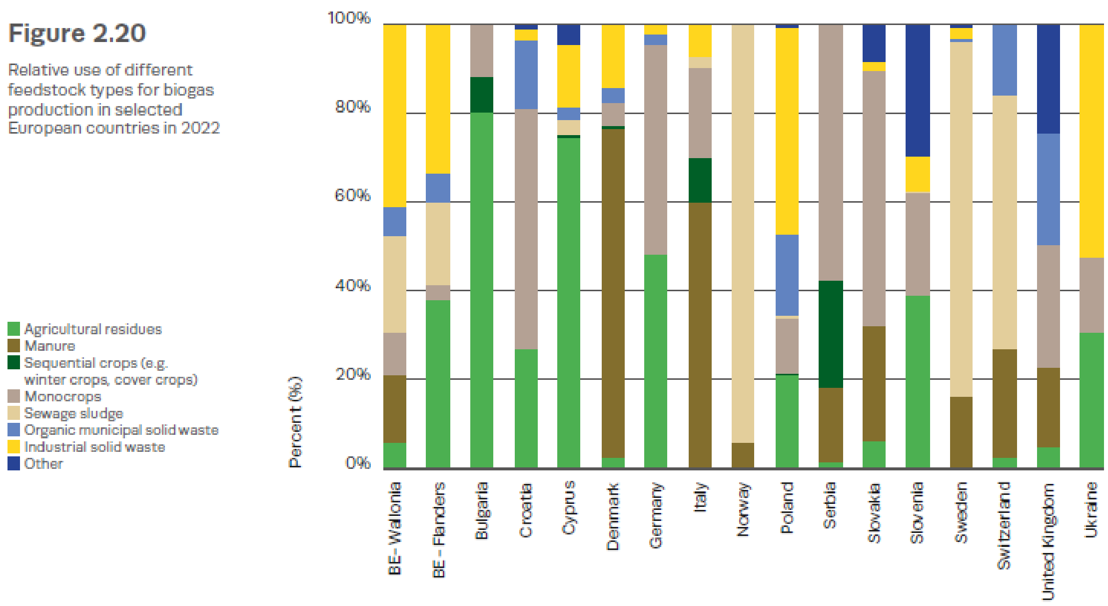


Figure 3. Relative use of different feedstock types for biogas production in selected European countries in 2022 (Source: EBA, 2023)

Since 2019, a trend for building agricultural biogas plants is noticed, using mainly agricultural residues, manure and plant residues (Figure 4), whereas almost none of the newly built plants are using monocrops (as is the case of Germany where the majority of the biogas plants are using energy maize).

[4] EBA, Statistical Report 2022 Tracking biogas and biomethane deployment across Europe

This project has received funding from the European Union's Horizon Europe Research and Innovation Programme under Grant Agreement No. 101075676.

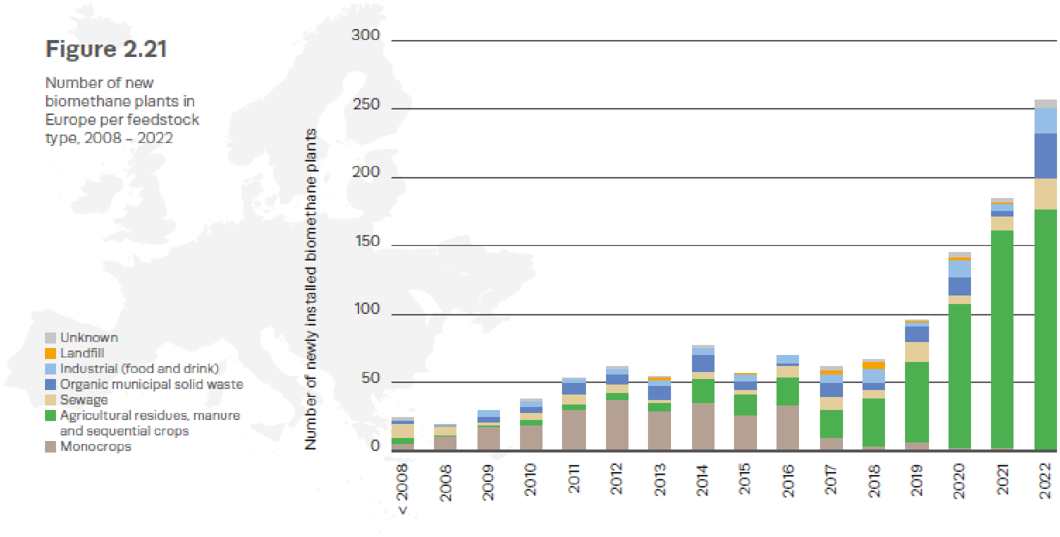


Figure 4. Total number of newly installed biomethane plants in Europe each year, 2008-2022, overall and per feedstock type (EBA, 2023)

3.1 Livestock manure

Livestock manure mainly comes from cows (dairy and meat production), pigs, goats, sheep, horses and chickens. According to FAO, there is a global potential of 1.5 billion cattle, 1 billion pigs, 22 billion chickens and 0.2 billion buffaloes, the manure of which could be available for anaerobic digestion and biogas/biomethane production[5]. Sheep, goats and horses are often fully grazed and consequently their manure is not available. Only the manure excreted by cows and chicken that are bred indoors, may be collected and managed through a variety of processes including anaerobic digestion. For these animals and mainly chicken, manure is often mixed with their bedded materials straw, wood chips or sand.

Manure is a source of nutrients and the traditional use is to be applied on the soil surface for crop fertilisation. However, this technique can lead to substantial emission of methane and nitrous oxide greenhouse gases as well as to nitrate leaching in the soil and water streams. Especially chicken manure is reported to be rich in organic nitrogen which can cause the production of ammonia that inhibits the anaerobic digestion[6]. The digested manure is rich in nitrogen, phosphorus and potassium, in a form that is more readily available to the crops. Therefore it can be applied on the field as organic fertiliser and improve the yields of crops compared to the untreated manure.

On top of that manure is responsible for methane release to the atmosphere, hence by collecting and anaerobically digesting manure from livestock, there is a potential to offset 13 to 18% of the current livestock-related greenhouse gas emissions per year[7].

[5] FAO Stat www.fao.org/faostat/en/#data
[6] I. M. Nasir, T. I. Mohd Ghazi, and R. Omar, "Anaerobic digestion technology in livestock manure treatment for biogas production: a review," Engineering in Life Sciences, vol. 12, pp. 258-269, 2012.
[7] www.fao.org/news/story/en/item/197623/icode/

This project has received funding from the European Union's Horizon Europe Research and Innovation Programme under Grant Agreement No. 101075676.

Based on the estimations of the World Biogas Association[8], it may be possible to generate globally 2,047 TWh and mitigate 570 Mt CO2 eq. emissions by 2030 and 4798 TWh and 1193 Mt CO2 eq. emissions by 2050 (Figure 5). In the case that the whole theoretical potential of livestock manure from cattle, buffaloes, pigs and chickens were to be collected, anaerobically digested and upgraded to biomethane, 250 to 370 bcm of biomethane could be produced globally.

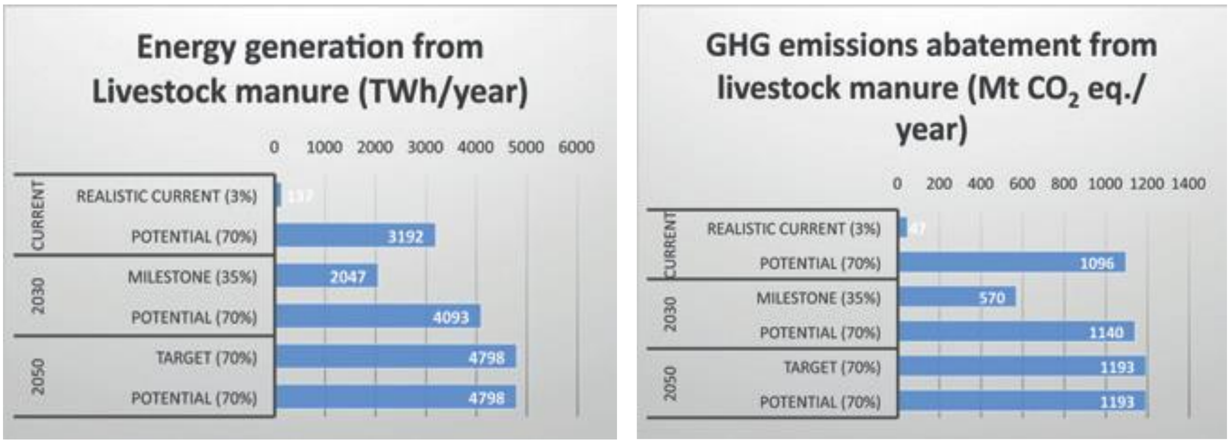


Figure 5. Energy generation (TWh/year) and GHG emissions abatement (Mt CO2 eq. /year) from livestock manure globally (Source WBA, 2019)

3.2 Energy crops (energy maize)

Crops that are grown with the only purpose to be used for energy production are defined as energy crops. Depending on geography and climate maize silage and other cereal silages, grass silages, oilseed crops and root crops like potatoes and beets may be used for biogas production.

As energy crops at the European context energy maize is grown, which however is a food crops being thus in direct competition with the maize used in the food market. That was the case of Germany where the majority of the biogas plants are using energy maize (Figure 3).

Whereas a large share of biomethane plants in Germany run on monocrops, the use of monocrops in existing plants is expected to be replaced in the future by other types of feedstocks with similar fuel characteristics, such as sustainable sequential cropping[9].

In order not to compete with the food markets in terms of the agricultural land they occupy and the use of irrigation water and fertilisers, sustainable agricultural practices such as crop rotation, cover cropping, and double cropping are recently adopted; they will be further analysed in sub-chapter 3.6.

[8] World Biogas Association. Global Potential of Biogas, June 2019

[9] EBA, Statistical Report 2022 Tracking biogas and biomethane deployment across Europe

This project has received funding from the European Union’s Horizon Europe Research and Innovation Programme under Grant Agreement No. 101075676.

3.3 Food waste – municipal solid wastes

According to FAO, a third of all food produced in the world every year reaching almost 1.6 billion tonnes is wasted[10]. It accounts for 4.4 Gt CO2 eq. greenhouse gas (GHG) emissions which represent 8% of all anthropogenic GHG emissions[11].

Food wastes can be generated on the farm, with spoilt and rotten fruits and vegetables or those that fail to meet the quality specifications of the food market. Food waste usually is integrated in the soil or it can go to the landfill. On bigger farms and food processing industries where large quantities of food wastes are produced, they are usually sent to the nearest biogas plants. Food waste accounts for 44% of organic waste going to landfills[12]. Food waste that ends to landfill mainly comes from households/businesses in cities and towns and is usually mixed with other residual waste, unless it is separately collected. The high concentration of water in food waste makes it a very good material for the anaerobic digestion process. The landfill gas produced has about 50% methane content that can be used for electricity or biomethane production.

Separate collection of food waste at the source is the key to unlock the potential of food waste in terms of energy generation, GHG emissions abatement and nutrient recovery.

Based on the estimations of the World Biogas Association[13], it may be possible to generate globally 305 TWh/year and 340 TWh/year in 2030 and 2025 respectively and relevant GHG abatement potential of 189 Mt CO2 eq./year and 271 Mt CO2 eq./year (Figure 6). In the case that the whole theoretical potential of food waste were to be collected, anaerobically digested and upgraded to biomethane, 85 to 100 bcm of biomethane could be produced globally.

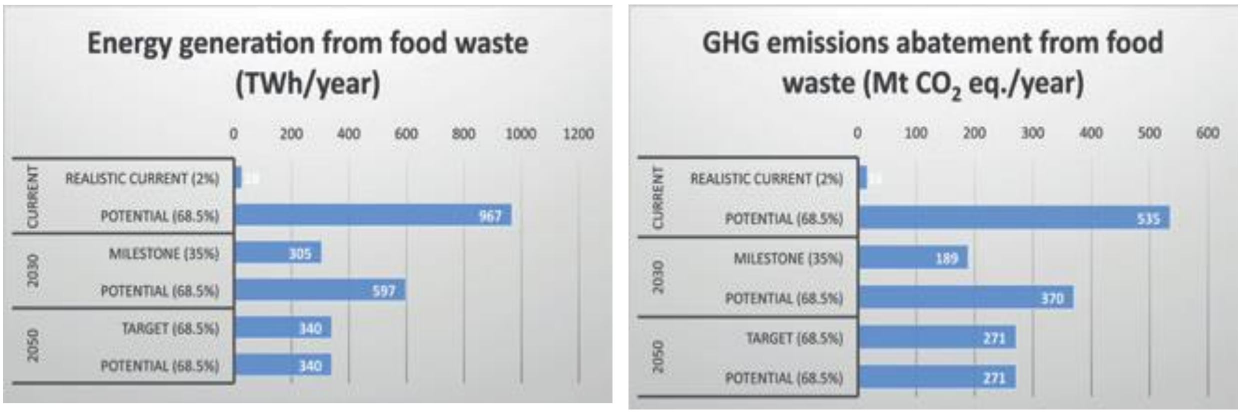


Figure 6. Energy generation (TWh/year) and GHG emissions abatement (Mt CO2 eq. /year) from food waste globally (Source WBA, 2019)

[10] www.fao.org/3/a-i3991e.pdf
[11] Food wastage footprint & Climate Change. www.fao.org/3/a-bb144e.pdf
[12] Silpa Kaza, Lisa Yao, Perinaz Bhada-Tata, Frank Van Woerden. What a Waste 2.0: A Global Snapshot of Solid Waste Management to 2050. https://openknowledge.worldbank.org/handle/10986/30317
[13] World Biogas Association. Global Potential of Biogas, June 2019

This project has received funding from the European Union's Horizon Europe Research and Innovation Programme under Grant Agreement No. 101075676.

3.4 Industrial and sewage sludge

Sewage sludge or residues from industrial processes are wastewaters with high organic content.

The digestate produced from sewage sludge is high in nitrogen and phosphorus content when compared with digestate from other feedstocks. Phosphorus is available in limited quantity elsewhere in the natural world which makes sewage sludge digestate highly desirable as a soil amendment. Extraction of phosphorus from digestate is also possible for use as a targeted fertiliser. Digested sludge is safer to apply to land than raw sludge as the digestion process reduces the pathogens and weeds in it. Industrial sewage that can possibly contain heavy metals and other chemicals may need further treatment.

Based on the estimations of the World Biogas Association, it may be possible to generate globally 153 TWh/year and 385 TWh/year in 2030 and 2050 respectively and relevant GHG abatement potential of 41 Mt CO2 eq./year and 95 Mt CO2 eq./year (Figure 7). In the case that the whole theoretical potential of sewage were to be collected, anaerobically digested and upgraded to biomethane, 22 to 32 bcm of biomethane could be produced globally.

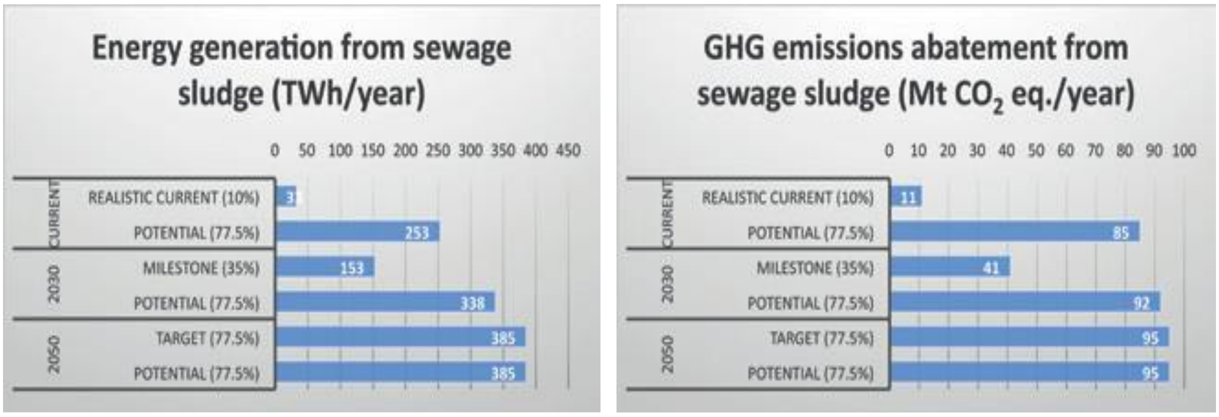


Figure 7. Energy generation (TWh/year) and GHG emissions abatement (Mt CO2 eq. /year) from sewage sludge globally (Source WBA, 2019)

3.5 Agricultural residues

The agricultural residues are the crop residues that stay in the field after the harvest of the edible parts of the crop (grains, fruits, bulbs, etc). Depending on the food crop, the residues can be stalks, roots, leaves, chaff. A number of studies estimated that agricultural residues that are available and meet the sustainability criteria range from 129 to 470 Mt in 2020, from 139 to 182 in 2030 and could reach 286 to 567 Mt dm in 2050[14]. The primary agricultural residues that are expected to play a key role in the

[14] Christou, M., Perez Ortiz, P., Martín Sastre, C., Ciria, P. Available agricultural/forest residues and process residues of common interest for EU and Brazil. BECOOL project, D1.6.

This project has received funding from the European Union's Horizon Europe Research and Innovation Programme under Grant Agreement No. 101075676.

future bioenergy scene are mainly cereal straw. In the majority of the European countries wheat straw is the dominant straw type comprising over 60% of the total straw production, followed by barley, oat, rye and triticale, apart from Spain where barley straw accounts for the 55% of the total straw production[15]. Straw however, apart from soil protection, is used for other competitive uses, like animal bedding and feeding, horticulture, energy, other industrial uses i.e building materials, paper and pulp, thatching. The livestock sector only is estimated to use the 88.2% of straw, energy as the second most important user uses 5.5% and horticulture with 4.8%. The rest 1.5% is used for other industrial uses.

For sustainability reasons, it is recommended to leave part of the harvested materials to be integrated back in the soil in order to prevent soil erosion and improve the water holding capacity of the soil, whereas when degraded the agricultural residues add humus to the soil that enhances soil fertility. Several studies estimated that 30-60% of crop residue can be sustainably recovered[16]

Agricultural residues have challenging characteristics, such as low energy density, high moisture content, dispersed geographic allocation leading to high transportation costs, topped off with seasonal availability that mat require long storage and therefore high costs.

A significant amount of these residues generated from agricultural practices, such as grain straw and fruit tree pruning, are currently underutilized or burned in the field, despite this being prohibited due to environmental concerns. This practice not only contributes to CO_2 emissions and soil erosion, but also results in the loss of valuable organic matter and nutrients. Recently, there is a growing shift away from field burning, recognizing the potential environmental benefits and the opportunity for energy utilization of agricultural residues.

Straw may be digested on their own or co-digested with other feedstocks, however its use in anaerobic digestion is challenging due to the high content of lignin in biomass that is difficult to break. Ensiling of chopped straw, briquetting and pressure cooking may offer efficient solutions allowing the use of straw for biogas /biomethane production.

An underutilized type of agro-residues, unavoidable, according to waste hierarchy, is pruning from permanent crops, namely vineyards, olive groves and orchards that is produced yearly and represent a significant potential for many EU countries, with a total area of 11.8 Mha (Eurostat, 2020). Only recently experimentation on their collection and handling to build cost-efficient supply chains for their energy exploitation has started (EU projects: Agroinlog, uP_running, Music, Greek project: Agrochains). Pruning, along with forest residues are a good feedstock option for the production of biomethane via gasification.

Based on the estimations of the World Biogas Association, it may be possible to generate globally 2,316 TWh/year and 5,432 TWh/year in 2030 and 2050 respectively and relevant GHG abatement potential of 531 Mt CO2 eq./year and 1,063 Mt CO2 eq./year (Figure 8). In the case that the whole theoretical potential of sewage were to be collected, anaerobically digested and upgraded, 300 to 380

---

[15] Spöttle, M., Alberici, S., Toop, G, Peters, D., Gamba, L., Ping, S., van Steen, H., Bellefleur, D. Low ILUC potential of wastes and residues for biofuels - Straw, forestry residues, UCO, corn cobs. Ecofys 2013. Available at: http://www.mvak.eu/test5674213467/Ecofys_2013_low_ILUC.pdf

[16] Einarsson R, Persson UM (2017) Analysing key constraints to biogas production from crop residues and manure in the EUĐA spatially explicit model. DOI: 10.1371/journal.pone.0171001

This project has received funding from the European Union's Horizon Europe Research and Innovation Programme under Grant Agreement No. 101075676.

bcm of biomethane could be produced globally.

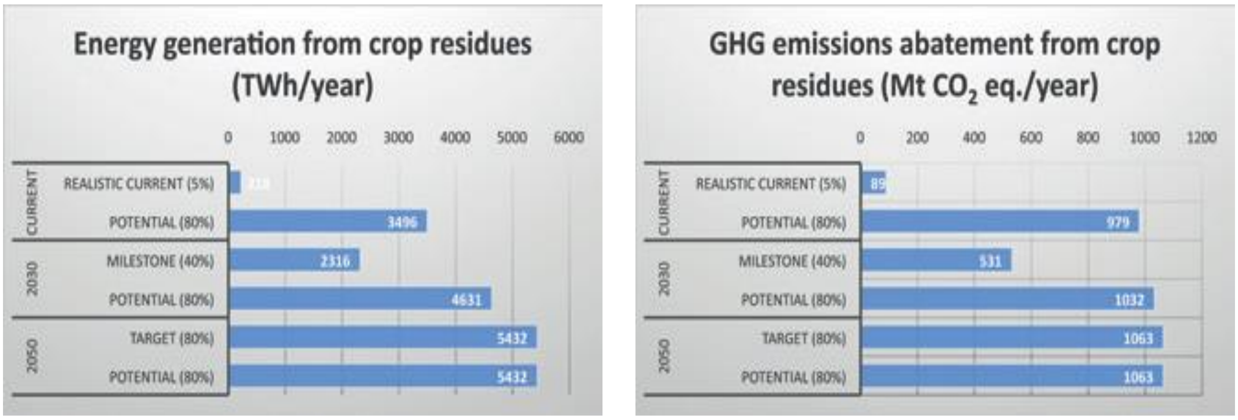


Figure 8. Energy generation (TWh/year) and GHG emissions abatement (Mt CO2 eq. /year) from agricultural residues globally (Source WBA, 2019)

3.6 Sequential cropping

Sequential cropping is a technique used to cultivate two or more crops in the same field over a defined period, in specific sequences with the goal of maximizing the use of land resources and increasing crop productivity. The second crop is planted after the primary crop has been harvested[17]. In recent years, there has been growing interest in using sequential cropping as a feedstock for biomethane production. In this case, sequential cropping combines food and energy crops, with the food crop being the main crop and the energy crop being the supplementary. Sequential cropping can be possible with short season crop varieties that could complete their growing cycle within the selected crop sequence.

The concept of sequential cropping involves planting different crops in the same field over time, rather than the traditional practice of planting the same crop year after year. This approach allows for more efficient use of resources such as agrochemicals and synthetic fertilizers, especially when legume crops are involved in the cropping sequence.

Longer periods of land cover with cover crops in sequential cropping can help to improve soil health, reduce erosion, improve soil water storage capacity and help maintenance of long-term productivity and organic matter[18] [19]. Sequential cropping can help to break up pest and disease cycles and provide a more diverse and resilient crop portfolio. The diversified choice of multiple crops can assure time-diluted farming activities throughout the year and not at specific times and narrow harvesting windows, which can lead to greater market opportunities and lower economic and climatic risks[20].

[17] Andrews, D.J.; Kassam, A.H. The Importance of Multiple Cropping in IncreasingWorld Food Supplies. Mult. Crop. 1976, 27, 1–10.
[18] Karlen DL, Varvel GE, Bullock DG, Cruse RM. Crop rotations for the 21st century. Adv Agron 1994;53:1e45.
[19] Giller KE, Beare MH, Lavelle P, Izac MN, Swift MJ. Agricultural intensification, soil biodiversity and agroecosystem function. Appl Soil Ecol 1997;6:3e16.
[20] Zegada-Lizarazu, W., Monti, A. Energy crops in rotation. A review. Biomass and Bioenergy 35 (2011) 12-25 doi:10.1016/j.biombioe.2010.08.001

This project has received funding from the European Union's Horizon Europe Research and Innovation Programme under Grant Agreement No. 101075676.

In addition to improving the efficiency and sustainability of biomethane production, sequential cropping can also provide economic benefits for farmers. By diversifying their crop portfolio, farmers can reduce their reliance on a single crop and improve their resilience to market fluctuations. In addition, the use of cover crops can help to reduce the need for expensive inputs such as fertilizers and pesticides, further reducing costs.

Nevertheless, sequential cropping is not always possible as it is greatly affected by the climate conditions that affect the growing capacity and cycle of each crop.

When it comes to biomethane production, sequential cropping involved the cultivation of a food, being the primary crop and an energy crop, being the supplementary one.

Recently in Italy, sequential cropping is largely applied through the so-called model called Biogasdoneright™ (BDR™)[21], and serves food, feed and biogas production in a sustainable and integrated approach. It this system, the primary crop (i.e maize) grows as spring crops and produces food or feed. The sequential crop is a winter cover crop that grows during winter time on the same land, which in traditional agricultural practices would remain fallow until spring (Figure 9).

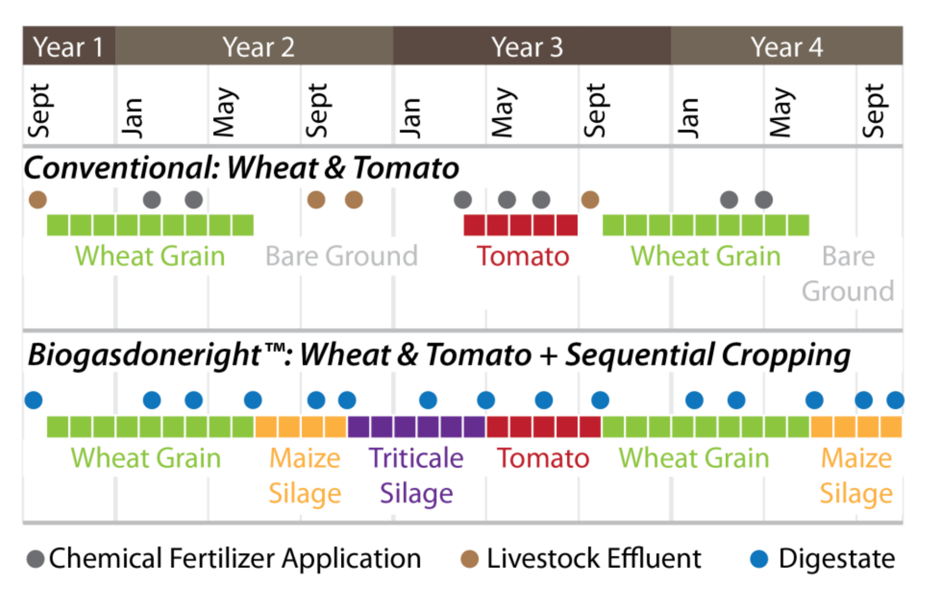


Figure 9. Two Cropping Cycles: Conventional vs. Biogasdoneright ™[22]

Apart from the residual streams, new feedstocks can be grown under sustainable cultivating practices, such as sequential cropping and growing dedicated crops on marginal and phyto-remediated lands.

There is ongoing work recently under the Biomethane Industrial Platform, on the potential crops that can be cultivated in marginal lands, which can be unused, abandoned, contaminated or severely degraded areas, in Europe. Cultivating biomass on marginal lands may very well address the food vs fuel competition, preserve the soils from erosion and offer the opportunity to increase carbon stock,

[21] Dale, B.E.; Sibilla, F.; Fabbri, C.; Pezzaglia, M.; Pecorino, B.; Veggia, E.; Baronchelli, A.; Gattoni, P.; Bozzetto, S. BiogasdonerightTM: An Innovative New System Is Commercialized in Italy. Biofuels Bioprod. Biorefin. 2016, 10, 341–345.
[22] https://www.globalmethane.org/gmf2018/presentations/0417Biogasdoneright.pdf

This project has received funding from the European Union's Horizon Europe Research and Innovation Programme under Grant Agreement No. 101075676.

while producing additional biomass. Moreover, adopting phytoremediation solutions help recover contaminated lands, which is a double opportunity to produce biomass and capture contaminants from soil. Nevertheless cultivating these lands is challenging due to the limited inputs and expected low biomass yields.

However, competing claims and debates over the definition of such lands for biomass production still exist. Locating and quantifying their untapped biomass potential, together with the key issues to address from legislation, remain a challenge. Moreover, biomass supply potential, biogas productivity and economics remain still studied only at demo-scale. For instance, this deliverable refers to initiatives as EU projects (e.g. BIKE, S2Biom, MAGIC, PANACEA, SoilCare, GOLD, CERESIS, Phy4climate, BIO4A and BECOOL), technical studies and feedback from experts, policy makers and industry to deliver results.

Further research on the sequential cropping should include specific crop calendars to be developed for determined agro-climatic zones (i.e. Mediterranean, Continental or Atlantic) where suitable dedicated secondary crops will be grown during the period of the year in between the main crops. A recent study proposes suitable sequential crops to be incorporated into the conventional rotational systems allowing to obtain food, feed, energy and fertilisers production (Figure 10)[23].

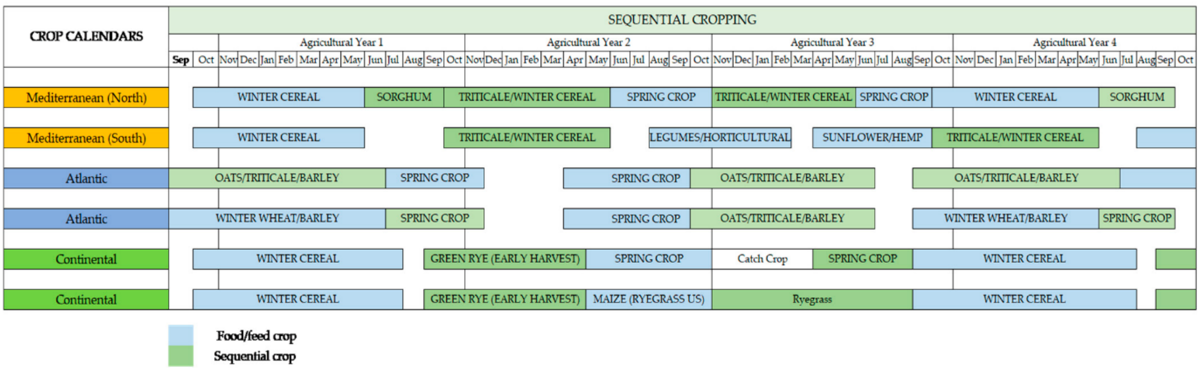


Figure 10. Sequential cropping

According to the study, the application of sequential cropping following the BDR™ system could be agronomically feasible for at least 15% of arable land in Europe and a total EU biomethane potential of 46 bcm per year and 185 bcm per year could be produced, depending on the primary crop land area dedicated to the sequential cropping.

There is already a number of EU research and demonstration projects aiming to provide evidence on the biomass potential in sequential cropping systems, i.e BECOOL, BIKE, whereas more are expected to follow.

[23] Magnolo, F.; Dekker, H.;Decorte, M.; Bezzi, G.; Rossi, L.; Meers, E.; Speelman, S. The Role of Sequential Cropping and Biogasdoneright™ in Enhancing the Sustainability of Agricultural Systems in Europe. Agronomy 2021, 11, 2102. https://doi.org/10.3390/agronomy11112102.

This project has received funding from the European Union's Horizon Europe Research and Innovation Programme under Grant Agreement No. 101075676.

3.7 Cultivation in marginal and contaminated lands

There is ongoing work recently under the Biomethane Industrial Platform, on the potential crops that can be cultivated in marginal, unused, abandoned, contaminated or severely degraded lands in Europe. Cultivating biomass on marginal lands may very well address the food vs fuel competition, preserve the soils from erosion and offer the opportunity to increase carbon stock, while producing additional biomass. Moreover, adopting phytoremediation solutions help recover contaminated lands, which is a double opportunity to produce biomass and capture contaminants from soil. Nevertheless cultivating these lands is challenging due to the limited inputs (limited soil fertility or access to irrigation), low soil depth, lack or excess of soil water content, stony fields to name only a few parameters, thus the expected biomass yields can be considerably low.

There is already a number of EU research and demonstration projects aiming to provide evidence on the biomass potential of these lands, i.e BECOOL, BIKE, BIO4A, CERESIS, GOLD, GRACE, MAGIC, MIDAS, PANACEA, S2Biom, SoilCare, Phy4climate.

3.8 The Biomethane Industrial Partnership

In September 2022, the European Commission and industry leaders have officially launched the Biomethane Industrial Partnership (BIP). The BIP is a public-private partnership industrial partnership in which policy makers, industry and other stakeholders team up with the goal to support the achievement of the target of 35 billion cubic meters annual production and use of sustainable biomethane by 2030, and to create the preconditions for a further ramp-up of its potential towards 2050[24]. The work of the Biomethane Industrial Partnership is structured in six Task Forces dedicated to specific pre-defined actions and are committed to deliver findings that are crucial to assist in reaching the defined target.

A specific Task Force 3 is working to identify the EU-wide potential for innovative (additional) biomass sources that help to achieve the 2030 target. This Task Force is mainly composed of companies and experts active in the biomethane value chain.

Task Force 3 is composed of four subgroups:

- TF 3.1, which aims to assess the EU-wide potential for sustainable rotational/sequential cropping to produce biomethane feedstock by improving sustainable farming practices and reducing food and biogas carbon intensity;

---

[24] https://bip-europe.eu/

This project has received funding from the European Union's Horizon Europe Research and Innovation Programme under Grant Agreement No. 101075676.

- TF 3.2, which focuses on evaluating the potential for feedstock production on marginal and contaminated land across the European Union;
- TF 3.3, which concentrates on analyzing the implications on carbon budget, soil nutrient, water, and biodiversity resulting from rotational/sequential cropping;
- TF 3.4, which is tasked with identifying additional innovative sustainable biomethane feedstocks, including wastes and residues.

It is thus evident that updated information of all kinds of feedstocks to be used for biomethane production will derive from the work of these task forces. This information will be added and discussed in the Deliverable 1.8, which is the updated version of this one and will be submitted at the end of the project.

3.9 Methodology

This report focuses exclusively on the use of livestock manure (cattle, pigs, and sheep/goats), food waste in general, milk by-products and straw from cereal cultivation as the main types of feedstock that would support biomethane production in European Union by 2030, in order to provide an estimation of the potential of this type of feedstock for biomethane production. The results could be used to support and justify EU policies related to the use of various type of organic waste as source of renewable energy and biogas in particular.

The reference point of the study is the estimation of the theoretical biomass potential in the EU27, and the subsequent estimation of the biogas produced through Anaerobic Digestion (AD) and the biomethane after biogas upgrading.

Biogas yields from anaerobic digestion in the case of farm manure vary depending on the type of feedstock (species, breed, age, body weight, feed, etc.) due to its specific chemical and physical composition and, in particular, to the difference of total solids, organic matter, carbohydrate and fat content. The same stands for other type of organic material that may be used for feeding an AD reactor.

The estimation of the potential is a difficult process, due to the particularities it presents, and specifically to the difficulty of estimating and recording the elements of the raw material (quantity, availability) with precision and completeness. The present study is based on the experience gained by the Biomass Department of CRES, from 1989 until today

- from the participation and transfer of knowledge, in relevant competitive EU programs,
- from the creation of primary domain databases based on accurate and reliable information and including tables, spreadsheets, forms, reports, queries, graphics, macros with sufficient detail,
- from the electronic collection of numerous journals and studies related to biomass energy utilization and potential assessment,
- from the electronic collection data. Data extracted on 22/11/2023 10:51:49 from Eurostat [ESTAT] Number of bovine animals, Number of dairy cows, Goats population, Number of

This project has received funding from the European Union's Horizon Europe Research and Innovation Programme under Grant Agreement No. 101075676.

sheep, Number of pigs, Production of milk on farms, Food waste, Wheat-Barley-Rye-Oats by area, production from European Union - 27 countries (Timeframe: 2023).

In this way, the theoretical biomass potential is obtained with a high degree of accuracy.

In addition, with flow charts, use of process simulation code and numerical sub-routines, mass-energy balance was calculated, resulting in the estimation of biogas production.

The availability fraction of manure, which represents the amount of feedstock that could be actually used for feeding the AD plant, strongly depends on species' current farming systems and disposal practices. The amount of manure used for the calculations was estimated based on factors that derived from common agricultural best practises for every type of livestock species.

Then, using data from leading European technology service providers specializing in biogas upgrading, the biomethane that will be produced from the available biogas is calculated, according to the selected type of biomass.

The calculated parameters are: methane content of biogas (m^3), biogas (m^3), energy content of biogas (MWh), power of biogas (kW), biomethane (m^3) and energy content of biomethane (MWh) per type of waste and animal (in relation to the category of the animal and its age) per 27 countries .

Where required, biomethane calorific value (9.94 kWh/Nm³) was used to convert from m^3 to MWh and vice versa. For the calculation of the e-installed power in MW, 8,760 annual operating hours of the biogas/biomethane plant were considered. Also methane recovery 98% , availability 95%.

The biomass categories examined in the context of this specific study are livestock waste (manure), agricultural residues from winter grains (straw), agro-industrial waste (whey from milk,) and the organic fraction of Municipal Solid Waste (MSW). The above waste will be used as raw materials for the production of biogas/biomethane and is in accordance with Annex XI of the amended Energy and Climate Directive (RED II).

Particularly important is the fact that for the supply or purchase of biomass, there should be fuel (biomass) contracts. Fuel contracts, in addition to legal validity and clauses on the part of the producer for his obligation to the investor regarding the delivery of a specified amount of biomass in a specific period of time, also provide the guarantee of required quality characteristics of the biomass desired by the investor of the biogas plant/ biomethane.

3.10 Feedstock availability for biomethane production

In EU-27, the theoretical biomass potential from livestock manure, grain straw, agro-industrial waste and food waste amounts to 1,393,068,304 tons/year (Table 1), with a biomethane energy content of 382,89 TWh/year or 39,71 bcm/year (Table 2 and Figure 11). The availability of biomass production throughout the year in the wider area of EU is guaranteed by at least 40% if it is accompanied by contract farming conditions.

France is leading the way with 247 Mt/year of biomass, followed by Germany (228 Mt/y), Spain (135 Mt/y), Poland (123 Mt/y) and Italy with 118Mt/year.

This project has received funding from the European Union's Horizon Europe Research and Innovation Programme under Grant Agreement No. 101075676.

Table 1. Theoretical biomass potential in EU27

BIOMASS POTENTIAL	TOTAL MANURE t/year	TOTAL WHEY & FOOD WASTE t /year	TOTAL STRAW t /year	TOTAL BIOMASS t /year
European Union - 27 Countries	**1,156,438,767**	**168,149,203**	**68,480,334**	**1,393,068,304**
Belgium	35,110,673	6,139,903	480,060	41,730,636
Bulgaria	9,899,104	1,312,214	2,449,800	13,661,118
Czech Republic	19,089,469	3,295,566	2,171,862	24,556,897
Denmark	36,896,198	5,262,826	2,191,806	44,350,830
Germany	184,883,767	33,755,814	9,486,540	228,126,120
Estonia	3,875,716	760,075	608,436	5,244,227
Ireland	81,988,690	7,147,567	484,038	89,620,295
Greece	11,986,000	3,439,221	900,234	16,325,455
Spain	116,121,184	10,197,502	8,805,546	135,124,232
France	208,218,257	26,308,707	12,577,428	247,104,392
Croatia	6,248,905	661,081	142,740	7,052,726
Italy	96,503,067	17,794,569	4,054,770	118,352,406
Cyprus	2,084,265	608,897	41,040	2,734,202
Latvia	5,853,871	973,138	392,940	7,219,949
Lithuania	9,903,437	1,457,178	2,225,880	13,586,495
Luxembourg	2,555,053	411,574	38,196	3,004,823
Hungary	15,854,301	2,336,392	2,730,078	20,920,771
Malta	274,630	108,935	0	383,566
Netherlands	73,268,818	13,328,955	68,652	86,666,425
Austria	28,261,258	4,014,011	835,884	33,111,153
Poland	100,380,380	14,913,024	8,198,082	123,491,486
Portugal	20,098,545	3,242,343	137,214	23,478,102
Romania	45,025,314	3,127,554	5,089,212	53,242,080
Slovenia	5,587,297	1,017,059	92,970	6,697,326
Slovakia	6,149,358	1,291,642	974,232	8,415,232
Finland	12,215,913	2,519,574	1,681,200	16,416,687
Sweden	18,105,398	2,723,896	1,621,476	22,450,770

This project has received funding from the European Union's Horizon Europe Research and Innovation Programme under Grant Agreement No. 101075676.

Table 2. Potential biomethane production (in bcm) for the natural gas grid and energy content (TWh/y)

2022	POTENTIAL BIOMETHANE FOR GAS NETWORK bcm/year	BIOMETHANE ENERGY CONTENT TWh/y
European Union - 27 countries	**39.71**	**382.89**
BOVINE	7.87	75.88
DAIRY COW	5.77	55.59
SHEEP	1.3	12.58
GOATS	0.25	2.4
SWINE/PIGS	1.97	18.99
TOTAL	**17.16**	**165.44**
WHEAT STAW	10.07	97.07
OAT	1.15	11.12
BARLEY	4.5	43.4
RYE	0.85	8.19
TOTAL	**16.57**	**159.78**
WHEY/MILK	1.58	15.22
BIO-FOOD WASTE	4.4	42.45
TOTAL	**5.98**	**57.67**

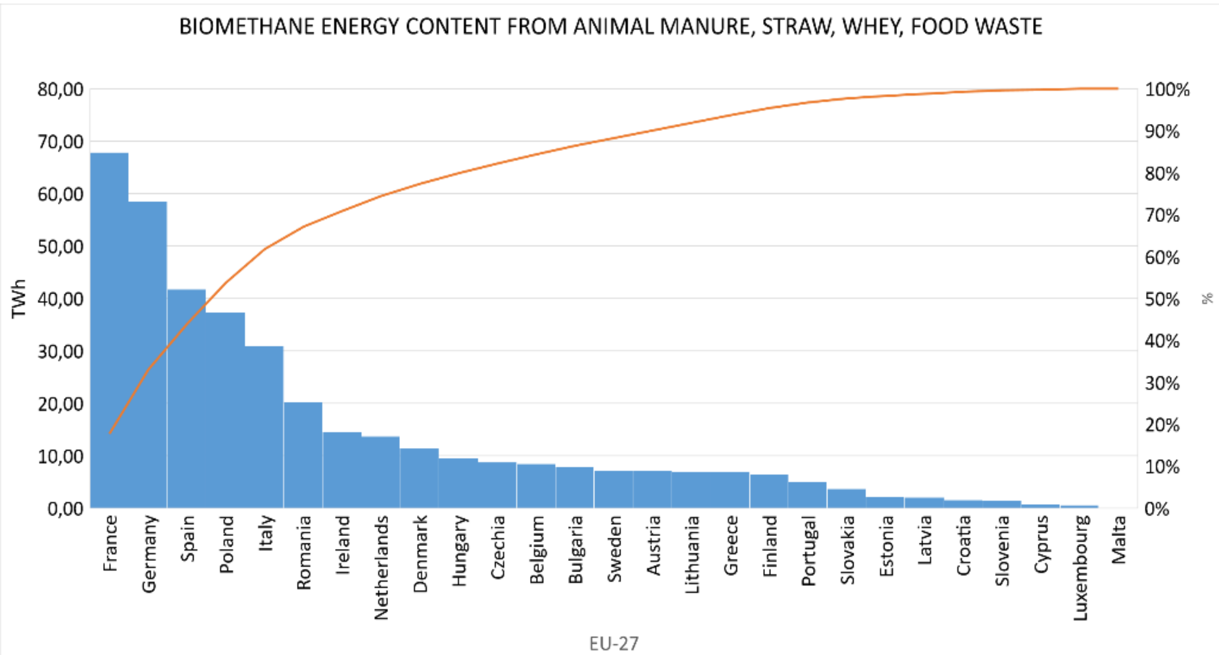


Figure 11. Biomethane energy content (TWh/y)

This project has received funding from the European Union's Horizon Europe Research and Innovation Programme under Grant Agreement No. 101075676.

3.10.1Manure

Fluctuations in the population of the main species of animals (cattle, pigs, goats, sheep) have been noticed from 2010 to 2021 according to EUROSTAT, with the most significant decrease in the population of sheep and goats (Figure 12).

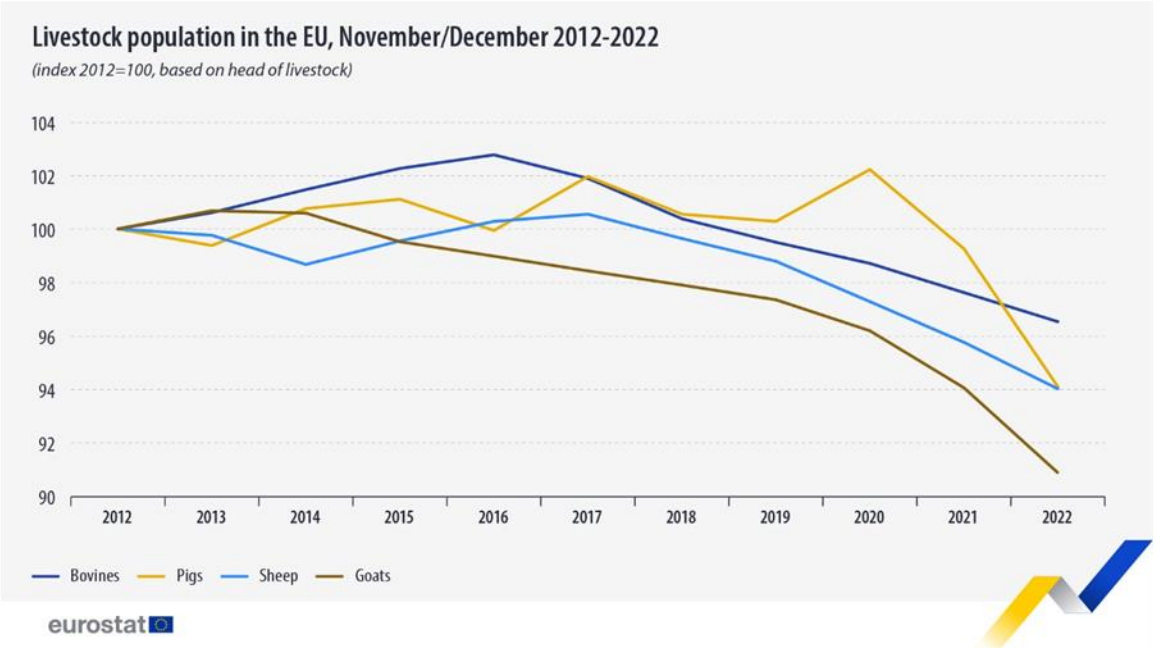


Figure 12. Livestock population in EU, 2010 – 2022.

Around 134 million pigs, 78 million Bovine, 20 million Dairy caw, 60 million sheep and 11 million goats are reared in the EU in 2022, with the majority of European livestock recorded in just a few Member States (Figure 13).

Swine (pigs) proved to be the most common livestock in EU, followed by bovine in the most northern European states (France, Germany, the Nederland, Poland, etc.) In the most southern states great share of the livestock belongs to sheep and goats. In Greece, according to the data, 25% of the EU goat population is bred.

In general, the largest Member States raise the most animals.

- Spain accounted for 25.4% of EU pigs, 7.66% of EU cattle, 24.5% of EU sheep and 21.8% of EU goats.
- France accounted for 9.1 % of EU pigs, 21.31% of EU cattle, 11.2% of EU sheep and 11.6% of EU goats.
- Germany accounted for 15.9% of EU pigs and 15.61% of EU cattle, 2.6% of EU sheep and 1.4% of EU goats.
- Greece accounted for 0.6% of EU pigs and 0.7% of EU cattle, 12.5% of EU sheep and 26.2% of EU goats.

This project has received funding from the European Union's Horizon Europe Research and Innovation Programme under Grant Agreement No. 101075676.

Since usually swine, bovine and dairy cows grow in large organised farms, the handling of manure is more systematic and therefore it is easier to be collected and used for feedstock in AD plants. Sheep and goats, usually grow in small installations, or even sometimes they are grassed in open land; therefore, their manure is difficult to be retrieved.

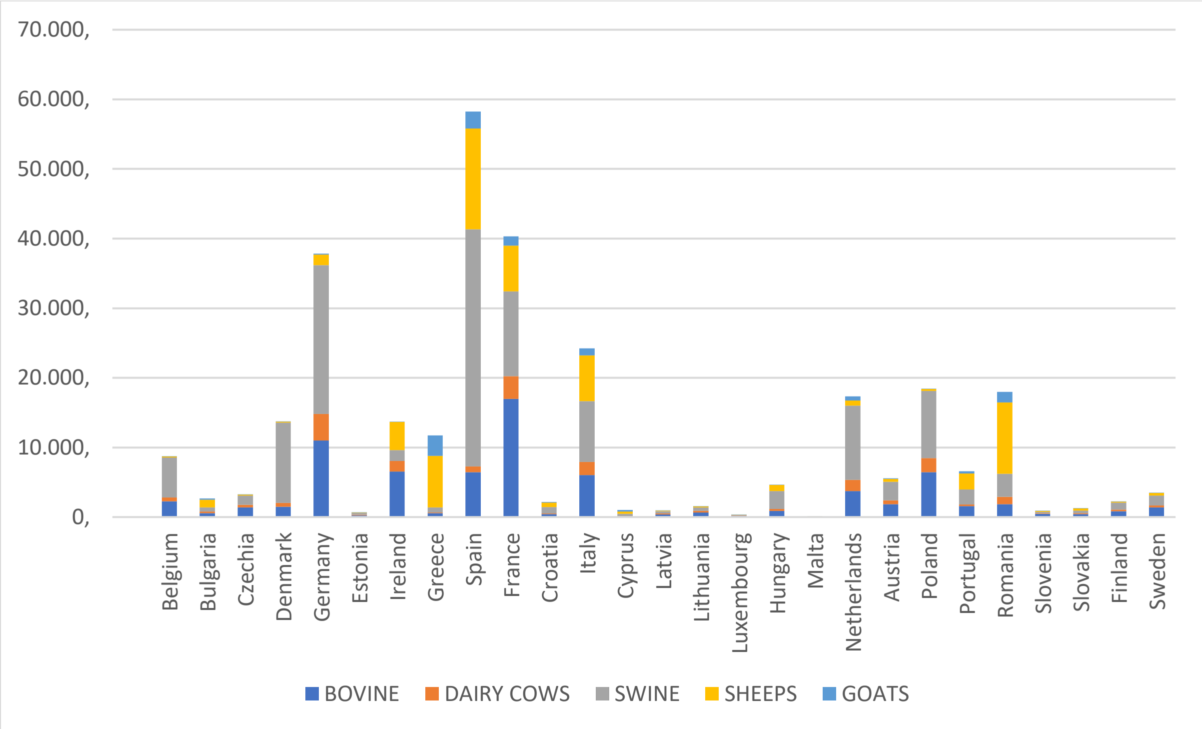


Figure 13. Livestock species per EU State (in thousands livestock heads)

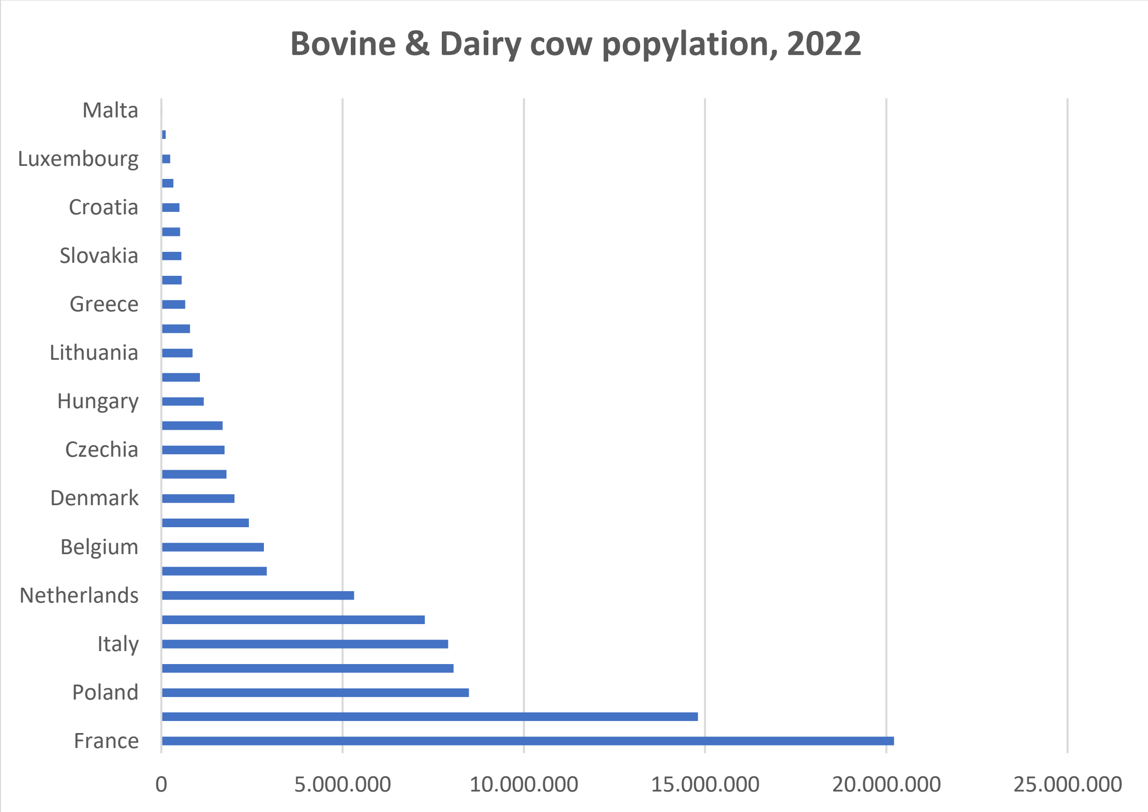
The countries with the largest number of animals in the EU by category are (Figure 14):

- France accounted for 21.3% of the EU cattle population.
- Spain accounted for 25.4 % of the EU pig population.
- Spain accounted for 24.5% of the EU sheep population.
- Greece accounted for 26.2% of the EU goat population.

There were some other member states that were relatively specialized.

- Denmark accounted for 9% of the EU pig population and the Netherlands a further 8%.
- Ireland accounted for 8.5% of the EU cattle population.
- Romania accounted for 17.4% of the EU sheep population.

This project has received funding from the European Union's Horizon Europe Research and Innovation Programme under Grant Agreement No. 101075676.



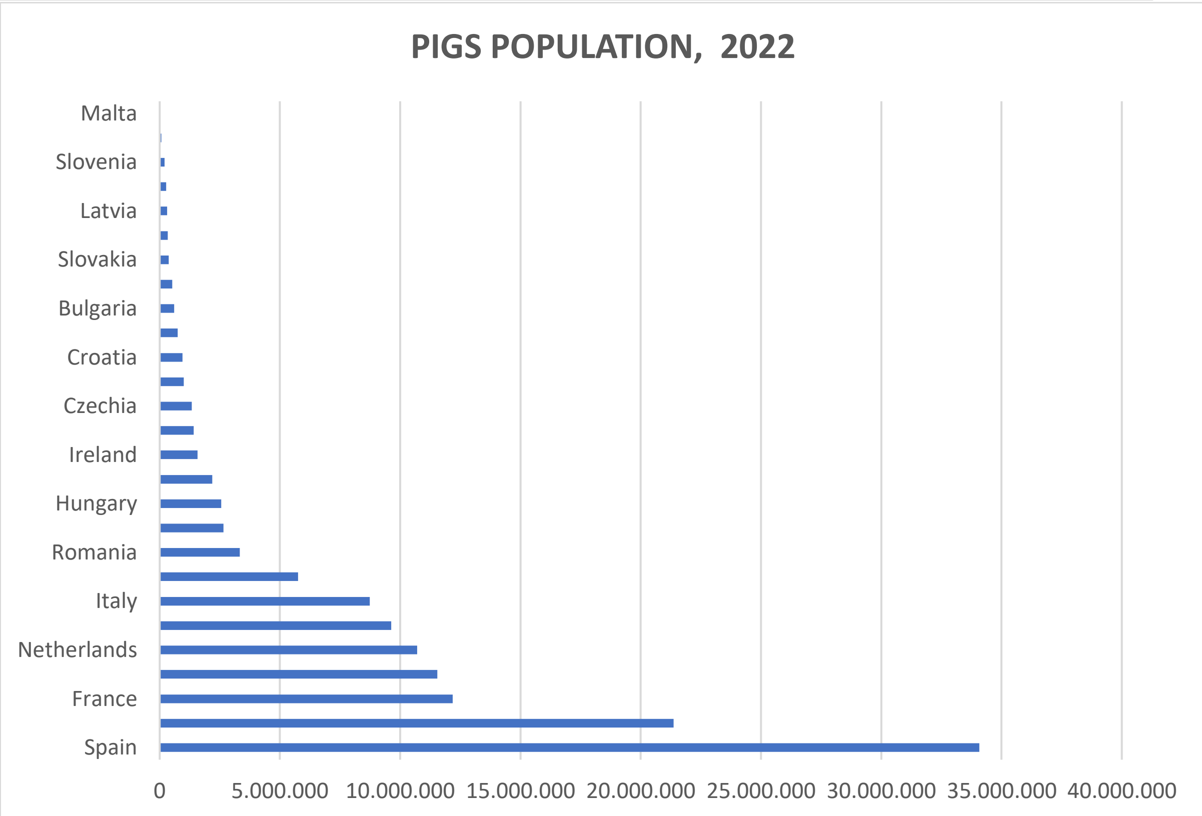


Figure 14. Bovines, dairy cows and pigs populations in 2022

This project has received funding from the European Union's Horizon Europe Research and Innovation Programme under Grant Agreement No. 101075676.

3.10.2Food waste and milk by-products

As far as food waste and milk by-products that are examined in this report, data comes from Eurostat and are based on national data derived from the waste management organisations of each Member State. Under the category 'Food waste' is the organic fraction of the household waste, the waste from the primary production of food, the waste from the food and beverage industry and the waste from retail and food distribution sector and the waste from restaurants and food services. The quality of data for the various categories varies between Member States but the aggregate number is considered reliable (Table 3).

Table 3. Available food waste and whey in EU Countries.

	FOOD AND WASTE tons/year	WHEY tons/year
Total European Union - 27 Countries (Form 2020)	**56,608,830**	**111,540,373**
Belgium	2,907,303	3,232,600
Bulgaria	704,194	608,020
Czech Republic	957,699	2,337,867
Denmark	1,298,026	3,964,800
Germany	11,060,680	22,695,134
Estonia	166,055	594,020
Ireland	771,771	6,375,796
Greece	2,039,620	1,399,601
Spain	4,259,402	5,938,100
France	8,788,512	17,520,195
Croatia	286,581	374,500
Italy	8,014,393	9,780,176
Cyprus	352,536	256,361
Latvia	290,435	682,703
Lithuania	391,820	1,065,358
Luxembourg	94,873	316,701
Hungary	904,962	1,431,430
Malta	79,479	29,456
Netherlands	2,840,225	10,488,730
Austria	1,227,808	2,786,203
Poland	4,260,368	10,652,656
Portugal	1,820,685	1,421,658
Slovenia	144,224	2,983,330
Slovakia	577,382	439,677
Finland	642,756	648,886
Sweden	938,533	1,581,041

This project has received funding from the European Union's Horizon Europe Research and Innovation Programme under Grant Agreement No. 101075676.

The milk quantity produced in each Member State is officially recorded. As feedstock in an AD plant, whey is used, which is a by-product of the dairy industry. For the purposes of this report whey is estimated, using factors that are derived from the best practises of the dairy industry. Here it must be noted that whey has competitive uses, which may hinder its availability. However, we have included it in our calculations, since it has large biogas potential. This option may become a favourable one in the future if market conditions allow for it.

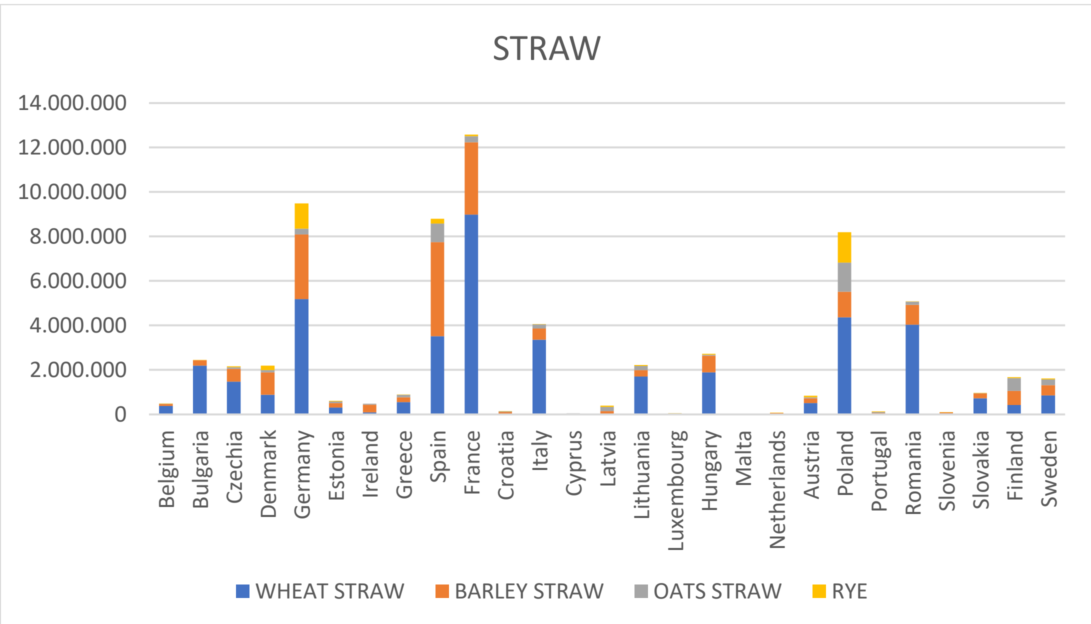
3.10.3Agricultural residues

Finally, the last organic waste category examined in this report is the straw from cereal cultivation. Cereal production in the EU registered a negative sign in 2022, due to extensive drought that prevailed in the main agricultural countries of EU. According to Eurostat data, in 2022 the EU produced 270.9 million tonnes of cereals, 26.7 million tonnes less than in 2021, equivalent to a 9% decrease. In terms of the producing countries, Germany harvested 9.4 million tons of straw (13.9% of the EU total), Spain 8.8 million tons (12.9%), 8.1 million tons (12%), and Romania 5 million tons (7.4 % of the EU total).

Nevertheless, there were countries with increased total grain harvest. The list includes Germany, which increased production by 3% (1.1 million tons), Finland by 39% (1 million tons recovery after a poor harvest in 2021) and Poland by 3% (increase 1 million)

The basic use of straw is for animal feed. In order not to distort the feed market, for the scope of this report the estimated quantities that can be used as feedstock for AD plants is the straw portion that remains unexploited. The data derived also from Eurostat and the values are from 2023. The following Figure 15. Total straw production in EU (in tons)

Table 4 presents the available quantities of straw from the four main species of cereals, wheat, oats, barley and rye.



This project has received funding from the European Union's Horizon Europe Research and Innovation Programme under Grant Agreement No. 101075676.

Figure 15. Total straw production in EU (in tons)

Table 4. Available straw for AD feedstock use in EU Countries.

	WHEAT tons/year	OAT tons/year	BARLEY tons/year	RYE tons/year
European Union - 27 Countries (From 2020)	**41,604,876**	**4,764,366**	**18,599,832**	**3511260**
Belgium	384,300	5,400	88,380	1,980
Bulgaria	2,187,000	0	248,400	14,400
Czech Republic	1,471,968	77,490	578,034	44,370
Denmark	880,344	105,696	1,010,268	195,498
Germany	5,191,200	267,840	2,895,660	1,131,840
Estonia	310,932	64,764	202,158	30,582
Ireland	100,260	48,582	335,196	0
Greece	559,458	112,572	214,164	14,040
Spain	3,510,720	829,278	4,237,020	228,528
France	8,981,856	269,118	3,256,938	69,516
Croatia		27,000	113,400	2,340
Italy	3,361,608	184,014	502,452	6,696
Cyprus	19,800	540	20,700	0
Latvia		177,480	156,420	59,040
Lithuania	1,703,160	180,000	291,420	51,300
Luxembourg	22,446	2,538	10,368	2,844
Hungary	1,896,444	39,240	742,392	52,002
Malta	0	0	0	0
Netherlands		0	64,422	4,230
Austria	507,564	34,092	220,878	73,350
Poland	4,366,314	1,313,622	1,153,980	1,364,166
Portugal	47,502	43,452	21,474	24,786
Slovenia	4,030,902	132,840	903,870	21,600
Slovakia	51,660	0	39,474	1,836
Finland	730,404	18,144	204,516	21,168
Sweden	427,140	569,700	636,120	48,240

This project has received funding from the European Union's Horizon Europe Research and Innovation Programme under Grant Agreement No. 101075676.

4. Biomethane Production

Following the methodology described in the previous paragraph and using the available feedstock data, the potential production of biomethane in all the 27 EU States can be estimated. The results of this estimation are presented by different type of feedstock in the following tables (Table 5 - Table 11):

Table 5. Potential biomethane produced from bovine manure in EU

LIVE BOVINE ANIMALS	LIVESTOCK (number)	MANURE (tons/year)	PRODUCED BIOGAS (bcm/year)	POTENTIAL BIOMETHANE FOR GAS NETWORK (bcm/year)	BIOMETHANE ENERGY CONTENT (TWh/year)
European Union - 27 Countries	**74,807,630**	**546,095,699**	**13.76**	**7.87**	**75.88**
Belgium	2,286,110	16,688,603	0.42	0.24	2.32
Bulgaria	579,860	4,232,978	0.11	0.06	0.59
Czech Republic	1,390,490	10,150,577	0.26	0.15	1.41
Denmark	1,466,000	10,701,800	0.27	0.15	1.49
Germany	10,996,960	80,277,808	2.02	1.16	11.15
Estonia	249,620	1,822,226	0.05	0.03	0.25
Ireland	6,551,830	47,828,359	1.21	0.69	6.65
Greece	581,600	4,245,680	0.11	0.06	0.59
Spain	6,455,130	47,122,449	1.19	0.68	6.55
France	16,986,190	123,999,187	3.12	1.79	17.23
Croatia	422,000	3,080,600	0.08	0.04	0.43
Italy	6,049,000	44,157,700	1.11	0.64	6.14
Cyprus	81,440	594,512	0.01	0.01	0.08
Latvia	391,350	2,856,855	0.07	0.04	0.40
Lithuania	641,920	4,686,016	0.12	0.07	0.65
Luxembourg	186,130	1,358,749	0.03	0.02	0.19
Hungary	894,000	6,526,200	0.16	0.09	0.91
Malta	14,200	103,660	0.00	0.00	0.01
Netherlands	3,751,000	27,382,300	0.69	0.39	3.80
Austria	1,861,070	13,585,811	0.34	0.20	1.89
Poland	6,448,290	47,072,517	1.19	0.68	6.54
Portugal	1,579,140	11,527,722	0.29	0.17	1.60
Romania	1,833,700	13,386,010	0.34	0.19	1.86
Slovenia	464,910	3,393,843	0.09	0.05	0.47
Slovakia	433,180	3,162,214	0.08	0.05	0.44
Finland	821,970	6,000,381	0.15	0.09	0.83
Sweden	1,390,550	10,151,015	0.26	0.15	1.41

This project has received funding from the European Union's Horizon Europe Research and Innovation Programme under Grant Agreement No. 101075676.

Table 6. Potential biomethane produced from dairy cows manure in EU

LIVE DAIRY COWS	LIVESTOCK (number)	MANURE (tons/year)	PRODUCED BIOGAS (bcm/year)	POTENTIAL BIOMETHANE FOR GAS NETWORK (bcm/year)	BIOMETHANE ENERGY CONTENT (TWh/year)
European Union - 27 Countries	**20,073,770**	**400,070,236**	**10.08**	**5.77**	**55.59**
Belgium	543,680	10,835,542	0.27	0.16	1.51
Bulgaria	212,840	4,241,901	0.11	0.06	0.59
Czech Republic	356,650	7,108,035	0.18	0.10	0.99
Denmark	556,000	11,081,080	0.28	0.16	1.54
Germany	3,809,720	75,927,720	1.91	1.09	10.55
Estonia	83,740	1,668,938	0.04	0.02	0.23
Ireland	1,510,310	30,100,478	0.76	0.43	4.18
Greece	80,500	1,604,365	0.04	0.02	0.22
Spain	809,990	16,143,101	0.41	0.23	2.24
France	3,230,860	64,391,040	1.62	0.93	8.95
Croatia	79,000	1,574,470	0.04	0.02	0.22
Italy	1,865,000	37,169,450	0.94	0.54	5.16
Cyprus	38,220	761,725	0.02	0.01	0.11
Latvia	127,760	2,546,257	0.06	0.04	0.35
Lithuania	224,180	4,467,907	0.11	0.06	0.62
Luxembourg	55,330	1,102,727	0.03	0.02	0.15
Hungary	277,900	5,538,547	0.14	0.08	0.77
Malta	6,120	121,972	0.00	0.00	0.02
Netherlands	1,570,000	31,290,100	0.79	0.45	4.35
Austria	550,550	10,972,462	0.28	0.16	1.52
Poland	2,037,280	40,602,990	1.02	0.59	5.64
Portugal	221,540	4,415,292	0.11	0.06	0.61
Romania	1,075,600	21,436,708	0.54	0.31	2.98
Slovenia	93,250	1,858,473	0.05	0.03	0.26
Slovakia	116,910	2,330,016	0.06	0.03	0.32
Finland	243,170	4,846,378	0.12	0.07	0.67
Sweden	297,670	5,932,563	0.15	0.09	0.82

This project has received funding from the European Union's Horizon Europe Research and Innovation Programme under Grant Agreement No. 101075676.

Table 7. Potential biomethane produced from swine manure in EU

Live swine (pigs)	LIVESTOCK (number)	MANURE (tons/year)	PRODUCED BIOGAS (bcm/year)	POTENTIAL BIOMETHANE FOR GAS NETWORK (bcm/year)	BIOMETHANE ENERGY CONTENT (TWh/year)
European Union - 27 Countries	**134,410,040**	**175,136,282**	**3.44**	**1.97**	**18.99**
Belgium	5,751,180	7,493,788	0.15	0.08	0.81
Bulgaria	601,700	784,015	0.02	0.01	0.09
Czech Republic	1,328,820	1,731,452	0.03	0.02	0.19
Denmark	11,541,000	15,037,923	0.30	0.17	1.63
Germany	21,366,300	27,840,289	0.55	0.31	3.02
Estonia	269,380	351,002	0.01	0.00	0.04
Ireland	1,570,390	2,046,218	0.04	0.02	0.22
Greece	741,600	966,305	0.02	0.01	0.10
Spain	34,073,380	44,397,614	0.87	0.50	4.81
France	12,182,590	15,873,915	0.31	0.18	1.72
Croatia	945,000	1,231,335	0.02	0.01	0.13
Italy	8,739,000	11,386,917	0.22	0.13	1.23
Cyprus	330,870	431,124	0.01	0.00	0.05
Latvia	307,950	401,259	0.01	0.00	0.04
Lithuania	517,420	674,198	0.01	0.01	0.07
Luxembourg	66,410	86,532	0.00	0.00	0.01
Hungary	2,558,100	3,333,204	0.07	0.04	0.36
Malta	29,550	38,504	0.00	0.00	0.00
Netherlands	10,706,000	13,949,918	0.27	0.16	1.51
Austria	2,650,150	3,453,145	0.07	0.04	0.37
Poland	9,624,250	12,540,398	0.25	0.14	1.36
Portugal	2,183,320	2,844,866	0.06	0.03	0.31
Romania	3,328,700	4,337,296	0.09	0.05	0.47
Slovenia	202,150	263,401	0.01	0.00	0.03
Slovakia	380,900	496,313	0.01	0.01	0.05
Finland	997,670	1,299,964	0.03	0.01	0.14
Sweden	1,416,270	1,845,400	0.04	0.02	0.20

This project has received funding from the European Union's Horizon Europe Research and Innovation Programme under Grant Agreement No. 101075676.

Table 8. Potential biomethane produced from sheep manure in EU

Live sheep	LIVESTOCK (number)	MANURE (tons/year)	PRODUCED BIOGAS (bcm/year)	POTENTIAL BIOMETHANE FOR GAS NETWORK (bcm/year)	BIOMETHANE ENERGY CONTENT (TWh/year)
European Union - 27 Countries	**59,010,250**	**29,505,125**	**2.28**	**1.30**	**12.58**
Belgium	110,120	55,060	0.00	0.00	0.02
Bulgaria	1,096,400	548,200	0.04	0.02	0.23
Czech Republic	174,200	87,100	0.01	0.00	0.04
Denmark	132,510	66,255	0.01	0.00	0.03
Germany	1,516,900	758,450	0.06	0.03	0.32
Estonia	63,100	31,550	0.00	0.00	0.01
Ireland	4,018,030	2,009,015	0.16	0.09	0.86
Greece	7,378,400	3,689,200	0.29	0.16	1.57
Spain	14,452,590	7,226,295	0.56	0.32	3.08
France	6,597,520	3,298,760	0.26	0.15	1.41
Croatia	643,000	321,500	0.02	0.01	0.14
Italy	6,568,000	3,284,000	0.25	0.15	1.40
Cyprus	343,400	171,700	0.01	0.01	0.07
Latvia	87,320	43,660	0.00	0.00	0.02
Lithuania	135,640	67,820	0.01	0.00	0.03
Luxembourg	9,000	4,500	0.00	0.00	0.00
Hungary	871,700	435,850	0.03	0.02	0.19
Malta	14,470	7,235	0.00	0.00	0.00
Netherlands	723,000	361,500	0.03	0.02	0.15
Austria	400,660	200,330	0.02	0.01	0.09
Poland	266,370	133,185	0.01	0.01	0.06
Portugal	2,269,280	1,134,640	0.09	0.05	0.48
Romania	10,247,400	5,123,700	0.40	0.23	2.18
Slovenia	117,200	58,600	0.00	0.00	0.02
Slovakia	301,130	150,565	0.01	0.01	0.06
Finland	132,080	66,040	0.01	0.00	0.03
Sweden	340,840	170,420	0.01	0.01	0.07

This project has received funding from the European Union's Horizon Europe Research and Innovation Programme under Grant Agreement No. 101075676.

Table 9. Potential biomethane produced from goats manure in EU

LIVE GOATS	LIVESTOCK (number)	MANURE (tons/year)	PRODUCED BIOGAS (bcm/year)	POTENTIAL BIOMETHANE FOR GAS NETWORK (bcm/year)	BIOMETHANE ENERGY CONTENT (TWh/year)
European Union - 27 Countries	**11,262,850**	**5,631,425**	**0.44**	**0.25**	**2.40**
Belgium	75,360	37,680	0.00	0.00	0.02
Bulgaria	184,020	92,010	0.01	0.00	0.04
Czech Republic	24,610	12,305	0.00	0.00	0.01
Denmark	18,280	9,140	0.00	0.00	0.00
Germany	159,000	79,500	0.01	0.00	0.03
Estonia	4,000	2,000	0.00	0.00	0.00
Ireland	9,240	4,620	0.00	0.00	0.00
Greece	2,960,900	1,480,450	0.11	0.07	0.63
Spain	2,463,450	1,231,725	0.10	0.05	0.53
France	1,310,710	655,355	0.05	0.03	0.28
Croatia	82,000	41,000	0.00	0.00	0.02
Italy	1,010,000	505,000	0.04	0.02	0.22
Cyprus	250,410	125,205	0.01	0.01	0.05
Latvia	11,680	5,840	0.00	0.00	0.00
Lithuania	14,990	7,495	0.00	0.00	0.00
Luxembourg	5,090	2,545	0.00	0.00	0.00
Hungary	41,000	20,500	0.00	0.00	0.01
Malta	6,520	3,260	0.00	0.00	0.00
Netherlands	570,000	285,000	0.02	0.01	0.12
Austria	99,020	49,510	0.00	0.00	0.02
Poland	62,580	31,290	0.00	0.00	0.01
Portugal	352,050	176,025	0.01	0.01	0.08
Romania	1,483,200	741,600	0.06	0.03	0.32
Slovenia	25,960	12,980	0.00	0.00	0.01
Slovakia	20,500	10,250	0.00	0.00	0.00
Finland	6,300	3,150	0.00	0.00	0.00
Sweden	12,000	6,000	0.00	0.00	0.00

This project has received funding from the European Union's Horizon Europe Research and Innovation Programme under Grant Agreement No. 101075676.

Table 10. Potential biomethane produced from food waste in EU

FOOD WASTE	FOOD WASTE - HOUSEHOLD AND SIMILAR WASTE tons/year	PRODUCED BIOGAS bcm/year	POTENTIAL BIOMETHANE FOR GAS NETWORK bcm/year	BIOMETHANE ENERGY CONTENT TWh/year
European Union - 27 Countries	**56,608,830**	**7.70**	**4.40**	**42.45**
Belgium	2,907,303	0.40	0.23	2.18
Bulgaria	704,194	0.10	0.05	0.53
Czech Republic	957,699	0.13	0.07	0.72
Denmark	1,298,026	0.18	0.10	0.97
Germany	11,060,680	1.50	0.86	8.29
Estonia	166,055	0.02	0.01	0.12
Ireland	771,771	0.10	0.06	0.58
Greece	2,039,620	0.28	0.16	1.53
Spain	4,259,402	0.58	0.33	3.19
France	8,788,512	1.20	0.68	6.59
Croatia	286,581	0.04	0.02	0.21
Italy	8,014,393	1.09	0.62	6.01
Cyprus	352,536	0.05	0.03	0.26
Latvia	290,435	0.04	0.02	0.22
Lithuania	391,820	0.05	0.03	0.29
Luxembourg	94,873	0.01	0.01	0.07
Hungary	904,962	0.12	0.07	0.68
Malta	79,479	0.01	0.01	0.06
Netherlands	2,840,225	0.39	0.22	2.13
Austria	1,227,808	0.17	0.10	0.92
Poland	4,260,368	0.58	0.33	3.19
Portugal	1,820,685	0.25	0.14	1.37
Romania	144,224	0.02	0.01	0.11
Slovenia	577,382	0.08	0.04	0.43
Slovakia	642,756	0.09	0.05	0.48
Finland	938,533	0.13	0.07	0.70
Sweden	788,508	0.11	0.06	0.59

This project has received funding from the European Union’s Horizon Europe Research and Innovation Programme under Grant Agreement No. 101075676.

Table 11. Potential biomethane produced from milk by-products (whey) in EU

MILK BY-PRODUCTS (WHEY)	PRODUCTION OF MILK ON FARMS tons/year	WHEY tons/year	PRODUCED BIOGAS bcm/year	POTENTIAL BIOMETHANE FOR GAS NETWORK bcm/year	BIOMETHANE ENERGY CONTENT TWh/year
European Union - 27 Countries	**159,343,390**	**111,540,373**	**2.76**	**1.58**	**15.22**
Belgium	4,618,000	3,232,600	0.08	0.05	0.44
Bulgaria	868,600	608,020	0.02	0.01	0.08
Czech Republic	3,339,810	2,337,867	0.06	0.03	0.32
Denmark	5,664,000	3,964,800	0.10	0.06	0.54
Germany	32,421,620	22,695,134	0.56	0.32	3.10
Estonia	848,600	594,020	0.01	0.01	0.08
Ireland	9,108,280	6,375,796	0.16	0.09	0.87
Greece	1,999,430	1,399,601	0.03	0.02	0.19
Spain	8,483,000	5,938,100	0.15	0.08	0.81
France	25,028,850	17,520,195	0.43	0.25	2.39
Croatia	535,000	374,500	0.01	0.01	0.05
Italy	13,971,680	9,780,176	0.24	0.14	1.33
Cyprus	366,230	256,361	0.01	0.00	0.03
Latvia	975,290	682,703	0.02	0.01	0.09
Lithuania	1,521,940	1,065,358	0.03	0.02	0.15
Luxembourg	452,430	316,701	0.01	0.00	0.04
Hungary	2,044,900	1,431,430	0.04	0.02	0.20
Malta	42,080	29,456	0.00	0.00	0.00
Netherlands	14,983,900	10,488,730	0.26	0.15	1.43
Austria	3,980,290	2,786,203	0.07	0.04	0.38
Poland	15,218,080	10,652,656	0.26	0.15	1.45
Portugal	2,030,940	1,421,658	0.04	0.02	0.19
Romania	4,261,900	2,983,330	0.07	0.04	0.41
Slovenia	628,110	439,677	0.01	0.01	0.06
Slovakia	926,980	648,886	0.02	0.01	0.09
Finland	2,258,630	1,581,041	0.04	0.02	0.22
Sweden	2,764,840	1,935,388	0.05	0.03	0.26

As it can be seen from the above data, the examined categories of feedstock theoretically can produce 23.14 bcm of biomethane per year, with an energy content of 223.11 TWh. This amount of energy can cover the 5.02% of the total EU natural gas demand for the year 2022, which was 16.000.000 Tj, ie. 4,444.44 TWh (Figure 16).

This project has received funding from the European Union's Horizon Europe Research and Innovation Programme under Grant Agreement No. 101075676.

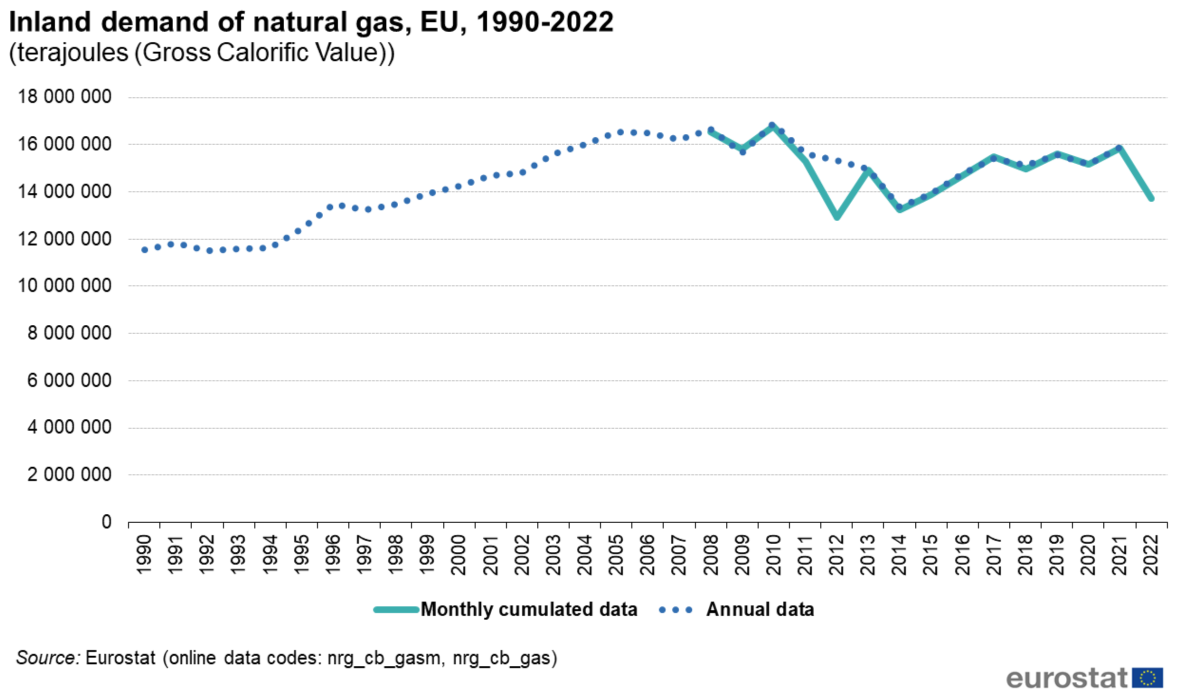


Figure 16. Annual Natural Gas Demand in EU (1990-2022)

It also must be taken into consideration that those values are based on the assumption that all the available feedstock is collected and utilised for AD. In reality, only a portion of this feedstock can be collected. It is estimated that around 40% of the total available feedstock can be utilised therefore the amount of biogas and biomethane decreases accordingly[25].

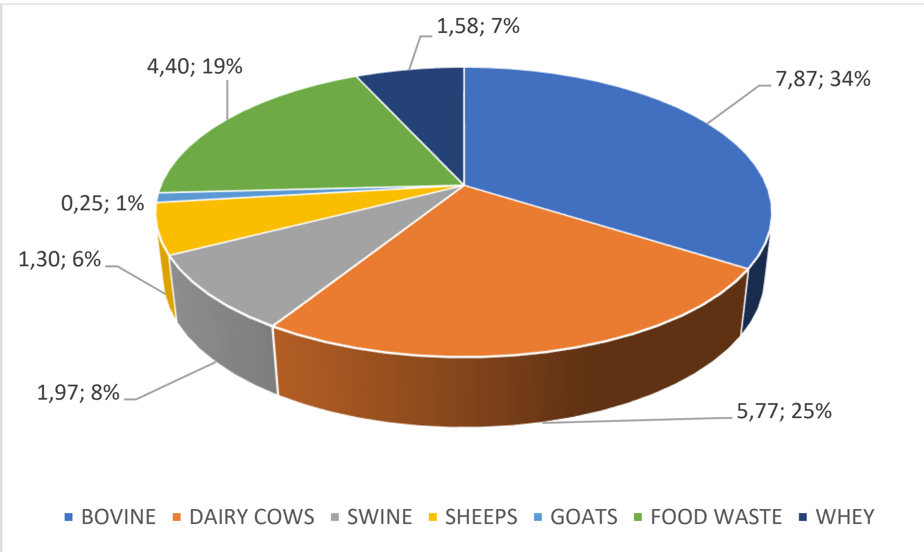


Figure 17. Feedstock contribution in biomethane production, (bcm)

[25] Scarlat, N., Fahl, F., Dallemand, JF., Monforti, F., and Motola, V. A spatial analysis of biogas potential from manure in Europe. Renewable and Sustainable Energy Reviews, Volume 94, 2018, Pages 915-930. doi.org/10.1016/j.rser.2018.06.035

This project has received funding from the European Union's Horizon Europe Research and Innovation Programme under Grant Agreement No. 101075676.

Our results are in compliance with the estimated potentials made by the Gas for Climate report (Figure 18). Countries that present the larger bovine and cattle population, like France, Germany and Polland present the higher biomethane potential from Manure. Spain also is included in this group due to its exceptional large swine population.

A general comment is that the major feedstock for methane population remains the animal manure, followed by the agricultural residues, which according to the Gas for Climate Report projections will remain until 2030.

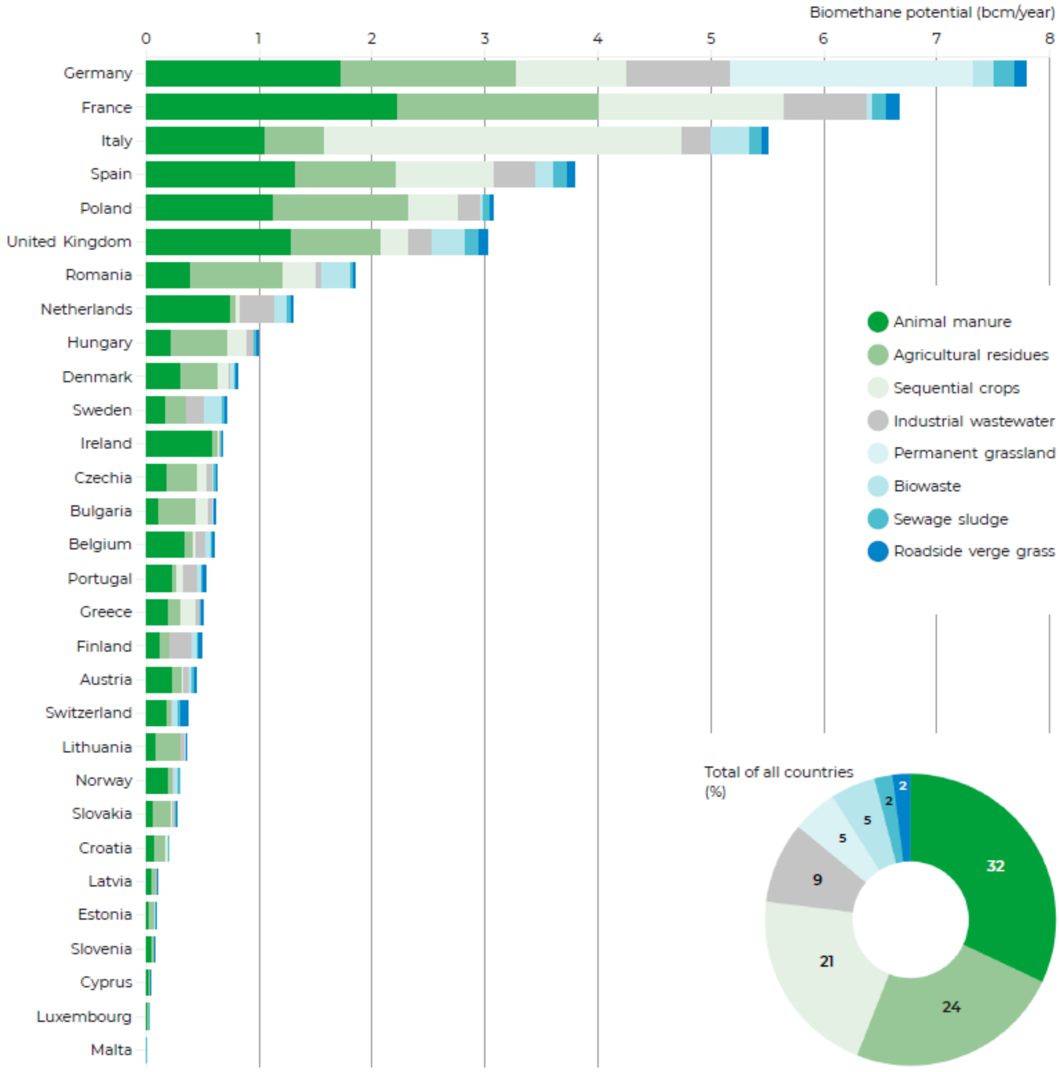


Figure 18. Biomethane potential in Europe (in bcm/year) for 2030 (Source: A Gas for Climate report 2022)

This project has received funding from the European Union's Horizon Europe Research and Innovation Programme under Grant Agreement No. 101075676.

Based on the presented data it is clear that the greatest portion of the potential biomethane will be produced from bovine and cows' manure (almost 60% of the total), whereas smaller livestock species like goats and sheep are not expected to contribute much. The portion of food waste is also quite important (19%) (Figure 17). This observation corresponds to the spatial distribution of the potential AD biogas which is shown in the map below (Figure 19).

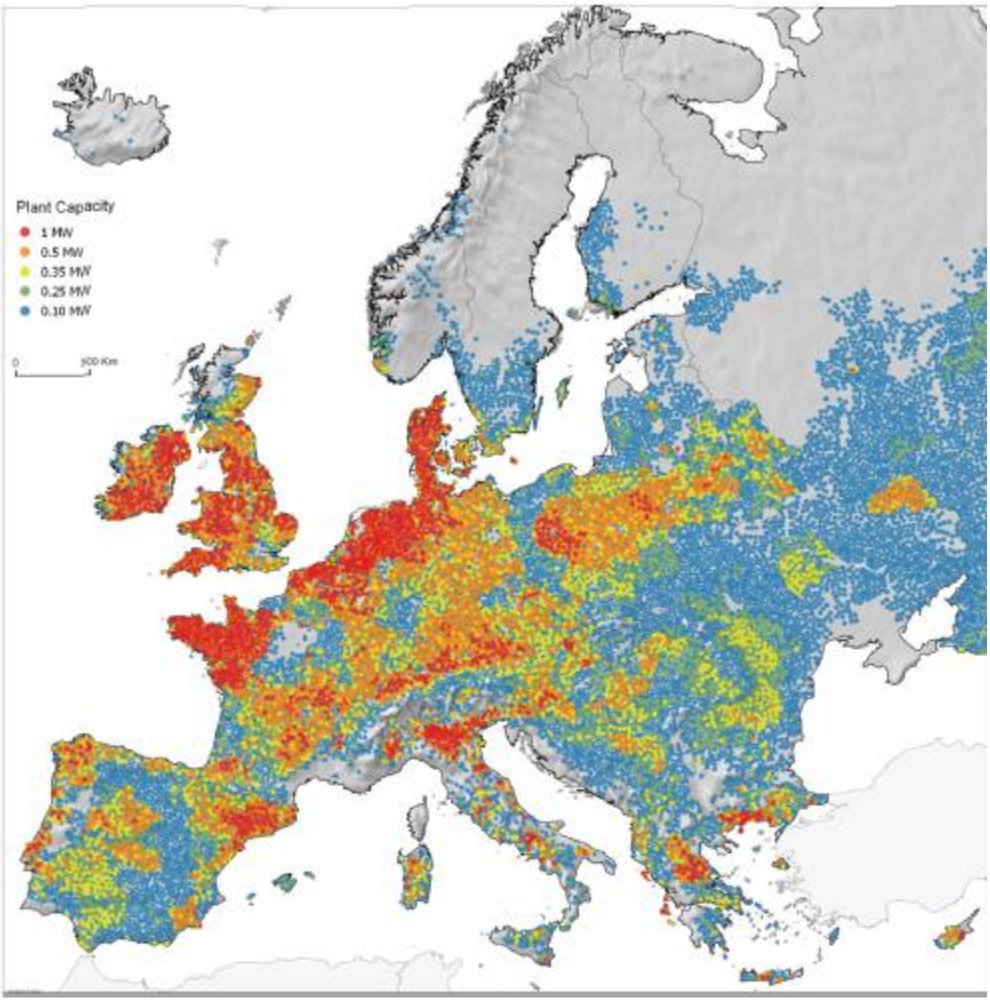


Figure 19. Suitability map for biogas plant location[26]

The denser concentration of biogas plants at the north western part of Europe where the larger population of bovine and dairy cows exists.

Since the examined feedstock sources for AD seemed to be inadequate for covering the EU target for biomethane production, other feedstock sources should also be considered. Straw is a potential source that is quite abundant in EU. As it is written in the above paragraph the quantities that are considered are not used for animal feed, therefore they can be available for utilisation in an AD plant.

[26] A spatial analysis of biogas potential from manure in Europe, Nicolae Scarlat, Fernando Fahl, Jean-François Dallemand, Fabio Monforti, Vicenzo Motola)

This project has received funding from the European Union's Horizon Europe Research and Innovation Programme under Grant Agreement No. 101075676.

Straw is not widespread yet as a typical AD plant feedstock. The reason is that due to its physical properties it cannot be fed directly to the digester. Therefore, a pre-treatment stage is essential in order to become suitable for the digestion process. This is a briquetting process, which changes the physical formation of straw, allowing for extensive contact with water, that facilitates the microorganism to break down the molecular structure of straw and release methane. The following tables (

Table 12 - Table 15) present the biomethane potential derived from the utilisation of straw.

Table 12. Potential biomethane produced from wheat in EU

Wheat (2023)	CULTIVATED AREA ha	STRAW tons/year	PRODUCED BIOGAS bcm/year	POTENTIAL BIOMETHANE FOR GAS NETWORK bcm/year	BIOMETHANE ENERGY CONTENT TWh/year
European Union - 27 Countries	**23,113,820**	**41,604,876**	**17.61**	**10.07**	**97.07**
Belgium	213,500	384,300	0.16	0.09	0.90
Bulgaria	1,215,000	2,187,000	0.93	0.53	5.10
Czech Republic	817,760	1,471,968	0.62	0.36	3.43
Denmark	489,080	880,344	0.37	0.21	2.05
Germany	2,884,000	5,191,200	2.20	1.26	12.11
Estonia	172,740	310,932	0.13	0.08	0.73
Ireland	55,700	100,260	0.04	0.02	0.23
Greece	310,810	559,458	0.24	0.14	1.31
Spain	1,950,400	3,510,720	1.49	0.85	8.19
France	4,989,920	8,981,856	3.80	2.17	20.96
Croatia	0	0	0.00	0.00	0.00
Italy	1,867,560	3,361,608	1.42	0.81	7.84
Cyprus	11,000	19,800	0.01	0.00	0.05
Latvia	0	0	0.00	0.00	0.00
Lithuania	946,200	1,703,160	0.72	0.41	3.97
Luxembourg	12,470	22,446	0.01	0.01	0.05
Hungary	1,053,580	1,896,444	0.80	0.46	4.42
Malta	0	0	0.00	0.00	0.00
Netherlands	0	0	0.00	0.00	0.00
Austria	281,980	507,564	0.21	0.12	1.18
Poland	2,425,730	4,366,314	1.85	1.06	10.19
Portugal	26,390	47,502	0.02	0.01	0.11
Romania	2,239,390	4,030,902	1.71	0.98	9.40
Slovenia	28,700	51,660	0.02	0.01	0.12
Slovakia	405,780	730,404	0.31	0.18	1.70
Finland	237,300	427,140	0.18	0.10	1.00

This project has received funding from the European Union's Horizon Europe Research and Innovation Programme under Grant Agreement No. 101075676.

Sweden	478,830	861,894	0.36	0.21	2.01

This project has received funding from the European Union's Horizon Europe Research and Innovation Programme under Grant Agreement No. 101075676.

Table 13. Potential biomethane produced from oats in EU

OAT (2023)	CULTIVATED AREA ha	STRAW tons/year	PRODUCED BIOGAS bcm/year	POTENTIAL BIOMETHANE FOR GAS NETWORK bcm/year	BIOMETHANE ENERGY CONTENT TWh/year
European Union - 27 Countries	**2,646,870**	**4,764,366**	**2.02**	**1.15**	**11.12**
Belgium	3,000	5,400	0.00	0.00	0.01
Bulgaria	0	0	0.00	0.00	0.00
Czech Republic	43,050	77,490	0.03	0.02	0.18
Denmark	58,720	105,696	0.04	0.03	0.25
Germany	148,800	267,840	0.11	0.06	0.62
Estonia	35,980	64,764	0.03	0.02	0.15
Ireland	26,990	48,582	0.02	0.01	0.11
Greece	62,540	112,572	0.05	0.03	0.26
Spain	460,710	829,278	0.35	0.20	1.93
France	149,510	269,118	0.11	0.07	0.63
Croatia	15,000	27,000	0.01	0.01	0.06
Italy	102,230	184,014	0.08	0.04	0.43
Cyprus	300	540	0.00	0.00	0.00
Latvia	98,600	177,480	0.08	0.04	0.41
Lithuania	100,000	180,000	0.08	0.04	0.42
Luxembourg	1,410	2,538	0.00	0.00	0.01
Hungary	21,800	39,240	0.02	0.01	0.09
Malta	0	0	0.00	0.00	0.00
Netherlands	0	0	0.00	0.00	0.00
Austria	18,940	34,092	0.01	0.01	0.08
Poland	729,790	1,313,622	0.56	0.32	3.06
Portugal	24,140	43,452	0.02	0.01	0.10
Romania	73,800	132,840	0.06	0.03	0.31
Slovenia	0	0	0.00	0.00	0.00
Slovakia	10,080	18,144	0.01	0.00	0.04
Finland	316,500	569,700	0.24	0.14	1.33
Sweden	144,980	260,964	0.11	0.06	0.61

This project has received funding from the European Union's Horizon Europe Research and Innovation Programme under Grant Agreement No. 101075676.

Table 14. Potential biomethane produced from barley in EU

BARLEY (2023)	CULTIVATED AREA ha	STRAW tons/year	PRODUCED BIOGAS bcm/year	POTENTIAL BIOMETHANE FOR GAS NETWORK bcm/year	BIOMETHANE ENERGY CONTENT TWh/year
European Union - 27 Countries	**10,333,240**	**18,599,832**	**7.87**	**4.50**	**43.40**
Belgium	49,100	88,380	0.04	0.02	0.21
Bulgaria	138,000	248,400	0.11	0.06	0.58
Czech Republic	321,130	578,034	0.24	0.14	1.35
Denmark	561,260	1,010,268	0.43	0.24	2.36
Germany	1,608,700	2,895,660	1.23	0.70	6.76
Estonia	112,310	202,158	0.09	0.05	0.47
Ireland	186,220	335,196	0.14	0.08	0.78
Greece	118,980	214,164	0.09	0.05	0.50
Spain	2,353,900	4,237,020	1.79	1.03	9.89
France	1,809,410	3,256,938	1.38	0.79	7.60
Croatia	63,000	113,400	0.05	0.03	0.26
Italy	279,140	502,452	0.21	0.12	1.17
Cyprus	11,500	20,700	0.01	0.01	0.05
Latvia	86,900	156,420	0.07	0.04	0.36
Lithuania	161,900	291,420	0.12	0.07	0.68
Luxembourg	5,760	10,368	0.00	0.00	0.02
Hungary	412,440	742,392	0.31	0.18	1.73
Malta	0	0	0.00	0.00	0.00
Netherlands	35,790	64,422	0.03	0.02	0.15
Austria	122,710	220,878	0.09	0.05	0.52
Poland	641,100	1,153,980	0.49	0.28	2.69
Portugal	11,930	21,474	0.01	0.01	0.05
Romania	502,150	903,870	0.38	0.22	2.11
Slovenia	21,930	39,474	0.02	0.01	0.09
Slovakia	113,620	204,516	0.09	0.05	0.48
Finland	353,400	636,120	0.27	0.15	1.48
Sweden	250,950	451,710	0.19	0.11	1.05

This project has received funding from the European Union's Horizon Europe Research and Innovation Programme under Grant Agreement No. 101075676.

Table 15. Potential biomethane produced from rye in EU

Rye (2023)	CULTIVATED AREA ha	STRAW tons/year	PRODUCED BIOGAS bcm/year	POTENTIAL BIOMETHANE FOR GAS NETWORK bcm/year	BIOMETHANE ENERGY CONTENT TWh/year
European Union - 27 Countries	**1,950,700**	**3,511,260**	**1.49**	**0.85**	**8.19**
Belgium	1,100	1,980	0.00	0.00	0.00
Bulgaria	8,000	14,400	0.01	0.00	0.03
Czech Republic	24,650	44,370	0.02	0.01	0.10
Denmark	108,610	195,498	0.08	0.05	0.46
Germany	628,800	1,131,840	0.48	0.27	2.64
Estonia	16,990	30,582	0.01	0.01	0.07
Ireland	0	0	0.00	0.00	0.00
Greece	7,800	14,040	0.01	0.00	0.03
Spain	126,960	228,528	0.10	0.06	0.53
France	38,620	69,516	0.03	0.02	0.16
Croatia	1,300	2,340	0.00	0.00	0.01
Italy	3,720	6,696	0.00	0.00	0.02
Cyprus	0	0	0.00	0.00	0.00
Latvia	32,800	59,040	0.02	0.01	0.14
Lithuania	28,500	51,300	0.02	0.01	0.12
Luxembourg	1,580	2,844	0.00	0.00	0.01
Hungary	28,890	52,002	0.02	0.01	0.12
Malta	0	0	0.00	0.00	0.00
Netherlands	2,350	4,230	0.00	0.00	0.01
Austria	40,750	73,350	0.03	0.02	0.17
Poland	757,870	1,364,166	0.58	0.33	3.18
Portugal	13,770	24,786	0.01	0.01	0.06
Romania	12,000	21,600	0.01	0.01	0.05
Slovenia	1,020	1,836	0.00	0.00	0.00
Slovakia	11,760	21,168	0.01	0.01	0.05
Finland	26,800	48,240	0.02	0.01	0.11
Sweden	26,060	46,908	0.02	0.01	0.11

As can be seen from those tables, the valorisation of available straw can offer 16.57 bcm more biomethane to the European natural gas market. This quantity added to the potential biomethane production from the livestock and food waste mentioned above is enough for achieving the EU target for 2030.

This project has received funding from the European Union's Horizon Europe Research and Innovation Programme under Grant Agreement No. 101075676.

5. Conclusions

Anaerobic digestion of organic residues can provide renewable energy in the form of biomethane, contributing in the reduction of conventional natural gas demand within EU. The analysis shown that if all the available feedstock consisting from livestock manure, food waste and whey, is utilised, then 23.14 bcm of biomethane can be produced. This quantity approaches the target that is set by EU and foresees delivering 35 bcm of biomethane in the natural gas network by 2030. On the other hand, if we consider that it is not feasible to valorise all this feedstock, it is obvious that other types of feedstocks should be considered in order to achieve this target value.

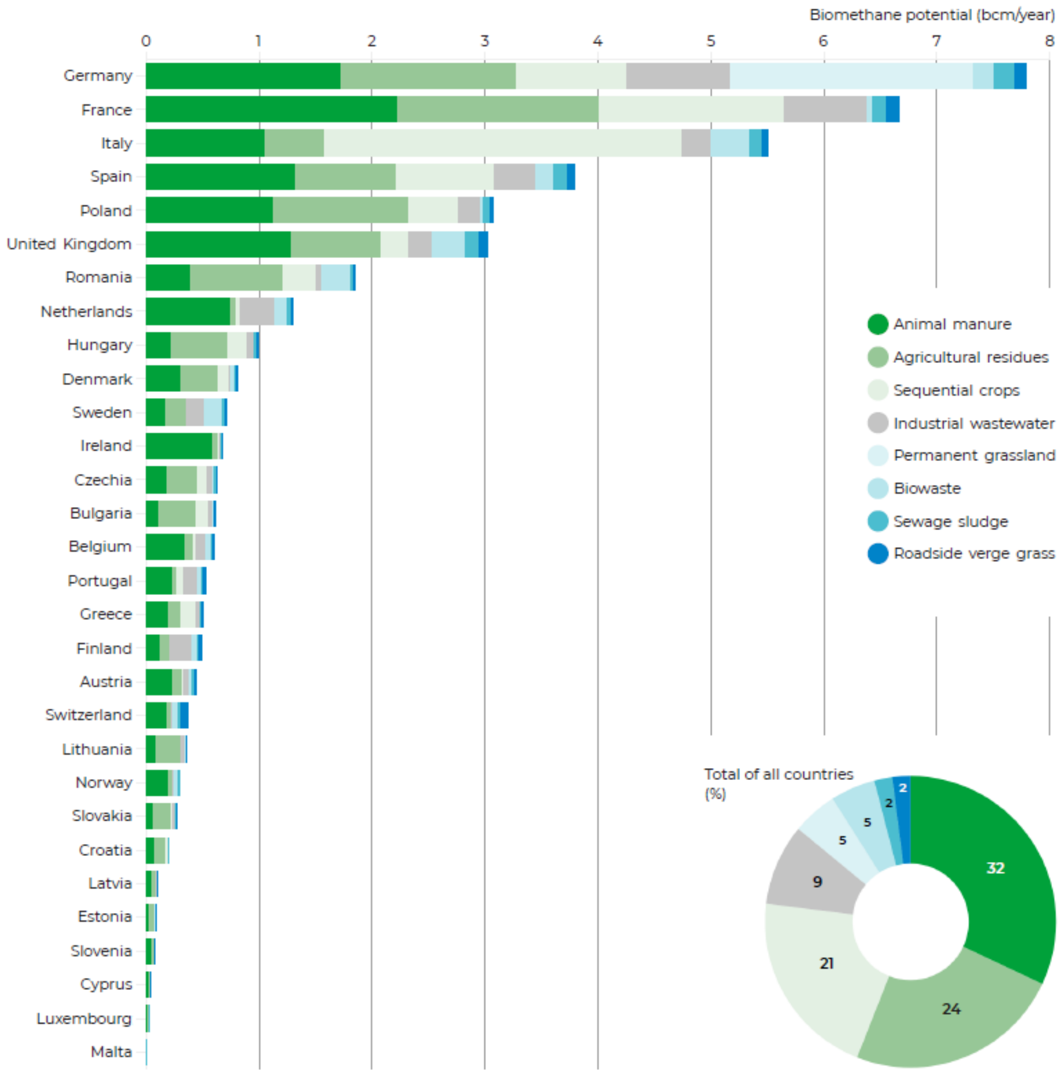
Considerable contributions may be given by the available quantities of cereal straw that is not used for animal feeding. Straw demonstrates some technical challenges when it has to be used as feedstock for AD. This is the reason that its utilisation is not that widespread till now. Those challenges, though, can be tackled successfully and its utilisation becomes more popular. According to the analysis performed in this report, there are enough quantities of straw in EU for complementing the rest AD feedstock sources in order to achieve the biomethane target for 2030.

Another type of feedstock that has to be considered is the sewage sludge derived primarily form municipal waste water treatment plants. This sludge has considerable biogas generation potential and there no other competitive uses that compete the valorisation as AD feedstock.

Competitive uses in general are something that has to be considered when we are talking about waste valorisation. This is the case also with the whey which is used as ingredient in the production of food supplements and animal feed. Policy measures may help to make the use of whey or similar wastes as AD feedstock more feasible offering an alternative for the other markets.

Finally, there is great potential of woody biomass which are not considered as feedstock for AD plants since cannot be decomposed by the microorganisms. This type of biomass can produce biomethane following other technology pathways like gasification and methanation. Those pathways are technologically mature and may assist in the achieving the 2030 target.

This project has received funding from the European Union's Horizon Europe Research and Innovation Programme under Grant Agreement No. 101075676.



Source: Gas for Climate report 2022

This project has received funding from the European Union's Horizon Europe Research and Innovation Programme under Grant Agreement No. 101075676.