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BIOGAS AND BIOMETHANE IN EUROPE
Lessons from Denmark, Germany and Italy

Marc-Antoine EYL-MAZZEGA and Carole MATHIEU (eds.)

With Knud BOESGAARD, Sylvie CORNOT-GANDOLPHE, Jaqueline DANIEL-GROMKE, Velina DENYSENKO, Jan LIEBETRAU

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Executive Summary

At a time when the European Union (EU) is discussing its long-term climate strategy and drafting new legislation to foster the decarbonization of its gas sector, a close look at the experience of Denmark, Germany and Italy with renewable gas production can provide valuable lessons. For more than a decade, these three countries have supported biogas technologies and developed support schemes to facilitate their large-scale deployment. They have more recently focused on developing their biomethane potential.

Committed to reaching carbon neutrality by 2050 and facing the depletion of its gas fields in the North Sea, Denmark has a clear interest in making biogas and biomethane central pillars of its future smart energy system. Likewise, Germany's *Energiewende* and its focus on renewable-based electricity generation has led to a robust development of biogas plants with onsite electricity conversion and satellite Combined Heat & Power (CHP) units. This way, Germany became – by far – the largest biogas producing country in the EU, with about 105 000 direct jobs in its bioenergy sector. In Italy, the high availability of agricultural feedstock and the widespread use of gas in transport activities have also been strong arguments in favour of biogas production and the upgrade into biomethane, to facilitate the achievement of the renewables expansion target for the transport sector and reduce the country's CO_2 emissions.

In Denmark, the biogas plants have been primarily used for CHP production in local towns. A base off-take is thus guaranteed but the sole reliance on local needs creates an obstacle to the expansion of biogas. Following the introduction of feed-in premiums in 2014, biomethane injection into the gas grid was given a strong impetus, widening the consumer base: it now accounts for over 10% of volumes transported in the natural gas grid. Concerns over subsidy costs and the switch to tenders as of 2020 is now limiting the sector's growth potential.

On a similar note, biomethane production has boomed in Germany following the introduction of a biogas upgrading bonus in 2009, but the investment in both biogas and biomethane projects has been substantially reduced in recent years due to the decrease in guaranteed tariff levels and the abolishment of both the substrate bonus for energy crops and of the biogas upgrading bonus in 2014. While two auctions have been run in 2017 and 2018, targeted volumes have not been fully allocated and no substantial cost decrease has been achieved. Another hurdle is the missing market perspectives and policy frameworks for deployment in other sectors so that the biomethane development in the country is expected to stall.

In Italy, the biogas industry took off in 2008, thanks to the introduction of advantageous feed-in tariffs. They were subsequently replaced by less favourable feed-in premiums and the preference was given to by-products and farming waste over energy crops, leading to a stagnation in biogas production and derived heat and electricity since 2012. Priorities have now shifted to biomethane production and, despite the length of the legislative process, the adoption of the March 2018 Biomethane decree is finally giving a strong boost to Italy's biomethane sector: while only 6 plants were operational at the start of the year, over 900 preliminary gas grid connection projects are being registered corresponding to 2.2 bcm/y. Considering the huge biomethane potential in Italy and its promotion as a transport fuel, the transport sector is expected to be a lever to scale up biomethane production rapidly and enable cost reductions, prior to an expansion of biomethane use to other sectors. The 2018 *Biomethane Decree* represents the fundamental step for the development of the biomethane chain in the country by promoting and supporting biomethane as a biofuel for transport.

A major policy priority in all countries is to avoid that subsidy costs spiral out of control. While Denmark is now shifting to a strategy similar to the one retained in Germany and turning to an auction-based system with price ceilings, there are concerns for the profitability of investments beyond 2020. In Germany, remuneration levels are too low to justify new projects and the only viable options are to expand existing plants, adjust plants for a more flexible operation and slightly extend small manure-based biogas plants and plants for biowaste digestion. With the upcoming expiry of the Renewables Energy Act (EEG) tariffs, even the continued operation of existing plants is under question. In Italy, a different policy framework has been established, as the support scheme for biomethane is fully financed by transport fuel suppliers as part of their biofuel blending obligations. Beyond the transport sector, guarantees of origin could support the expansion of biomethane, but their level remains too low to cover the investment costs.

The further development of the three markets is conditional on the success of cost reduction strategies alongside a strategic sector coupling approach to policies. In both Germany and Italy, initiatives have been launched to define alternative plant concepts that would be the most suitable with technical and economic constraints, while maximizing the environmental and agricultural benefits. Among cost reduction levers, targeting higher upgrading capacities such as by merging the raw biogas from several plants and reaching economies of scales is one option. The growing number of manufacturers of upgrading technologies is a contributing factor. Besides, the reliance on dedicated professionals leads to a more optimal operation of the plants, improving their overall cost performance. The focus on stable supplies of cheaper substrate is also a priority, with large-scale agricultural or industrial waste offering a promising way forward, the combination of both bringing good results. In addition, the development of new financing instruments could facilitate investments into upgrading and connection facilities, while the sale of the digestate as biofertilizers can create an additional revenue stream. In addition to locating projects at immediate distance from the grid, connection and injection rules (gas quality requirements, management of grid adjustment and compression needs, capacity allocation etc.) should also be defined in the most cost-efficient way, in close consultation with the grid operators.

In any case, the successful development of biogas and biomethane requires strong coordination between all relevant stakeholders and policies from the energy, environment/waste management, transport, agriculture& food sectors, to identify and maximize all energy and non-energy services that these technologies can provide and to harmonize regulation and standards at the EU level. Besides, important efforts need to be deployed in order to address social resistance to new infrastructures, through local awareness campaigns launched at the very start of project implementation and through wider communication initiatives informing the general public on the biogas chain, its economic and environmental benefits as well as transparent controls of odour and leakage.

The Danish, German and Italian experiences confirm that biomethane is a unique renewable fuel. A strict cost comparison with other renewable sources for power production tends to neglect the additional benefits in terms of versatility, storability and dispatchability. These features could be highly valuable in the perspective of smart energy systems, that both Denmark and Germany are pursuing with strong determination. Beyond power generation, biomethane is identified as a suitable option for decarbonizing the transport sector, yet only Italy is remarkably exploring this avenue, and is thus giving credible market perspectives. Conversely, the Danish example highlights how regulation and taxation can put obstacles to the deployment of biomethane as a vehicle fuel. The Italian example showcases the importance of guarantees of origin which should be developed and harmonized at the EU level and a comprehensive strategy involving a support to biomethane production and its utilization in the transport sector. Clarifying the long-term role of biogas and biomethane – for the energy sector and beyond – is a prerequisite to ensure full policy alignment, and thus a cost-efficient development of these fuels. There is also a need to properly take into account the close intertwining of energy, environmental and agricultural policies and strategies, especially when assessing costs of support schemes and better assessing, in each region, the availability and different costs related to the resources used, especially when needed at larger scale, and to take into account the carbon footprint of the supply system. An EU-wide approach is relevant, which the next Gas market package should reflect.

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Introduction

Marc-Antoine Eyl-Mazzega and Carole Mathieu

The EU energy transition process is at a turning point: the 2020 objectives are within reach, yet meeting the 2030 targets will be much more challenging, not to speak about a deep decarbonization pathway by 2050, which is unavoidable if the EU aims to align its policy with a +1.5°C trajectory. The 2020-2030 sequence will be marked by the sharp reduction of coal for power generation in many members, the start of the decarbonisation of the transport sector and efforts to better integrate energy end-use and supply through sector coupling strategies. That will give notably a key role for natural gas to provide flexibility to the power generation segment. This period will also see the start of the transformation of the gas industry to reduce its CO_2 emissions, which currently roughly represent 25% of EU's total CO_2 emissions and 20% of its power sector emissions. The production of biogas and its upgrade to biomethane is the best current option, alongside efforts to reduce methane leakage and gas flaring in the upstream part of the gas supply chain. It will be followed, in the longer term, by green hydrogen produced from renewable electricity or blue hydrogen from gas combined with carbon capture & storage/utilization. Hence why, it will also be an important issue for the new European "Gas market package" which is to be presented in 2020.

Biomethane, that is methane produced from anaerobic digestion of various feedstocks, followed by the conversion of raw biogas into biomethane from upgrading units, is at the crossroads of the energy, transport and agriculture sectors. It matters for energy security, efficient decarbonisation of energy systems, territorial development, and the optimization of the agricultural sector:

Energy security: The EU imported roughly 350 billion cubic meters (bcm) of natural gas in 2018, worth over EUR 60 billion and representing 20% of EU's total energy imports.[1] Imports, dominated by Gazprom

1. Note that 70% of EU's import bills in value comes from petroleum liquids, with the first external supplier being Russia, representing 30% of EU's demand, followed by Norway at 13%. EU's average monthly energy import bill decreased from a record of EUR 38 billion per month on average in 2012 to 25 billion EUR in H1 2018. See: https://ec.europa.eu.

(38.5% in value in H1 2018) will grow in the coming years as domestic production continues to slip and overall demand is expected to slightly pick up before starting a slow yet irreversible decline after 2025. Biomethane, which currently represents 2 bcm/year of gas injected into the grid,[2] could slow down the fall in domestic production and reduce the growth in imports during this period.

Efficient decarbonisation of energy systems: Biogas and biomethane are at the core of the circular economy: they use various feedstocks (energy crops, agricultural waste or residues, industrial residues, food or beverage waste and domestic waste), turn them into a storable fuel and the remaining digestate, which is a nutrient rich substance, can be used as organic fertiliser and thus reduce the demand for energy and CO_2 intensive chemical fertilizers, while limiting water and soil pollution. The agriculture sector represents 10% of the total EU greenhouse gas emissions (GHG).[3] Consumption of nitrogen fertilizers (produced from natural gas) has been growing per hectare in the EU in past years and reached 11.5 million tonnes in 2015. That could also help reduce EU's imports of fertilizers, amounting to EUR 4.29 billion in 2017 (with a trade deficit of roughly EUR 2 billion) while the EU's overall food imports are increasing.[4] Moreover, biomethane can be used for the transport sector, representing 24% of the total EU GHG emissions, especially in city buses, heavy duty trucks, passenger vehicles (over 1.4 million natural gas vehicles and 3400 filling stations on EU's roads currently) and shipping, helping to reduce CO_2 emissions from the transport sector, and pollutants, given that it has notably almost no nitrogen-oxide (NOx) emissions. It can thus be an enabler for meeting the objectives of the Clean Mobility Package recently adopted. It can also help make the best use of the existing gas infrastructures as it can be directly injected into the gas grid, thus in principle, reducing the overall costs of the energy transition. The overall contribution to GHG abatement is yet conditional on effective measures to prevent methane leakage in production and upgrade processes.

2. European Biogas Association, *Statistical Report 2018*, available at: http://biogas.org.rs.
3. "Greenhouse Gas Emission Statistics – Emission Inventories", *Statistics Explained*, Eurostat, June 2018, available at: https://ec.europa.eu.
4. It is noteworthy that the EU has an overall trade surplus in chemicals, whose exports topped 330 billion EUR in 2017 while imports reached 195 billion EUR in 2017. The EU has recently limited the amount of cadmium to 60 mg/kg of fertiliser and its recently adopted Fertiliser Product Regulation recognises digestate as a fertilizing product and encourages the use of organic materials as fertilising products. It should also facilitate the import of organic fertilisers. See: "Production and international trade in chemicals", *Statistics Explained*, Eurostat, August 2018, available at: https://ec.europa.eu; "Agri-environmental Indicator – Mineral Fertiliser Consumption", *Statistics Explained*, Eurostat, June 2017, available at: https://ec.europa.eu.

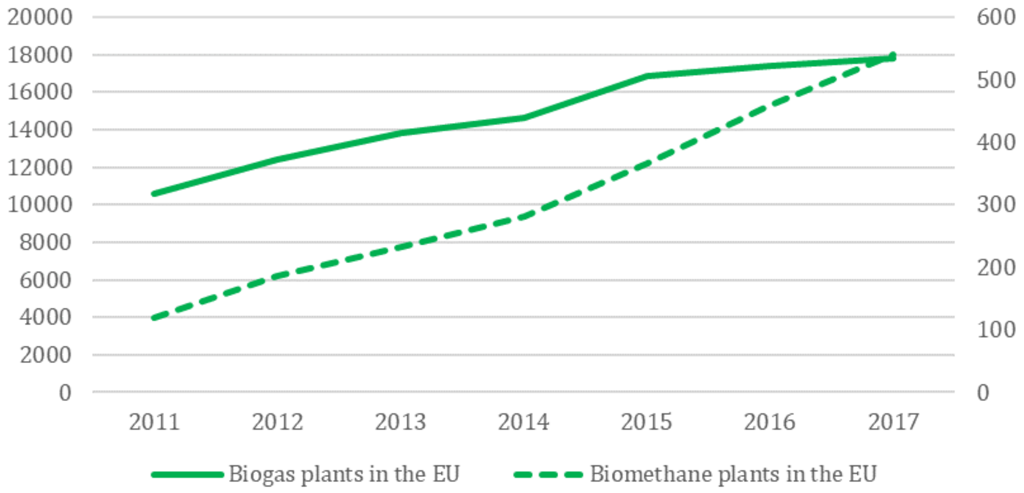
Territorial cohesion and development: the "Yellow Vests" movement in France has highlighted the growing tension related to the isolation of rural territories, the declining economic activities in these territories and the need for a fair distribution of costs and benefits of the energy transition process. Biogas and biomethane production in rural areas can be a tool to develop new economic activities and put in place stable jobs, with an average of 4 permanent jobs per larger installation,[5] alongside the construction related jobs and the waste/residue/crop supply jobs.

Optimization of the agriculture sector: biogas and biomethane can generate a new business segment with the use of intermediary crops and can help provide additional revenues to farmers in as much as it can value agriculture waste or residues and replace the increasingly costly nitrogen fertilizers with more competitive organic fertilisers. By decreasing the reliance on synthetic chemicals but also by fostering the development of intermediate crops with a positive impact on biodiversity, biogas production can contribute to the agro-ecological transition.

While for long time, biogas production for electricity production or combined heat and electricity generation has been the preferred option in many EU countries, especially in Germany, biomethane projects have been developing in past years, especially in Italy, Denmark, Sweden and most recently, in France, Germany or the United Kingdom. By year-end 2017, the European Biogas Association reports that there were 17,783 biogas plants (about half of them in Germany) producing 65.179 GWh of electricity and 540 biomethane plants in operation in the EU.[6]

5. GRDF, GRTgaz, SER, SPEGNN, Teréga, "Renewable Gas: French Panorama 2017", available at: www.grtgaz.com.
6. European Biogas Association, *Statistical Report 2018*, *op. cit.*

Number of biogas (left axis) and biomethane plants (right axis) in the EU, 2011-2017 over past years



Source: European Biogas Association Annual Reports.

Yet it comes with a number of issues and challenges. First and foremost, the production costs and related costs of public subsidies, which put biomethane roughly four times more expensive than natural gas currently. The recently released French medium term energy strategy plan (*Programmation pluriannuelle de l'énergie,* PPE) chose to give biomethane a serious try, conditioned by a sharp decrease in its costs. An initial target of covering 10% of total gas demand by 2030 has yet been lowered to 7%. The PPE calls for 14 to 22 TWh of biomethane production by 2028 (from over 1 TWh currently), with the upper limit conditioned by the ability to reduce costs from currently 95 EUR/MWh to 67 EUR/MWh by 2023 and then, 60 EUR/MWh by 2028. This has fuelled a strong disappointment from the industry and agriculture stakeholders, especially since the move to auctions is seen as not giving enough time to build up the right scale to decrease costs, which do not properly account for the positive externalities in terms of job creation in rural territories for example. Overall, the challenge here is to decrease investment costs, operational costs, to optimize feedstock supply & use as well as reduce their costs, to increase the availability of supplies in developing intermediary crops, to improve plant efficiency and operations, to factor in the carbon savings and to increase and monetize co-benefits, such as from the commercialization of the digestate. A major difference with other renewable energy sources is that scale matters less: while cost decreases are spectacular for solar and wind as their scale of deployment has increased, such trends are less at play with biogas and biomethane plants. Another challenge is to exactly assess the availability of resources and optimize their supply so as to reduce their costs (the greater the supply needs, the greater the logistics) and ensure their continued and sufficient supply. In particular, there is a need to further develop knowledge and experience with intermediary energy crops.

Other challenges include social acceptance: odour nuisances, landscape integration concerns and risk perception can not only delay project development, but also lead to projects being either called off or facing strong disapproval. Last but not least, the impact of trucks delivering the feedstock and then taking away the digestate must not be underestimated in terms of overall carbon footprint and social acceptance.

At this turning point for the European energy transition and the gas sector, Ifri's Centre for Energy chose to gather leading specialists to focus on three EU member countries that have a long-standing or very advanced experience with biogas and biomethane. This study aims at better understanding developments in Denmark, Germany and Italy and thus help assessing the opportunities and challenges of this technology, how they were addressed by the various stakeholders and what lessons can be learnt for other countries that seek to develop biomethane at a large scale. As such, this study also aims at informing discussions for the next Gas market package and to better assess the 2030 EU-wide biomethane production potential, which the European biogas association puts at 50 bcm, that is about 10-15% of EU-28 current demand and the Gas for climate initiative at 98 bcm by 2050.[7]

7. Gas for Climate, How to scale up renewable gas in Europe, available at: https://gasforclimate2050.eu; Gas for Climate, How gas can help to achieve the Paris Agreement target in an affordable way, available at: www.gasforclimate2050.eu.

The Danish Example

Knud Boesgaard

Denmark has a long history with biogas production, but volumes produced remained limited until 2014 and the introduction of a new subsidy scheme for biomethane injection into the Danish gas grid. With production and subsidy costs increasing sharply, public authorities have decided to amend the existing support scheme and turn to an auction-based system as of 2020. The Danish government has high ambitions for biogas and biomethane production but the industry is now facing a stronger competitive pressure and it will have to continue improving its performance, to ensure that biogas and biomethane can play a central role in Denmark's future energy system.

The rise of the Danish biogas industry

In Denmark, the production of biogas in Denmark started in the 1920's, at waste water treatment plants where the biogas produced was used for the heating of the process tanks. The first manure-based biogas plant in Denmark was constructed in 1975 and the first jointly owned biogas plant started operation in 1984.

The biogas sector developed through the 80's and 90's, with approximately 60 "jointly owned biogas plants"[8] constructed over these two decades. In Denmark, a traditional biogas plant is jointly owned and operated by around 10-20 local farmers. Biogas production from the jointly-owned biogas plants was typically used for CHP production in local towns. The local towns typically have a small district heating system securing a base off-take for the plants, but the limited local heat consumption is also an obstacle to the further development of the biogas plants.

For the Danish biogas industry, the real game changer was the adoption of the "Energy Agreement" in 2012. The new legislation introduced a feed-in-subsidy for injection into the gas grid. With access to

8. A jointly-owned biogas plant is a common description for a biogas plant owned by a cooperation of farmers. See: https://biogasbranchen.dk.

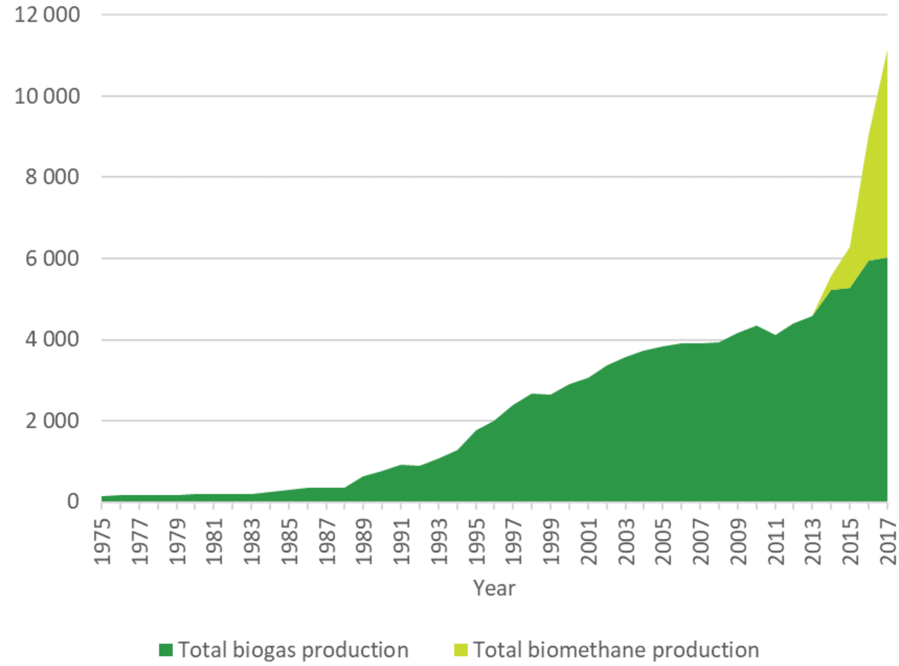
the gas grid, the upper limit on biogas off-take was waived, and a series of larger biogas plants was constructed. These grid-connected biogas plants are typically developed by large energy corporations such as EON, Nature Energy or Ørsted (formerly known as DONG), but multiple "farm biogas plants"[9] have also been successfully constructed by large farmers and private investors.

- By the end of 2018, there were more than 90 manure-based biogas plants in operation in Denmark, and 24 of these are upgrading biogas and injecting biomethane into the gas grid.
- In 2009, the Danish Government established a new objective: 50% of the manure from Danish livestock should be converted to energy before 2020. Given than approx. 37 million tonnes of manure are produced annually in Denmark, this would mean that more than 18 million tonnes of manure should be used in biogas production to achieve the official target.[10] In 2017, only about 10% of the manure was used for biogas production, but the potential for future development is very significant.

The history of Danish biogas industry can be divided in three main steps. Following the commissioning of the first biogas plant in 1975, biogas production remained marginal and used for private services only, until the jointly owned biogas plant started operation in 1984. From 1984, biogas production increased steadily until the Energy Agreement of 2012, which created a subsidy scheme for grid injected biogas. Since 1984, the primary use of biogas has been CHP production. Even though grid injection paves the way for more diverse uses, biogas is still primarily consumed in the same sectors, i.e. heat and power.

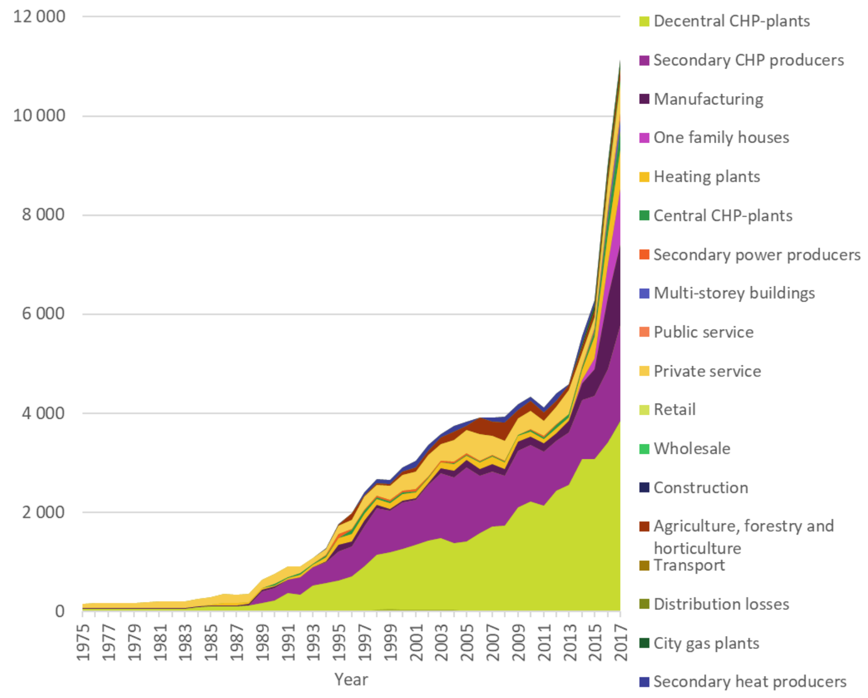
9. A farm biogas plant is a definition used in the Danish Energy Savings scheme. A farm biogas plant can be owned by up to 5 farmers.
10. The Danish Energy Agency (2014), "Status, barrierer og perspektiver", available at: https://ens.dk.

Biogas and biomethane production in Denmark (in TJ_{LHV})



Source: Energistyrelsen (2018).

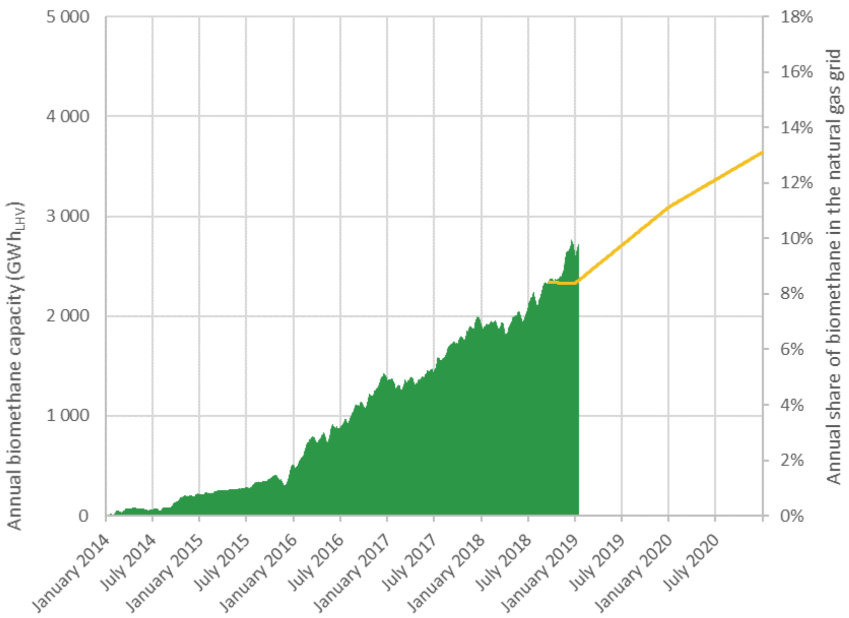
Biogas consumption in Denmark (TJ)



Source: Energistyrelsen (2018).

Since biomethane started to be injected into the Danish gas grid in 2014, there has been a sharp increase in the biomethane content of the natural gas grid which has exceeded 10% in 2019 and is expected to increase beyond 13% by the end of 2020, according to the Danish Energy Agency.

Biomethane injection into the Danish gas grid (2014-2020e)

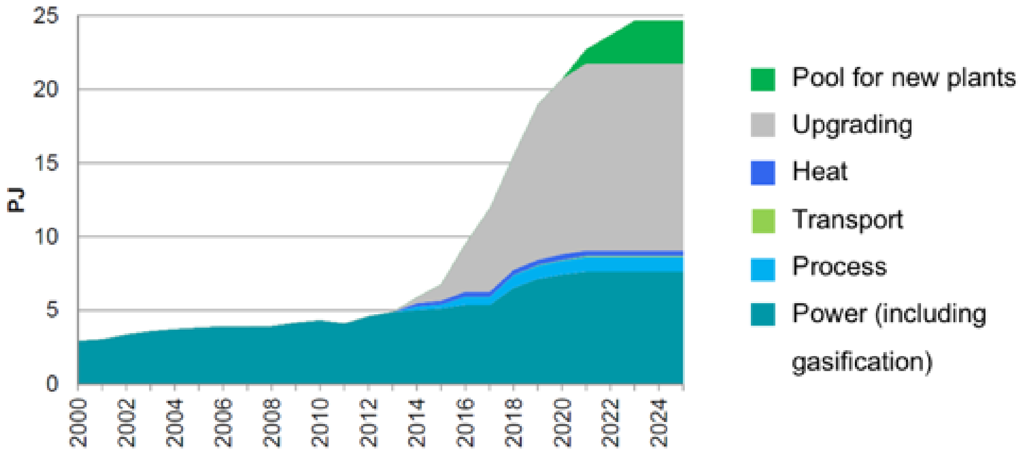


Source: Fremsyn, 2019.

The new subsidy scheme and the implications for biogas production

In 2018, a new subsidy scheme was presented, and it will come into force in 2020 for new biogas plants. This new scheme will be in the form of tenders, where a biogas project can bid on the level of subsidy that they need to trigger the investment. There will be an annual subsidy pool of 240 million Danish kroner (DKK) (EUR 32 million) to be allocated to the best bids. This scheme will put a quantitative limit to the deployment of new biogas plants.

Expected biogas development following the adoption of the new energy act, 2000-2024e

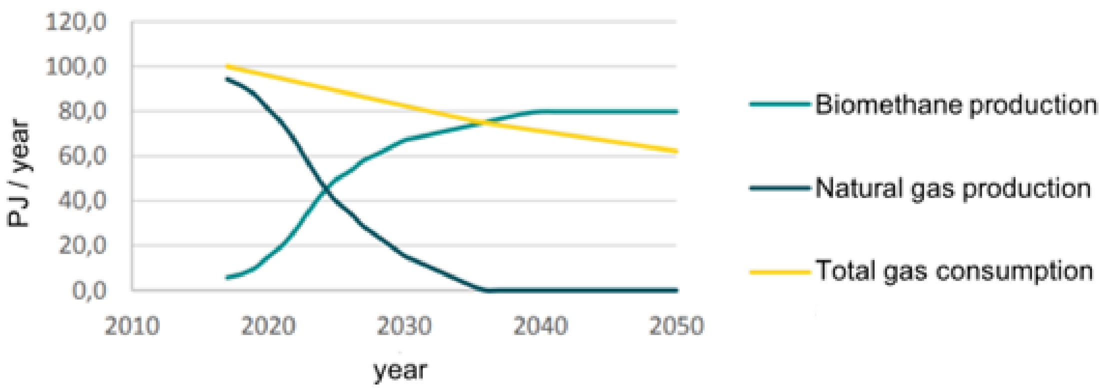


Source: Marianna Nielsen, the Danish Energy Agency (2018).

With this tender-based subsidy scheme, biogas production is expected to develop more slowly. There are no official targets for which sectors biogas should be utilised in. The pool of DKK 240 million (EUR 32 million) is expected to increase the biogas production by 3.5 Pétajoules (PJ), corresponding to a 16% growth in biogas production compared to today's level.

For now, the production of biogas corresponds to more than 8% of the annual domestic gas consumption, and it is broadly recognised as a very significant success. For comparison, it took wind turbines more than 30 years of development to reach 5% of the Danish power production – a task completed in just four years (2014-2018) by the biogas industry.

Danish gas production and consumption as projected by the Danish gas industry, 2010-2050e



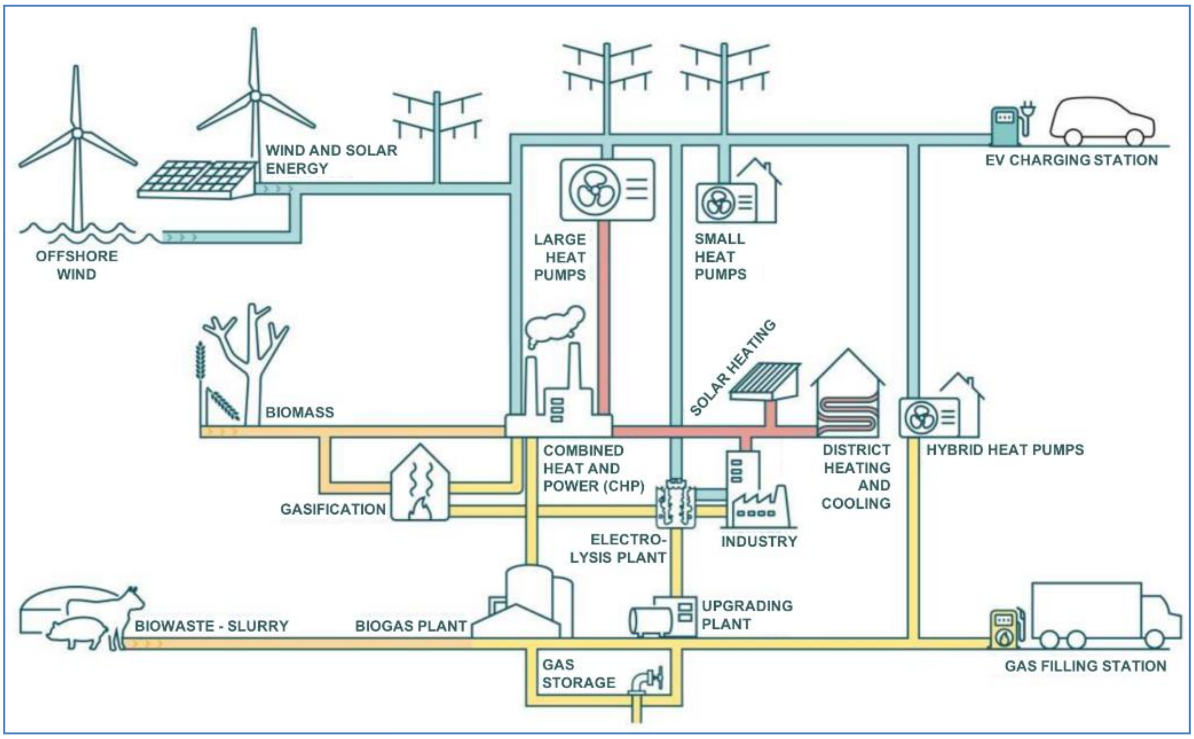
Source: Grøn Gas Danmark, 2018, translated by Fremsyn.

The Danish gas grid is expected to undergo significant changes within the next decade. The production of natural gas from the Danish part of the North Sea will drop as the gas fields deplete. In this context, there is a very significant political pressure to increase the renewable gas production.

Besides, Denmark officially aims at becoming a net CO_2 neutral society in 2050 and to achieve this goal, the current natural gas production must be replaced with biogas and other renewable gasses. A combined sustainable energy system is being developed in Denmark, with the power grid, gas grid and district heating systems as its central elements.

Wind turbines produce a very significant part of the power production in Denmark, but like solar power wind turbines hold the inherent problem that they only produce power when wind blows and the sun shines. Biogas is a renewable energy that is produced at a stable pace and as it is storable, and it is therefore broadly recognised as a vital part of the future energy system.

Overview of the combined energy system being developed in Denmark



Source: Energinet, 2018, translated by Fremsyn.

Key issues in the Danish policy debate

Biogas subsidy spiralling out of control

The biogas subsidy scheme has been a key issue in the policy debate since the annual cost increased past DKK one billion (EUR 134.6 million) in 2016. In 2017, it soared above DKK 1.6 billion (EUR 215.4 million). The Danish Parliament became increasingly concerned that the costs of the biogas subsidy scheme would go out of control. The new subsidy scheme, relying on a fixed annual pool of DKK 240 million (EUR 32 million), is a direct response to this growing concern.

Neighbour complaints

A lot of new biogas plants have also been delayed by neighbours, who have been worried about traffic and odour issues. Thus, a lot of municipal governments have received complaints about the construction of new biogas plants. Delays and even cancellations of new biogas plants have been observed. Yet, experience shows that when awareness campaigns are launched early in the process, the number of complaints is reduced. Before the biogas plant can be constructed, it must be granted an environmental permit. The environmental permit outlines the acceptable odour limits. If a plant exceeds the allowed odour emissions, the municipality can shut down the plant. It has also been observed that certain municipalities require the biomass to be handled at the biogas plant in a building with negative pressure. Yet, this solution is relatively expensive for smaller biogas plants.

Methane losses

There has also been a lot of debate about methane losses from Danish biogas plants, which has caused controversy about the actual climate-friendliness of biogas as a technology. Surveys in 2016 have found that on average 1.7% of the produced biogas is lost to the atmosphere. But multiple plants have been found to have methane losses of more than 5%. As a result, the Danish biogas industry issued a voluntary program to measure plant specific leakages and has set an industry-wide target to limit methane losses to a maximum of 1%.

Biogas for the transport sector

Several industry stakeholders have pointed out that biogas is best utilised in the transportation sector. However, the policies which should enable this utilisation have not been implemented at this stage. On the contrary, policies recently enacted have increased taxation on bio-CNG vehicles. In addition to this, the national Government has presented in 2019 a policy plan which will forbid new bio-CNG shuttle busses from 2025, by only allowing new zero-emissions buses. Another issue is that the tax system does not allow a distinction between biomethane and natural gas as soon as it has first entered the natural gas system. Bio-CNG as a vehicle fuel is thus taxed as natural gas, at a higher rate than fossil diesel. As a result of this, biogas and biomethane is used primarily to produce heat and power.

Mapping of the available support schemes

There are several support schemes for biogas, depending on whether the targeted use is power production, heating production, delivery to the natural gas grid, delivery to transport directly (outside the natural gas grid) or process.

The main requirement is that the biogas plant does not use more than 12% energy crops, measured in weight.[11] Maize, grain and sugar beets are considered energy crops, whereas straw is considered an agricultural waste product – all in line with the European Renewable Energy Directive.

All Danish biogas plants must supply Energinet with information about the use of biomasses as well as a statement including the cost of the biogas production and upgrading of biogas. Energinet uses this information to monitor that the subsidy doesn't exceed the European rules for overcompensation.

A problem with the current subsidy scheme is that it is not neutral, as different rates are awarded for different usages. Another problem is that it is very difficult to control and predict the financial costs of the subsidy scheme as the sector develops. As the consequence, the cost of the subsidy has increased past DKK 1.6 billion (EUR 215.4 million) in 2017. Due to a grandfathering clause, existing plants will continue under the old subsidy scheme until 2032, or 20 years after the latest commissioning.

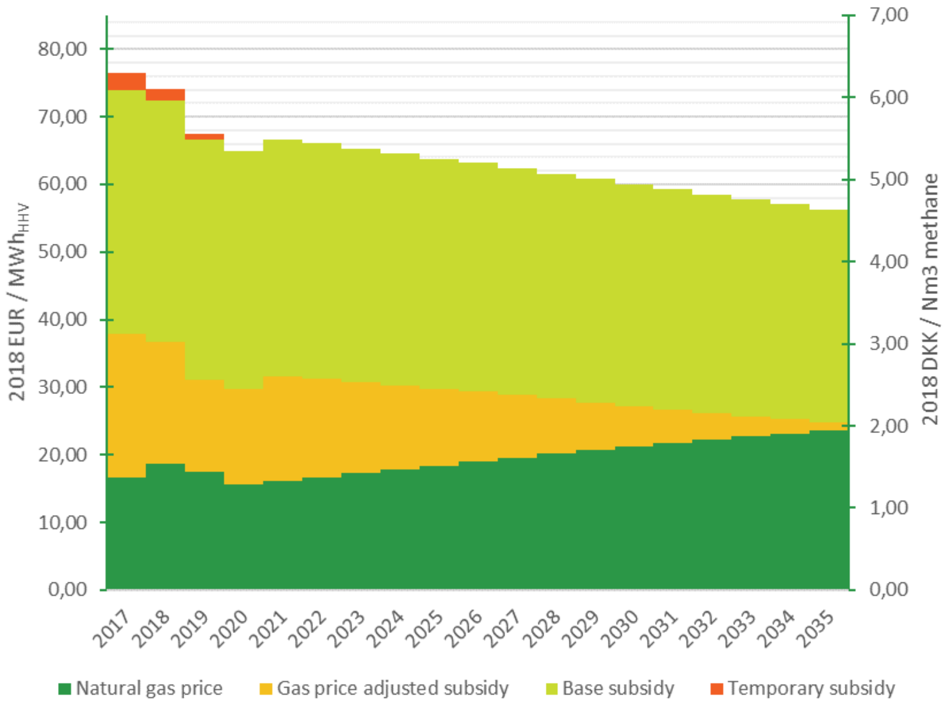
11. Retsinformation, "Bekendtgørelse om bæredygtig produktion af biogas", LOV No.576, 18 June 2012, available at: www.retsinformation.dk.

Current biogas subsidy schemes (until 2020)

Before the Energy Agreement of 2012 and its subsequently implementation in Danish legislation, Danish subsidies only supported heat and power produced from biogas. The subsidies announced in 2012 was implemented in Danish legislation in 2013 and ratified by EU in 2014, and that started a boom of biomethane in Denmark.

The current subsidy scheme for biogas injected to the natural gas grid consists of three feed-in-premiums. All premiums are adjusted annually in January.[12]

Projection of the biomethane grid injection subsidy



Source: Fremsyn based on projections of natural gas price and consumer price index from the Danish Energy Agency, 2018.

- **Base subsidy**: For biogas upgrading and grid injection, the base subsidy is set at DKK 79/Gigajoule (GJ) $_{LHV}$ (EUR 0.038/kWh) in 2013 level. The price is regulated annually with 60% of the change of the consumer price index. In 2018 the feed-in-premium is DKK 81.8/GJ$_{LHV}$ (EUR 0.039/kWh). The subsidy serves as a base of which the plant owner is certain to receive in the future.

12. Retsinformation: "Executive Order of the Act on Natural Gas Supply", available at: www.retsinformation.dk.

- Power producers using biogas can choose between a fixed power price of DKK 0.79/kWh (EUR 0.105/kWh) or a price add-on of DKK 0.43/kWh (EUR 0.06/kWh), both of which is annually regulated with 60% of the change of the consumer price index.
- Biogas to process or directly to transport receives a base subsidy of DKK 39/GJ_{LHV} (EUR 0.019/kWh), regulated as aforementioned.
- Biogas to heat receives a base subsidy of DKK 26/GJ_{LHV} (EUR 0.013/kWh) regulated as aforementioned.

- **Temporary subsidy**: Set at DKK 10/GJ_{LHV} (EUR 0.005/kWh), decreasing by DKK 2/GJ_{LHV} (EUR 0.001/kWh) annually from the beginning of 2016 until the end of 2019 when it is reduced to 0. The point of the subsidy is to initiate biogas projects as soon as possible.
  - Power producers receives DKK 0.10/kWh (EUR 0.013/kWh) power produced.
- **Gas price adjusted subsidy:** A feed-in-premium consisting of a base subsidy of DKK 26/GJ_{LHV} (EUR 0.013/kWh) plus the difference between DKK 53.2 DKK/GJ_{LHV} (EUR 0.026/kWh) and the average natural gas price of the previous year on Gaspoint Nordic. For power producers using biogas, the rate is DKK 0.26/kWh (EUR 0.035/kWh). When the gas price is reduced, the premium increases proportionally and vice versa. This subsidy ensures the income of the biomethane producer even if the natural gas price plummets and secures the state from overcompensating biogas plant owners if the natural gas price increases. The base subsidy of the premium was reduced to DKK 21/GJ_{LHV} (EUR 0.01/kWh) in 2019. For electricity producers the base subsidy was reduced to DKK 0.18/kWh (EUR 0.024/kWh).

The new subsidy scheme (beyond 2020)

On 29 June 2018, the Danish Parliament adopted a new Energy Agreement. The parties agreed to establish a pool of DKK 240 million (EUR 32 million) (nominal) annually over 20 years for the development of biogas and other green gasses for upgrading, transport and industrial processes. The pool is to be implemented in the period of 2021 to 2023, with the objective of further developing the technology in Denmark. The subsidy from the pool will be assigned in tenders with price ceilings. The details of the new subsidy scheme have not yet been published but will be developed in consultation with the biogas industry. Part of the pool will be set aside for ecological biogas.

The new Energy Act also includes a number of initiatives aimed at securing the ongoing development of the renewable energy sector in Denmark. The initiatives can be summarized as follows:

Existing biogas plants are guaranteed to benefit from the current subsidy regime during 20 years after their commissioning, or at least until 2032. For example, this means that a plant commissioned in 2015 is guaranteed support until 2035, while a plant commissioned in 2008 will be guaranteed support until 2032.

In 2020, the current subsidy scheme will be phased out for new plants. The exact date and conditions for this phase out will be defined by the Danish Energy Agency.

From 2021, new biogas plants will be allocated subsidies on a tender based principle. A pool of DKK 240 million (EUR 32 million)/year nominal is set aside for 20 years from 2021. The tenders for the pool will be put forward in 2021-2023. A part of the pool will be reserved for organic biogas.

New biogas-for-power will have to compete directly with other means of renewable power generation including PV and wind turbines.

A new gas strategy will be developed to include methanization.

Potential obstacles to the further development of the Danish biogas industry

The Danish biogas industry has faced and overcome multiple problems and limitations. But there are still several issues that still have to be addressed, most of them revolving around the grid connection structure.

Financing

A primary barrier to entry is the high construction cost for biogas plants. It has proved difficult for many farmers to achieve the necessary financing for establishing a biogas plant. Particularly, the plant which connects a biogas plant to the gas grid has proven difficult to finance. The issue being that the plant owner must bear the cost of the connection plant, while the ownership is immediately transferred to the grid owner. Therefore, it has not been possible to invest in this connection plant for many farmers. Instead large energy corporations have invested in the upgrading and connection plants and installed them at the farmers' biogas plants.

The grid connection typically costs EUR 1-2 million, depending on size and distance from the grid. The upgrading and connection plant together is usually between 10 to 30% of the total CAPEX of a biogas plant. Danish law states that all handling of piped gas in natural gas quality must be licensed, and that licenses will only be issued for public distribution system operators. This is partly to ensure a high professional level of operation, but also to ensure that all infrastructure is public and that society at large can use spare capacity in energy network infrastructures.

Historically, biogas production from farmers' biogas plants was counted as energy savings, which could be sold to other sectors. The proceeds therefrom have been used to finance connection plants. However, biogas plants are not included in the energy savings scheme anymore. No alternative schemes have been made available to help finance the connection plants.

Monopsony

The financing solution has been non-optimal in solving the problems of monopsony that many farmers have faced. Traditionally, the only recipient of biogas has been the local heat and power plants, which has put the biogas plants in a poor situation for negotiation. By allowing upgrading and connection plants to be installed at the biogas plant, the possible recipients have increased slightly, but are still very limited. If farmers manage to finance their own upgrading and connection plants, they would face an unlimited number of potential recipients of biogas, as everybody connected to the natural gas grid would become potential customers. Ideally, the farmers would like to own the upgrading and connection plant themselves but they have pragmatically been forced to accept large energy corporations onto their sites.

Grid connection monopoly

Another issue with the connection plants are that the grid owners solely decide the price and supplier of the technology. Due to a lack of competition, the price of the connection plants can be observed to be much higher compared to for example the Netherlands, where multiple suppliers can be chosen, if they uphold certain standards.

Limited demand in warmer periods

Local combined heat and power plants have limited demand for heat during warmer periods. This has caused a lot of biogas to be wasted, as there was nobody to supply to. The solution is to connect the production to the natural gas grid, where there is demand for biogas all the time. However, as the connection is typically performed to the local distribution grid for natural gas, there is also a limit in how much this grid can accept.

A solution to this problem would be to prevent grid operators from rejecting biomethane injection when the capacity of the distribution grid has proven to be too small, and require them to recompress the gas upstream to the transmission grid. In this scenario, the cost for recompression would be covered by the grid operators and lead to an increase in transmission prices for their customers.

Competition for industrial biomasses

As the production of biogas has increased dramatically over the recent years, so has the competition for industrial biomasses. The competition has caused the price of for example glycerine to rise to a level where many biogas plants can no longer afford it. Today, the key to profitability in operating biogas plants is about securing a stable supply of cheap industrial biomasses. Biogas from industrial biomasses accounts for more than half of the total biogas production today.

Professional operation

As many farmers have traditionally operated the biogas plants themselves, they have faced operational issues, particularly in busy farming periods such as the harvest season. As the economy of many biogas plants have tightened and many larger energy corporations have entered the market, many plants opt for a more professional operation, by hiring external operators for their biogas plants.

Foreign objects in biomasses

Manure and deep litter, however, are still the most important biomasses as they provide a stable baseload and beneficial micro bacterial cultures. Many plants have experienced problems with deep litter, as it has been contaminated with large foreign objects such as rocks and large metal pieces, which has caused costly breakdowns in the feeding lines to the biogas plants. Biomass feeding technologies addresses this by separating foreign objects. Another solution has been by contractually enforcing deep litter suppliers to deliver clean deep litter.

Bad mixing of straw and deep litter

There have also been issues in preparing deep litter and straw for biogas production. Historically, it has just been cut into small pieces, which does not mix well into the rest of the substrate, causing it to float on top, reducing the both the volume and production capacity. New feeding technologies have improved the mixability of straw, deep litter and other dry biomasses significantly, allowing more dry matter input, and thus larger biogas production to be achieved.

Performance and cost reduction strategies

The performance of Danish biogas plant has steadily increased. Several key factors have contributed to this:

Use of industrial biomass

Traditionally Danish biogas was purely manure based. Manure with relatively low dry matter content has a limited potential for biogas production. Biogas production has increased relative to reactor size in recent years, as more industrial biomasses have been fed to the anaerobic digesters.

Better feed lines

There has also been a development in the feed technologies for dry biomasses such as silage biomasses, deep litter, straw and similar biomasses. This has increased the organic content in the digesters, allowing for larger gas production. With higher organic content, the risk of foaming has also increased, which has increased the necessity of anti-foaming agents.

Larger centralised biogas plants

A trend for larger and more centralised biogas plants can also be observed after the introduction of grid injection subsidies. There is significant potential for economies of scale when making the biogas plants larger, and thus Denmark today has some of the largest biogas plants in the world, for example Nature Energy's plant at Korskro digests 710,000 tonnes of biomass and produces 22 million Nm3 biogas for the gas grid annually. A grid connection is necessary to have very large biogas plants, as the local combined heat and power demand is very often very limited.

New technologies for hydrogen sulfide (H2S) removal

A large part of the cost of biogas plants is due to the removal of H2S from the gas. Historically, the cleaning has been performed by adding Iron Chloride to the reactors. One of the most recent cost reduction developments in Denmark is the addition of bio scrubbers for cleaning H2S from the gas. This equipment has a relatively large CAPEX but is typically paid back within a few years.

Professional operators

The single most important factor for cost-efficient performance at biogas plants is a professional operation of the biogas plant. Many plants have performed subpar because of lack of knowledge by farmers trying to operate the plants themselves. It requires intense market knowledge and technical proficiency to secure an optimal operation of a biogas plant, which includes stable supplies of biomasses, a steady biogas production and minimal downtime.

Germany’s Experience with Biogas and Biomethane

Jaqueline Daniel-Gromke, Velina Denysenko and Jan Liebetrau

Germany is the leading market for biogas generation in the EU. The predominant generation of biogas in rural areas and within the agricultural sector is different compared to other European countries with respect to the higher share on energy crops for energy production. With 32.15 TWh_e produced, biogas (incl. biomethane) accounts for 14.2% of the electricity generation from renewable energy sources (RES) in 2018. The heat supply from biogas amounted to around 16.7 TWh_t in 2018, which corresponds to about 1.4% of the end energy consumption in the heat sector resp. 10% of the energy supply provided by RES.[13]

The latest reform of the EEG law resulted in a significant reduction of the feed-in-tariffs or, which is more important, in the abolishment of substrate bonus for energy crops and the biogas upgrading bonus for biomethane plants to be built. Further, the introduction of specific growth targets for different technologies is a new development for the German renewables support scheme. In order to ensure the shift from state support to free market competition, an auction model was introduced within the EEG 2017. Against this background, the development and increase of installed capacity in the biogas sector is currently resulting from plant expansions, adjustments for flexible plant operation as well as newly constructed small manure- and waste-based plants.

Due to expiring subsidies for existing biogas plants in Germany from 2021 on, biogas plant operators are faced with new requirements and challenges to operate their plant economically. The upgrading of biogas to produce biomethane offers a promising option within the smart energy system that Germany is pursuing.

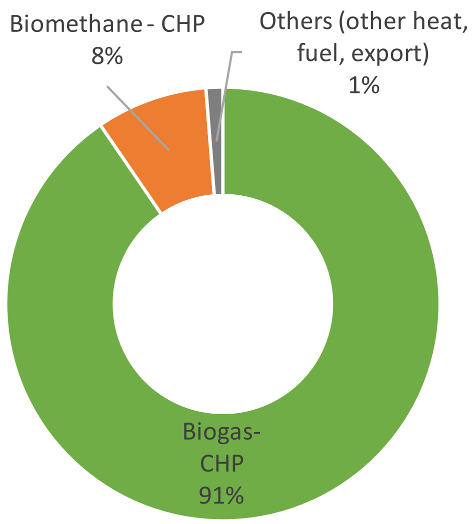
13. “Time Series for the Development of Renewable Energy Sources in Germany”, Federal Ministry for Economic Affairs and Energy, February 2019, available at: www.erneuerbare-energien.de.

Overview of the biogas and biomethane markets in Germany

The number of biogas plants has increased continuously since the EEG came into force in 2000. Due to the amendments of the EEG in 2004 und 2009, the number and installed electric capacity of biogas plants has received significant impetus. Therefore, both the number and the installed capacity of on-site electricity generation as well as of biogas plants with upgrading technology to biomethane have increased significantly.

At the end of 2018, around 8,980 biogas production plants incl. upgrading plants for biomethane were in operation in Germany. Most of them (8,780 plants) are in operation with an on-site electricity conversion of biogas and satellite CHP-units and 203 biogas plants with upgrading technologies to produce biomethane. In total, the biogas production accounts around 10 billion m^3 per year in Germany, whereof the biogas plants with upgrading technologies producing around 2.7 million m^3 per day, or around 0.9 billion m^3 per year.

Biogas und biomethane production in Germany in 2018 and its utilization pathways



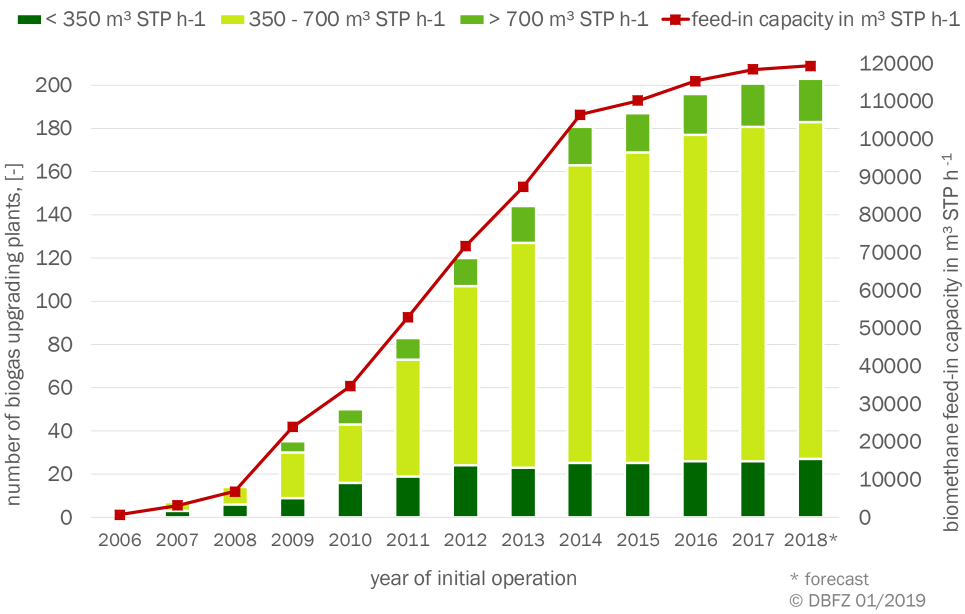
Source: DBFZ 2019, based on data from AGEE 2019 and dena 2018.

At the end of 2018, the feed-in capacity in Germany accounts more than 120,000 m^3_{STP} h^{-1}. Due to the increasing full-load-hours of the plants the feed-in reached in 2017 9.8 TWh_{Hs} (2015: 8.6 TWh_{Hs}, 2016:

9.3 TWh_{Hs}).[14] In total, it is estimated that in 2017 around 950 million m³ of biomethane were produced in Germany.[15]

The major driver for the expansion of biomethane in Germany were the ambitious goals of the German government and, more specifically, the introduction of the bonus for biogas upgrading within the amendment of the EEG in 2009. The annual growth rates were, however, substantially reduced after the abolishment of the biogas upgrading bonus in 2014.

Development of biogas upgrading and feed-in units in Germany from 2006 to 2018

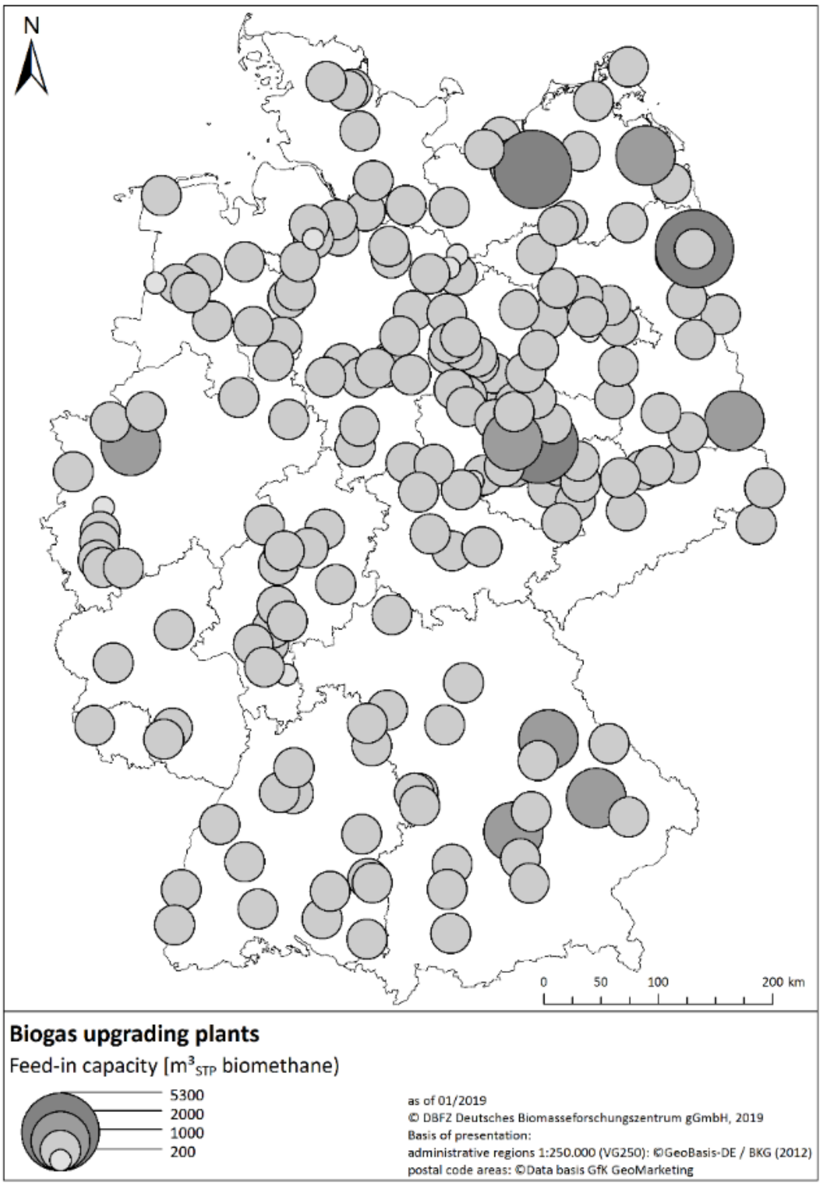


Source: DBFZ biomethane plants' database as of 01/2019.

The average biogas plant with upgrading technology is operated with higher capacity than biogas plants with on-site electricity generation. The highest upgrading capacities are installed in Eastern Germany, due to the agricultural infrastructure specifically in the federal states Mecklenburg-Western Pomerania and Saxony-Anhalt. Due to the agricultural infrastructure and biomass potential, there is a higher feed-in of biomethane in eastern part of Germany, whereas the higher demand for biomethane (biomethane-based CHP) is located in the western part of Germany (higher population density).

14. Dena-Analyse – Branchenbarometer Biomethan 2017/18. Stand 04/2018.
15. *Ibid.*

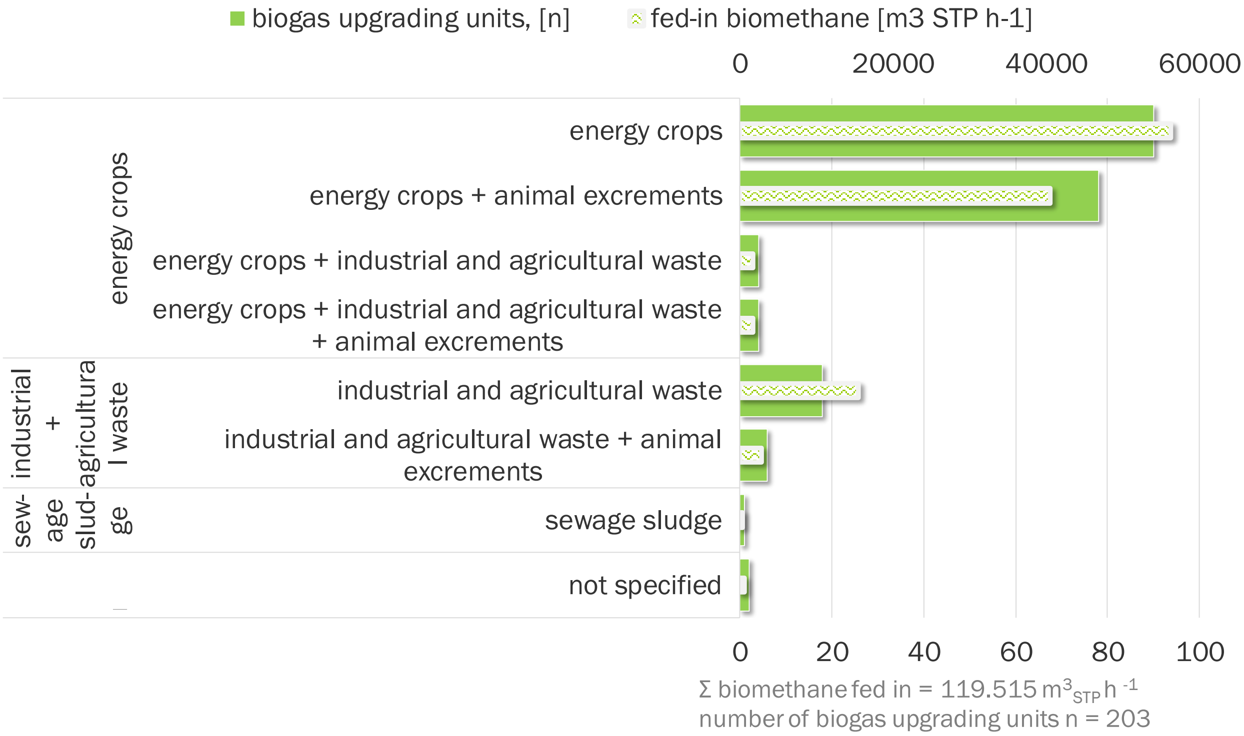
Location of the operating biogas upgrading and feed-in units in Germany



Source: DBFZ biomethane plants' database as of 01/2019.

In comparison with biogas production and on-site conversion, the production of biogas that is subsequently upgraded to biomethane is predominantly based on energy crops and, to a lesser extent, on energy crops in combination with animal excrements as substrate related to mass-input.

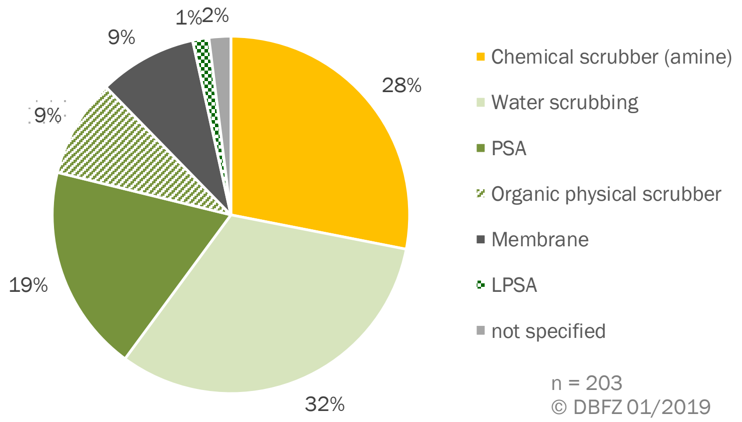
Substrates for biomethane production corresponding to the number of biogas upgrading units and respective amount of the fed-in biomethane in 2018



Source: DBFZ biomethane plants' database as of 01/2019.

To upgrade biogas to biomethane, a separation of water vapour, hydrogen sulfide and carbon dioxide is needed. The major challenge is the removal of carbon dioxide. In the last years, different processes have been established to upgrade biogas to biomethane. Since 2006, the predominant technologies in Germany have been chemical scrubber, water scrubber and pressure swing adsorption (PSA). Occasionally, upgrading by physical absorption with organic solvents has been used. In comparison to preceding years, membrane separation upgrading technologies have been utilized increasingly.

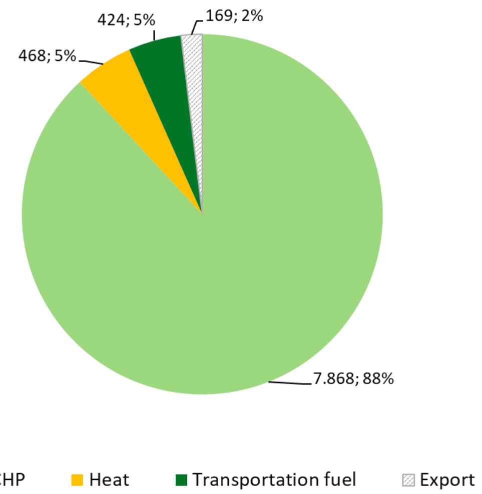
Market shares of technologies to upgrade biomethane in Germany in 2018



Source: DBFZ biomethane plants' database as of 01/2019.

Biomethane produced in plants receiving EEG tariffs is mainly utilised in CHP processes – over the last three years, 90% of the biomethane produced was used in CHP plants.[16] Further utilisation options include the heating and fuel sector, but on lower level. Based on dena, 88% of biomethane was converted in CHP units (EEG) in 2017.

Biomethane according to its utilization pathways in 2017 (Amount of biomethane in GWh and % share)



Source: T. Reinholz, K. Völler, "Kurzstudie – Daten für den Biomethanmarkt – Zusammenstellung und Analyse verfügbarer aktueller Daten sowie rückwirkender Zeitreihen", Dena, Berlin, July 2018.

16. *Ibid.*

In the CHP plants, which receive EEG-tariffs, biomethane is used for cogeneration of heat and power since the EEG is focusing on support to electricity generation. In 2018, the electricity production from biomethane-based CHP resulted in 2.7 TWh_e and heat utilization with around 3.4 TWh_t.[17] According to dena, the number of biomethane CHP-units accounts for around 1320 with the overall installed electrical capacity of around 530 MW_e in 2017.

Number of biomethane CHPs in Germany in 2017 according to their installed electrical capacity

Installed electrical capacity (kWe)	Number of CHP	Total installed eletricical capacity (MWe)
≤ 70	420	12
71 - 150	171	21
151 - 300	210	49
301 - 500	203	79
501 - 750	140	84
751 – 1.000	54	46
> 1.000	125	237
Total	1323	529

Source: T. Reinholz, K. Völler, "Kurzstudie – Daten für den Biomethanmarkt – Zusammenstellung und Analyse verfügbarer aktueller Daten sowie rückwirkender Zeitreihen", Dena, Berlin, July 2018.

The amount of biomethane used for transportation in 2018 accounted for 0.41 TWh resp. 1.1% of the end energy consumption of renewable energies in the transport sector. Biomethane produced from organic waste, manure or dung can be double counted for the national biofuel target (36. BImSchV). According to the Fourth Progress Report of the Initiative for natural gas-based mobility, the number of filling stations offering biomethane (partly or up to 100%) decreased from 293 to 251 in 2015 (data from 05/2016).[18] As a result of the now negligible use of pure fuels, their

17."Time Series for the Development of Renewable Energy Sources in Germany", *op. cit.*
18. "Sustainable Mobility Based on Natural Gas and Biomethane: Market Development 2015/2016", Fourth Progress Report, Dena, 2016, available at: www.erdgasmobilitaet.info.

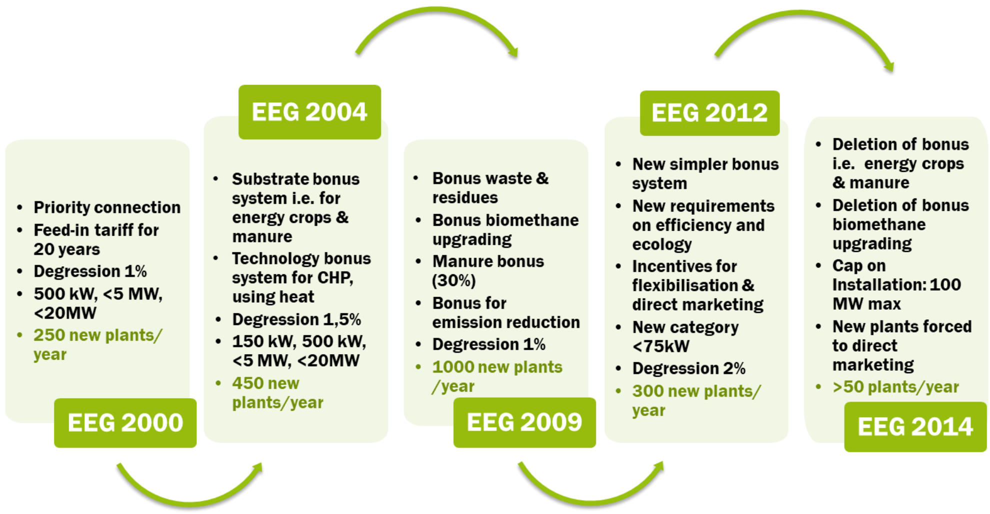
filling station infrastructure has been reduced to a minimum.[19] The tank infrastructure for alternative fuels, such as natural gas (CNG) or hydrogen, which are to be used with a high share of renewables in the future, requires further expansion.

Evolution of the support scheme

The EEG plays a key role in the success of the German energy transition. The three resting pillars of the EEG consist of (i) the right of grid connection for renewable energy facilities, (ii) the obligation for net operators to preferentially purchase electricity based on renewables and (iii) a minimum feed-in-tariff to be paid for the generated electricity.

Since the year 2000, the EEG was amended several times to enforce the promotion of renewable energies or to correct undesirable developments.

Renewable Energy Sources Act (EEG) - Focus Biogas



Source: M. Nelles, J. Daniel-Gromke, V. Denysenko, R. Kittler, M. Scheftelowitz, R. Rensberg, W. Stinner, J. Liebetrau, "Recent Development in Biogas Generation and Utilisation in Germany", Presentation Great Cycle 2015 – Symposium of Bioenergy Science and Technology, China Agricultural University. Beijing, August 2015.

With the restructuring of the EEG in 2012 and 2014, the commissioning of new biogas plants has significantly decreased as a result of the tariff reductions. Thus, since the latest amendment of EEG, it was not possible to achieve a significant increase of electricity production, because the newly built manure based small scale plants and biowaste based biogas plants have only limited impact on the overall output.

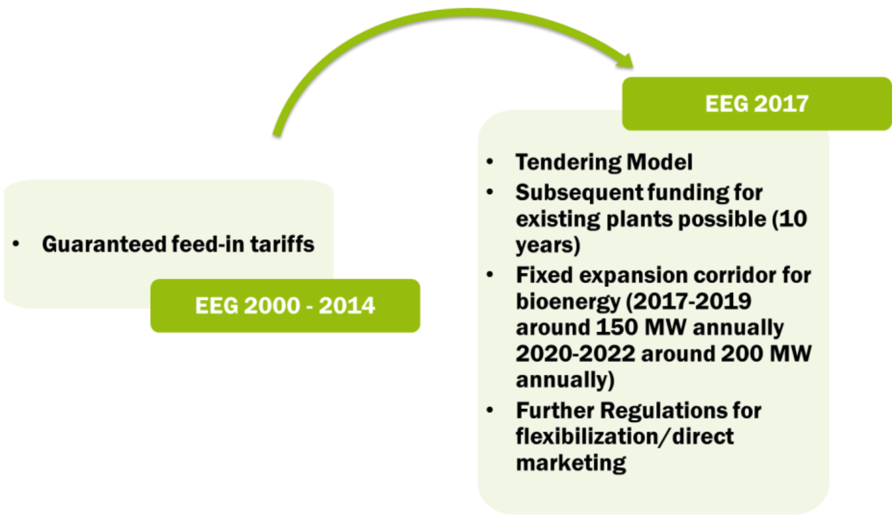
19. K. Naumann, J. Schröder, K. Oehmichen, H. Etzold, F. Müller-Langer, E. Remmele, K. Thuneke, T. Raksha, P. Schmidt, "Monitoring Biokraftstoffsektor. 4. überarbeitete und erweiterte Auflage", DBFZ, 2019, available at: www.dbfz.de.

Due to dynamic developments over the past few years, biogas technology has been adapted to a changing set of framework conditions. The input materials used in biogas plants are mainly different types of manure and energy crops, as the implementation of specific substrate bonuses within the framework of the EEG has encouraged their utilization. The EEG amendments of 2004 and 2009 provided incentives to increase biogas generation capacity by creating the economic framework conditions for using energy crops, and thus increased biogas production. Against the backdrop of the amended legal framework conditions since 2012, the extension of capacity in the biogas sector has mainly comprised plant expansions, adjustments for a flexible plant operation as well as a slight extension of small manure-based biogas plants and plants for biowaste digestion. The former EEG promoted biogas plants with a fixed feed-in tariff for 20 years, whereas the new funding scheme established in 2017 is based on auctions.

After a biogas boom between 2009 and 2011, the further increase of installed capacity was considerably slowed down by the restructuring and decrease in the tariff system following the EEG amendment of 2012, 2014 and 2017. Additionally, the introduction of the market and flexibility premium in the EEG 2012 set course for future requirements in the bioenergy sector.

Finally, EEG 2017 triggered a switch from guaranteed feed-in tariffs for electricity from RES to bidding systems.

Renewable Energy Sources Act (EEG) System Change in 2017



Source: M. Nelles, J. Daniel-Gromke, V. Denysenko, R. Kittler, M. Scheftelowitz, R. Rensberg, W. Stinner, J. Liebetrau, "Recent Development in Biogas Generation and Utilisation in Germany", Presentation Great Cycle 2015 – Symposium of Bioenergy Science and Technology, China Agricultural University. Beijing, August 2015.

The latest amendments of the EEG resulted either in a significant reduction of the feed-in-tariffs or, which is more important, in the abolishment of substrate bonus for energy crops and the biogas upgrading bonus for biomethane plants to be built. Further, the introduction of specific growth targets for different technologies is a new development for the German renewables support scheme. The annual growth of biomass including biogas is limited to a maximum of 150 MW_e in 2019 (200 MW_e from 2020 on) compared to 2,800 MW_e for onshore wind resp. 2,500 MW_e for solar power. The main political arguments for the introduction of the defined growth targets for biomass and the auction system are the reduction of costs, the need to favour market integration and the establishment of the competitive renewables, as well as the (limited) biomass potentials. The auctions are based on a pay-as-bid model with two auctions already run in 2017 and 2018.

Results of the biomass auctions in Germany in 2017-2018

Date of auction	Volume of auction, [MW_e]	Number of awarded plants, [n]	Awarded installed el. capacity, [MW_e]
01/09/2017	122.4	21 biogas plants + 1 biomethane-CHP	27.5
01/09/2018	225	79	77

Source: Data from The Bundesnetzagentur for Electricity, Gas, Telecommunications, Post and Railway (BNetzA), 2018.

The biogas plants to be built with an installed electrical capacity of more than 150 kW_e as well as already existing biogas facilities can participate in the auctions. The existing biogas plants can bid in order to receive the follow-up 10-years funding only by compliance with the flexible operation and remaining remuneration period of not more than 8 years. Thus, it is necessary to install at least a twofold CHP overcapacity in relation to the average rated power output. The maximum bidding value for new biomass plants in 2018 amounted to 14.73 c/kWh_e, whereas the maximum bidding value for existing biomass plants was 16.73 c/kWh_e with the digression of 1 % p.a. (in comparison to the last auction round in 2018 with 6.26 c/kWh$_e$ for onshore wind and 4.69 c/kWh$_e$ for solar). Despite the compliance requirements for the bidding system (plant retrofitting, capital investments, bureaucratic burden), the result of the auctions run so far is that neither was the auctioned volume for biomass completely used nor were substantial cost reductions achieved.

Against the background of the current framework, small-scale biogas upgrading plants cannot be operated economically. Low rates of remuneration in the EEG 2014 and upper limits for bids in the EEG 2017 have meant that the generation of biomethane in biomethane CHP plants with high heat utilization is rarely competitive. The cuts mainly include the removal of the gas treatment bonus and the additional compensation for the use of energy crops. The reduced remuneration cannot compensate the production costs of biomethane.

While biomethane based on energy crops is predominantly used in the CHP sector, biomethane as a fuel is mainly produced from waste and residual materials. The EEG 2017 offers hardly any prospects for the use of biomethane from energy crops. Thus, sales opportunities are currently seen only for biomethane from residual and waste materials.

The cost reduction potential

The cost reduction potential of an optimised constellation of biogas upgrading and biomethane feed-in of smaller capacities is evaluated within the context of the joint project "Efficient micro biogas upgrading plants" (eMikroBGAA).[20] The aim is to show the potential of economically optimised biogas feed-in referred to the whole of Germany and to deduce recommendations for actions for an economic operation of those plants.

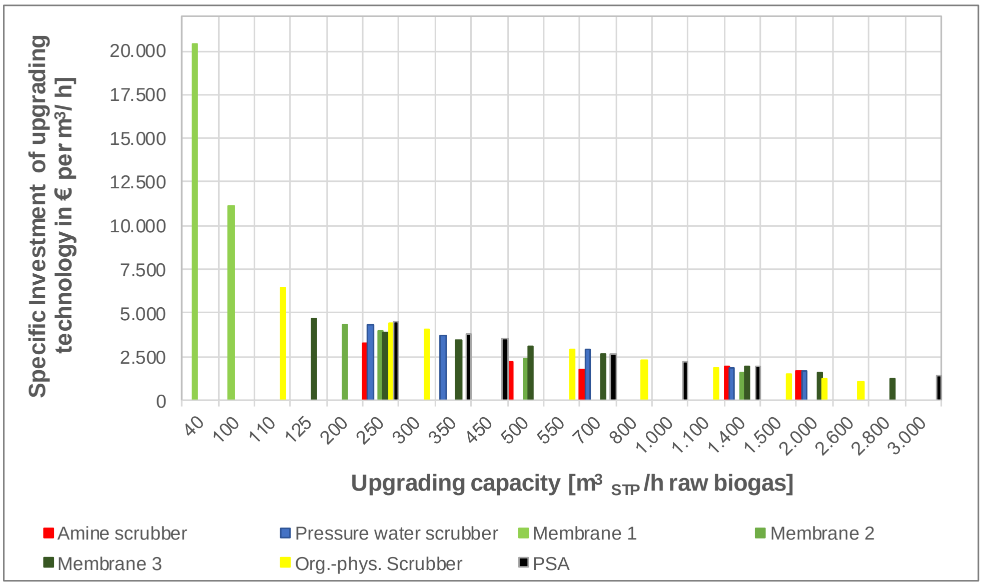
In 2016/2017, the DBFZ carried out a manufacturers' survey of upgrading technologies for the cost analysis of the upgrading of biogas in order to analyse the economic and technical parameters of the upgrading technologies currently available on the market with different upgrading capacities. Compared to previous years, there are significantly more manufacturers of upgrading plants on the market. In addition, more membrane technologies are currently used.

The evaluation shows a large range depending on the upgrading capacity. The specific costs for upgrading biogas to biomethane depend on the upgrading size. For standard upgrading capacities, it generally ranged

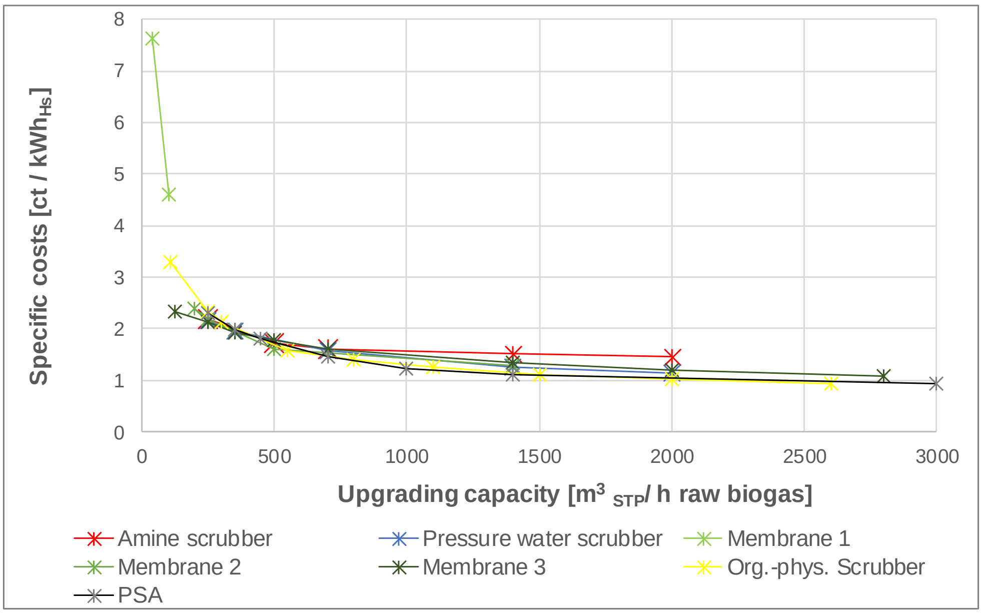
20. The joint project – headed by Fraunhofer IEE and the project partners DBFZ, DBI and dena – is supported by the Federal Ministry of Food and Agriculture through Fachagentur Nachwachsende Rohstoffe e.V. (FNR) with a project duration from 11/2015 to 1/2018 (published by M. Beil *et al.*, 2019).

between 1-2 c kWh^{-1}. Due to the economies of scale, the specific costs are higher for smaller upgrading capacities. In addition to the upgrading technology itself, other specific investments include the costs of lean gas treatment, commissioning, approval and planning, ancillary construction costs, replacement costs, if necessary (e.g. replacement of membranes after 10 years), and the maintenance and service costs.

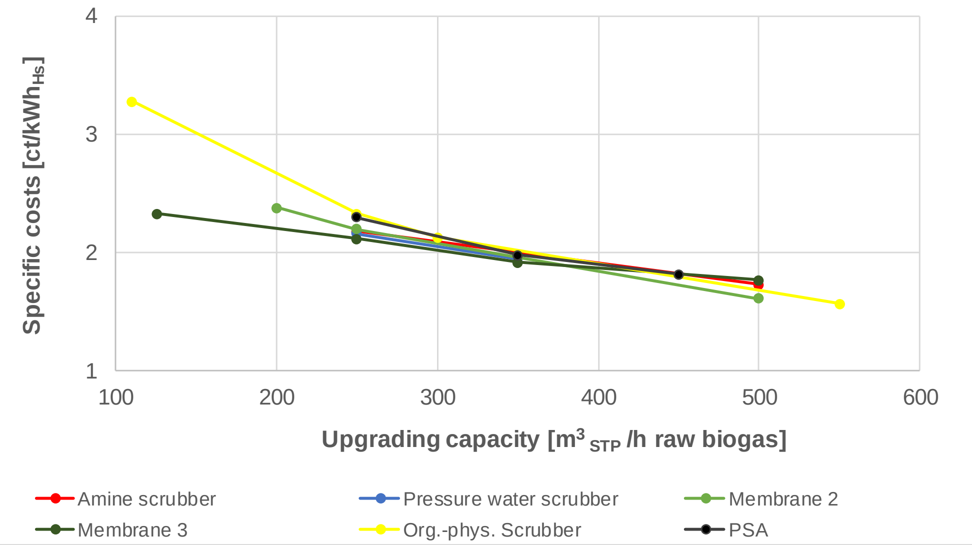
Specific investment into upgrading technology per m³ / h raw biogas depend on the capacity and kind of technology



Specific costs of upgrading biogas to biomethane in cent per kWh_{Hs} in the range from 40 to 3,000 m^3_{STP} raw biogas h^{-1}



Specific costs of upgrading biogas to biomethane for small upgrading capacities depending on upgrading capacity and kind of upgrading technology



Source of the three graphs: M. Beil et al., *"Efficient small scale upgrading plants (eMikroBGAA)", Final report, DFBZ, February 2019, available at: http://download.fnr-server.de.*

The economic analysis shows significant digression effects concerning the upgrading capacity. The highest upgrading costs are determined by the smallest upgrading plants with capacities up to 100 m^3_{STP} raw biogas h^{-1}.

In terms of capacity between 100 and 125 m^3/h, the costs for upgrading biogas to biomethane are between 4.6 and 2.3 c/kWh_{Hs}, while for capacities between 200 to 550 m^3/h a range between 2.4 and 1.6 c/kWh_{Hs} has been determined. Compared to the other capacities, the smallest capacity (40 m^3/h, Membran1 diaphragm 1) with 7.6 c/kWh_{Hs} had significantly higher specific costs for upgrading biogas to provide biomethane.

If lean gas treatment was not planned for plants with a capacity ≤ 150 m^3/h of raw biogas, the investment savings might reduce the specific costs of raw biogas upgrading for the 40 m^3/h raw biogas plant by approx. 0.7 c/kWh_{Hs}; at 100 and 110 m^3/h of raw biogas by approx. 0.3 c/kWh_{Hs}.

According to the Federal Network Agency (BNetzA), specific costs of grid feed-in (cost allocation of all grid operators for using the gas grid by costumers) were determined with 2.9 c kWh^{-1} in 2011 resp. 2,1 c kWh^{-1} in 2015.[21] The costs of compression of biomethane are the most relevant part.

21. "Monitoringbericht Biogas 2016", Bundesnetzagentur, available at: www.bundesnetzagentur.de.

The feed-in of upgraded biogas into natural gas grid is more cost-intensive for smaller upgrading capacities compared to the feed-in of larger ones with the same feed-in pressure. It is expected that the feed-in of biomethane into gas distribution grids with lower pressure levels leads to (significantly) reduced costs for investments and operation.

In total, due to the different pressure levels and capacities, the costs of upgrading biogas and feeding biomethane into the natural gas grid resulted in a range of 4.1-4.7 c/kWh$_{Hs}$ (250 m^3/h of raw gas) and 2.4-2.7 c/kWh$_{Hs}$ (700 m^3/h raw gas).

The comparison between the upgrading processes highlights that the membrane, pressure water scrubbing and amine scrubbing are cost-effective methods. Taking into account the costs of upgrading and feed-in, membrane processes and the pressure water scrubbing are the most cost-effective at low pressure levels (1 and 4 bar).

In addition, the type of substrate determines the cost of biogas production. The costs of supplying raw gas from waste and residual materials are generally 1 to 3 c/kWh$_{Hs}$ lower than biogas based on energy crops.[22]

Historically, due to its high methane yield, maize was the predominant crop used for biogas and especially for biomethane production. In order to respond to the public food versus fuel and, more recently, food-feed-fuel debate, the utilization of maize silage and grain (including whole crop silage, corn-cob-mix, grain maize and ground ear maize) was limited to 60% by so-called maize cap in 2012. Currently, the maize cap is set at 47% and will be further reduced to 44% in 2021-2022. Consequently, there are efforts towards further utilization of alternative substrates such as wild plants (cup plants) and agricultural residues (straw, chaff, sugar beet leaves) for biogas resp. biomethane production.[23] Despite the positive environmental effects and cost reduction potentials while using alternative crops for biogas generation, the limitations are set by the efficient process chain and availability at the regional scale for agricultural residues and harmonization of national and European legal frameworks for wild plants. More specifically, there should be an allowance for using cup plants from ecological conservation areas according to the second pillar of the Common Agricultural Policy (so-called greening measures) for biogas production.

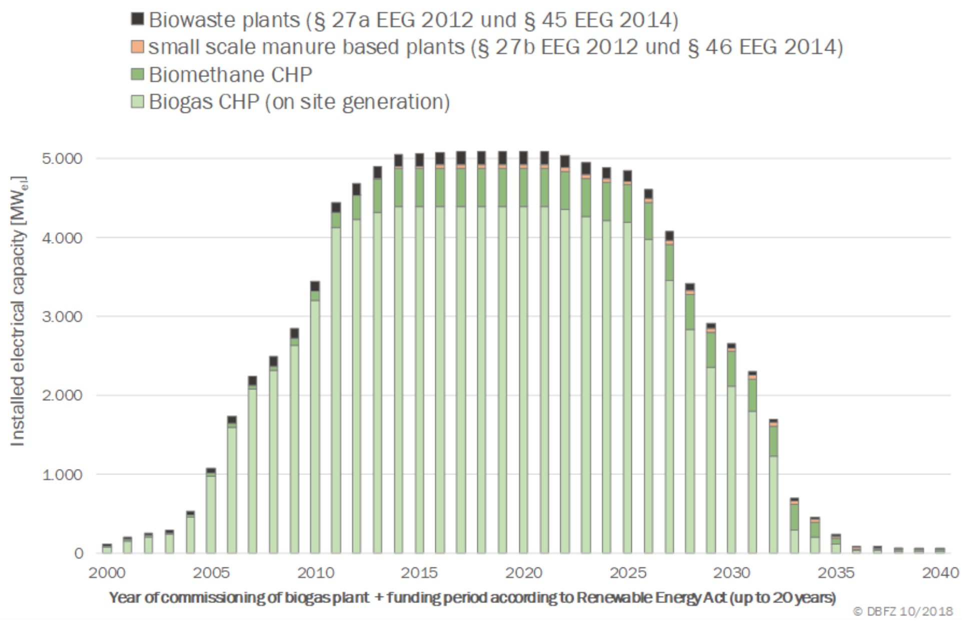
22. F. Scholwin *et al.*, "Perspektiven der Biomethaneinspeisung. Perspektiven der Biogaseinspeisung und instrumentelle Weiterentwicklung des Förderrahmens", Projektbericht im Auftrag des BMWi (FKZ 03MAP283), Universität Rostock, 2015, available at: www.auf.uni-rostock.de.

23. W. Stinner *et al.*, "Agricultural Residues as a Component of Future Biogas Production", 2018.

The uncertain future of biomethane in Germany

By 2030, the fixed remuneration under the EEG will expire for a large number of existing biogas plants. At the same time, the share of fluctuating renewable energies in the energy system will increase sharply. For the operators of biogas plants, this results in a variety of new requirements. The central question for existing plants is still which economically viable options exist for the continued operation of biogas plants. If there is no chance for an economic operation of existing biogas plants after the expiry of the feed-in tariff according to EEG, the required investments and maintenance of the existing plants will be deferred, and with the expiry of the EEG tariff, the available plant capacity will decrease.[24]

Scenario - Development of the installed capacity of existing biogas plants in case of expiry of the EEG-funding after 20 years without follow-up funding



Source: J. Daniel-Gromke et al.*, "Anlagenbestand Biogas und Biomethan – Biogaserzeugung und -nutzung in Deutschland", Report No30, DBFZ, 2017, available at: www.dbfz.de; based on database from BNetzA 2016 with development until 2016 and without additional constructions from 2017.*

Previous findings show that ecological plant concepts are particularly effective at plants that are operated on the basis of residual and waste

24. J. Daniel-Gromke, N. Rensberg, V. Denysenko, W. Stinner, T. Schmalfuß, M. Scheftelowitz, M. Nelles, J. Liebetrau, "Current Developments in Production and Utilization of Biogas and Biomethane in Germany", Chem. Ing. Tech. 2018, 90, No. 1-2, available at: https://doi.org.

materials. Especially with the use of manure, high GHG savings compared to conventional manure handling can be achieved. The use of cultivated biomass requires particular attention to sustainable cultivation and regional adaptation.[25]

With regard to the use of biogas, the CHP path continues to represent the utilization option with the highest GHG saving.[26] Due to the new requirements and transformation processes in the energy system, the flexibility of biogas plants is of particular importance in order to optimize the degree of utilization and security of supply.

In the fuel sector, the proportion of fossil fuels and the associated emissions remains high. Biomethane can also be usefully used here - through comparatively high GHG savings compared to fossil and alternative fuels. However, recent developments in this sector do not suggest an increase in the use of biomethane. Biomethane is also flexible in terms of location, time and type of gas utilization compared to plants with on-site electricity generation concepts, and can be used equally to provide heat, electricity and fuel and is therefore an instrument for successful sector coupling. This flexibility is paid for with additional costs for treatment and feed-in, as well as greater restrictions on site selection. Biomethane also offers the perspective of the option of interfacing with the development of other renewable gases, such as power-to-gas. Against this background, the focus should be on upgrading biomethane plants for suitable biogas plants. In particular, the use of biomethane in CHP plants or as fuel is considered to be the most efficient use option.

Biomethane for prospects of sector coupling (biomethane strategy) can be drawn as follows:

- Biomethane-CHP especially in urban regions with gas infrastructure (short/medium -term);
- Biomethane as transportation fuel (CNG, LNG, persp. fuel cell) (medium/long-term);
- Biomethane for industrial processes (process steam), if changeover to electricity difficultly (medium/long-term).[27]

25. *Ibid*.
26. F. Scholwin *et al*., "Perspektiven der Biomethaneinspeisung. Perspektiven der Biogaseinspeisung und instrumentelle Weiterentwicklung des Förderrahmens", *op. cit*.
27. T. Barchmann, J. Daniel-Gromke, T. Schmalfuß, V. Denysenko, N. Rensberg, J. Liebetrau, M. Nelles, "Strategien und Perspektiven für Biogas in Deutschland im Rahmen der Sektorenkopplung", in Universität Rostock (Hrsg.): 12. Rostocker Bioenergieforum, Tagungsband.

Key issues in the German policy debate

The current scenarios for bioenergy that are discussed by the responsible governmental decision-makers are not consistent and do not set the right conditions to ensure the long-term development of this technology. Thus, it is necessary to examine which alternative plant concepts can be particularly valuable for the changing energy system, for which plants a change towards one of these concepts is technically possible, economically sustainable and ecologically reasonable, and which constraints must be faced in order to implement these alternative plant concepts.

The Federal Ministry for Economic Affairs and Energy focusses on low costs for energy production (compared to wind and solar energy), however without considering the positive externalities that bioenergy can provide regarding the agriculture, flexible energy supply, closing nutrient cycle by using the digestate as fertilizer or added value in rural areas. Whereas the international data indicates that there are 344,253 jobs in the biogas sector in Germany by the end of 2017 (including direct and indirect employment, the latter with the upstream industries), the national sources provide assumptions only for direct employment and evaluates that there are 105,600 jobs in the bioenergy sector, a decrease in 2016 compared to 2013 (115,800).

Regarding the political point of view, the short/medium-term view focusses on flexible biogas plant operation (e.g. for power system stability) in CHP units (e.g. heat storage facilities and district heating). The perspective for CHP as part of the political framework is seen at least until 2030; a flexibility of power generation combined with high heat utilization can be a promising option to combined electricity and heat demand. Therefore, the utilization of biomethane in CHP units (especially in urban areas) can contribute to a sustainable heat transition (*Wärmewende*) by promoting efficient power-heat-systems.

Moreover, bioenergy (here: biogas/biomethane) is seen for applications where electrification is not possible. The future use of biomethane as fuel can be considered especially within heavy goods transport and shipping sectors due to the fact, that in these sectors there are no renewable alternatives to substitute fossil fuels besides biomethane. Moreover, biomethane as transportation fuels contribute to GHG-savings compared to fossil transportation fuels.[28]

28. K. Naumann, J. Schröder, K. Oehmichen, H. Etzold, F. Müller-Langer, E. Remmele, K. Thuneke, T. Raksha, P. Schmidt, "Monitoring Biokraftstoffsektor. 4. E.; überarbeitete und erweiterte Auflage", *op. cit.*

In Germany, the policy focusses on wastes and residues; less energy crops for energy production due to the discussion of cultivation of energy crops on agricultural land. Moreover, in general the specific cost of biogas/biomethane from energy crops is 1-3 c/kWh_{Hs} higher than residues. Due to the cost debate of bioenergy in comparison to other RES, the government currently does not want more biomethane production. Biomethane is associated with higher specific costs due the upgrading step and is finally more expensive than biogas. However, biomethane allows a more flexible use. Objectives for biomethane might be the grid injection and a flexible use in CHP or a focus on the transport sector.

The potential for refitting existing biogas plants by adding upgrading technologies was evaluated in the project "eMikroBGAA".[29] Economics calculations show that the upgrading of biogas to biomethane can be profitable when at least 250 m^3 raw gas/h can be used. However, from the economic point of view, larger plant concepts are more interesting. Concept of heat utilisation used on-site and the amount of revenues earned by selling the heat are important factors to decide which kind of biogas utilisation is the most profitable – either upgrading or on-site electricity production.[30] The biogas upgrading technology for existing biogas plants is especially seen for larger biogas plants or merged biogas plants.

Increased incentives should be achieved either by reducing the costs of upgrading of biogas and feed-in of biomethane or by providing financial incentives for the implementation of small-scale plants. By merging the raw biogas from several biogas plants into central upgrading plants, the potential of existing biomethane supply plants can be increased. This requires a more detailed regional consideration of the framework conditions.

With respect to the feed-in of biomethane into the natural gas grid, there are further cost reduction potentials, since cost-efficiency incentives are currently not given.[31] Another option for cost saving are using only partial amount of biogas to be upgraded or to feed-in biomethane with lower CH_4-content depending on the respective gas consumers without substantially compromising the overall gas quality within the natural gas grid. The options regarding injection into the national gas grid have to be

29. M. Beil *et al.*, "Efficient Small Scale Upgrading Plants (eMikroBGAA)", Final Report, February 2019, available at: http://download.fnr-server.de.

30. J. Daniel-Gromke, N. Rensberg, V. Denysenko, G. Erdmann, T. Schmalfuß, J. Hüttenrauch, E. Schuhmann, R. Erler, M. Beil, "Efficient Small-Scale Biogas Upgrading Plants -Potential Analysis & Economic Assessment", in Proc. European Biomass Conference 2017, (EUBCE), Stockholm, 2017, p. 1105-1109.

31. M. Beil *et al.*, "Efficient Small Scale Upgrading Plants (eMikroBGAA)", *op. cit*.

discussed with the German gas transmission industry to analyse these alternatives.

Missing market perspective

The installation of new biomethane CHP units is completely unprofitable, leading to a decline of investment in potential sites.[32] However, biomethane exceeds the potential of other biofuels with regard to their GHG-mitigation potential.[33] Moreover, the utilization of cheap substrates such as biowaste or other residues and the subsequent lower production costs lead to strong economic advantages. However, the potential of these substrates, and thus the potential of biomethane produced from them is limited. Furthermore, this competitive advantage towards liquid biofuels has been reduced in consequence of decreasing prices for natural gas as well as of the GHG-quota that replaced the former double counting for fuels based on waste and residues in 2015, which had been an essential incentive for the production and utilization of biomethane.[34]

In perspective, numerous renewable energy sources are suitable for use in the transport sector. However, their potential is limited and their use as power or fuel competes both with potential use in other sectors (e.g. electricity and heat supply) and within the transport sector between the different applications (road, rail, water, air).[35]

The use of biomethane in the transport sector can also be an attractive option for heavy-duty and ship traffic in form of liquefied biogas to further reduce GHG-emissions in the transport sector.[36] However, the transportation sector for gaseous fuel is not well-established in Germany and need more political support and improved legal framework. Another option would be to increase biomethane sales outside the German market.

Nevertheless, currently the main problem for promoting biomethane in Germany is the missing market perspective. Evaluating the different available biomethane conversion pathways, it should be considered that

32. J. Daniel-Gromke *et al.*, "Current Developments in Production and Utilization of Biogas and Biomethane in Germany", *op. cit.*
33. K. Naumann *et al.*, "Monitoring Biokraftstoffsektor. 4. überarbeitete und erweiterte Auflage", *op. cit.*
34. "Sustainable Mobility Based on Natural Gas and Biomethane: Market Development 2015/2016", *op. cit.*
35. K. Naumann *et al.*, "Monitoring Biokraftstoffsektor. 4. überarbeitete und erweiterte Auflage", *op. cit.*
36. "Sustainable Mobility Based on Natural Gas and Biomethane: Market Development 2015/2016", *op. cit.*

the higher production cost for biomethane allow a higher flexibility with regard to place, time and kind of the final usage.[37]

Without a new credible economic perspective for existing plants necessary investments will be held off and the plant portfolio will decrease. Signals for a new framework combined with better economic conditions for biogas/biomethane in Germany are required.

37. J. Daniel-Gromke *et al.*, "Current Developments in Production and Utilization of Biogas and Biomethane in Germany", *op. cit.*

Italy's Experience with Biogas and Biomethane

Sylvie Cornot-Gandolphe

According to the European Biogas Association and the Italian Consortium for Biogas (CIB), Italy had 1,555 biogas plants in 2017.[38] In terms of number of plants, it is the second biogas market in Europe after Germany, and the third one in terms of biogas production (2.2 bcm/year), after Germany and the United Kingdom.[39] The Italian biogas sector is characterized by a high percentage of plants in the agriculture sector. More than 80% of biogas plants use biomass of agricultural origin, 12% landfill waste, 3% organic fractions of municipal solid waste (OFMSW) and 5% biomass-derived water treatment.

Biogas is almost exclusively used to produce electricity and heat as biogas upgrading into biomethane has just started in Italy. At the end of 2017, biogas power plants had an installed electricity capacity of 1,400 MW, of which just under 1,000 MW in the agricultural sector.[40] Northern Italy dominates biogas electricity generation (82.8% of the total). In 2017, the first region is Lombardy, with 34.4%, followed by Veneto and Emilia Romagna (14.8% and 14.4%) and Piedmont (12.3%).

Biogas development expanded considerably from 2008 to 2012, thanks to an "all inclusive" Feed-in Tariff (FiT) (*tariffa onnicomprensiva*) that guaranteed the highest European FiT for small biogas electricity plants from agricultural feedstock (EUR 280/MWh for plants <1 MW), including energy crops. The FiT unlocked the potential of the sector. The number of biogas plants rose from 510 in 2010 to 1264 in 2012. Electricity generation from biogas (all biogas, including landfill gas) skyrocketed from 1.6 TWh generated in 2008 to 7.4 TWh in 2013, according to data from Terna, the Italian electricity transmission system operator. In 2012, with effect on January 2013, the government shifted its policy on biogas and adjusted its

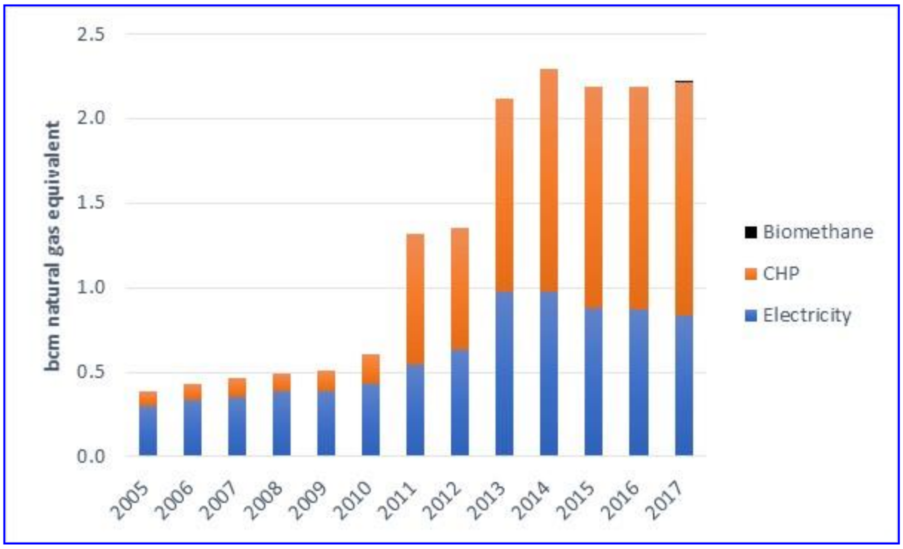
38. European Biogas Association (EBA), *Statistical Report 2017*, February 2018, available at: https://european-biogas.eu; L. Maggioni, C. Pieroni, M. Pezzaglia, "The Biogas and Biomethane Market in Italy", *Gas for Energy*, No. 2, 2018.

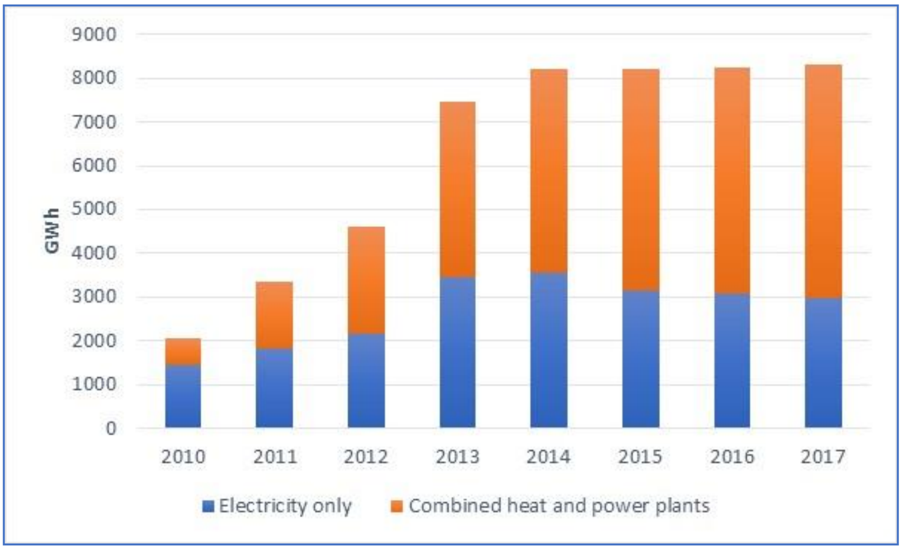
39. EurObersv'ER, *Biogas Barometer 2017*, available at: www.eurobserv-er.org.

40. QualEnergia.it, "Il biometano in Italia oggi e domani", 11 October 2018, available at: www.qualenergia.it.

incentives downwards and moved to a Feed-in-Premium, except for small plants (Ministerial Decree of 6 July 2012). The new policy gave preference to the use of by-products and farming waste over energy crops and encouraged the development of small plants (up to 600 kW). The initial effects of this new policy were felt from 2013, when the number of newly installed biogas plant dropped (only 140 plants in 2013 compared with 684 in 2012). Since then, the number of biogas plants and their electricity generation have stagnated (8.3 TWh in 2017). Heat generation from biogas totalled 3.1 TWh in 2017 from 2.1 TWh in 2012.[41]

Biogas production and use





Source: Eurostat.

41. Gestore dei Servizi Energetici (GSE), *Rapporto Statistico 2017- Fonti rinovabili*, December 2018, available at: www.gse.it.

In 2013, the government also re-oriented its biogas policy from electricity generation (except for small plants) to biomethane production and set up a FiT for biomethane production for natural gas vehicles (NGVs), high-efficiency cogeneration and grid injection (Ministerial Decree of 5 December 2013 for the promotion of biomethane, hereafter 2013 Biomethane Decree). However, due to the lack of secondary legislation, the biomethane did not take off. Despite its huge biogas potential, Italy had only 8 biomethane plants operational at the end of 2017, consisting of only one large biomethane plant and seven small pilot plants. Biomethane production was 49 GWh in 2016 and is estimated at some 100 GWh in 2017. But this is changing radically. In March 2018, the Italian government adopted the Ministerial Decree on the promotion of biomethane and advanced biofuels in transport for the period 2018-2022 (hereafter 2018 Biomethane Decree).[42] The Decree has given a strong boost to the sector (see below).

Another notable fact is that Italy is the European leader for Natural Gas Vehicles (NGVs) accounting for three quarters of the European NGV fleet, with around 1 million light compressed natural gas (CNG) vehicles, and a fleet of about 3,300 methane-fueled buses. This development has been driven by policy and financial measures focused on vehicle and infrastructure as well as a large tax advantage of natural gas over diesel and petrol. The infrastructure network is well-developed with 1,250 CNG refueling stations and is constantly increasing. Italy consumes 1.1 bcm/y of natural gas in road transport. This provides for a solid context for the development of the use of biomethane in transport.

Also, LNG is becoming increasingly important in the heavy transport sector. There are already 22 LNG stations in operation in Italy, and around 1,000 heavy vehicles powered by LNG. In maritime transportation, Legislative Decree 257/2016, implementing Directive 2014/94/EU on the creation of an alternative fuels infrastructure (DAFI) provides for the provision of refueling points in LNG ports for inland and maritime navigation, and results in an increase of the number of gas refueling stations to around 2,400 for CNG and to around 800 for LNG in 2030. The objectives of Legislative Decree 257/2016 have been translated into the 2017 National Energy Strategy under which, in 2030 LNG should cover roughly half of the sea bunkering and 30% of heavy goods transport (in terms of ton-km).

42. "Promozione dell'uso del biometano e degli altri biocarburanti avanzati nel settore dei trasporti (18A01821)", Decreto 2 Marzo 2018, Gazzetta Ufficiale Serie Generale No65, 19 March 2018, available at: www.gazzettaufficiale.it.

The 2018 Biomethane Decree and recent policies

On 2 March 2018, the government adopted the 2018 Biomethane Decree.[43] The decree aims at promoting the production of biomethane and advanced biofuels to increase the share of renewable fuels in the transport sector. With this decree, Italy aims at achieving an overall 9% renewable target in the transport sector by 2020, and a secondary target for advanced biofuels starting at 0.6% in 2018 and rising to 1.85% in 2022. The decree introduces a support scheme for advanced biofuels, biomethane and advanced biomethane injected into the natural gas grids to be used in the transport sector. The decree allocates EUR 4.7 billion of funds between 2018 and 2022 and covers a maximum amount of 1.1 bcm/y (standard cubic meters) of biomethane production.

The scheme is fully financed by transport fuel suppliers under their biofuel blending obligation. Contrary to the 2013 Biomethane Decree, only biomethane injected into the natural gas grids to be used in the transport sector can have access to the support mechanisms. The preamble of the 2018 Biomethane Decree states that Italy has already achieved its overall energy and electricity targets for 2020, but it is not on track to meet its targets for the transport sector. To spur the growth of renewable energy in this sector, the Decree establishes that priority should be given to promoting the use of biomethane in the transport sector, while for the remaining uses, an update of the Decree will be issued after the transport target has been fulfilled. Grids have a wide definition: they are all the networks, transport and distribution systems, including for instance transport systems using cylinder trucks, and natural gas distributors for transport (CNG and LNG stations), even if not connected to the main networks. The 2018 Biomethane Decree puts more emphasis on the production of bio-LNG than the 2013 Biomethane Decree.

A support scheme based on biofuel blending obligation

The biomethane promotion scheme is based on the allocation of certificates of release for consumption (*Certificati di Immissione in Consumo di biocarburanti,* better known as "CIC") allocated to biomethane producers by GSE (*Gestore dei Servizi Energetici*, the National Agency in charge of managing all the support schemes for renewables deployment) to be sold to

43. *Ibid.*; "Il futuro della mobilita", *Biogas Informa, Speciale Biometano*, No. 24 2018, CIB, available at: www.consorziobiogas.it.

fuel suppliers subjected to a mandatory blending quota. The number of CIC that these suppliers are obliged to hold is determined every year. A mandatory quota for advanced biofuels has been introduced (1.85% in 2022). The Decree specifies that 75% of the sub-target for advanced biofuels must be met with biomethane and the remaining 25% with must be met with other advanced biofuels.

Mandatory quota for biofuels and advanced biofuels

	Percentage of biofuels	Percentage of Advanced biomethane	Percentage of Other advanced biofuels
2015	5%		
2016	5.5%		
2017	6.5%		
2018	7%	0.45%	0.15%
2019	8%	0.60%	0.20%
2020	9%	0.68%	0.23%
2021	9%	1.13%	0.38%
2022	9%	1.39%	0.46%

Source: "Italy – 2018 Update, Bioenergy Policies and Status of Implementation", IEA Bioenergy, *IEA, September 2018, available at: www.ieabioenergy.com.*

The definition of advanced biomethane refers to the use of certain feedstocks listed in Annex 3 of Ministerial Decree of 10 October 2014, such as waste, by-products and integration crops, crops that do not cause an Indirect Land Use Change (ILUC) for their production. This ensures consistency with current legislation on incentives for the electricity and biofuel production and with harmonized sustainable criteria of the new EU renewable energy directive (RED II). Overall, the Decree puts strong emphasis on the sustainability of biofuels. Biomethane and all biofuels are valid only if they comply with sustainable certification defined by decree in 2012 and by subsequent amendments concerning the certification of sustainability.

As a basic rule, one CIC is assigned every 10 Gigacalories (Gcal) of conventional biofuels/biomethane produced and released for consumption; the CIC is assigned every 5 GCal (double counting) in the case of advanced biomethane.

In order to have access to the measures provided by the Decree, the producers must first qualify with the GSE according to a specific procedure defined in June 2018. Once an installation has entered into service and has been certified by GSE, the CIC allocation period is not subject to time limits and is available until the blending obligation for biofuels is operational.

Advanced biomethane

The introduction of specific measures dedicated to advanced biomethane is among the main innovations contained in the 2018 Biomethane Decree. The Decree includes a specific favourable tariff for advanced biomethane. For the first ten years of operation of the plant, producers can decide to sell the biomethane produced to GSE, obtaining the gas market price (MPGAS, Spot Market for Gas, equal to the monthly weighted average price for natural gas on the market, for instance EUR 19.44/MWh in February 2019), minus 5%. Producers will also obtain a premium corresponding to the value of the CICs, set at EUR 375 for every 5 GCal of advanced biomethane (≈ EUR 61/MWh). The producers can alternatively decide to trade directly their biomethane without the intervention of GSE, obtaining only the premium of EUR 375/CIC. Following this ten-year period, producers have access to the ordinary method of valuing CICs for the remaining period of the law, namely through the private sale to the obliged parties. In order to help the CIC trade market, GME (*Gestore dei Mercati Energetici*, the Energy Market Operator) must set up an organized exchange platform. Currently, operators can exchange CICs through a dedicated platform created by GSE (BIOCAR).

Incentives for biomethane and advanced biométhane

Type	Incentive	Sales revenues	Duration
Biomethane	CIC + Premium for raw materials	Biomethane on the market	Plant life
Advanced biomethane	EUR 375 / CIC + Premium for relevant plants	Withdrawal of biomethane GSE, or Biomethane on the market	Maximum 10 years (after 10 years, normal CIC regime)

Additional subsidies for infrastructure developments

To support the development of biomethane-related infrastructures, the 2018 Biomethane Decree introduces an additional amount of CIC for the construction of new distribution systems for bio-CNG or bio-LNG. More specifically, if the producer sustains a certain share of the infrastructural cost of a new distribution plant (at least 51 % individually or together with other producers), this will result in an increase by 20% in the allocated CIC, up to 70 % of the cost of the distribution system built with a maximum value of EUR 600,000 per CNG filling station or EUR 1,200,000 per LNG filling station.

Existing biogas plants; Co-digestion

The Decree applies to production plants starting operations between 2018 and 2022, and to plants already supported under the 2013 Biomethane Decree, that opt for the provisions of the new Decree. The scheme is also open to existing plants for the production of biogas which is converted, partially or totally, in plants for the production of biomethane between 2018 and 2022. The Decree thus opens the possibility of a progressive shift from electricity production to the biomethane sector (with some specific rules for biogas plants continuing to produce renewable electricity).

A novelty of the 2018 Biomethane Decree is represented by the incentive system for co-digestion: the double counting and the advanced biomethane qualification is also recognized for the production of biomethane deriving from processes that use the materials for obtaining the double counting and advanced biomethane in co-digestion with other products of biological origin, the latter not being higher than 30% by weight. In such cases, the double counting and the advanced biomethane qualification will be recognized only at 70% of the production.

Guarantees of Origin

While only biomethane used in the transportation sector is supported under the scheme, the Decree also provides measures for biomethane injected into the natural gas grid without a specific intended use through the establishment of Guarantees of Origin (GOs). They serve to prove to the consumer the origin and sustainability of renewable gas used. Although the system of GOs concerns only a limited portion of the production of biomethane (the GOs are in fact assigned only to the production of non-incentivized biomethane and only to biomethane produced from certain animal, food, agro, and industrial by-products), its introduction represents an element of considerable importance towards an effective development of the direct use of biomethane in all sectors and not just in transport. The GOs can be used to be offset against an emission quota obligation under the EU-ETS. In this way, the sale of GOs by a biomethane producer to operators of installations covered under the EU-ETS allows the producer to generate extra income. The creation of a biomethane registry will also create the possibility to exchange GOs with foreign countries. The registry will be operated by GSE. It is currently operated by CIB on a voluntary basis.

Connection to gas networks

Resolution 46/15/R/Gas by ARERA (*Autorità di Regolazione per Energia Reti e Ambiente*, the regulatory Authority) of 2015 established directives for connecting biomethane plants to the natural gas networks and requested transmission grid operators to modify their grid codes in order to implement these new directives. In the case of Snam, the Grid Code of Snam Rete Gas was already integrated to allow the injection of biomethane.[44] Furthermore, Snam has added a dedicated section on its website on biomethane connections (Preliminary Contacts Portal) through which it is possible to exchange preparatory considerations for a subsequent formalization of a connection request. For the distribution companies, instead, ARERA did not provide for the updating of the Grid Code but left the distribution network operators free to adopt solutions adapted to their specificities, as long as they were in line with the provisions of the directives.

In 2016 and 2017, the Italian standardization organisation UNI transposed into Italian standards the European standards EN 16723-1 and EN 16723-2 on gas quality specifications for biomethane for injection into the natural gas networks and for biomethane used in vehicle motors.

By Resolution 27/2019/R/Gas of 29 January 2019, ARERA updated the rules governing the connection of biomethane plants to natural gas networks, as previously defined by Resolution 46/2015/R/Gas.[45] The resolution implements the 2018 Biomethane Decree and was made necessary by the disappearance of the standstill condition, thanks to the publication of the CEN EN 16723-1 standard. Specifically, the Resolution has introduced, inter alia, specific provisions regarding the determination

44. See: Snam, "Construction and Management of Delivery and Redelivery Points", available at: www.snam.it.

45. ARERA, "Resolution of 29 January 2019 27/2019/R/gas", available at: www.arera.it.

and certification of the quantity of biomethane eligible to the incentives provided for by the 2018 Biomethane Decree.

Articles 17 of Resolution 27/2019/R/Gas establishes a cost distribution mechanism between the network operator and the biomethane producer with regard to the connection to the gas network. Article 17 determines that the costs for the operator of the biomethane plant requesting a connection consists of the cost for network investment minus the expected network tariff income for the network operator, and minus a 20% discount for the operator of the plant.

The role of biomethane in Italy's energy and climate strategy

Two policy documents published recently shed light on Italy's energy and climate ambitions, and give directions for the biomethane market:

- The 2017 National Energy Strategy (*Strategia Energetica Nazionale*, or SEN) for 2030, adopted in November 2017.[46]
- The Proposal for an Integrated National Plan for Energy and Climate (PNIEC) sent to the European Commission at the beginning of January 2019, as required by the European regulation on the Energy Union Governance.[47]

As far as biomethane is concerned, the documents highlight the role of biomethane in the transport sector. The Italian government pushes for the transition to alternative fuels in the transport sector (electricity, natural gas, biomethane and hydrogen) and the construction of the related infrastructures.

The SEN (published before the adoption of 2018 Biomethane Decree) points to biomethane as the most efficient way to incentivize the sector to meet the renewables target for the transport sector without further burdening electricity and gas consumers. Although there is a clear focus on transport, the injection of biomethane into the gas network may in any case contribute, through the GOs, to the use of biomethane for other purposes, including electricity production.

The PNIEC foresees an increase in the share of renewables in gross final energy consumption from 18.3% in 2017 to 30% in 2030, 2 percentage points lower than the EU target. It is broken down as follows: 55.4% of

46. Ministry of Economic Development (MISE), *National Energy Strategy 2017*, November 2017, available at: www.mise.gov.it.

47.Ministry of Economic Development (MISE), *Proposal for an Integrated National Plan for Energy and Climate* (PNIEC), 31 December 2018, available at: www.mise.gov.it.

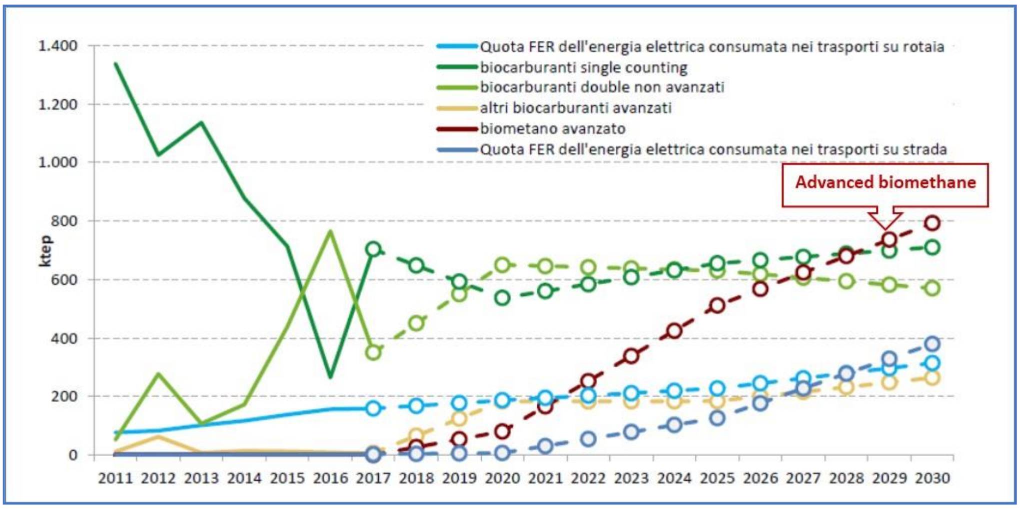
renewables in the electricity sector (34.1% in 2017), 33.1% in the heating and cooling sector (20.1% in 2017) and 21.6% in transport (5.5% in 2017).

The increase in the share of renewable energy in electricity generation mainly comes from solar, wind, and hydro power. Due to the increase in variable renewable sources, there is a growing need for balancing these intermittent sources. Natural gas is expected to play an important role as a back-up source for electricity generation and heating. This will require an expansion of existing gas infrastructure, including LNG import terminals. The contribution of bioenergy in electricity generation decreases from 19.3 TWh in 2017 to 15.7 TWh in 2030. But the Plan foresees a significant reduction in imports of bioliquids, which should be offset by a greater contribution from national bioenergy, in particular from residues and by-products, in compliance with the circular economy principles.

In the heat sector, the increase in the share of renewables mainly comes from a doubling of the contribution of heat pumps (electric, gas). The role of bioenergy is expected to remain stable or slightly decrease, due to the expected greater penetration of higher efficiency technologies, with the possibility of increasing the share of pre-treated fuels such as pellets.

In order to contribute to the challenging overall target of 30% of total gross final consumption met by renewables, the Plan projects a much higher share of renewables in the transport sector than foreseen at EU level (21.6% in 2030 vs. 14% at EU level), with a view to optimizing system costs. The contribution of advanced biofuels is expected to largely exceed the specific target set by the EU, equal to 3.5% to 2030, through the incentive mechanism envisaged for biomethane and other advanced biofuels (with the 2018 Biomethane Decree and subsequent decrees) up to achievement of a target of around 8%. The target for advanced biofuels is to be fulfilled with 75% of advanced biomethane (0.8 Mtoe) and 25% of other advanced biofuels (0.26 Mtoe). For the advanced biomethane coming from agricultural waste and municipal solid waste, the target of at least 1.1 bcm/y to 2030 is confirmed. This gives a stable and long-term framework for the expansion of advanced biomethane in the transport sector.

The role of advanced biomethane in the PNIEC



Source: PNEIC.

With electricity and other alternative fuels (hydrogen), biomethane is expected to be the Italian way for low-carbon transportation. This is particularly the case in heavy duty transport (road and maritime) where LNG and bio-LNG are expected to play a substantial role in the decarbonization of the sector.

Ongoing and expected developments

The 2018 Biomethane Decree and the strong willingness of Italian operators to develop the market give a real boost to the biomethane sector in Italy. The interest in biomethane is confirmed by data on connections to Snam's gas transport grid: at the beginning of 2019, there were almost 900 preliminary gas grid connection requests from potential biomethane producers (compared with 500 in March 2018). These preliminary connection requests correspond to 6 million cubic meters (mcm) per day of transmission capacity (almost 2.2 bcm/y). Snam has already formalized 168 requests (2.8 mcm/d of transmission capacity, or the equivalent of 1 bcm/y) and 23 connections are in progress (0.729 mcm/d of transmission capacity or 266 mcm/y and a production capacity of 170 mcm/y).

Biomethane connections to Snam grid (Beginning of 2019)

Source: Snam.[48]

At the beginning of 2019, six biomethane production facilities were operational, of which three were connected to Snam's grid. Six additional plants were expected to start production soon (at the time of writing, two have started). Their combined biomethane production capacity totaled 72 million cubic meters per year (mcm/y). The main feedstock is OFMSW, followed by agricultural biomass, and agri-food production waste.

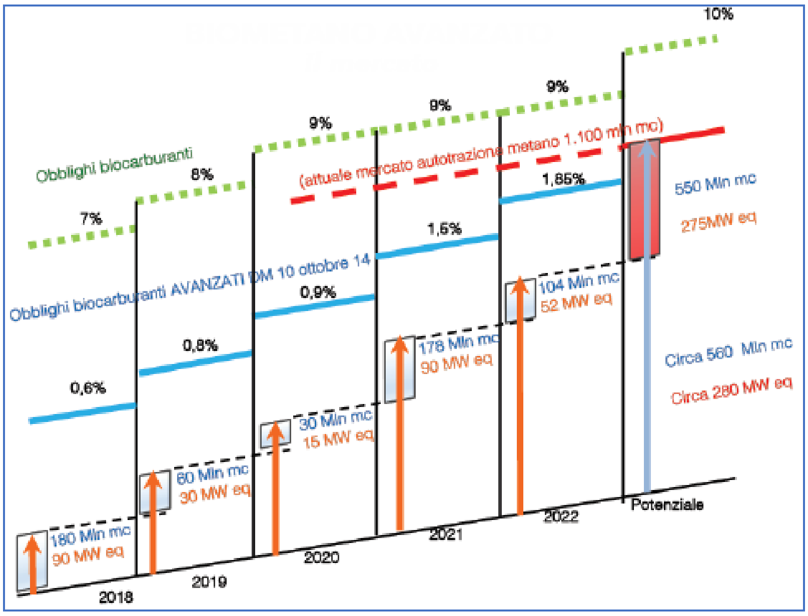
OFMSW offers significant opportunities to expand biomethane production rapidly in Italy, in the context of the adoption of the new EU Circular Economy Package in July 2018. The Montello Spa plant in Bergamo is the first example of biomethane production exclusively from the treatment of OFMSW. It is also the first plant where biomethane is injected into Snam's transmission network. The plant has been in operation since June 2017 and is able to produce about 32 mcm/y. In addition, the plant is also the first carbon negative plant in Italy: it also recovers CO_2 from the biogas generated to produce 38,000 tons a year of liquid CO_2 for industrial use. Biomethane is involving the whole country, as evidenced by the first biomethane plant commissioned in September 2018

48. Snam, Gas quality situation in Italy - gas (natural gas and biomethane) quality specifications, laws and how it is controlled, Workshop on conformity assessment of biomethane, Delft, 22 January 2019, available at: http://empir.npl.co.uk.

in the south of the country in Rende, Calabria (built by French Prodeval biogas upgrading supplier). The Rende facility was the first plant inaugurated after the adoption of the 2018 Biomethane Decree. Also based on OFMSW, the plant connected to Snam's network is able to produce 4.5 mcm/y of biomethane from 40,000 tons of organic waste. Still in September 2018, the first biomethane fueling station based on OFMSW was inaugurated in Vittorio Veneto. The biomethane is derived from biogas produced at the SESA plant in Este (Padua), and is used to power the fleet of the municipal waste collection company Savno, active in 44 municipalities in the province of Treviso. In October 2018, HERAmbiente opened a biomethane plant in Sant Agata. The facility, located near the City of Bologna, will produce 7.5 mcm/y of biomethane for the Italian gas network. The biogas plant can treat 135,000 tonnes of food waste per year. In January 2019, environmental service provider AIMAG opened a biomethane plant in Modena. The plant, able to produce 3 mcm/y, injects biomethane into the local gas grid of AS RETIGAS.

In the next few years, biomethane production is going to expand exponentially. By 2022, about 2 bcm/y of gas is expected to be consumed in the transport sector, of which 25% (0.5 bcm) is expected to come from bio-CNG and bio-LNG.[49] By 2030, according to the SEN, about 5 bcm/y of natural gas is expected to be consumed in the transport sector, and at least 1.1 bcm/y of advanced biomethane.

Potential of advanced biomethane production – 2018-2022



Source: CIB.

49. Snam, "Snam Investor Day: New Businesses in the Green Mobility Space", 7 November 2018, available at: www.snam.it.

While the transport sector serves as a lever for the initial development of biomethane, applications other than transport are also expected to develop in view of the huge biomethane potential in Italy and the flexibility of use of biomethane. In particular, the programmability and storability of biomethane injected into the grid could help to balance and integrate wind and solar, and its versality could contribute to the greening of gas demand in all energy sectors and in industrial processes. No targets for biomethane in other sectors are given in the SEN or the PNIEC. The GOs are so far the only tool that the documents mention to support the use of biomethane in non-transport sectors. At this stage, this suggests that either the support scheme will be updated when the target for biomethane in the transportation sector is reached (as stated in the preamble of the 2018 Biomethane Decree) or that the GOs will be sufficient to incentivize biomethane production for its use in other sectors. In which case, companies covered by the EU ETS would buy GOs to meet their GHG emission reductions. This would require a higher CO_2 price (expected after 2020 with more stringent conditions in the EU ETS), combined with biomethane production cost reductions.

A huge potential with a unique model: BiogasDoneRight

Italy has a substantial biogas potential, in particular in the agriculture sector. According to CIB estimates, Italy would be able to reach a production of 10 bcm/y of renewable gas by 2030, of which at least 8 bcm from the agricultural sector, 0.8 bcm from OFMSW and 1.2 bcm from gasification and power-to-gas.[50] This represents about 13% of the current annual demand for natural gas (75 bcm consumed in 2017). By 2050, the total estimated biogas resource is expected to increase to 18.5 bcm/y (natural gas equivalent) with 75% of this resource coming from the co-digestion of biomass.[51] Including gasification and power-to-gas, the total renewable gas potential in 2050 is estimated to be 30-35 bcm/y.

The biomethane potential from agriculture (18.5 bcm) corresponds to more than three times the current domestic natural gas production. This potential is significant for Italy, a country which is dependent on external supplies for 78% of its energy consumption and a country with a utilised agricultural area (UAA)/inhabitant ratio among the lowest in the world. It

50. QualEnergia.it, "Il modello italiano biogas-biometano: esportabile, ma ancora va spinto da noi", 15 February 2018, available at: www.qualenergia.it.

51. IEA, "Green Gas – Facilitating a Future Green Gas Grid through the Production of Renewable Gas", *IEA Bioenergy*, April 2018, available at: www.ieabioenergy.com; L. Maggioni, *Italian Biomethane Roadmap*, Green Gas Grid, CIB, October 2014, available at: www.greengasgrids.eu.

represents a valuable contribution for the reduction of fossil fuel imports. Moreover, it could contribute significantly to greening the existing and well-developed gas grid. It also constitutes a strategic development for the Italian agriculture sector.

To mobilize high amount of biomass and reduce costs, the CIB with Italian farmers have developed a unique model for producing sustainable biogas/biomethane from agriculture, BiogasDoneRight (BDR).[52] BDR is a sustainable and proven model for the production of food, fodder and renewable energy at the same time that allows the decarbonization of the agricultural sector. The BDR model is based on innovative agricultural technologies integrating biogas/biomethane production, sequential cropping and precision farming, to ensure a carbon negative agriculture, capable of emitting less GHG, while capturing and sequestering carbon (bioenergy with carbon capture and storage, BECCS) and generating positive environmental externalities, such as increased carbon content of soils, increased soil fertility and lower input of chemical fertilizers, thanks to the efficient use of digestate (bio-fertilizer). With the BDR model, agriculture becomes a circular economic model with a strategic role in the fight against climate change. The model also increases economic and environmental resilience of agriculture. The BDR model has been demonstrated by Italian farmers in the Po Valley and recent works with international partners have shown that the concept is scalable and exportable.[53] For example, Argentina could completely replace its imports of natural gas with biogas produced according to the BDR model. The BDR model is tested in France. The concept is aligned with the French initiative "4pour1000", launched at COP21, which emphasizes the role of agriculture in the fight against climate change: an annual growth rate of carbon into the agricultural soil of 4‰ would stop the CO_2 human emission in the atmosphere.

Cost reduction potential

Biofuels in general have higher costs than competing conventional fuels. Currently, this is also true for biomethane produced from monocrops in Italy, which has a production cost of EUR 80-100/MWh (2017 data).[54] But biomethane is still in its infancy, and there is a substantial potential for cost reduction. A study published by Italian biogas experts in 2017 has

52. "Biogasdoneright®", CIB, May 2017, available at: www.consorziobiogas.it.
53. See: "Presentations" at Biogas Italy, 2018 Edition, Rome, 14-15 February 2018, available at: www.biogasitaly.com.
54. S. Bozzetto, *et al.*, "The Development of Biomethane: A Sustainable Choice for the Economy and the Environment", CIB, February 2017, available at: www.consorziobiogas.it.

examined the potential for cost reductions and in particular the trajectory and the actions needed to reduce feedstock costs as well as biogas and biomethane production costs.[55] The study is based on the development of biogas refineries using the BDR model of production. A biogas refinery is a flexible plant connected to both the gas network and the electricity grid, capable of producing biomethane, electricity, heat and bio-fertilizers.

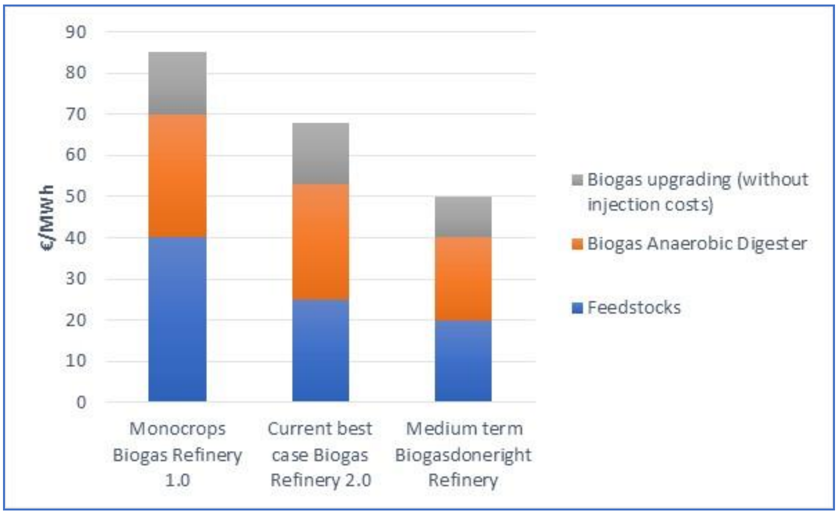
To produce large biomethane quantities with low production costs, there is a need to shift from monocrops as feedstocks to the biomass of the BDR model. Feedstock cost reductions are allowed by the increase in crop yield, sequential cropping and the use of the digestate.

Reductions in biogas production costs can be obtained through an increase of the biogas plant unit size from the current 300-500 Nm³/h to 700-1,000 Nm³/h to achieve economies of scale of industrial fixed costs. Economies of scale can be realized also by connecting several biogas plants to a joint biogas upgrading facility, shared by more farmers, where biomethane is injected into the grid.

Reductions in biogas upgrading costs are also foreseen through reduction of the electricity costs via self-produced electricity in cogeneration, reduction of the investment unit cost and reduction of the CO_2 concentration in the biogas (for instance through CO_2 hydrogenation).

Currently the best cases of Italian biogas from agriculture have a production cost of EUR 60-80/MWh. Cost reduction measures are expected to reduce the costs to EUR 50/MWh by 2030. This does not include connection and injection costs.

Potential cost reductions with BiogasDoneRight



Source: S. Bozzetto et al.

55. *Ibid*.

Barriers to overcome

The regulatory framework for biomethane has been a long process in Italy. Efforts started in 2011, with the publication of the Legislative Decree 28/2011 but the biomethane supply chain in Italy had to wait for legal clarifications before taking off.

A regulatory process still under development

The 2018 Biomethane Decree introduces an explicit incentive but the regulatory process is still in its finishing stage with some key pieces of legislation only adopted recently (e.g. new standards and updated rules for connection to gas networks; incentives for small biogas plants up to 300 kW) and some still under development stage (GSE biomethane registry, GME platform for CICs). The delays in the legislation have opened to controversial interpretations, to bureaucratic-administrative procedures of authorization different from region to region and produced scarce knowledge of the subject by many administrations, thus in turn delaying the development of biomethane in Italy. Different interpretations of the law, especially related to agricultural feedstocks (for which the legislation is extremely complex, especially for double crop) or for the use of digestate (also a very complex legislation with limits depending on various cases) have delayed the conversion of biogas plants in the agriculture sector to biomethane.

Social resistance: NYMBY issues

Despite the huge biogas potential in Italy, non-technical barriers that impede a more widespread diffusion are still present. According to the EU-funded project ISAAC (Increasing Social Awarness and ACceptance of biogas and biomethane), biogas potential has not been fully developed due to the fragmented landscape amongst main industries, stakeholders and biomass producers coupled with the lack of social awareness of the economic and environmental benefits of biogas.[56] The NIMBY syndrome (Not in My Back Yard) is the most difficult barrier to overcome in Italy. Despite the positive effect on local areas due to reduction of pollution and emission of CO_2, the social acceptability of biogas plants is controversial as local communities are afraid of potential local negative externalities including smell, heavy traffic and congestion, noise, badly managed fertilizer, damage to health and visual disamenities. The ISSAC project, which run from 2015 to 2018, was therefore established to remove non-

56. "ISAAC –Increasing Social Awareness and Acceptance of Biogas and Biomethane", National Research Council of Italy, available at: www.iia.cnr.it.

technical barriers that hinder biogas/biomethane market penetration in Italy and make plants implementation easier within the national context.

Social resistance to biogas/biomethane plants is not specific to the biogas sector. Italy is well known for social resistance to infrastructure projects. However, acceptability issues are particularly strong for energy and waste projects. According to the Nimby Forum Observatory, in 2017, there were 317 protest activities against public works or against new plant projects (against 359 in 2016). Energy is the most contested sector (57.4%), followed by waste (35.9%). Among the disputed energy plants, 73.3% are renewable energy sources (biomass, biogas for composting, geothermal, and wind).

To overcome these challenges, the ISAAC project has worked in two directions: increasing social acceptance and reducing fragmentation. ISAAC has developed a model of participatory process to overcome doubts and suspicions about biogas/biomethane plants, informing citizens and entities involved through training meetings and sharing moments in which the parties can make proposals to improve projects in an attempt to prevent or reduce conflicts. ISAAC has also placed a strong focus on boosting collaboration between farmers, foresters and other stakeholders. This enabled them to optimise plant size and technical characteristics to reduce costs (both realisation and maintenance ones), transport and space requirements for a biomethane plant.

Thanks to the ISAAC project, participation processes have been developed and better understanding of the benefits of the biomethane chain has been achieved in the territories involved in the construction of biogas plants and biomethane, in particular in Sardinia and Puglia, the two pilot regions of the project, which also involved Marche, Lazio, Campania, Calabria and Sicily.

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