IEA Bioenergy Task 37

A perspective on the state of the biogas industry from selected member countries

This publication contains a compilation of summaries of country reports from member countries of IEA Bioenergy Task 37 (Energy from Biogas). Each country report summary includes information on the number of biogas plants in operation, biogas production data, how the biogas is utilised, the number of biogas upgrading plants, the number of vehicles using biomethane as fuel, the number of biomethane filling stations, details of financial support schemes in each country and some information on national biogas projects and production facilities. The publication is a regular update and is valid for information collected in 2020-2021. Reference year for production and utilisation is 2020, unless stated otherwise.

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IEA Bioenergy Task 37 – A perspective on the state of the biogas industry from selected member countries

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Front Cover Photo: Chicken manure biogas plant in Dafeng City, Jiangsu Province

The biogas plant in Dafeng utilises chicken manure with high sand content as feedstock; the facility uses a three-stage de-sanding technology to achieve a sand removal rate of more than 85%. The plant includes for 4 continuously stirred tank reactors with a total volume of 3,500 m^3; it employs a fermentation temperature of 35 °C and 28 days retention time. It treats 200,000 tonnes of chicken manure and produces 7 million m^3 of biogas per year. The biogas is upgraded to biomethane, with an annual output of about 4 million m^3, which is integrated into the Hong Kong and China gas pipeline network. The annual production of 150,000 tonnes of digestate is used as biofertiliser in nearby rice and wheat fields.

IEA BIOENERGY Task 37 – Energy from Biogas

IEA Bioenergy aims to accelerate the use of environmentally sustainable and cost competitive bioenergy that will contribute to future low-carbon energy demands. This report is the result of work carried out by IEA Bioenergy Task 37: Energy from Biogas.

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1 Introduction

The International Energy Agency acts as energy policy advisor to 28 member countries plus the European Commission, in their effort to ensure reliable, affordable, and clean energy for their citizens. Founded during the oil crisis of 1973-74, the IEA's initial role was to co-ordinate measures in times of oil supply emergencies. As energy markets have changed, so has the IEA. The IEA now has four main areas of focus: energy security, economic development, environmental awareness and engagement worldwide.

Activities within IEA are set up under the Technology Collaboration Programmes, formerly Implementing Agreements. These are independent bodies operating in a framework provided by the IEA. There are 42 currently active Technology Collaboration Programmes (Implementing Agreements), one of which is IEA Bioenergy. IEA Bioenergy is an organisation set up in 1978 by the International Energy Agency (IEA) with the aim of improving cooperation and information exchange between countries that have national programmes in bioenergy research, development and deployment. IEA Bioenergy's vision is to achieve a substantial bioenergy contribution to future global energy demands by accelerating the production and use of environmentally sound, socially accepted and cost-competitive bioenergy on a sustainable basis, thus providing increased security of supply whilst reducing greenhouse gas emissions from energy use. The work of IEA Bioenergy is structured in a number of Tasks, which have well defined objectives, budgets, and time frames.

IEA Bioenergy Task 37 addresses the challenges related to the economic and environmental sustainability of biogas production, by anaerobic digestion, and utilisation. While there are thousands of biogas plants in OECD countries, operation in the vast majority of cases can only be sustained with the help of subsidies to be able to compete with the fossil energy industrial sector. There is a clear need to enhance many of the process steps in the biogas production chain to reduce both investment and operating costs. Publications from Task 37 provide important information intended to be used to improve both economic and environmental performance of the biogas value chain where the end product can be heat, electricity or vehicle fuel, or combinations of these products. The other product from a biogas plant, the digestate, is a very important contributor to the overall sustainability of the biogas value chain and is also addressed in various Task 37 publications.

The Task 37 working group meets at least twice each year to discuss the progress of the work programme. At these meetings, the national representatives also present the latest information within the field of biogas from their respective countries. These presentations are available for free download at the homepage of Task 37[1]. This current publication is collated from the presentations made at meetings and from additional background details provided by the national representatives. It is hoped that this publication will ease the dissemination of national biogas information to third parties.

The way information is gathered, recorded and reported varies from one member country to another and as a consequence direct comparison of country data is not always straight forward. Direct comparison is hampered by countries using different units to compile the available biogas statistics. The largest difference is how the biogas production is expressed. The following three methods exist: i) the energy content in the produced biogas from different plant types independent of losses and the utilisation; ii) the energy content in the produced and utilised energy (such as electricity, heat and vehicle gas); iii) installed capacity for energy production. While every attempt has been made to harmonise data in this publication, the different ways original data have been collected for national databases has made harmonisation and subsequent comparison difficult or even impossible in some cases. Of further issue is the availability of complete data,

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[1] http://task37.ieabioenergy.com/country-reports.html

which due to commercial sensitivities is not always available. This as such is a best attempt by country delegates to provide a perspective on the state of the biogas industry from their countries.

Biogas production is presented for the following plant types:

- Wastewater treatment plants (WWTP);
- Bio-waste – co-digestion or mono-digestion of food waste and other types of bio-waste;
- Agricultural – digestion at farms (mainly manure, energy crops and other crops/agricultural waste);
- Industrial – digestion of waste streams from various industries (e.g. food industries);
- Landfill – landfills with collection of the landfill gas.

2 Summary and Conclusions

China has the highest number of biogas plants among the IEA Bioenergy Task 37-member countries, with more than 100,000 biogas plants, followed by Germany with over 10,000 plants. In addition to the 100,000 biogas plants, China also has a large number of household biogas units. None of the other member countries have more than 700 biogas plants (Figure 2.1). Austria has not reported their biogas production per feedstock, but presented a total number of biogas plants.

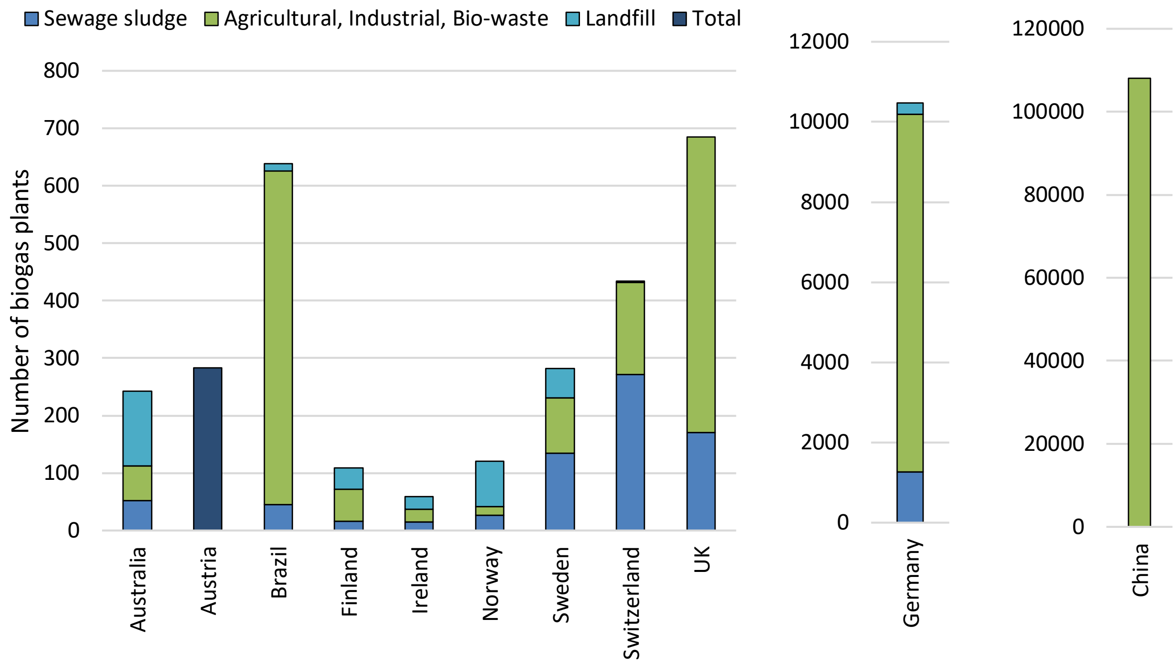

Figure 2.1. Number of biogas plants in operation in selected IEA Bioenergy Task 37 member countries

China also has the highest annual biogas production, around 72,000 TWh (Figure 2.2). Germany produces around 120 TWh per year, UK 26 TWh[2] and Brazil 12 TWh. The other member countries produce less than 3 TWh. In countries like Australia and UK, landfills are the largest source for biogas production, while they are only a minor contributor in countries like Germany and Switzerland, indicating the low level of landfilling of organic waste material. The actual biogas production is not reported in all countries; thus in some cases in this report it has been calculated, based mostly on the heat and electricity production with an assumed efficiency of 35%. In other cases, it has not been possible to get a good estimate of the indigenous biogas production.

In most of the member countries, biogas is mainly used for heat and electricity generation. Sweden stands out, with more than half of the produced biogas being used as vehicle fuel. Germany is second in absolute numbers in terms of biogas as a transport fuel.

[2] Only biogas for electricity generation, excluding landfills and biomethane plants (estimation production potential 2.5 TWh end 2016) and renewable heat (RHI, negligible amounts)

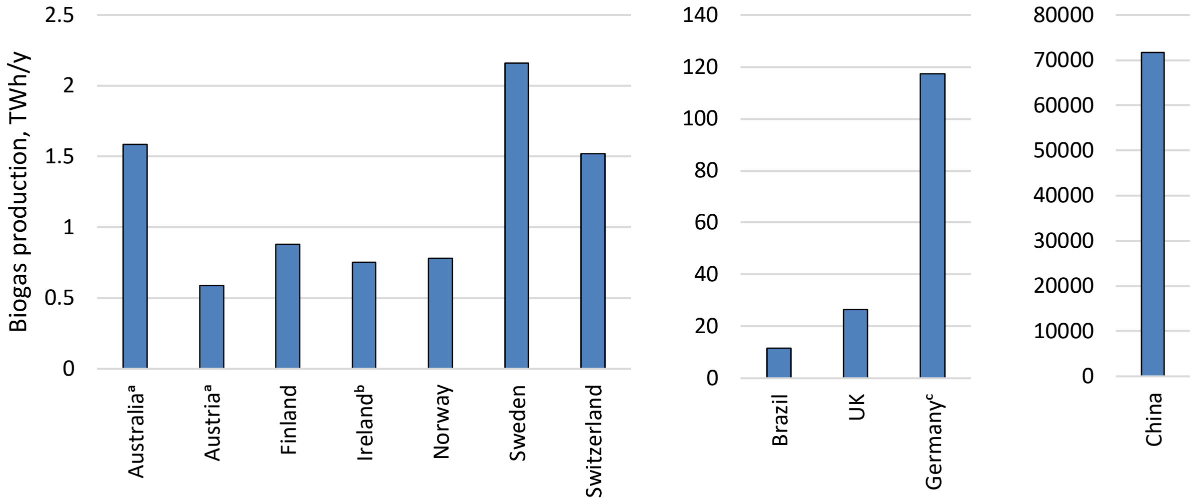

Figure 2.2. Annual biogas production in selected IEA Bioenergy Task 37-member countries

[a] *Calculated from installed capacity*
[b] *Calculated from 80% of installed capacity for electricity production, assuming 35% efficiency*
[c] *Calculated assuming 35% efficiency in electricity production*

Germany and Sweden have had the largest markets for biomethane in recent years, but a growing interest is seen in other countries as well. UK has now taken over the second position from Sweden, using more and more biomethane for heat and electricity production, but also as vehicle fuel.

Financial support systems are very different from country to country. Various systems with feed-in tariffs, investment grants and tax exemptions exist. A clear correlation between the financial support system and the way biogas is utilised is evident in the Task 37 member countries. In countries like the UK, Germany and Austria, feed-in tariffs for electricity have led to most of the biogas being used to produce electricity, while the system with tax exemption in Sweden favours utilisation of the biogas (biomethane) as a vehicle fuel. In several countries, financial support systems have led to an increased share of biogas in the gas grids.

Lastly, there are many exciting innovative biogas projects going on in the member countries, including dry digestion, CO_2 utilisation and cross-sectoral synergies.

3 Australia

The Australian biogas industry remains emerging. In 2018-2019, electricity generation from biogas was about 4,444 GWh, or 1.7% of the national electricity generation (Australian Energy Statistics, 2020). Australia's biogas potential has been estimated as 103 TWh (371 PJ), which is equivalent to almost 8.5% of Australia's total energy consumption of 4,390 PJ in 2018-2019 (Australian Energy Statistics, 2020). Considering the current average size of biogas units in Australia, this could represent up to 90,000 biogas units.

3.1 Production of biogas

The total number of AD plants is estimated at around 247 (sourced from the survey for Australian biogas (Australian Energy Statistics, 2020)). The majority are associated with municipal wastewater treatment plants (WWTP) and landfill gas power units. WWTP use various technologies for the mono-digestion of sewage sludge. The majority of agricultural AD plants use waste manure from piggeries (20 systems) with the remainder using manure slurry from dairies and poultry. Feedlot manure is not used for the production of biogas but stockpiled and used as a fertiliser on agricultural land. More than half (approximately 20) of the industrial AD plants use wastewater from red meat processing and rendering plants as feedstock for biogas production. Although a number of different technologies are used, covered anaerobic lagoons (CAL) are widely employed in AD plants treating agricultural and industrial waste.

There has been recent interest in the feasibility of using co-digestion (e.g., using trucked organic waste, other waste streams and glycerol) at WWTP, intensive agriculture industries and red meat processing plants. Australia does not use energy crops for the production of biogas.

Table 3.1. Status of biogas production in Australia (data from 2021)

Plant type	Number of plants, estimated	Number of plants, from survey	Potential production (GWh/year)[a]
WWTP	52	22	381
Bio-waste	5	3	63
Agricultural	22	10	24
Industrial	38	14	44
Landfill	130[b]	73	1,075
Total	**247**	**122**	**1,587**

[a] Calculated from the installed capacity of the survey respondents.

[b] From 2006 Sustainable Power Plant Register, Australian Business Council for Sustainable Energy

Opportunities exist for the urban waste industry, driven by a combination of rising landfill gate fees and falling technology costs, and the intensive livestock and food processing industries, driven by readily available feedstock from process waste, higher electricity process and demand for onsite electricity, heat or steam.

3.2 Utilisation of biogas

The main use for biogas in Australia is for electricity production, heat and combined heat and power. Excess biogas is flared at WWTPs, agricultural industries and industrial food processing. This is due in part to uncertainty in the quantity of biogas produced and associated sizing of generators.

Table 3.2 below shows how biogas is utilised across each of the categories for the 46 survey respondents. There are insufficient data at present to obtain a reliable %-value for how the biogas is utilised and the associated quantity in terms of GWh.

Table 3.2. Utilisation of biogas in Australia (data from survey in 2017 – 122 respondents)

Plant type	Electricity (%)	Heat (%)	CHP (%)	Flare (%)	Other
WWTP	33.3	26.2	21.4	19.0	
Bio-waste	40.0		20.0	20	20
Agricultural	8.3		50	41.7	
Industrial	15	30	5	50	
Landfill	53.7			46.3	

Australia's first biomethane project, Malabar Biomethane Project, was commissioned in late 2020 (see section 3.4).

3.3 Policy and financial support systems

Despite the many benefits, the biogas industry in Australia still faces a number of challenges that are slowing down the development of biogas projects. These challenges include:

- Financial viability of projects: although some financial incentives are available to improve projects' viability, the high level of investment required as well as the complexity of securing revenue sources for a project can be a barrier to overcome for project proponents. Nonetheless, some projects do stack-up financially. Based on feedback from project developers, projects for on-site consumption (behind-the-meter) usually demonstrate better financial viability.
- The need for more favourable policy conditions: although some support mechanisms are already available for the biogas sector, gaps still exist. Therefore, more favourable policy conditions could increase the uptake of project development. This could contribute to the growth of a mature and sustainable biogas industry in Australia.
- The complexity of project development and operation: project proponents regularly face several obstacles in developing and operating biogas plants, including:
    - Securing feedstock and revenue sources
    - Going through various approval processes
    - Inconsistent state by state digestate regulations
    - Accessing private funding
- Lack of widespread industry experience, given the infancy of the biogas industry in Australia.

The 2019 Biogas Opportunities for Australia report by ENEA Consulting and Bioenergy Australia, with the support from Australian Renewable Agency (ARENA), Clean Energy Finance Corporation (CEFC), Energy Networks Australia (ENA) and the International Energy Agency (IEA) Bioenergy, provided a number of recommendations for Australian Governments and industry stakeholders to consider, aiming to advance Australia's biogas sector (Carlu et al., 2019). These include:

1. Setting renewable gas target(s);
2. Launching industry stakeholder consultation for policy design;
3. Introducing waste management strategies to support feedstock quality and quantity;
4. Encouraging plant operators, especially landfill operators, to maximise biogas use.

3.4 Innovative biogas projects

Malabar Biomethane Project at the Sydney Water Malabar Wastewater Treatment Plant, Sydney, NSW, Australia

The Malabar Biomethane Project was commissioned in November 2020 and is currently in the design phased with construction planned to commence in late 2021 and the completion of commissioning in the first half of 2022. This will be the first biomethane project in Australia.

The project is a partnership between:

- **Jemena** – an Australian energy company that owns major utility infrastructure including the NSW gas network. Jemena are constructing and operating the biomethane facility and network connection.
- **Sydney Water -** is a New South Wales Government–owned corporation that provides potable drinking water, wastewater and some storm water services in NSW. Sydney Water are providing the biogas for upgrading and are collaborating on the project optimisation.
- **Australian Renewable Energy Agency (ARENA) -** supports renewable energy projects to improve the competitiveness of technologies and have provided funding and support.

Plant capacity: The Malabar wastewater treatment plant is the largest primary wastewater treatment plant in Australia and currently produces biogas for electricity and flaring (see figures 3.1 & 3.2). The biomethane facility will process over 95 TJ/year of biogas that is at present, mostly flared, with the capacity to process over 200 TJ/year.

Technology: Eneraque will provide a Bright Biomethane membrane upgrader and a 1,100m^3 biogas dome will balance variations in the supply of biogas and optimise the operation.

Capital investment: A$14 million.

Government support and funding:

- The project has received 5.9 million AUD grant funding from ARENA.
- The project will be the first project to receive Renewable Gas Certificates (RGCs) as part of an initial two-year pilot scheme run by GreenPower. GreenPower is a NSW government run program that led the development of renewable electricity in Australia. (GreenPower, 2021)

Revenues: The facility will generate revenues from the sale of wholesale gas and RGCs that will be sold to customers on the Jemena Gas Network.

Learnings and Innovation: The innovation of this project lies in its integration and optimisation in the Australian context and less so on the technology as it is well established overseas. The limited support for biomethane injection in Australia requires innovation in processes, application of technology, stacking of value streams and co-ordination for scale to drive down the cost of injection to a customer's willingness to pay to develop a self-sustaining market. Currently, this project is driving a range of research and development in biomethane processing, management and storage.

GHG savings: The plant is estimated to contribute to approximately 5,000 tonnes CO_2-eq emission savings. However, the main benefit in GHG savings is that it will provide the first commercial scale solution for customers with hard to decarbonise gas demand to decarbonise through the gas network.

Figure 3.1. Anaerobic digester Sydney Water Malabar Wastewater Treatment Plant

Figure 3.2. Flares on the Sydney Water Malabar Wastewater Treatment Plant that currently flare biogas

4 Austria

In general, biogas production is more or less stable in Austria. Electricity supply from biogas declines by 1% each year according to the Ökostrombericht 2020 (renewable electricity report 2020) (E-control, 2020).

Recent times have been quite active with regard to legal developments for biogas in Austria. In 2018 an amendment of the Ökostromgesetz 2012 (law on renewable electricity) came into force which has the same influence on biogas plants (Austrian Parliament, 2017). The most important points are:

- Biogas plants which drop out of the feed-in tariff in the years 2020 and 2021 can apply for a prolongation until end of 2022;
- The overall fuel efficiency has to reach at least 67.5%;
- Grains (e.g. maize) in the feedstock mix must not exceed 30%;
- The feed-in tariff depends on the year of application;
- Limitation of plants up to 150 kW_{el} (which is the current limit for newly erected plants).

The next real big step with regard to renewable energy is the Erneuerbare Energien Ausbaugesetz (renewable energy expansion law) which is currently under review and expected to come into force in 2021. One of its strategic aims is to achieve 100% renewable electricity by 2030. However, there has been some criticism as the support of renewable (green) gas has been largely neglected.

4.1 Production of biogas

In total 394 approved biogas plants exist in Austria, but only 283 plants had a contract with OeMAG in 2019, the joint venture for the Austrian electricity grid (Table 4.1). In Austria, the discussion about the efficiency has led to the classification of the biogas plants by average full load hours (Table 4.2); 72 biogas plants produced electricity for more than 8,483 h per year.

Table 4.1. Status of biogas production in Austria, contract with OeMAG (E-control, 2020)

Number of plants with electricity generation	Energy production (GWh/year)[a]
283	**561.41**

[a] Produced energy as electricity excluding efficiency losses.

Table 4.2. Average full load hours of electricity-producing biogas plants (E-control, 2020)

Average full load hours biogas in 2019		
Classification	**Full load hours**	**Number of plants**
Best third	8,483	72
Middle third	7,712	74
Poor third	3,753	121
All plants	6,126	267

4.2 Utilisation of biogas

In Austria biogas is utilised mainly for electricity and heat production. Even though the aim is to upgrade more biogas to biomethane for use as a vehicle fuel, this change is taking place rather slowly. There are around 10,000 natural gas vehicles (NGVs) in Austria. The amount of NGVs in Austria increased from 2017 to 2018 by around 3% or 234 new vehicles. At the moment there are 149 compressed natural gas (CNG) filling stations in Austria. Three of the filling stations are situated at biogas upgrading plants.

There are 15 biogas upgrading plants in Austria. All commercial technologies are represented (amine scrubber, water scrubber, membrane and PSA). Most upgrading plants are rather small, 600 – 800 Nm^3/h, and have a combined capacity around 16.5 million Nm^3 biomethane annually.

4.3 Policy and financial support systems

Support is provided for electricity production via the Green Electricity Feed-in Regulation (Austrian Parliament, 2018). Feed-in tariffs for 2018 are limited to anaerobic digestion plants up to 150 kW. Above this size, no feed-in tariff exists. The tariff depends on the date of application. For biogas from landfills and sewage sludge, a lower tariff is given (Table 4.3).

Table 4.3. Feed-in tariffs for electricity from biogas in Austria (Austrian Parliament, 2018)

Feed-in tariff, EUR/kWh		
	2018	**2019**
Electricity from biogas	0.1914	0.1897
Landfill gas	*0.0470*	*0.0466*
Sewage sludge gas	*0.0565*	*0.0560*
Electricity from biomethane	0.1624	0.1610

To qualify for the feed-in tariff, it is required that a minimum of 30% manure is used as a substrate. Older biogas plants, can apply for an extended period of subsidies (when subsidies are running out) up to a total of 20 years. Furthermore, a supportive measure for existing plants (built before 2009) of up to 0.04 EUR/kWh$_e$ can be granted to assist with procurement of substrate.

For new plants, investment grants of up to 10 million €/year is provided. This budget includes solid and liquid biomass utilisation.

Figure 4.1. Biogas plant in Strem nearby Güssing

4.4 Innovative biogas projects

BioFlock – Utilisation of biological and sustainable flocking agents for digestate treatment

Due to the permitted nutrient loads on agricultural land per hectare per year, biogas plants are increasingly relying on digestate treatment to reduce the volume of digestate to be spread on their fields. As during sewage sludge treatment, the flocculant polyacrylamide is usually used to separate the fine particles of the digestate. Since polyacrylamide is produced synthetically and is not (or hardly) biodegradable, its use, currently especially in Germany, has led to major discussions regarding its impact on humans and the environment. Biogas plant operators strive to produce a high-quality, marketable fertilizer by processing fermentation residues. Therefore, many plant operators want to avoid or minimize the use of polyacrylamide as a flocculant and search for alternatives, like natural flocculants such as starch or chitosan.

Due to the impact on humans and the environment, the present project aims at the substitution of synthetic (polyacrylamide) by natural biodegradable polymers (starch, chitosan) and the general optimization of "flocculation" to reduce polymer consumption.

LOCON

Steel production is one of the most energy intensive production processes and is responsible for 7% of global CO_2 emissions. Therefore, an increase in energy efficiency of the process as well as the reduction of CO_2 emissions have become subjects of extensive research. Generally, most existing CO_2 conversion technologies use purified industrial gases. However, by including energy intensive purification steps, the overall reduction of greenhouse gas emissions from the whole process is limited. The project LOCON focuses on the conversion of untreated steel mill gases to methane through biological processes, namely: the conversion of CO_2/CO with H_2 in exploited gas reservoirs (geomethanation) and the bioelectrochemical conversion to methane. A major benefit of CO_2 conversion inside exploited gas reservoirs is their large and long-term storage capability. The project should result in the quantification of the increased energy efficiency of steel production compared to the state-of-the-art process and the CO_2 savings potential, when the aforementioned technologies are applied.

5 Brazil

In 2016, according to Brazil's national 10-Year Plan for Energy-2026, 46% of the internal energy supply originated from renewable sources, which includes hydro power, firewood and charcoal, by-products of sugar cane and other renewable sources (solar energy, wind power and biomass). According to estimates, this contribution is to increase to 48% of the internal energy supply by the year 2026.

The biogas sector in Brazil has been growing steadily in the last few years. Helping this progress is the 2015 regulation for biomethane, which establishes a standard definition for biomethane produced from biodegradable materials originating from agroforestry and organic waste. The regulation applies to nationwide use of biomethane as a fuel for vehicles, commercial shipping and for residential use. It includes obligations regarding quality control to be met by the various economic agents who trade biomethane throughout Brazil. In addition, in 2017, the National Oil Agency (ANP) resolution No 685 established rules to approve quality and specification of biomethane from landfills and sewage treatment stations for mobility use, as well as for residential, industrial and commercial uses. Recently, the National Policy on Biofuels (RenovaBio) was also approved. The program stimulates biofuel production in Brazil, including biomethane, including for forecasting of environmental, economic and social sustainability, as well as compatibility with market. A bigger contribution of biofuel in the energy matrix will facilitate reduction in carbon emissions in the transportation sector, as per the objective of the agreement signed in Paris, at COP21, whereby Brazil committed to reduce greenhouse gas emissions by up to 43% by 2030.

In 2017, the Energy Expansion Ten Year Plan (Plano Decenal de Expansão de Energia) included, for the first time, a significant amount of biogas as an electric matrix component, indicating that this source can reach about 300 MW in 2026.

5.1 Production of biogas

According to CIBiogás (International Center on Renewable Energies – Biogás), there were 638 plants in operation in Brazil in 2020, with a total biogas production of around 1,800 million Nm^3/year, or 11.7 TWh/year in terms of energy (Table 5.1). A majority of the biogas plants were agricultural (79%), but most of the biogas (73%) was produced in sanitary landfills and WWTPs (which are reported as one category in the statistics).

Table 5.1. Current biogas production in Brazil (CIBiogás, 2021)

Plant type	Number of plants	Production (MNm^3/year)	Production (GWh/year)[a]	Share (%)
WWTP and landfill	57	1,342	8,590	73%
Agricultural	503	203	1,300	11%
Industrial	78	284	1,820	16%
Total	**638**	**1,829**	**11,700**	

[a] *Calculated from the reported or estimated raw biogas production in volume (Nm^3/y) and an assumption of 64% CH_4 content*

Brazil has a very large energy potential in biomass. ABiogás (Associação Brasileira do Biogás e do Biometano – Brazilian Biogas and Biomethane Association) has estimated the potential for biogas production to be 82.58 billion Nm^3/year (ABiogás, 2021), which would suggest that only 2% of the potential is currently exploited.

5.2 Utilisation of biogas

In 2020, 8% of the biogas in Brazil was used to generate thermal energy, and 73% to generate electric energy (Table 5.2). Lately, the use of biogas for electric energy generation is increasing in Brazil due to the regulation changes, and especially due to the new business models, originated from the distributed generation regulations, from 2015, mainly due to the modifications in function of the ANP Resolution No 687/2015, which modified the ANP Resolution No 482/2012.

There are 8 biogas plants in Brazil where all the gas is upgraded to biomethane. In addition, there are 7 plants that upgrade a smaller share of the gas produced (CIBiogás, 2021). The biomethane produced is utilised to generate electricity and vehicle fuel. The biomethane market in the country is still incipient, with some projects in planning or installation, but there is a great prospect of growth. In 6 locations, biogas is used for generating mechanical energy, more specifically for pumping the liquid slurry originating from the pig production facilities for the purpose of crop fertilisation.

Table 5.2. Utilisation of biogas in Brazil (CIBiogás, 2021)

Utilisation type	Number of plants	Utilisation (MNm^3/year)	Utilisation (GWh/y)[a]	Share (%)
Electricity	543	1,328	8,500	73%
Heat	81	149	950	8%
Mechanical	6	8	50	0.4%
Biomethane	8	335	2,140	19%
Total	**165**	**1,819**	**11,640**	

[a] Calculated from the reported or estimated raw biogas production in volume (Nm^3/y) and an assumption of 64% CH_4 content

5.3 Policy and financial support systems

The steady growth of biogas in Brazil results from a series of policies, research and initiatives directly or indirectly connected to this sector. They are described as follows:

Political grounds and Funding Sources

- **The National Policy on Solid Waste** points to the integrated management and the environmentally adequate management of solid wastes and ensures the adoption of initiatives related to biomass in energy production.
- **Sectoral Plan for the Mitigation and Adaptation to Climate Change for the Consolidation of a Low Carbon Emission Economy in Agriculture**: public policy that provides detailed descriptions of procedures for mitigation and similar activities in relation to climate change in the agricultural sector.
- **Normative Resolution n. 687/2015 replacing the Normative Resolution n. 482/2012 by the Brazilian Electricity Regulatory Agency – ANEEL:** establishes the general criteria for the access of micro and mini distributed generation to the systems of electrical energy distribution and the system of electrical energy compensation.
- **Resolution 08/2015 by the National Petroleum Agency - ANP**, which regulates the biomethane originated from organic agrisilvopastoral products and residues directed to vehicle application (CNG) and to residential and commercial facilities.
- **Program ABC - Program for Low Carbon Agriculture (*Programa Agricultura de Baixo Carbono*)**: Provides credit facilities for initiatives within the context of the Low Carbon Agriculture Plan, with resources for the treatment of animal wastes.
- **PRONAF Sustentável**: Credit facility for aspects concerning environmental sustainability for family agriculture with the application of credit resources from the National Program for Family Agriculture - PRONAF (*Programa Nacional para Agricultura Familiar*).
- **Auction A-5 ANEEL on electric energy:** For the first time a large-scale biogas project won an auction on energy generation, Auction A-5 (this means 5 years to start the operation), promoted by

ANEEL. The winner project is called Raízen, and trades 20.8 MW energy with the company Biogas Bonfim, representing BRL 251 per MWh. The substrate used to produce the biogas will be sugar cane industry effluent**.**

- **RenovaBio**: The Ministry of Mines and Energy (MME) launched in February 2017 a public call for an incentive program to expand biofuels in Brazil. In December 2017, the program was sanctioned through Law 13.576/2017, creating the National Policy on Biofuels (RenovaBio). Biomethane is one of the fuels to be fostered by this program
- **Resolution ANP Nº 685, dated 29 June 2017:** Established rules to approve quality and specifications of biomethane from landfills, sewage treatment stations for mobility use, as well as for residential, industrial and commercial uses.

Actions by the private initiative, civil society and Research, Development, and Innovation organisations

- **The Brazilian Association of Biogas and Biomethane** – **Abiogás:** (*Associação Brasileira do Biogás e Biometano*) was founded in 2013. It comprises public and private companies and institutions operating in different segments of the biogas chain. In 2015, ABiogas launched the proposal for a National Program of Biogas and Biomethane.
- **Biogas and Biomethane National Program – PNBB:** In the year 2015, the Brazilian Association for Biogas and Biomethane - ABIOGAS (*AssociaçãoBrasileira de Biogás e Biometano*) submitted the Proposal for a Biogas and Biomethane National Program - PNBB (*Programa Nacional de Biogás e Biometano*) for evaluation. The Plan aims at the creation of an institutional economic, normative and regulatory scenario that promotes the necessary favourable and stable conditions for the advancement of important projects for the sustainability of the Brazilian energy matrix.
- **Public Call 014/2012 - R&D by ANEEL:** Call for research and development projects on the biogas theme: "Strategic Project: Technical and Commercial Arrangements for the Insertion of Electrical Energy Generation with the use of Biogas originated from Residues and Liquid Effluents in the Brazilian Energy Matrix".
- **CIBiogás-ER**, established in 2013, is an institution for research, development and innovation with the objective of transforming biogas knowledge into a product by means of the development of new business undertakings and their effective implementation in the Brazilian energy matrix.
- **Project Brazil-Germany for the Promotion of Biogas Energy Application in Brazil - PROBIOGAS:** The Brazilian Ministry of Cities (*Ministério das Cidades*) has implemented initiatives with the German Government, through GIZ (*Deutsche Gesellschaft für Internationale Zusammenarbeit*), for the application of biogas energy in Brazil. In 2016 this project made a publication on various studies compiling technical results obtained during its execution.
- **IV Biogas Forum:** in October 2017 ABiogás organised an event with more than 300 participants registered to discuss the Brazilian biogas sector development. The event was considered the biggest one specifically on biogas in 2017**.**

5.4 Innovative biogas projects

Stein Ceramics

The model employs a completely mixed digester, a biomass heating system, gas drying and hydrogen sulphide removal by means of biological desulphurisation (Figure 5.1). Approximately 750 m³ of biogas is produced daily, which is converted into electrical energy in a generator set of 112 kVa (estimated at ca. 64 kW_e). The facility has generated an avoided cost of between 4,350 to 7,250 USD per month and paid for itself in a 2-year period. The primary benefits were twofold: the environmental service of manure treatment and the economic benefit of revenues from biogas electricity. The size of this unit is similar to many other farms in the South of Brazil – a region, which produces 50% of the swine meat in the country. A key aspect of biogas project success is that the suppliers of technologies are all from the same region, demonstrating that it is a model of success that has been adapted and deployed throughout a region.

Figure 5.1. Stein Ceramics biogas plant

Termoverde Caieiras

Termoverde Caieiras, controlled by Solví Valorização Energética, is located at the Environmental Treatment and Valorization Center (CTVA), belonging to Essencis, in the municipality of Caieiras (Figure 5.2). It is the largest thermoelectric powered biogas from landfill facilities in Brazil and one of the largest in the world. With initial installed capacity of 29.5 MW, it generates clean energy from the municipal waste deposited in the landfill. The generation of energy from the methane present in the biogas is a sustainable form of valorisation of the gases of the landfill, besides generating credits of carbon. It generates 250 thousand MWh energy per year, capable of serving a city of about 300 thousand inhabitants with sustainable electricity. Termoverde Caieiras was built in an area of 15,000 m² and was authorised by the National Electric Energy Agency (Aneel) to start the operation in July 2016. In addition to being an important energy boost for the region, Termoverde Caieiras's positioning has a strong commitment to social and environmental responsibility. Among the benefits of the thermoelectric plant to the environment are: the preservation of vegetation and local fauna; maintenance of existing topography; the non-generation of odors; and the exemption of pollution risks from water sources and the atmosphere.

Figure 5.2. Termoverde Caieiras biogas power plant

6 China

China had it first biogas project initiated as early as in 1929, when Mr. Luo Guorui from Taiwan opened his biogas business "Guorui Gas Light Company" in Guangdong, exploring the road to energy self-sufficiency and energy saving. Through the mid-1900s, China supported the rapid development of biogas through legislation and industrial policies. After the phases of initial development (1920-1980), technical maturity (1981-2000), and rapid development (2000-2006), the development of biogas in China's agricultural and rural areas entered the phase of construction and management (2007-2014) and transformation and upgrading (2015-) after the official implementation of the Renewable Energy Law in 2006.

6.1 Production of biogas

Since 2006, China's biogas production has developed from scattered one-family biogas digesters in rural areas to large-scale biogas plants. Clean energy production has developed from a single provision of biogas in the past to multiple forms of energy such as biogas power generation and biomethane, accumulating several valuable, replicable, and mature technology models, forming a set of independent intellectual property rights and a more robust standardisation system. The National Development and Reform Commission and the Ministry of Agriculture and Rural Development invested 2 billion CNY per year during 2015-2017 to jointly carry out pilot demonstrations of rural biogas production and upgrading. Since then, many leading industry enterprises have joined the ranks of investment, construction and operation and maintenance of biogas plants, using livestock and poultry manure, straw, tailing vegetables, kitchen waste and other agricultural and rural bio-waste to produce clean biogas energy as well as biofertiliser (digestates). According to the statistics of the 2019 China Agricultural Statistics Yearbook, by the end of 2018, there were 39,076,700 household biogas digesters (Figure 6.1), 108,100 biogas plants (Figure 6.2), and 11.216 billion m^3 of annual biogas production (Table 6.1). The number of enterprises in China's biogas industry reached 1,298, with 12,000 employees and an annual gross output value of 1.846 billion CNY (China Rural Energy Industry Association, 2019).

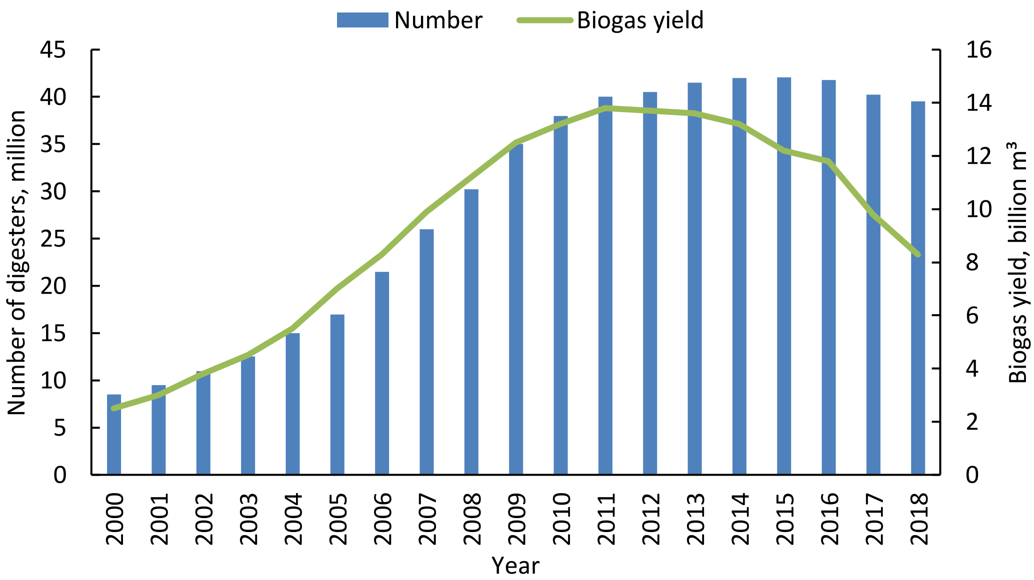

Figure 6.1 Number of household biogas digesters in China and their total biogas yield

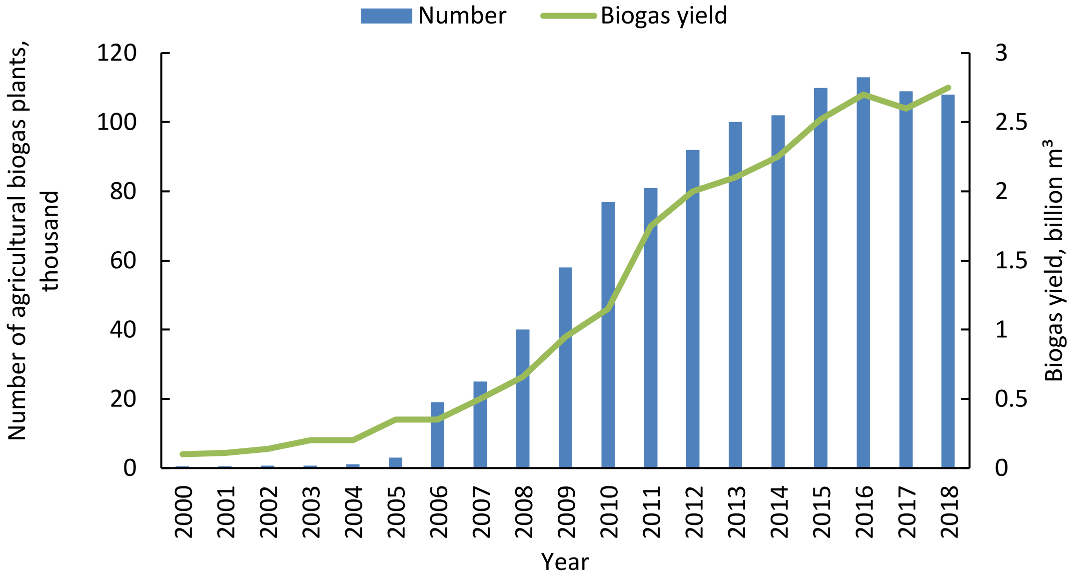

Figure 6.2 Number of agricultural biogas plants in China and their total biogas yield

By the end of 2019, 60 AD plants for food waste have been built or under construction nationwide, with a total treatment capacity of 22,900 t/d; 25 AD plants for municipal sludge have been completed, with a total treatment capacity of 13,467 t/d (80% water content); in addition, the landfill method of generating biogas is one of the main ways to treat municipal waste, with a total of 652 sanitary landfills for domestic waste in 2019. In the Hangzhou Tianziling landfill project, landfill gas (biogas) is collected and used for power generation connected directly to the grid, with a daily recovery of 19,131 m^3 of landfill gas, and a gas calorific value of 19,500 kJ/m^3.

China is now in a new era of comprehensive promotion of rural revitalisation and green agricultural development. The functional positioning of biogas has gradually shifted to five-in-one: biological waste treatment; clean energy production; chemical fertilizer substitution; arable land quality improvement; and greenhouse gas emission mitigation.

6.2 Utilisation of biogas

At present, biogas in China is mainly used for residential gas, and for power generation (including cogeneration). Only a small amount of biogas is upgraded and used as city gas or vehicle gas. The total amount of agricultural and rural bio-waste resources available for biogas production in China is about 1.5 to 1.7 billion tonnes per year (Table 6.1). The digestate is equivalent to 10 million tonnes of chemical fertiliser.

Table 6.1 Availability of biogas substrates, biogas potential, and current production in China

Bio-waste substrates	Resources available (10^8 t)	moisture content (%)	Biogas production potential (m^3/t wet base)	Total biogas production potential (10^8 m^3)	Current potential utilisation (%)	Biogas production (10^8 m^3)
Agriculture						
Manure	17[a]	70-80	60	1020	15	153
Straw	6.7[b]	6-12	200	1340	10	134
Fruit and vegetable waste	2.5[b]	80-90	30	75	10	7.5
Total	**26.2**			**2435**		**294.5**
City						
Municipal sludge	0.5[c]	80	40	20	20	4
Kitchen waste	1.8[d]	75-85	70	126	50	63
Domestic waste (landfill)	1.1[d]	50	120	132	40	53
Total	**3.4**			**278**		**120**

Sources: [a] Calculation based on data of livestock and poultry stocks (China National Bureau of Statistics, 2020a, 2020b, 2020c, 2020d); [b] Calculated based on (China National Bureau of Statistics, 2020c); [c] (E20 Research Institute, 2019); [d] (China National Bureau of Statistics, 2020a).

6.3 Policy and financial support systems

Renewable Energy Law of the People's Republic of China – 2006

The Renewable Energy Law is a framework policy that laid out the general conditions for renewable energy to become a more important energy source in the People's Republic of China. The law encourages and supports the development and utilisation of renewable energy in rural areas and promotes biogas and other biomass resources conversion and other technologies in accordance with local conditions.

The 13th Five-Year Plan for Biomass Energy Development – 2016

The development goals of the 13th five-year plan for bioenergy were bioenergy commercialisation and large-scale utilisation by 2020. The annual total installed capacity of biomass power generation should reach 15 GW, and the capacity of biogas power generation should reach 500 MW by 2020.

The 13th Five-Year Plan for National Rural Biogas Development – 2017

The plan focused on optimising the development structure and construction layout of rural biogas. The program encouraged the development of diversified utilisation models of biogas and fertiliser products for promoting the transformation and upgrading of rural biogas

Instructions on accelerating the resource utilisation of livestock and poultry manure – 2017

The State Council of the People's Republic of China released instructions on "Accelerating the Resource Utilization of Livestock and Poultry Manure". The main target was to establish and improve livestock and poultry manure utilisation systems. By 2020, the comprehensive utilisation rate of livestock and poultry manure reached over 75% on a national level.

Strategic Planning for Rural Revitalisation (2018-2022) – 2018

The State Council released a four-year "Strategic Planning for Rural Revitalisation (2018-2022)". The plan proposed promoting green agricultural production, focusing on managing outstanding problems in the agricultural environment, and improving the rural environment for farmers' life.

Guidelines on Promoting Bio-Natural Gas Industrialisation – 2019

The plan focused on coordinating various types of organic waste resources in urban and rural areas, establishing and improving the bio-natural gas industry system. By 2030, China's bio-natural gas should realise steady development, and bio-natural gas production should reach 20 billion m^3.

Rural Revitalisation Promotion Law of the People's Republic of China – 2021

The Rural Revitalisation Promotion Law has been formulated to fully implement the rural revitalisation strategy. It has proposed to strengthen the prevention and control of agricultural non-point source pollution and waste recycling and encourage the utilization of renewable energy.

Biomass Power Generation Project Construction Work Plan – 2021

The National Development and Reform Commission, the Ministry of Finance, and the Energy Administration have formulated the "Work Plan for the Construction of Biomass Power Generation Projects in 2021". In 2021, the total amount of central government subsidy funds for biomass power generation will be 2.5 billion yuan. The 0.3 billion yuan will be arranged for competition allocation projects related to agricultural and forestry biomass power generation and biogas power generation.

6.4 Innovative biogas projects

N2N Regional Biogas Project, Jiangxi Province

The N2N biogas project (Figure 6.3) focuses on nitrogen recirculation, integrating upstream N farming enterprises and downstream N planting enterprises. The digestates are applied to fields as fertiliser, reducing the use of chemical fertilisers and pesticides while also solving problems such as soil caking in farmland. The N2N biogas project adopts the CSTR AD technology with a temperature of 38 °C and a retention time of 20 days. The biogas plant treats 400,000 tonnes of bio-waste (livestock manure, pig carcasses, various agricultural crop straws, etc.) per year, producing 30,000 tonnes of solid commercial organic fertilizer and more than 8 million m^3 of biogas. The biogas is mainly used for grid-connected power generation and centralised gas supply. The project can give a centralized gas supply for 6,000 households, while obtaining an annual power generation of more than 18 GWh.

Figure 6.3. N2N regional biogas project in Xinyu City, Jiangxi Province

Liangjia Biogas Demonstration Project

The Liangjia biogas plant (Figure 6.4) is a demonstration project of the Ministry of Agriculture and Rural Affairs, which follows the concept of ecological recycling, and organically integrates the orchards and animal farm in Liangjiahe village in Yan'an city, the Red-army Revolutionary Base region, Shaanxi Province. This biogas project acts as the core part of the local agricultural and rural green circular development named as "fruit – biogas – livestock". The mesophilic biogas plant can process 1, 800 tonnes of livestock manure per year with a retention time of 25 days. It produces 70,000 m^3 of biogas per year for power generation of about 120 MWh per annum. 100 tonnes of solid digestate and 1500 tonnes of liquid digestate are produced and applied as fertiliser in the surrounding area of modern ecological orchards.

Figure 6.4. Liangjiahe Biogas Demonstration Project of the Ministry of Agriculture and Rural Affairs

Chicken manure biogas project in Dafeng City, Jiangsu Province

The biogas plant in Dafeng (Figure 6.5) utilises chicken manure with high sand content as feedstock; it adopts a three-stage de-sanding technology to achieve a sand removal rate of more than 85%. The plant's energy consumption is low, and the average biogas consumption of anaerobic system heating is less than 15% throughout the whole year. The project enjoys a central governmental financial subsidy of 20 million CNY and a local government transportation subsidy of 30 CNY/ton. The plant employs 4 CSTR anaerobic digesters (with a working volume of 3,500 m^3) using fermentation temperature of 35 °C and a 28 day retention time. The biogas plant treats 200,000 tonnes of chicken manure and produces 7 million m^3 of biogas per year. The biogas is upgraded to biomethane, with an annual output of about 4 million m^3, which is integrated into the Ganghua natural gas network. In addition, the annual production of 150,000 ton liquid digestates is concentrated with membrane technology and used as biofertiliser in nearby paddy and wheat fields.

Figure 6.5. Chicken manure biogas plant in Dafeng City, Jiangsu Province

7 Finland

7.1 Production of biogas

In 2020, the total recovered energy production from biogas was 877 GWh from 109 different biogas production plants (Table 7.1). Both the number of production facilities and the amount of produced energy have increased in recent years, but due to changes in data collection in 2019, the numbers might not be totally comparable to previous years. Data is now collected by Statistics Finland (Statistics Finland, 2021).

Table 7.1. Status of biogas production in Finland (2020)

Plant type	Number of plants	Production (GWh/year)[a]	Share (%)
WWTP	16	221	25
Bio-waste	30*	431	49
Agricultural	21	18	2
Industrial	5	8	2
Landfill	37	190	22
Total	**109**	**877**	

[a] Three plants started production during 2020, but there is no statistics on their production yet

7.2 Utilisation of biogas

In Finland, biogas has traditionally been used in power and heat production, but in recent years vehicle fuel use has increased remarkably (Table 7.2). There are over 50 public filling stations for biomethane/CNG and the number of vehicles is increasing, also in heavy transport.

Table 7.2. Utilisation of biogas in Finland (2019)

Utilisation type	Utilisation (GWh/y)	Share (%)
Electricity	177	21
Heat	275	32
Vehicle fuel[a]	110	13
Industry/internal use	147	17
Flaring	144	17
Total	**853**	

[a] Upgraded gas, partly injected to gas grid (some of which is utilized in industry)

7.3 Policy and financial support systems

Finnish biogas production is currently very dependent on financial support. The most important subsidies are three different investment support schemes for biogas plants, which depend on the size of the plant and the use of the biogas:

- Investment support for large industrial plants;
- Investment support for farm own energy production;
- Investment support for agricultural companies.

In addition, there has been a feed-in tariff for electricity production in large industrial plants and a fuel tax exemption for biomethane as vehicle fuel. However, both of these are now likely to be changed.

The investment support for large scale industrial plants is paid by the Ministry of Employment and Economy. A maximum of 30% of the acceptable investment costs are covered. From 2020 onwards, special attention has been given to digestate processing and use. Even higher support rate can be obtained, if there is a higher risk for economic profitability due to digestate handling. In 2020, four biogas project obtained altogether €14.6 million support.

Investment support for agricultural plants is paid from the EU Rural Development Programme 2014-2020 and is administered by the Ministry of Agriculture and Forestry. Farm-scale plants, which mainly use the energy themselves, and do not sell electricity outside the farm, are eligible for investment support of up to 40% of the acceptable investment costs. It is also possible to get the investment support when most of the energy is sold outside the farm, or the farm sells vehicle fuel. However, a separate company must be founded for this purpose. The agricultural company can then get an investment subsidy of up to 30% of the investment costs (Finnish Food Authority, 2019).

In addition to the investment support, it has previously been possible for a biogas plant to get production support for production of renewable electricity. However, the previous feed-in tariff for renewable electricity was replaced with a premium system from the beginning of 2019. The new system is technology neutral and those renewable energy plants that offer electricity at lowest premiums will be accepted into the system. No biogas projects were proposed to the authorities in the auction in 2018 (1.4 TWh in total), and all projects that were accepted into the premium program use wind power (Wind Power Monthly, 2019). New auctions have not yet been announced.

Moreover, to support biogas production, the use of biomethane as vehicle fuel has been exempted from fuel tax. However, the taxation of biomethane as vehicle fuel is currently under discussion. The taxation would allow use of the biofuel blending obligation for biomethane in vehicle gas, i.e. natural gas sold as vehicle gas would contain a certain amount of biomethane.

Both the former (2015 – 2019) and the current Government of Finland (2019 – 2023) have been very supportive towards biogas production and use. In 2015, several biogas related targets were agreed, such as to have 50,000 gas driven passenger cars by 2030, and to process 50% of all manure (such as in biogas production) by 2025. In 2019, more targets followed in the form of a biogas programme. The use of biomethane as vehicle fuel is hoped to be further encouraged with a blending obligation. Moreover, additional support mechanisms are planned for the use of manure as raw material for biogas production.

7.4 Innovative biogas projects

In Finland, the unused biogas production potential lies in agricultural biomass, forest biomass and organic fractions of municipal solid waste (OFMSW) that currently is mainly incinerated. None of these streams are competing with food production. In many, occasions agricultural biomass–even the ones with high solid content–can be processed in traditional wet fermentation plants, but forest biomass, OFMSW and agricultural biomass with high contamination from sand, stones or similar are not suitable for wet fermentation based solutions.

Since 2016, several dry digestion plants have started operation in Finland and one of them is Hardferm dry digestion plant for Jepuan Biokaasu built in 2020 (Figure 7.1). It is one of the few plants in Finland that uses considerable amounts of dry agricultural substrates containing impurities such as sand.

The capacity of the new dry digestion plant is 28,000 tonnes/year of mainly solid substrates. The raw materials used are solid manure, side streams from egg production, slaughter waste, and excess grass silage. Especially solid manure is a difficult substrate because it contains rocks and sand. The Hardferm dry anaerobic digestion concept enables continuous anaerobic digestion of these challenging substrates.

Figure 7.1. Hardferm dry anaerobic digestion plant designed by Doranova and built for Jepuan Biokaasu

The aim of Jepuan Biokaasu is to grow by refining side streams originating from farms and food production industry into biomethane and recycled fertilizers suitable for organic farming. The produced biogas is upgraded to biomethane and used by the local industry as well as vehicle fuel. The future plans are to produce concentrated organic fertilizers from the digestate. Removing water from the digestate and concentrating nutrients into recycled fertilizers enables transporting nutrients to longer distances. Jepuan Biokaasu is located in Ostrobothnia (Pohjanmaa), which is one of the regions in Finland with intensive animal husbandry thus the region has a surplus of nutrients.

8 Germany

In Germany, the share of renewable energy in total energy generation is to be raised to 40-45% by 2025, to 55-60% by 2035, and to 80% by 2050. Further, as a part of the German energy transition (“Energiewende”), a program for coal phase-out by 2038 was introduced in 2018 and a “climate package” was enforced in 2019. With the changes in the German government (2021), changes in this aspect are also to be expected. For example, an early coal phase-out in 2030 is under discussion by parts of the designated government.

However, the further development of the Renewable Energy Sources Act (EEG) plays a key role in the success of the transition within the German energy sector. The introduction of limits to the capacities which are put out to tender for the different technologies was a new development for the German renewables support scheme. In order to ensure more competition, an auction model was introduced within the EEG 2017. The main driver for the introduction of the limits for biomass and the auction system are the reduction of costs by means of competition, as well as the (limited) biomass potential. Furthermore, several regulations for biogas facilities are under revision or amendments are already enforced. The draft of the “Technical Instructions on Air Quality Control” (TA LUFT) was released in 2018, and the safety regulation “Technische Regel für Anlagensicherheit (TRAS 120)” was published in 2019. New regulations for emissions from CHP have been released as well in the national implementation of the European “Medium Combustion Plant Directive” (MCP). The so-called 44. BImSchV (44. Ordinance for the Implementation of the Federal Emission Control Act) introduces major changes such as the reduced NO_x threshold to 0.1 for new plants starting in 2023 and existing plants in 2023 and a newly introduced total C threshold of 1.3 g/m³ starting in 2023 for new and in 2029 for existing plants.

In addition, there are further requirements for biogas plant operators resulting from the revised German fertiliser ordinance and the recast renewable energy directive (RED II), which entered into force in 2017 and 2018, respectively. The German fertiliser ordinance foresees limits for N and P fertilisation depending on site and soil type, specific conditions for periods for manure application, as well as the regulation on storage capacities of organic fertilisers. Due to the revision of RED II, newly built biogas plants shall provide a proof of the achieved GHG emission reduction and more than a half of the currently existing biogas plants with a thermal capacity > 2 MW shall be certified in accordance with the sustainability criteria as posed within RED II. Strategy papers released at the end of 2016 from the Federal Ministry for Economic Affairs and Energy as well as the Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety state a clear shift for the biogas sector in regard of substrates and energy utilisation beyond the period of the EEG (in particular beyond 2030). Substrates shall be mainly waste materials and by-products; the energy should be used increasingly in the transportation sector. However, until 2030 energy provision from CHP shall even increase slightly. Details for the management of the necessary transition are still not given. The Ministry of Agriculture stated the increase of energetic use of manure as major target for reductions of emissions from the agricultural sector.

8.1 Production of biogas

Due to the change of the latest EEG regulations (2014 and 2016) as well as the introduced auction model in 2017 and the low maximum achievable tariffs, the number of new installations has been negligible since 2017 and also the application of existing facilities within the new tender system is far below the available capacities. A number of landfills and older bio-waste plants have closed down. Regarding the energy provision, the 8,400 biogas plants in the agricultural sector made the biggest contribution to biogas production in 2020 with electricity and heat supplies of 27.8 TWh/year and 13.6 TWh/year, respectively (Table 8.1). A total number of 232 biogas upgrading plants were in operation with a feed-in capacity to the gas grid of almost 150,000 Nm³/h biomethane. There are over 1,200 CHP plants in Germany running on biomethane.

Table 8.1. Status of biogas production in Germany (2020)

Plant type	Number of plants	Energy production (GWh/year)[a]	
		Gross electricity	Gross heat
WWTP	1,271[b]	1,600	2,400
Bio-waste	292 (142 + 150)	1,000	500
Agricultural	8,400[c]	27,800	13,600
Biomethane	232	2,900	3,900
Landfill	280[b]	300	100
Total	**10,551**	**33,600**	**20,500**

Sources: [a] (BMWi, 2021); [b] (DESTATIS, 2020); [c] (DBFZ, 2021)

The calculated total technical biogas potential available for energy provision varies between 155 and 265 TWh/year, depending on restrictions on usage of cultivated biomass for energy purposes. Around 30% of the calculated potential is currently used for biogas generation in Germany. Table 8.2 provides an overview of the total technical potential with respect to the substrates used for biogas production (Das et al., 2017).

Table 8.2. Calculated total technical biogas potential in Germany in 2015 (Das et al., 2017)

Substrate	Biogas potential (TWh /y)
Energy crops (incl. legumes)	106.9
Grassland	69.9
Animal excrements	39.7
Straw	31.1
Municipal residues	13.0
Industrial residues	33.0
Total	**293.6**

8.2 Utilisation of biogas

In 2020, most of the German biogas was used for electricity and heat production, while utilisation of biomethane as a vehicle fuel increased (from 389 GWh/year in 2019) but is still at a relatively low level (Table 8.3). The number of filling stations offering pure or blended biomethane has increased from around 100 in 2018 to nearly 550 stations in 2021 (CNG Club, 2021).

Table 8.3. Utilisation of biogas in Germany (2020)

Utilisation type	Utilisation (GWh/y)	Share (%)
Electricity*	31,706	62.7
Heat	18,000	35.6
Vehicle fuel	884	1.7
Flaring	n.d.	-
Total	**50,590**	

** = according to the DBFZ analysis as of 10/2021 based on TSO data for electricity production of biomass 2021 (reference year 2020) for biogas as well as biomethane data (Dena 8/2021)*

8.3 Policy and financial support systems

The amendment of the Renewable Energy Sources Act (EEG) 2021, which entered into force on 01.01.2021 modified the former regulations of the EEG 2017. Because of some mistakes in this version of the EEG and a conflict with European regulations (especially in §105 EEG 2021), it was necessary to establish the so-called “EEG-repair act”. These changes entered into force on 27.07.2021.

The EEG 2021 contains several new aspects, mainly concerning adjustments for the tendering system introduced in 2017. To consider the different levels of development of renewable energy across Germany, a regional differentiation was introduced. Initially, the spatial differentiation between local regulations is quite coarse (a northern and a southern region). The effects of this shall be monitored in the future.

To consider the mentioned spatial aspect for the tendering system the "southern quota" in the regular tender segment (§39d EEG 2021) was added. Specifically, this means that from 2022, 50% of the capacity will awarded in the southern region. One other aspect is the determination and increase of annual tender volume until 2028. For biomass the volume was changed to 600 MW/y. An additional value of 150 MW/y for biomethane CHP from 2022 exclusively for the "southern region" was introduced.

Furthermore, there was an adjustment of the bidding value for electrical power. Existing plants paid with 18.4 ct/kWh and new plants with 16.4 ct/kWh after EEG 2021 came into force (Table 8.4). Also a bonus for small plants (< 500 kW) in the tenders from 2021 till 2025 was established (+0.5 ct/kWh).

The funding in the new EEG will promote flexible power generation. The previous flexibility cap has been cancelled, and compensation for providing flexibility has been raised from 40 to 65 €/kW$_e$ for new plants, while existing plants receive 50 €/kW$_e$. In addition, the new tender segment for new high flexible biomethane CHP plants is an interesting point of change.

Not only flexibility is the focus of interest but also increasing the utilisation of manure. To support the small manure plants segment the allowed installed capacity was raised up to 150 kW (previously 75 kW). To fulfil the aim of increased manure utilisation, special regulations beyond the EEG are in preparation. For example, investment-funding programs will be established on several scales (details are not public yet).

Table 8.4. Results of the biomass auctions in Germany in 2017-2021 (Bundesnetzagentur, 2021)

Date of auction	Volume of auction (MW$_e$)	Number of awarded plants	Awarded installed el. capacity (MW$_e$)	Max. bidding value (c/kWh$_e$) (new vs. existing plants)
09/2017	122.4	21 biogas plants + 1 biomethane-CHP	27.5	14.88 / 16.9
09/2018	225.8	79	76.5	14.73 / 16.73
04/2019	133.3	19	25.5	14.58 / 16.56
11/2019	133.3	50	56.7	14.58 / 16.56
04/2020	168	38	90	14.44 / 16.40
11/2020	168	19	28.5	14.44 / 16.40
03/2021	300	38	34	16.40 / 18.40
09/2021	275	73	70	16.40 / 18.40

8.4 Innovative biogas projects

BIoSim

The application of numerical process models provides valuable information for automated, efficient and safe operation of AD plants. However, due to complex model structures with a multitude of unknown model parameters and input variables, model-based automation concepts cannot be applied in regular plant operation. Detailed investigations on the implementation of model-based simulation or control procedures for dynamic state monitoring and process control in control systems of full-scale AD plants are still missing. Thus, specific possibilities and limitations of available simulation concepts and control procedures for automation of agricultural and industrial AD plants are rarely known.

In the junior research group, relevant methods for model-based process monitoring and control are implemented, evaluated and extended for direct application in control systems of full-scale AD plants. The interdisciplinary research project thereby creates the fundamental requirements for establishing model-based automation concepts in regular plant operation.

Effektor

For the instantaneous assessment of the energetic efficiency of biomass conversion plants for power generation a dispassionate key figure–ideally independent of feedstock properties and available intermediately–is still lacking. This is where the proposed project "Effektor" aims to combine biological and energetic balancing methods in order to combine them into a continuous supervision of the technical efficiency of biogas plants. The result of the knowledge transfer partnership between science and industry is going to be a publicly available software tool, which enables biogas plant operators to generate an up-to-date and intuitive assessment of the plant's efficiency. Prospectively, the developed algorithm can be the basis for an efficiency-based incentive system as well.

By combining and integrating the already established methods of energetic plant balancing and the balancing of biological conversion rates, differentiated recommendations for action for the plant operators can be derived. The aforementioned combination of balancing methods herein is supposed to close the currently existing gap between biogas production and utilisation. Hereby, the search for weak spots in the operation of biogas plants is refined and plant operation can be improved economically and therefore ecologically. To achieve these goals, currently unmonitored biogas emissions are quantified by equipping the pressure relief vales as well as the emergency flares with monitoring equipment.

In an exemplary integration of the combined algorithm in the process information system "PIMOS" by "OPTUM Systemtechnik GmbH", the system benefits from the direct access to the measurement technology for data acquisition installed on site. For verification purposes, the developed algorithm will be tested with scientific support on the research biogas plant of the DBFZ and two further commercial biogas plants.

Pilot SBG

In the PILOT-SBG project, previously unused biogenic residual materials, by-products and wastes are to be converted as complementary raw material mixtures to biomethane as the main product. To this end, DBFZ is planning the construction of a plant on a pilot scale at its Leipzig site. The plant concept basically combines anaerobic fermentation with innovative preparation and post-treatment processes such as hydrothermal processes in order to finally provide methane as an energy source/fuel by means of synthesis. The individual modules are each operated continuously or as a batch.

The individual project objectives include:

- Use of biogenic residues, by-products and waste for fuel production
    - complementary raw material mixtures for an optimal process;

    - mobilisation of raw materials for concrete requirements.

- Expansion of the product range and optimisation of yield
    - comparative analysis of innovative technology approaches for biogas production;
    - synthesis-based production of methane fuel using the carbon dioxide from the biogas process and hydrogen produced through electrolysis;
    - separation of valuable by-products;
    - conversion of waste-based fermentation residues into hydrothermally carbonised biochar.

- Construction and operation of a pilot plant at the DBFZ to outline the process chain
    - Raw materials: monthly approx.. 0.2 to 1.2 tonnes;
    - main product: monthly 25 to 80 standard cubic meters of renewable methane .

- Preparation of the demonstration scale
    - technical conception for a demonstration plant based on experiences from the pilot phase;
    - comprehensive feasibility analysis including location identification, market development, etc.

ZertGas

With the adoption of the Renewable Energy Directive (RED), the EU has introduced sustainability criteria for liquid biofuels. Consequently, various voluntary sustainability certification schemes have become established in practice. The continuation of the guideline (RED II) provides an extension of the sustainability certification to the electricity and heat sector from a plant size of 2 MW of installed capacity. As a result, a certification process for the generation of electricity and heat from biomass is to be established. The project ZertGas "Implementation of the RED II and development of practicable certification solutions and options for operators of biogas and biomethane plants" develops transferable solutions in Germany and supports the realisation of a practicable certification process. Within the project, a methodology for the calculation of GHG emissions from biogas and biomethane plants, which is coherent with the RED II framework, will be developed. It will be further applied to calculate GHG emissions on 10 selected biogas plants. In the next step, test certifications will be conducted under participation of the official certification body. From the results, recommendations for action will be developed as well as practical guidelines targeting to support plant operators, certification systems, and auditors.

9 Ireland

The biogas industry in the Republic of Ireland is nascent, with a lot of studies showing the potential of the industry. Recently, a support scheme for renewable heat, open to commercial, industrial and other non-domestic heat users, was introduced. Scale challenges and dispersed resource are a big factor for biogas development in rural Ireland. Improving the evidence base for sustainability and lowering the cost of grass production will be a key building block for any large AD based industry. A report published by the Irish Energy Agency (Sustainable Energy Authority of Ireland, SEAI) identifies a number of barriers to the development of the industry in Ireland outside of cost competitiveness. The results were based on a survey of the supply chain in Ireland. Limitations in the available feedstock resource, unavailability of local heat loads for biogas-CHP systems, increased capital and operating costs, and increased patristic heat demand due to need for pasteurisation of slurry imports and investment risk are some of the barriers mentioned. Ireland's Climate Action Plan projects 1.6 TWh of biomethane injection into the national gas grid by 2030.

9.1 Production of biogas

The exact number of biogas plants in the Republic of Ireland is hard to access accurately. Many wastewater treatment facilities have digesters but as they are in private ownership the data is somewhat hard to collate. The main use of biogas produced in waste water treatment plants is the production of heat and electricity in onsite CHP units, and the thermal drying of dewatered digestate to produce a high grade biofertiliser. The Irish Bioenergy Association (IrBEA) state that there are numerous other facilities at an advanced state of desktop development. Data from a range of sources such as IrBEA, Renewable Gas Forum Ireland (RGFI), NVPenergy and Cre (Composting and Anaerobic Digestion Association of Ireland) provided the data on landfill, wastewater facilities and biogas plants in Table 9.1 and Table *9.2*.

Table 9.1. Biogas production in the Republic of Ireland

Plant type	Number of plants	Production (GWh/year)	Share (%)
WWTP	15[a]	n.d.	
Bio-waste	3	30.7	4.1
Agricultural	12	56	7.4
Industrial	4	76.2	10.1
Biomethane	3	22.8	3.0
Landfill	22	566.8	75.3
Total	**59**	**752.4**	

Source: RGFI, Cre and IrBEA, nvpenergy, according to latest available data; n.d. = no data; [a] Data difficult to obtain

Table 9.2. Biogas plants under construction/in planning in the Republic of Ireland (data assessed in 2019)

Plant type	Number of plants	Installed capacity (MW_e)
WWTP		
Bio-waste	4	8.0
Agricultural	6	2.6
Industrial	6	10.1
Landfill	6	4.1
Total	**22**	

Source: RGFI, Cre and IrBEA, nvpenergy, according to latest available data

KPMG is working with the Renewable Gas Forum Ireland (RGFI) and leading agri-food companies in Ireland to develop an initiative (Project Clover) that would see increased anaerobic digestion in the agrifood sector. There is significant scope for biomethane production above the 1.6 TWh/y that is set out in Ireland's National Energy & Climate Plan.

Planning permission has been granted for a new flagship gas central grid injection (CGI) facility in Mitchelstown, Co. Cork. This development will allow for 590 GWh of biomethane to be injected into the national gas grid. More than 20 AD plants are planned for the region, from which the biomethane produced will be transported via truck to the CGI facility. Construction on the CGI facility was due to begin in mid-2021, and was expected to be operational by mid-to-late-2022.

9.2 Utilisation of biogas

Existing facilities at present are dominated by provision of electricity and/or heat. This is reflective of the REFIT scheme. However, there is a viewpoint that if the biogas industry is to take off in the country it is likely to require gas grid injection to facilitate better returns on the biogas produced. The biofuel obligation certificate (BOC) system operated by the National Oil Reserve Agency (NORA) in theory allows for payment of three certificates to producers of gaseous biofuel with an energy value in excess of 35 MJ/Nm^3 if produced from residues or from second or third generation substrates and used for transport fuel. The certificates trade at a price that reflects the difference between 1 L of diesel and 1 L of biodiesel. It is very likely that the return on biogas as a transport fuel is superior to the return on electricity from biogas. However, at this stage there are no vehicles operating on biomethane and earning certificates in the Republic of Ireland.

A decision paper by the Commission for Energy Regulation (CER) in Ireland has granted Gas Networks Ireland (GNI) the operator of the Gas Network funding of €12.8 million to install 13 CNG service stations in Ireland to reduce emissions from transport and facilitate gas grid injection of biomethane. A total network of 70 Compressed Natural Gas (CNG) filling stations, distributed on sites around the country, has been proposed by GNI. As many as 20,000 HGVs and 12,000 buses are being targeted to switch. Each station would be developed at a cost of around €1 million each. Six CNG service stations were due to be built by the end of 2017.

GNI is proposing a 'hub and pod' system whereby on-farm anaerobic digesters in regional clusters (pods) would produce and purify renewable gas, which would then be transported to central injection points (hubs). GNI is currently undertaking its Causeway Project to develop a biomethane injection facility and a national compressed natural gas (CNG) refuelling network. SEAI estimates that 2-4 TWh of biogas could be produced from sustainable feedstocks in Ireland by 2030. This resource would be highly dependent on animal herd size, fodder growing productivity and clover growing productivity. If the number of animals reduces, then up to 6 TWh may be possible. Climate Action Plan 2019 referenced a policy assumption of 1.6 TWh (138 ktoe) of biomethane injection by 2030 and committed to establishing a target for indigenous biomethane injection for 2030.

Public access stations have been constructed at the Circle K Service Station in Dublin Port, and at Circle K Cashel on the M8 motorway. The stations are fully operational and have been integrated with Circle K's systems, and as such CNG is now sold through the forecourt in a similar fashion to diesel and petrol. A further nine publicly accessible sites are contracted with Forecourt Operators, with project plans in place to deliver these stations over the next 2 years. In addition, a private fast-fill CNG station is fully operational at the Clean Ireland Recycling premises in Smithstown Industrial Estate, Shannon, Co. Clare. Clean Ireland Recycling have replaced a portion of their diesel-powered fleet with dedicated CNG waste collection vehicles, the first of their kind to be operated in Ireland. The company plan to transition the rest of their fleet to these lower-emission CNG trucks in the coming years.

GNI released a strategy document in October 2019 entitled *Vision 2050: A net zero carbon gas network for Ireland* (GNI, 2019). This sets a target for 2030 of 11 TWh/y (39.6 PJ/y) of biomethane injected to the gas grid, equivalent to 20% of current natural gas demand. The target for 2050 is to inject 50% net zero carbon gases into the network. This is suggested as a mix of biomethane and hydrogen produced from power to gas systems. The actual split of biomethane and hydrogen will depend on the evolution of technology between now and 2050. At this stage, the assumption is for 37% biomethane and 13% hydrogen. GNI suggest abating the 50% natural gas still required to meet overall demand by carbon capture and storage (CCS) associated with natural gas fired power plants and large industry. By 2050 biomethane, hydrogen and CCS will deliver net zero carbon gas for home heating transport, industry and electricity generation.

Annual gas demand for 2019/20 was 1.5% higher than 2018/19 following on from a similar increase (2.0%) in the previous year. The increase in demand may be influenced by temperature, by increased home heating associated with the COVID pandemic and/or the low availability of the Moneypoint coal power station in 2020. Industrial and Commercial (I/C) annual gas demand was the only sector which experienced negative growth in 2019/20 against the previous year. Gas demand in this sector decreased by 1.6%. Gas Networks Ireland is targeting the conversion of 24% of heavy goods vehicles (HGV) and 13% of buses to Compressed Natural Gas (CNG) by 2030. By the end of the current national development plan (NDP) period (2028/29), Gas Networks Ireland is expecting to see annual CNG demand of circa 837.8 GWh/y (3.016 PJ/y). Gas Networks Ireland is conducting a project for a nationwide CNG fuelling network, co-located in existing forecourts, on major routes and/or close to urban centres. This will help satisfy the requirements of the EU's (European Union) Alternative Fuels Directive which aims to establish CNG refuelling facilities along the TEN-T Core Road Network. The initial phase of this network rollout is through the Causeway Study which has begun to deliver this essential infrastructure. The CNG Stations will be strategically located to deliver the required outputs of the Causeway Study and to maximise utilisation of the assets.

GNI opened the first gas grid injection point in Cush Co. Kildare, Ireland, which began injection of biomethane into the grid in 2019. This is effected through a virtual pipe system. The upgraded biomethane is transported by truck from the biogas facility to the above ground installation where it is injected to the transmission gas grid.

9.3 Policy and financial support systems

Support to biogas in the Republic of Ireland includes for REFIT (Table 9.3), a support scheme for renewable heat, and landfill taxes. REFIT closed to new applicants in 2017.

Table 9.3. Feed-in tariffs for renewable electricity production in Republic of Ireland 2019-2020

		Feed-in tariff (€/MWh_{el})	
Plant type	**Capacity**	**2019**	**2020**
AD (CHP)	≤ 500 kW	159.035	160.466
	> 500 kW	137.83	139.071
AD (non-CHP)	≤ 500 kW	116.626	117.675
	> 500 kW	106.023	106.978

In late 2017 a Support Scheme for Renewable Heat for Ireland was announced. The Scheme Overview initially targets biomass and anaerobic digestion heating systems for non-domestic users. An ongoing operational support, for up to 15 years, will be applied to new installations or installations that currently use a fossil fuel heating system and convert to using anaerobic digestion heating systems. The first 1,000 MWh/y will be paid at 2.95 €ct/kWh of energy produced from anaerobic digestion heating systems. From 1,000 to 2,400 MWh pa the rate is 0.5 €ct/kWh, with any additional output not receiving a tariff, attempting to reflect the economy of scale associated with these systems. Under this phase of the scheme, the production of biomethane from anaerobic digestion and its injection into the natural gas grid will not be covered however, future iterations of the scheme are set to support such configurations. Final details of the scheme are yet to be announced.

A landfill levy of €75/tonne is in place as of July 2013. Also as of July 2013 there is a requirement to provide collection of source segregated food waste for population centres in excess of 25,000 persons. As of July 2015, this was required for populations of 500 persons. These regulations provide an incentive to digest the organic fraction of municipal solid waste.

9.4 Innovative biogas projects

SEAI Research Development and Demonstration fund (RD&D)

The RD&D Funding Programme invests in innovative energy Research, Development and Demonstration (RD&D) projects, which contribute to Ireland's transition to a clean and secure energy future. It focuses on technologies at higher levels of readiness and on other policy and market relevant research. Approximately 20% of SEAI RD&D funding over the last 10 years has been invested in the bioenergy/biofuels area. In 2017 alone SEAI funded several projects in the area of biogas and biomethane including:

- EcoAD – Developing Economic solutions for on-farm Anaerobic Digestion technologies under Irish conditions
- High value sustainable renewable fuels and bio-products from forest residues in Ireland
- PIGergy - Development of novel antimicrobial cocktails to mitigate GHG emissions from stored slurries and manures
- FLEET - Farm Level Economic, Environmental and Transport modelling of alternative feedstock solutions for regional anaerobic digestion plants in Ireland

The 2019 programme call attracted great interest and as such was extremely competitive, with €11 million in funding awarded to 50 research projects (SEAI, 2019). The SEAI is responsible for awarding and administering the fund to companies and research institutions nationwide. €1m of this funding came from three strategic co-funding partners, the ESB, Gas Networks Ireland and Geological Survey Ireland.

Science Foundation Ireland (SFI) MaREI centre for Marine and Renewable Energy

The SFI MaREI Centre (MaREI, 2021) is a cluster of key university and industrial partners dedicated to solving the main scientific, technological and socio-economic challenges related to energy, climate and marine. The centre has amassed cumulative funding of ca. €65M and includes for 220 researchers from 13 universities or research centres, and 75 industrial partners including start-ups, SMEs, and large enterprises. 36 collaborating countries contribute to MaREI, across industry, academia, and government. MaREI includes for a number of research themes including for Bioenergy. MaREI's Advanced Fuels in the Circular Economy Group focus on renewable gaseous biofuel production (biohydrogen and biomethane) from 2nd generation biofuel substrates such as wastes, agricultural residues and lignocellulosic energy crops, and 3rd generation biofuel substrates such as macro-algae (seaweed) and micro-algae. Research covers biological and thermochemical bioenergy pathways. The research group's work facilitates the development of roadmaps, which describe how Ireland can initiate a green gas industry, which would contribute to mandatory renewable energy targets for renewable heat and transport fuel. The three main branches of focus are:

- Bioenergy Life Cycle Analysis
- Sustainable Bioresource Assessment
- Bioenergy Systems and Design

Sustainable Energy and Fuel Efficiency Spoke (SEFE)

This project deals with generating biogas from agricultural and food wastes as a renewable gas source with four areas of innovation. Task 1 deals with laboratory digestion systems to assess optimal process sustainability, biomethane yields and biosafety. Task 2 up-scales the digestion system and investigates co-digestion in meso- and pilot-scale digesters. Task 3 will undertake life cycle assessment to quantify the GHG mitigation that can be achieved through the green gas concept in order to estimate its sustainability, and Task 4 will develop a roadmap for Ireland to promote the greening of the gas grid.

Irish Environmental Protection Agency Advanced Gaseous Methane

Integrating power to gas (P2G) with AD offers an innovative means to upgrade biogas to green gas whilst supporting intermittent renewable electricity and producing advanced renewable transport fuel. This proposal will evaluate a future integrated bioenergy system, including the concepts of cascading bioenergy and circular bioeconomy. This project aims to achieve (1) systems integration and optimisation for biogas production and upgrading to green gas, and (2) sustainability validation of green gas production.

EFACE (ElectroFuels in A Circular Economy)

EFACE investigates the development of a Power to Gas facility, to introduce electrofuels in the form of hydrogen and methane to the Cork Lower Harbour, providing storage for electricity generated from wind turbines at times when demand for electricity is low. The proposal is to situate an electrolyser at a wastewater treatment facility and use the oxygen produced to decarbonise waste water treatment and the hydrogen to upgrade the existing biogas into synthetic renewable methane through use of ex-situ biomethane.

BioWILL

BioWILL focuses on Integrated "Zero Waste" Biorefinery utilising all fractions of Willow feedstock for the production of high to medium based Bio-Chemicals/Materials and Renewable Energy. BioWILL will deliver a biorefinery model for Northwest Europe using Willow, by producing high value salicylates from willow bark for medical applications. The bark residue and bark-free willow pulp will be converted into safe food quality packaging material to replace fossil derived plastics. The end of life packaging will be hydrolysed and used as a feedstock in an innovative bio-energy anaerobic digestion system producing biogas suitable for gas grid injection.

How to Achieve a Carbon Neutral Distillery?

The industry collaborative research project with a alcohol production facility which aims to identify potential pathways to decarbonise the production facility. The focus of this research project is to identify alternative uses of by-products generated during the distillation process and the potential to convert these into renewable energy. A key technology to achieve this is anaerobic digestion to produce biogas which can then replace natural gas used onsite.

Sequential Temperature-phased Enhanced Anaerobic digestion using Microbes and Enzymes (STEAME)

The STEAME project is aimed at developing a cost-effective technology for the efficient conversion of farm-animal waste and surplus grass silage to biogas. Key innovations are developed in the areas of: pre-treatment; thermophilic semi-dry anaerobic digestion; and microbial and enzyme applications. These are expected to improve the economics of farm-based AD systems thorough increased biogas yields; avoidance of slurry storage; and production of stable class-A biosolids as a value-added product for agricultural land applications.

Advanced Gaseous and Liquid Biofuels for the Haulage, Aviation and Maritime Sector

Biomethane as a transport fuel for freight is commercialised but the same is not true for hydrogen fuel cell vehicles or for the production of advanced liquid biofuels. What will be the renewable transport fuel for haulage, aviation and maritime sectors? This project will assess the techno-economic and sustainability of advanced fuel scenarios for the haulage, aviation and maritime sectors.

Renewable Gas Systems Modelling and Policy

This project aims to collate the resource of biomethane in Ireland, with a view to certifying the emissions saved from biomass-to-biomethane pathways. The influence of EU energy and emissions policies will have implications for the type of infrastructure that countries will need to facilitate use of this renewable resource.

Techno-economic evaluation of Power-to-Gas (PtG)

The sustainability of PtG (both hydrogen and methane) was examined financially (capital, levelised costs, future cost) and in terms of emissions (carbon footprint, potential to displace diesel) using various methods and for a range of scenarios. The system wide benefits of PtG make it highly suitable for incentivisation especially in light of increased VRE penetration and ambitious renewable transport energy targets.

10 Norway

Biogas production in Norway is mainly based on sewage sludge and food waste from households and industry, but the amount of marine waste treated by anaerobic digestion is increasing. During the last number of years, several new anaerobic digestion plants have been established, which has led to an increase in the annual production from 400 GWh in 2009 to 1 TWh in 2019 (Statistics Norway, 2021). The financial support system consists of investment support, support per tonne manure treated and tax exemption for biogas used as a vehicle fuel. All new large-scale plants and several existing plants have invested in upgrading facilities to produce biomethane for use in the transport sector. As the gas grid infrastructure is limited, the compressed biogas (CBG) is mostly distributed by truck. There are around 30 filling stations available, mostly located in the eastern part of the country. In 2019 there were two biogas plants producing liquid biogas (LBG) and two LBG filling stations.

The numbers in this section are mainly calculated based on information retrieved from the Norwegian Environment Agency, supplemented with information from Norwegian Agriculture Agency regarding manure for biogas production. In addition, numbers have been collected from the National Energy balance. There are some deviations between data received from different sources.

10.1 Production of biogas

In Norway, biogas is mainly produced from sewage sludge and food waste (Figure *10.1*). Figures are calculated based on data from the Norwegian Environment Agency and Norwegian Agriculture Agency. It should be noted that there may be data gaps for feedstock in the industrial plants, as the statistics and data collection is mainly directed towards the waste sector.

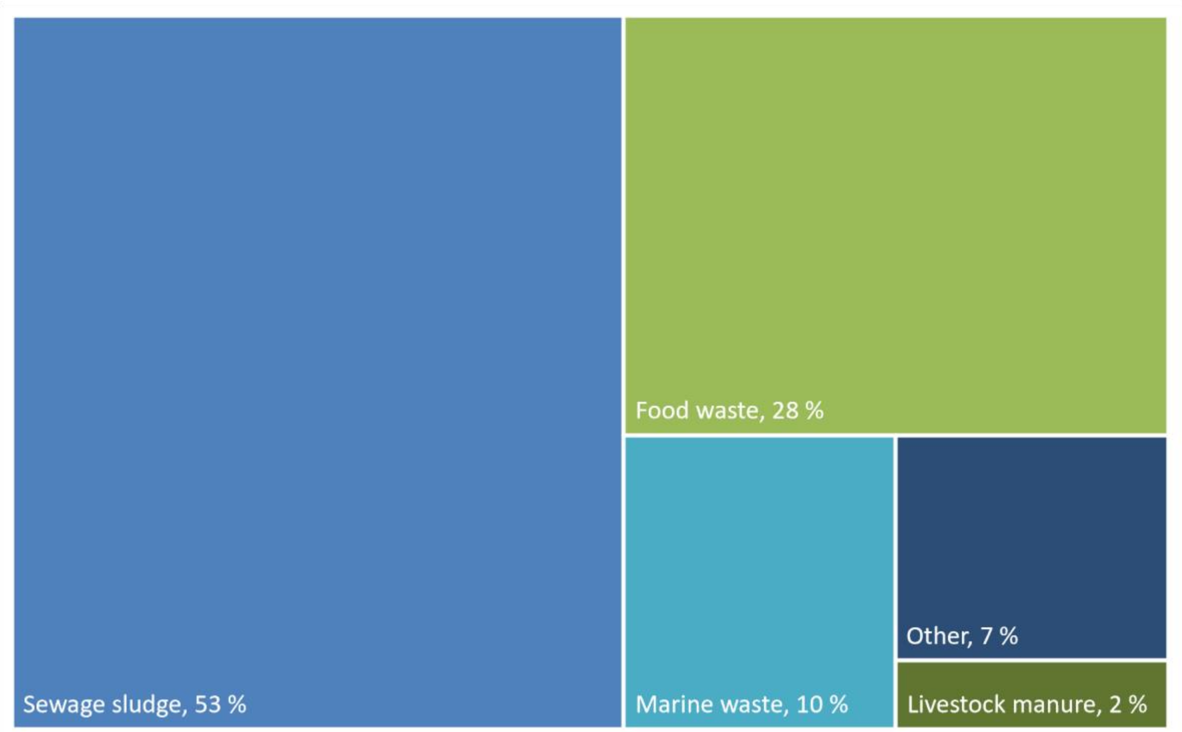

Figure 10.1 Relative shares of feedstock used for biogas production in Norway (per tonne of dry matter)

The treatment of livestock manure in biogas plants has increased from about 3,000 tonnes in 2014 to 70,000 tonnes in 2019. It has been estimated that about 1% of manure from cattle and pig currently goes to biogas production (Lyng et al., 2019). The use of marine waste resources such as fish sludge and fish silage has also increased and will continue to increase due to several new plants currently under construction.

During the last number of years, several large-scale biogas plants have been established, and the share of biogas upgraded and used for transport has increased. A national overview of number of biogas plants, plant types and production volumes is shown in Table 10.1. Data was calculated based on information from the Norwegian Environment Agency and Norwegian Agriculture Agency, and may not be exhaustive. The majority of the biogas in Norway is produced in waste water treatment plants (WWTP), in bio-waste plants (food waste from household and industry) and in industrial plants. Agricultural plants represent less than 1% of the biogas produced.

Table 10.1. Biogas plants and distribution of biogas production in Norway (2019)

Plant type	Number of plants	Production (GWh/year)	Share (%)
WWTP	27	305	39%
Bio-waste	6	180	23%
Agricultural	6	2	0%
Industrial	3	176	23%
Landfill	78	119	15%
Total	**162**	**782**	

10.2 Utilisation of biogas

The utilization of biogas in Norway in 2019 is presented in Table 10.2 (landfill gas not included). About half of the biogas produced is upgraded to fuel quality. Of the upgraded biogas produced, the share is almost equally divided between industrial, bio-waste and wastewater treatment plants, as shown in Figure *10.2*. Of the biogas produced at industrial plants, 65% was produced on a plant with upgrading, while the figure is 62% for biogas produced at bio-waste plants and 37% for biogas produced at wastewater treatment plants.

Table 10.2. Utilisation of biogas in Norway (2019)

Utilisation type	Utilisation (GWh/y)	Share (%)
Electricity	35	5%
Heat	168	25%
Vehicle fuel	337	51%
Industry	30	5%
Flaring	92	14%
Total	**663**	

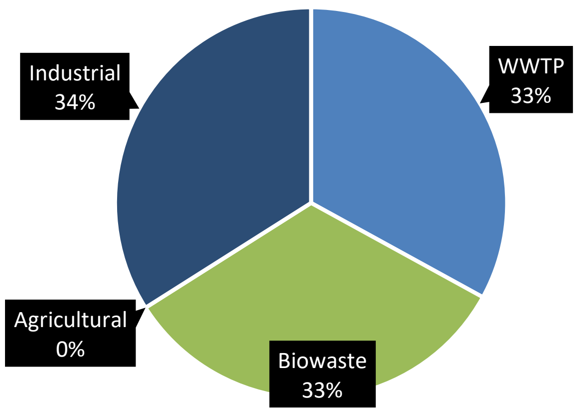

Figure 10.2. Share of upgraded biogas (biomethane) produced at different plant types

In 2019 there were around 30 filling stations, mostly located in the south-eastern part of the country (Figure 10.3). There were two biogas plants producing liquid biogas (LBG) and two LBG filling stations for biomethane. The gas grid infrastructure is limited, and thus the biogas is often transported by truck for the filling stations not located in close proximity to the biogas plant.

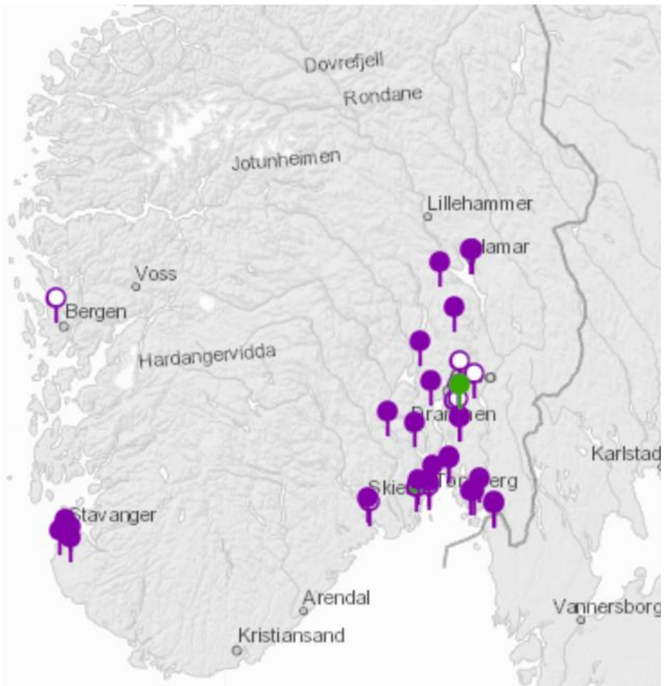

Figure 10.3. Map of available filling stations in Norway (Biogass Oslofjord, 2021)

As shown in Figure 10.4 biogas has a small but increasing share (4.5% in 2018) of the total consumption of renewable fuels.

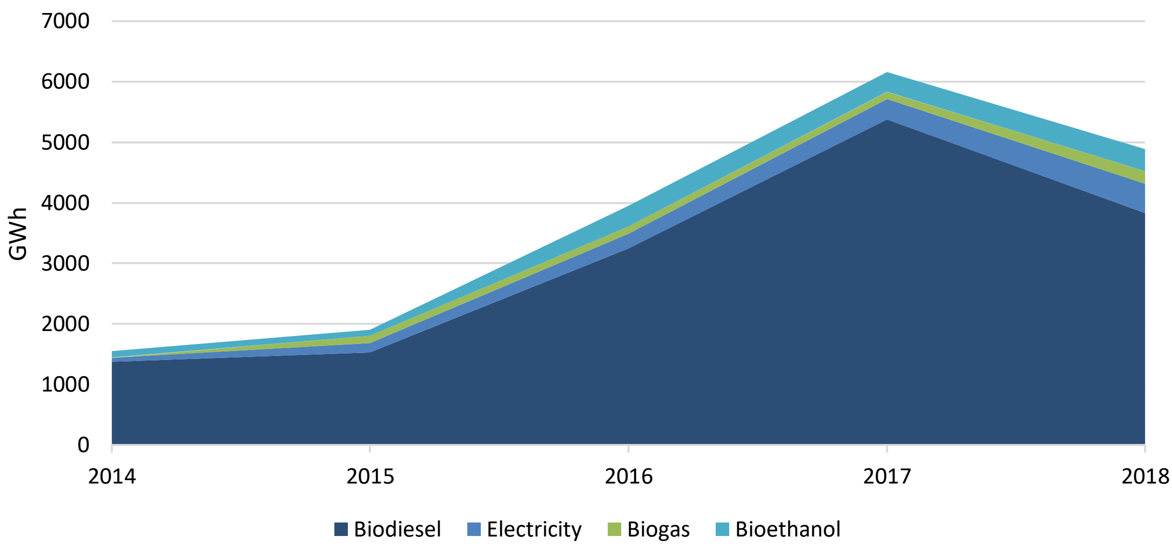

Figure 10.4. Consumption of renewable fuels in Norway (Statistics Norway, 2019)

Utilisation of digestate

The digestate is mostly applied on agricultural areas (Figure 10.5). The category “other” comprises landfill (1%), other treatment (1%) and other (2%). A large share of the digestate is dewatered, and thus the mass of the digestate is considerably lower than the feedstock treated. The majority of the digestate used at the agricultural area is produced at wastewater treatment plants. The type of agricultural land the digestate from sewage sludge can be used on is regulated by law.

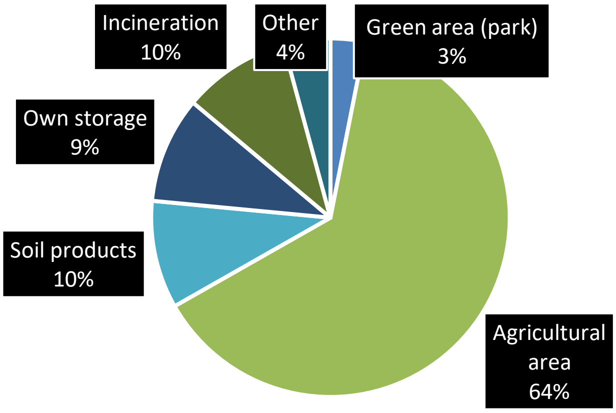

Figure 10.5. Application of digestate from Norwegian biogas plants in 2019

10.3 Policy and financial support systems

The financial support system consists of investment support (Enova and Innovation Norway), support per tonne manure treated (Norwegian Agriculture Agency) and tax exemption for biogas used as fuel for transport. Each of these schemes are described below.

Planned biogas plants with a minimum annual production of 1 GWh can apply for investment support from Enova. In 2019 the support was up to 45% for large enterprises and 50% for small and medium sized enterprises. Enova also supports investments in biogas vehicles and filling stations.

Farms and agricultural schools can apply for investment support for biogas plants from the bioenergy programme of Innovation Norway. Support can be given for feasibility studies and investment (up to 45%).

In 2013, a support per tonne manure treated by anaerobic digestion was introduced. The support is given to farmers and has increased each year. The current support is 82 €/ton dry matter (833 NOK) and is calculated based on number of animals for farm scale biogas plants and per tonne dry matter when manure is supplied to centralised farms.

There is no feed-in tariff or support for the amount of biogas produced. Biogas and other renewable fuels used for transport are exempted from road fee and CO_2 tax, which is a market benefit compared with fossil fuels. For wastewater treatment plants and bio-waste plants, income from the waste treatment service (gate fee) constitutes an important income (Lyng et al., 2020).

Increasing biogas production has been a political objective for more than ten years in Norway, as a waste treatment technology for organic waste and as a measure to reduce greenhouse gas emissions from agriculture. In 2009, a white paper stated a goal of 30% of livestock manure to biogas production within 2020 and a national cross-sectoral biogas strategy was published in 2014. In 2020, a working group led by the Agriculture Agency published a report reviewing political instruments for increased utilization of livestock manure for biogas production and the Norwegian Environmental Agency published a report regarding political instruments for increased biogas production. An action plan for biogas was published as part of the white paper Climate plan 2021–2030. In 2021, the Norwegian government decided that biogas vehicles should be equally treated as zero emission vehicles (hydrogen and electricity), which means reduced tolls on toll roads from 1st of January 2022.

10.4 Innovative biogas projects

Utilisation of industrial CO_2

When upgrading biogas to fuel quality, CO_2 is removed from the biogas to increase the share of methane. Until now it has not been common practice to utilise the flow of biogenic CO_2. As the first biogas plant in Norway, the Magic Factory ("Den magiske fabrikken") in Tønsberg has started to use CO_2 from the biogas upgrading in a greenhouse located next-door, producing tomatoes. The CO_2 enhances growth of the tomato plants and substitutes the use of industrial fossil-based CO_2.

11 Sweden

The Swedish energy and climate goals push for increased use of renewable energy, especially in transport. The national 2020 goals for renewable energy were reached a few years ago, namely 50% of the total energy utilisation and 10% goal in transports. Looking ahead, the following long-term climate and energy goals that were adopted by the Swedish parliament in 2017:

- 63% GHG emission reduction in EU non-ETS sector in 2030 and 75% by 2040 compared to 1990;
- 70% GHG emission reduction in domestic transport (excl. aviation) by 2030 compared to 2010;
- Vision to have a fossil free transportation sector by 2030;
- 100% renewable electricity production by 2040 (agreement between 5 of 8 parties in parliament);
- Climate neutral energy sector by 2045 with at least 85% GHG emission reduction; negative GHG emissions from 2045.

There is still no overall government strategy for meeting these goals, but a number of important steps and policies have been implemented or are being investigated in addition to the existing high CO_2 tax on fossil fuels and the green electricity certificate system as important drivers.

The Swedish Gas Association has a vision of "Green gas 2050", including goals of 50 TWh renewable gas production by 2050 and that green gas should contribute to a climate neutral industry sector, fossil free land transportation, cleaner shipping and fossil free heat and electricity generation (Swedish Gas Association, 2013). They have also, together with other important actors in the biogas industry, formulated a proposal for a National Biogas Strategy with a specific target of 15 TWh biomethane/biogas use in 2030, of which 12 TWh is proposed in the transport sector and 3 TWh in industry (Swedish Gas Association, 2018). Most of this biomethane should be produced in Sweden. An inquiry to update the biogas strategy was underway during 2018-2019, with the aim that the government will implement an official National Biogas Strategy. As a part of this, an official goal of 10 TWh biogas is proposed for 2030, out of which 7 TWh should come from anaerobic digestion (Westlund et al., 2019).

In Sweden only 2% (19 TWh) of the total energy supply (including imported energy) of 548 TWh was from gas (predominantly natural gas) in 2019 (Figure 11.1), which is rather low compared to many other countries in EU. Of these gases, 56% (10.5 TWh) was natural gas, 23% (4.5 TWh) was LPG and 21% (3.9 TWh) was biogas or biomethane. Biogas and LPG use have increased, and natural gas use has decreased over the last 10 years. Most of the biogas was upgraded to biomethane and used in the transport sector.

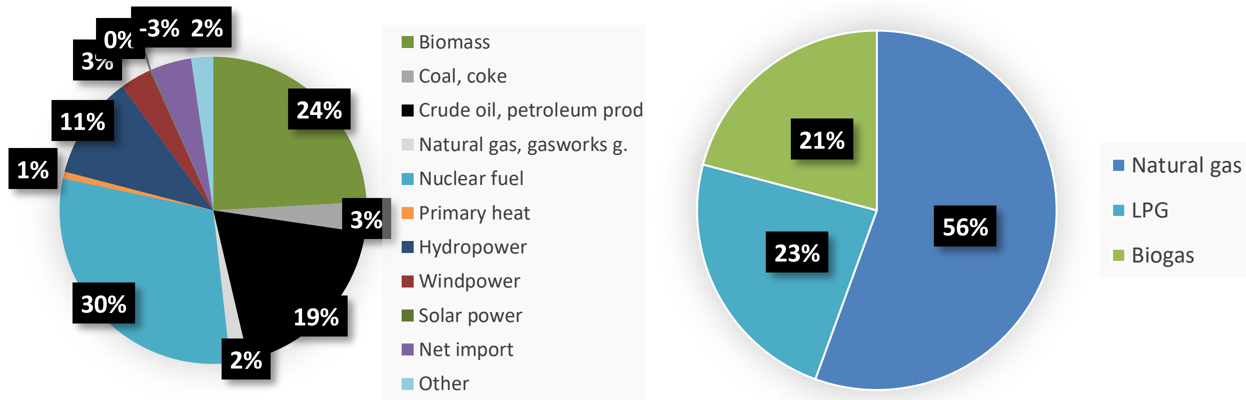

Figure 11.1. Total energy supply and deliveries (TWh) of energy (left) (Swedish Energy Agency, 2020) and gas (right) (Swedish Gas Association, 2021a) in Sweden 2019, including imports.

11.1 Production of biogas

There were 282 biogas plants in Sweden 2020, producing in total 2.16 TWh of biogas (Table 11.1). Most of the biogas was produced from different types of bio-waste and residues in co-digestion plants (52%) and from sewage sludge in wastewater treatment plants (33%).

Table 11.1. Biogas plants and distribution of biogas production in Sweden 2020 (Klackenberg, 2021)

Plant type	Number of plants	Production (GWh/y)	Share (%)
WWTP	134	721	33
Bio-waste	36	1,112	52
Agricultural	54	64	3
Industrial	7	135	6
Landfill	51	129	6
Total	**282**	**2,161**	

There were 68 biomethane upgrading plants producing more than 1.3 TWh biomethane per year (2020). About 0.5 TWh of this was injected to the south-western gas network and in the Stockholm gas grid via 14 injection sites, the rest was used locally or distributed further by truck to fuelling stations. There were also two biomethane liquefaction plants, producing 78 GWh/y.

Biomethane potential until 2030

A study from 2013 on the biomethane potential (estimating both digestion and gasification, including energy crops and forest residues) showed that when keeping current policies and implementing currently discussed ones, the realizable potential is 9-12 TWh until 2030 (Dahlgren et al., 2013). With improved policies, the potential increases to 11-22 TWh. With poor policies and bad economy, (e.g. by introducing energy taxation on biomethane and only a slow increase in oil price), the potential is not higher than the current production level (1.2-2.5 TWh).

Another study from 2008 showed a technical biomethane potential of 15 TWh from anaerobic digestion of available domestic waste and residues (Linné et al., 2008), and about 10 TWh with restrictions. If including thermal gasification of forestry residues, the total biomethane potential would go up to 74 TWh. Note that energy crops are not included in this potential, but may of course be significant, since there exists plenty of fallow or underused agricultural land in Sweden. So far, the use of energy crops for biomethane production is very limited due to economic constraints.

The biogas enquiry from 2019 found a technical potential of 14-15 TWh biogas from AD and 16-22 TWh biomethane from thermal gasification by year 2030 (Westlund et al., 2019). Aquatic substrates are usually omitted or estimated to have a very low potential in all of these studies.

11.2 Utilisation of biogas

The use of biogas for transportation has increased rapidly over the last 10 years, whereas the use for heating has decreased. In 2020, 65% of the produced biogas was upgraded and used mainly as transportation fuel, due to a favourable support system. Table 11.2 shows the utilisation of domestically produced biogas in Sweden (i.e. not including imported gas). The market for methane as transportation fuel is now rather developed in Sweden but is highly dependent on increased policy incentives and long-term support systems to take the next step. The use of methane as vehicle gas increased rapidly up until 2014 and has then stabilised at around 1,500 GWh for the last few years (Figure 11.2). In 2020, the demand for vehicle gas dropped to 1,400 GWh, as travelling reduced during the COVID-19 pandemic. The use of biomethane has however continued to increase and accounted for more than 95% of the vehicle gas use in 2019-2020.

Table 11.2. Utilisation of domestically produced biogas in Sweden (2020) (Klackenberg, 2021)

Utilisation type	Utilisation (GWh/y)	Share (%)
Electricity	40	2
Heat	400	19
Biomethane	1,401	65
Industry	66	3
Other	4	0.2
Flaring	242	11
Losses/n.d.	8	0.4
Total	**2,161**	

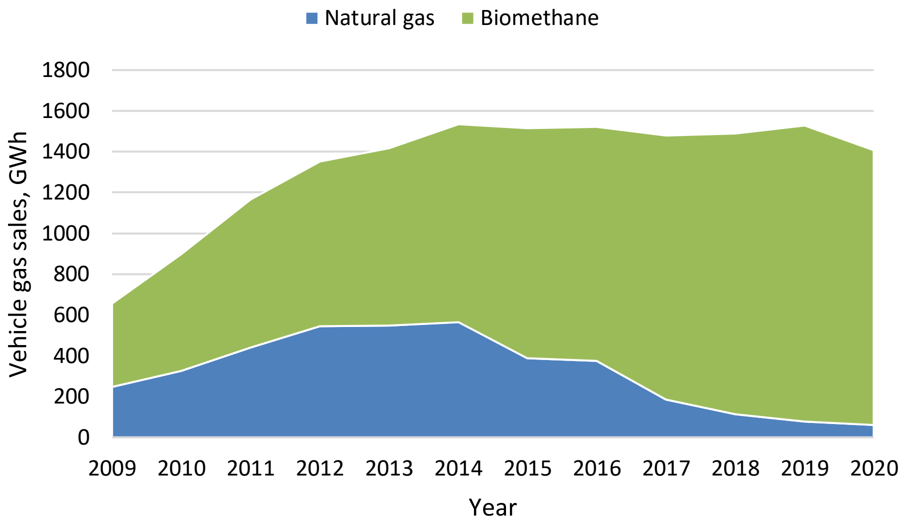

Figure 11.2. Sales of vehicle gas in Sweden 2009-2020 (Statistics Sweden, 2021)

In addition to the domestically produced biogas and biomethane, Sweden also used around 1.8 TWh of imported biomethane in 2019, giving a total utilisation of 3.9 TWh biogas and biomethane. This number has increased from 2.9 in 2017, even though the production has been stable, due to a twofold increase of imported gas. Most of the imported biogas and biomethane was used in industries and for heating, and a smaller share was used for vehicles (Swedish Gas Association, 2021b).

The Swedish biomethane market is to a large extent off-grid with small local or regional grids or stand-alone biogas gas plants and fuelling stations. A large part of the biomethane in Sweden is today transported on the road as compressed gas (200/260 bar) and to a small but increasing extent as liquefied gas (LNG and bio-LNG). The gas grid infrastructure is limited to the south-western part of Sweden where the transmission grid is connected to the European gas grid (connection with Denmark) via exit Dragör (Figure 11.3). There is also a gas grid in Stockholm, fuelled with locally injected biogas and shipped LNG.

The number of gas filling stations has increased from less than 20 in 2000 to over 200 stations in 2021, plus 60 non-public stations (Swedish Gas Association, 2021c). New filling stations for LNG are being built in several locations in Sweden. At the end of 2020 there were 23 filling stations for LNG (Swedish Gas Association, 2021c). The number of gas vehicles has during the same period increased from just a few hundred to in total 53,982 by the end of 2019; 2,618 of these were buses (about 15% of all buses) and 1,034 trucks, and the rest were passenger cars and other light vehicles. The number of gas buses and trucks have increased slightly since 2018, while the number of passenger cars and light vehicles have decreased, partly due to export of gas vehicles to other countries.

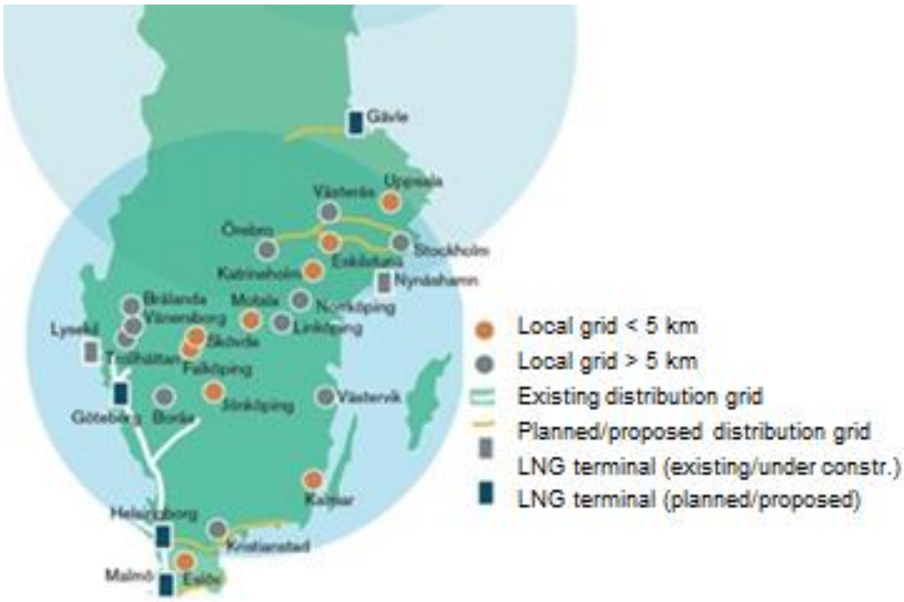

Figure 11.3. Gas grid infrastructure is limited to south-western Sweden and small local gas grids. There are two existing LNG import terminals (Lysekil and Nynäshamn) and a couple of more planned.

Liquefied biomethane for industry and heavy transport

There is an increasing interest in liquefied biomethane in Sweden. The higher energy density compared to compressed biomethane means that it can be distributed over longer distances despite the absence of a national gas grid. Moreover, it opens up new possibilities for utilisation, such as industries, shipping and heavy road transport, which require a fuel with a high volumetric energy content. There are currently two bio-LNG plants in operation in Sweden, and one more in the start-up phase. The Swedish truck manufacturers Volvo and Scania have both developed new engines for LNG, and two ferries on the lines Stockholm-Turku and Nynäshamn-Visby are running on LNG.

In 2018-2021, the Swedish Energy Agency were commissioned to set up an innovation cluster for bio-LNG, or LBG (liquefied biogas) as it is called in Sweden. This innovation cluster, *Drive LBG*, was hosted by the Swedish Gas Association, and was assigned to “act to collect, demonstrate and increase the knowledge, innovation and development opportunities in sustainable solutions for LBG in national as well as international level” (Swedish Gas Association, 2021d). As a part of this work, the cluster gave financial support to companies and organisations who chose to invest in heavy vehicles with LNG propulsion rather than diesel. New filling stations and bio-LNG production plants were also supported with money from Drive LBG.

Utilisation of digestate

Digestate from Swedish biogas plants is to a large extent used as biofertiliser. In 2020, 100% of the digestate from agricultural and co-digestion plants was used as biofertiliser, along with 43% of the digestate from wastewater treatment plants and 33% of the digestate from industrial biogas plants, resulting in an average of 87% for all biogas plants (2,600 out of 2,985 ktonne wet weight) (Klackenberg, 2021). Of the 36 co-digestion plants, 26 produced certified biofertiliser according to the certification SPCR 120. Similarly, 35 WWTPs, including all of the largest plants, were certified according to Revaq, and 32 of these produced biofertiliser. Digestate from WWTPs is usually dewatered to increase the share of solid substance (average TS = 25%), while digestate from other plants (despite a low TS; on average 5%) is often used without dewatering.

Increased import puts pressure on Swedish biomethane producers but increases market

Most of the biogas produced in Sweden is upgraded and used for transport. The use in industry has however increased over the last few years and is expected to continue to increase. The recent increasing imports of biomethane, mainly from Denmark, has pushed down the price and thus made it more competitive with natural gas in sectors where tax exemption is not effective, such as industry. However, the Swedish biomethane producers are having a difficult time competing with natural gas and imported biomethane. The situation is due to different support regimes in Sweden compared to other countries; in Sweden incentives are focused on the *use* of biomethane (of which the most important is the tax exemption), while in other member states the support is often directed towards production or injection of biogas and biomethane. This means that imported biomethane can be subsidised both in Sweden and in the exporting country. The biomethane imports from Denmark increased from 155 GWh in 2016 to more than 1.2 TWh in 2019.

11.3 Policy and financial support systems

The support system in Sweden is mainly focused on increasing the use of biomethane as vehicle fuel. High CO_2 tax and energy tax on fossil energy and tax exemption for renewables have been the main drivers so far, together with local and regional investments for biomethane within public transport accompanied with previous investment support programmes. During 2018-2019, an inquiry was conducted to investigate most suitable long-term policies for biogas and biomethane after 2020, at the expiry of the EC state aid approval for tax exemption. The proposals, which were presented to the government on December 17th 2019, included a maintained tax exemption for biogas as well as new incentives for production of biogas and biomethane (Westlund et al., 2019). The suggestions were met with broad political consensus, and the national budget for 2022 includes a new production support package for biogas of 50 M€ (500 MSEK), which will be increased to 70 M€/year from 2023. There have also been indications of a more long-term plan for this support, until 2040. In addition, a national biogas/biomethane register (guarantees of origin or certificates, etc.), to facilitate off-grid distribution, is still under investigation.

Existing policies:

- CO_2 tax and energy tax exemption for biomethane as transportation fuel until the end of 2030. CO_2 tax and energy tax for petrol are about 4.2 SEK/L (~44 €/MWh) and 2.6 SEK/L (~27 €/MWh).
- No CO_2 tax or energy tax on biogas for heating (including industry use) until end of 2030. Corresponding tax on natural gas is 3.4 SEK/Nm^3 (~29 €/MWh).
- Up to 0.40 SEK/kWh (~ € 0.043/kWh) production support for manure based biogas to reduce methane emissions from manure. Total budget 390 MSEK (2015-2023), and support given to each producer is dependent on the total domestic production of biogas from manure.
- A joint electricity certificate market between Norway and Sweden. The producer gets one certificate for every MWh electricity produced from renewable resources and electricity consumers must buy certificates in relation to their total use. Price span 2014-2015: 140-190 SEK/MWh (~13-18 €/MWh).
- *Klimatklivet (“Climate step”)* – local climate investment programme 2015-2023. Investment support (up to approx. 45%) for all types of investments or measures that leads to high GHG emission reductions. The budget for 2018 was 800 million SEK/year (~80 million €). A large part of the investment support that has been granted so far since 2015 has been given to biomethane investments and charging infrastructure for electric vehicles.
- A “Bonus-Malus” taxation system for light vehicles from July 1st 2018. Bonus up to 70,000 SEK (~6,700 €) for new low emission cars. Gas vehicles get a bonus of 10,000 SEK (~950 €). Malus in terms of increased CO_2-based tax the first three years for high emission cars (gasoline and diesel cars).

- Quota obligation for biofuels in gasoline and diesel from July 1st 2018. The obligation is expressed as a minimum GHG reduction that each supplier must reach for all sold gasoline and diesel respectively by blending of sustainable biofuels. Reduction levels for 2018 are 2.6% for gasoline and 19.3% for diesel with an indicative reduction level of 40% by 2030. The current CO_2- and energy tax exemption for low blend biofuels will be replaced with full tax. High blends such as E85 or HVO100 and biomethane are not part of the obligation and are still eligible to tax exemption.
- Environmental zones in cities from January 1st 2020. Cities are able to put up restriction zones for polluting (noise and emissions) vehicles in three different restriction levels. Only new gas engines, fuel cell and electric vehicles are allowed in all three zones.

Uncertainties for the future biogas/biomethane market development

- Non-harmonised support systems between member states leads to double subsidised imported biomethane and results in a difficult competition situation for domestic biogas production.
- Green gas concept not accepted or applicable for off-grid bio-LNG and in important support systems such as EU ETS, green electricity certificate system and climate investment programme (Klimatklivet), which is a barrier for large biomethane expansion in industry and long-distance transportation modes. A future biogas register or Guarantees of Origin system might be the solution currently discussed between industry and authorities.
- The strong focus on electrification in the road transport sector leads to uncertainty for the future use of biogas in Sweden. The government have considered banning all new vehicles with internal combustion engines from 2030 (currently, it looks like there will instead be a ban on fossil fuels) and changing the definition of "environmental friendly car" to only include cars with no tailpipe CO_2 emissions (a proposal which was withdrawn after heavy protests from many actors). In the long run, biogas may be facing a transition from use in vehicles to industrial applications.

11.4 Innovative biogas projects

Project Air, Perstorp Oxo

In Stenungsund in the south-west of Sweden, the chemical industry Perstorp Oxo have commenced a project to utilise CO_2 from biogas upgrading as well as from their own processes for production of methanol. The methanol, synthesised from biogas-CO_2 and hydrogen from wind power electrolysis, will replace methanol produced from natural gas, thereby contributing to reducing Perstorp Oxo's climate change impact. This will in turn allow Perstorp Oxo's customers to reach climate neutrality. The Danish biogas producer Nature Energy will be involved in developing the biogas production required for the project, while the energy companies Fortum and Uniper will build the electrolysis plant for green hydrogen production.

Fossil-free steel, SSAB

The Swedish steel producer SSAB aim to become pioneers in fossil-free steel. In order to achieve this, they will need to replace a large amount of fossil energy (coke) with biomethane. In collaboration with the national agricultural association and the Swedish Biogas Research Center (BRC), SSAB are investigating the potential for producing biogas in the region adjacent to their steel mill in Oxelösund, 100 km south of Stockholm. In order to meet their demand for biogas – about as large as the current total domestic production of Sweden – a dramatically increased regional production will not suffice, but will need to be complemented with imported biogas or biogas from other regions, thermal gasification, and methanation of biogas-CO_2 and green hydrogen.

12 Switzerland

Since January 1st, 2018 a total revision of the Swiss Energy Act is in force as part of the Energy Strategy 2050. Under this act, a significant development of new renewables is envisaged with an objective to ramp up production of electricity from new renewables from 3,800 GWh to 4,400 GWh in 2020 and 11,400 GWh in 2035. Accordingly, the Swiss Gas Industry is aiming at 30% renewable gases in the grid by 2030, which would correspond to 12,000 GWh compared with 1,049 GWh in 2019.

Domestic biomass offers a considerable potential for biogas and biomethane production. Compared to that already used for a total bioenergy production of 14,720 GWh/y (including wood) an additional sustainable biomass potential of 12,200 GWh/y is still unexploited. 8,300 GWh/y of this potential is non-woody biomass and will mostly be suitable for biogas production. The largest additional biogas potential has been identified as manure with a potential of 6,750 GWh/y. Agricultural by-products, industrial wastewaters, the organic fraction in municipal waste and separately collected green waste offer respective additional potential of 600-900 GWh/y each.

12.1 Production of biogas

The production of biogas per type of plant in Switzerland is summarized in Table *12.1*.

Anaerobic digestion of sewage sludge in domestic WWTP has been implemented for more than 30 years and most middle and large size WWTPs are equipped with liquid type digesters. Few installations accept industrial co-substrates with high energy potential. Biogas use is partly through electricity (120 GWh/y) and heat production (217 GWh/y, including parasitic heat) with a strong growth in biomethane upgrading and grid feeding (185 GWh/y, 25 installations). One installation sells upgraded biomethane directly as vehicle fuel. Due to the general ban of agricultural use of sewage sludge, digested sludge is dewatered, dried, and incinerated, mostly in incineration plants, partly in domestic incinerators or in cement kilns. P-recovery will be integrated in all large sludge incineration plants from 2026.

Most bio-waste treatment plants are of larger size in the range of 500-2,000 kW_{el}. Semi-solid plug-flow digesters are common with some dry AD installations in operation. Due to the high coverage of separate collection of green waste, development in numbers flattens out. Biogas use is partly through electricity (84 GWh/y) and heat production (36 GWh/y, without parasitic heat) with a strong growth in biomethane upgrading and grid feeding (140 GWh/y, 10 installations). Digestate from plug-flow digesters is separated into a liquid fraction, which is directly used in agriculture, and a solid fraction, which is frequently post-composted for agricultural or horticultural use.

Most agricultural plants are small to mid-sized in the range of 100-800 kWh_{el}. Liquid type digesters are common with few dry AD installations in operation. Many installations accept industrial co-substrates with high energy potential. Dedicated manure treatment plants however are slightly on the rise, as manure offers the largest untapped sustainable biogas potential (GWh/y). Biogas use is mainly through electricity production (160 GWh/y), heat is only partly used (58 GWh/y). A small fraction (10 GWh/y) is upgraded to biomethane and fed to the gas grid (2 installations) or sold directly as vehicle fuel (2 installations). Liquid or solid digestate is largely used directly as an organic fertilizer in agriculture. Few installations upgrade solid digestate through post-composting.

Treatment of industrial wastewater is largely directed towards food and beverage industries with only few installations in other sectors. Liquid type digesters, mainly UASB reactors are common. Compared to 56 GWh/y of produced biogas, there is still a domestic potential of 660 GWh/y for small to mid-sized installations. Biogas is largely used for in-house heat production (34 GWh/y), increasingly for grid injection (27 GWh/y, 3 installations) and only to a small part for electricity production (7 GWh/y). Treated digester effluent usually is directed to domestic WWTP for final treatment and discharge.

Landfill biogas is strongly decreasing in importance since 2000 and today no municipal solid waste is landfilled any longer. Two remaining landfills still deliver very low amounts of biogas to produce 0.6 GWh/y of electricity and marginal amounts of usable heat.

Table 12.1. Status of biogas production in Switzerland (data from 2019)

Plant type	Number of plants	Production* (GWh/year)	Share (%)
WWTP	271	638	42
Bio-waste	29	365	24
Agricultural	112	458	30
Industrial	20	56	4
Landfill	2	2	<1
Total	**434**	**1,519**	

12.2 Utilisation of biogas

Traditional use of biogas in Switzerland is mainly for electricity and heat production. Still today, about one quarter of biogas is used for electricity and heat respectively (Table *12.2*). With respect to the domestic production of new renewables, biogas accounts for 6% of renewable electricity. Heat from biogas covers about 3% of domestic renewable heat production. The overall heat numbers do not include parasitic heat used for digester heating on agricultural and industrial biogas installations. Considering the share of parasitic heat as well, total heat use from biogas rises from 23% to 36%.

Grid feeding of raw biogas and of upgraded biomethane underwent a considerable growth since 2009 and reached a peak with 401 GWh/y in 2019 which equals 1% of domestic natural gas use. An additional amount of 648 GWh/y of biomethane is imported. Of the domestic biomethane share, 42 GWh/y is used as vehicle fuel, equivalent to 23.6% of total gas consumed in transport (179 GWh/y). Biomethane use in transport is on a constant level whereas the overall contribution of natural gas to road transport is rather low. Local upgrading of biogas to biomethane and direct use as a vehicle fuel is still rare with 3 installations in operation so far. With 296 GWh/y, the main use of biogas from the natural gas grid is for domestic and industrial heating.

Table 12.2. Utilisation of biogas in Switzerland (data from 2018)

Utilisation type	Utilisation (GWh/y)	Share (%)
Electricity	372	25
Heat	345	23
Grid injection	401	26
Vehicle fuel	*42*	*3*
Domestic heat	*296*	*19*
Electricity	*63*	*4*
Parasitic heat (estimate)	200	13
Flaring and unused heat	200	13
Total	**1,519**	

Utilisation of digestate

Only biogas installations treating agricultural manure and residues as well as bio-waste deliver their digestate back into the natural cycle as soil amendment and as an organic fertilizer. From a total amount of 707,000 tonnes/year of manure and 1,254,000 tonnes/year of organic wastes from separate collection and industry, 990,000 tonnes/year of liquid digestates and 370,000 tonnes/year of solid digestates and compost were used in agriculture. An additional amount of 150,000 tonnes/year of compost was used in private gardening and, mainly, commercial horticulture.

12.3 Policy and financial support systems

During the last decades, mainly renewable electricity and to a lesser extent renewable heat production were promoted through cost-oriented feed-in tariffs (KEV). These are limited by law and expire at the end of 2022, and as such Switzerland is currently undergoing a transition with respect to promotion of AD. In order to further promote the development of all renewable energy technologies and to achieve the guideline values of the Swiss Energy Act, a continuation of financial incentives is necessary. It was proposed by the Federal Council that all technologies generating renewable electricity should receive investment support.

Although the economic efficiency of industrial biogas plants strongly depends on gate fees, which are prone to local variations, industrial plants are often not economical without subsidies. Net electricity production cost reaches 25-50 €ct/kWh. In the case of small industrial biogas plants, an economic operation can be reached by combining investment contributions of 60% plus guaranteed gate fees. For agricultural biogas plants without significant gate fees for waste co-substrates, net electricity production costs can reach 30-70 €ct/kWh. At this cost level even investment contributions of 60% cannot guarantee an economically feasible operation in the near future. Reasons for this are high overall investment costs as well as a high share of operating costs.

To overcome this situation, additional instruments have been initiated or proposed:

- The Swiss gas industry has created a biogas promotion fund as an important instrument for promoting renewable gases. In addition to investment grants for biomethane upgrading and power-to-gas plants, it also provides feed-in tariffs.
- Large AD plants have been given the task of directly marketing the energy produced.
- A feed-in premium tariff, which includes both investment and operating costs, has been proposed as an effective support instrument.
- Activities have been initiated for pooling of small agricultural installations to generate flexible use of plant capacities and therefor get access to higher electricity price tags.
- Initiatives to strengthen support and to further expand district heating networks will aim at a higher percentage of unused heat to be brought to the market. At the currently low price level for renewable heat, this measure however will have limited impact only.
- An increase in the CO_2 tax, as foreseen in the next revision of the Swiss CO_2-legislation, would increase the prices for heat from CO_2-intensive energy sources and thus take some pressure off heat from biogas.
- A significant amount of fermentable biomass in household waste is still incinerated. About 30% of municipal solid waste is organic and could be used more efficiently in biogas plants.
- By increasing the disposal fees for green and industrial waste the revenues of commercial and industrial biogas plants would increase.
- Finally, incentives to financially compensate co-benefits from agricultural biogas production and digestate management could add to the economic viability of agricultural AD plants. These installations not only produce renewable energy but as well organic fertilisers rich in nutrients, which can replace synthetic fertilisers. Furthermore, soil conditioner and GHG reduction benefits shall be included in co-benefit remuneration.

12.4 Innovative biogas projects

With the above-mentioned additional instruments on the horizon, many AD and biomethane upgrading projects are being planned. Implementation and operation of new installations however are still showing only slow progress. Only few real innovations directly linked to the core AD process were realized in 2020. Several promising innovative projects will however demonstrate their power in the next years.

Thermal/microbial pre-treatment demonstrator

New interest has arisen with respect to pre-treatment technologies to enhance degradation and biogas production from hard to degrade substrates. Within the framework of a research project supported by the Federal Office of Energy, a two-stage thermal/microbial pre-treatment demonstrator was erected at the agricultural AD plant in Suederen BE in September 2020 (Figure 12.1). The project will continue to show benefits, potentials, and bottlenecks of enhancing biogas production from single substrates by separate and combined high temperature and anaerobic hydrolysis pre-treatment. The project runs until end 2021.

Figure 12.1. Demonstrator for thermal & microbial pretreatment of substrates at Suederen BE. ©ZHAW

Steam-explosion pre-treatment demonstrator

With support from the Federal Office of Energy, a steam-explosion pre-treatment demonstrator has been installed at the agricultural AD plant in Grangeneuve VD to treat the solid fraction of cattle manure from a 50 livestock unit (LSU) farm (Figure 12.2). Preliminary tests have shown a potential to increase biogas production from solid manure by 50%. The steam explosion demonstrator will show the potential of this technology to enhance biogas yield from lignocellulosic substrates and will help to promote economic feasibility of agricultural AD plants. Furthermore, the technology aims at developing a technology for lignin separation from lignocellulosic feedstock (LCF), thus offering production of lignin as a raw material for non-energetic use.

Figure 12.2. Steam Explosion test rig at the Grangeneuve AD Installation. ©BFH

Biological methanation

After successful operation of the Store&Go biological methanation demonstrator in Solothurn for more than 1 year, the first biological methanation at commercial level will be built in Dietikon near Zurich (Figure 12.3). The methanation plant will use a stirred tank reactor concept to treat 200 m^3/h of raw biogas from a domestic sewage sludge digester and upgrade it to grid ready biomethane. 450 m^3/h of renewable H_2 will be produced by a 2.5 MW electrolyser operated on 10,000-15,000 MWh/y renewable electricity from the nearby waste incineration plant. The installation is currently under construction and start of operation is expected in winter 2021/2022. This biological methanation plant will significantly contribute to greening the Swiss gas grid.

Figure 12.3. Visualization of the 1st commercial biological methanation at Dietikon WWTP. ©Limeco.

13 United Kingdom

There are 685 AD plants (WWTP, bio-waste, agricultural and industrial) in the UK of which 120 produce biomethane for injection into the gas distribution network. Policy initiatives to encourage a further development of the biogas sector include the Green Gas Support Scheme (GGSS), the Sustainable Farming Incentive (SFI) and the Slurry Investment Scheme (SIS). In the longer term, the government's adoption of a net zero target for greenhouse gas emissions and the 25 Year Environment Plan offer a longer-term vision for the waste and agriculture sector while recognizing the need to address the challenges in the sector. These policies recognise AD as an effective treatment of organic waste for the production of renewable fuel, heat or electricity. It further recognises the output of nutrient rich digestate which reduces GHG emissions from manure storage and landfill and the role of biogas in accelerating the decarbonisation of the gas grid.

13.1 Production of biogas

The production of biogas in the UK is summarised in Table 13.1. Most of the biogas plants are in the agricultural sector, but when compared with those in other sectors they are significantly smaller in terms of capacity. This sector has been most successful in the development of the industry.

Table 13.1. Status of biogas production in the UK (2020) (ADBA, 2021)

Plant type	Number of plants	Capacity (MW_e)	Average plant capacity (MW_e)
WWTP	170	203	1.2
Bio-waste	127	200	2.2
Agricultural	342	191	0.7
Industrial	46	43	1.2
Total	**685**		

The overall development of new biogas production in the UK has been very slow in the last few years (Figure 13.1). After a rather quick increase in the number of new plants from 2010 to 2017 (from 200 to 650), the development since 2017 has been more or less stagnant.

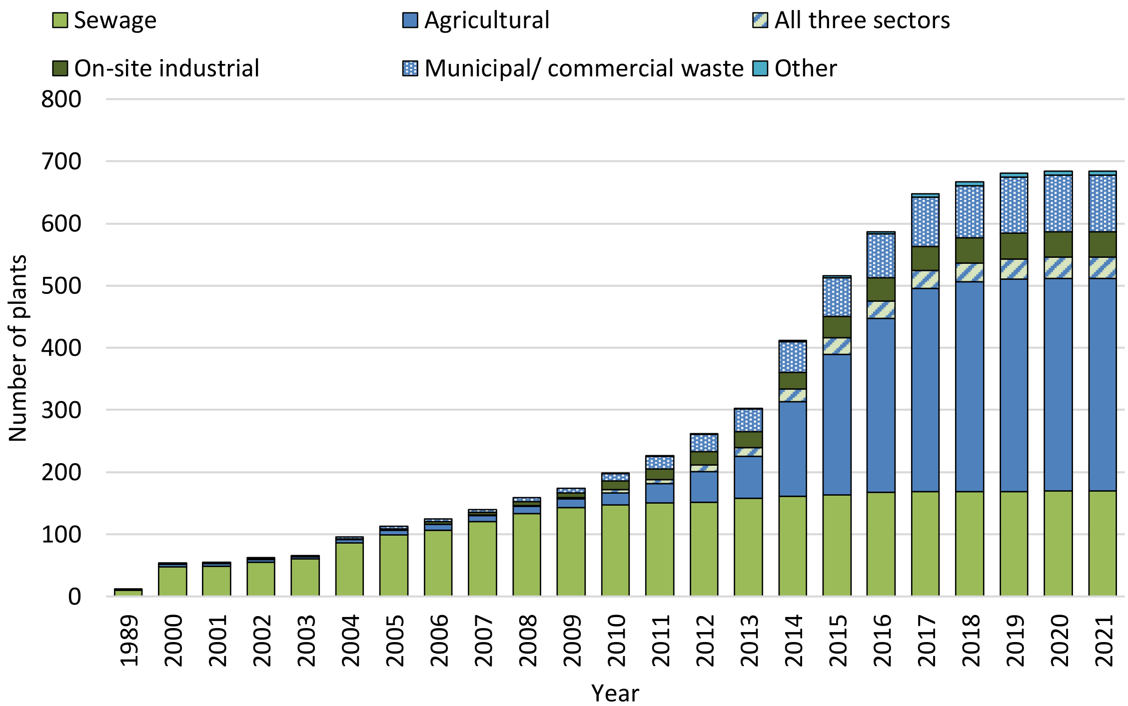

Figure 13.1. Number of biogas plants by feedstock sector (ADBA, 2019)

13.2 Utilisation of biogas

In 2020, there were 558 AD plants in the UK producing electricity (including CHP), 7 plants producing heat only and 120 plants upgrading biogas to biomethane (Table 13.2). There were 10 vehicle filling stations providing CNG blended with biomethane from the gas grid (NGVA Europe, 2020), with an average share of 67% biomethane (Hörmann, 2020).

Table 13.2. Production of electricity, heat and biomethane at biogas plants in the UK (ADBA, 2021)

Plant type	Number of plants	Capacity	Unit
Electricity/CHP	558	702	MW_e
Heat only	7	0.4	MW_{th}
Biomethane	120	96,171	Nm^3/h

13.3 Policy and financial support systems

The UK Government recently published a Net Zero Strategy (UK Government, 2021a) laying out how the UK will reach its net zero target for 2050 and intermediate carbon budget targets which have currently been set up to 2033-2037. Also, the Government has announced that a biomass strategy will be published during the 2022/23 financial year. On the 4th November 2021 the UK Government published a Biomass Policy Statement (UK Government, 2021b) which sets out the strategic aims for the role of biomass across the economy in the short, medium and long term to deliver towards net zero.

The priority in UK energy policy development for anaerobic digestion is the production of biomethane for injection into the natural gas grid. This is partly because of the rapidly reducing costs of sources of low carbon electricity generation such as offshore wind turbines and solar photovoltaics when deployed at scale, which make AD sourced electricity uncompetitive on cost and carbon savings. While AD remains eligible for the support mechanism for low carbon electricity (which is currently a series of auctions under the *Contracts For Difference* scheme) the AD sector is currently uncompetitive in that contracts under previous schemes such as the Renewables Obligation and the Feed in Tariff will reach the end of support contracts over the next decade.

However, the UK energy system currently uses natural gas as the dominant fuel for heating with a widespread natural gas distribution network. A major challenge for meeting the UK's net zero target is the decarbonisation of heat. The use of AD derived biomethane will bring forward heat decarbonisation with low stakeholder impact as the fuel is indistinguishable at the point of use to the consumer. The previous support scheme, the Renewable Heat Incentive (RHI), which rewarded renewable heat including grid injection of biomethane as well as direct heat production closed to new applications in March 2021. To address the need to decarbonise heat following the closure of the RHI, the UK Government opened the Green Gas Support Scheme (GGSS) to applications (UK Office of Gas and Electricity Markets (Ofgem), 2021) on 30th November 2021 to support the injection of biomethane from anaerobic digestion. The GGSS will be open for four years and will have a mid-scheme review at which modifications may be made. The GGSS is expected to deliver 2.8 TWh of renewable heat per year by 2030/31. The GGSS will provide a fixed tariff rate for biomethane injection (£/MWh) secured for a 15 year period to increase the willingness to invest in the projects. The tariff rate will be tiered for each plant, so that the first 60 GWh will receive 5.51 p/kWh, the next 40 GWh will receive 3.53 p/kWh and any further biomethane will be supported at 1.56 p/kWh. A range of cost control mechanisms have been put in place to avoid excessive burden on consumers. The biogas will only be eligible if it meets certain sustainability criteria:

- More than 50% of the biogas is derived from waste or residues.
- The plant must avoid ammonia emissions through the covering of feedstock and digestate stores and the use of low emissions digestate spreading technologies. This may limit that land types on which digestate may be spread.

- The life cycle GHG emissions must be less than 24 g CO_2-eq/MJ using an approach aligned with the European Union's Renewable Energy Directive.

The GGSS will be funded by a levy (the Green Gas Levy) on natural gas consumers which will add around 1% to domestic and industrial consumer bills. It is expected that the Government in England will shortly mandate the separate collection of food waste by local authorities which is currently voluntary. As a result, it is expected that feedstock supply will increase in regions that have to date not had a food waste collection scheme. Funded through the new Green Gas Levy, the government model the GGSS will bring up to £150 million per year to the AD industry. ADBA estimate that this could support the development of approximately 45 new biomethane plants in total.

Looking beyond the GGSS, the Government has also committed to explore the development of commercial-scale gasification and the replacement of the GGSS with a long-term biomethane support scheme. In the longer term, there is a suggestion that the gas grid may in part move to hydrogen distribution, in the production of which AD combined with carbon capture may have a role. Decisions on the use of hydrogen beyond the currently planned close coupled industrial use may be made in the middle of the current decade. Approaches that may be explored include alternative business models for hub and spoke systems for biomethane grid injection and carbon dioxide transport to Carbon Capture and Storage hubs. These are however speculative at this time.

There are some new additional policies that may assist small scale agricultural AD plants in the UK. The Slurry Investment scheme can potentially give indirect support for AD. This scheme will help livestock farmers invest in new slurry stores that exceed current regulatory requirements. It will also help farmers meet future regulatory standards to be introduced as part of the Clean Air Strategy. The slurry investment scheme will help to reduce pollution from farming and contribute to the government's 25 Year Environment Plan and Net Zero commitments. It was announced as part of the Agricultural Transition Plan and is expected to provide grant funding for new, covered slurry stores and equipment from 2022/23 to 2024/25.

Funding released from reductions in direct payments will be re-invested into delivering new schemes, primarily schemes that provide environmental and climate outcomes. Over this Parliament, the UK envisages spending 30% of the funding released for environment, climate and animal health and welfare outcomes on farm-level actions such as the Sustainable Farming Incentive.

The Green Gas Certificates will focus on the production of methane for injection into the gas distribution networks as a renewable fuel, alongside hydrogen when that eventually reaches commercial production. Currently, biomethane production is about to be supported by new Green Gas Support Scheme with the closure of the Renewable Heat Incentive. The GGSS is a valuable contribution which may encourage the construction of large biogas plants based on food waste and other waste streams which must be at least 50% of the feedstock. The inclusion of manure with its low biogas potential leads to a lower gas output than forage crops but its inclusion injects additional microbes beneficial to the digestion process. It also helps to reduce the dry matter fraction in the digester.

Green Gas for grid injection as biomethane however, is just part of the much larger equation of farm biogas production including that from manure. It has a significant and key role to play in meeting the aims of the government's policy – the 25 Year Environment Plan and its Sustainable Farming Incentive for the country from 2022. This Incentive seeks to increase the productivity of arable and grassland, reduce operating costs, and reducing use of fertilisers and GHG emissions from their production and application. Reduced odours, reduced nutrient run off into watercourses and reduced droplet pollution from some application techniques would make a significant contribution to the public good for which a graded system of capital payment will begin dependent of the public goods delivered. Ultimately all lead the way to reduced GHG emissions.

The new plan has six goals. These aim to create clean air, thriving plant life, reduced risk of harm from environmental hazards of flooding and drought, enhanced beauty of the landscape, engagement with the natural environment, mitigation and adapting to climate change and a contribution to Carbon Net Zero. The optimum use of livestock manure and agricultural residues such as vegetable trimmings to produce biogas can contribute to those goals.

13.4 Innovative biogas projects

Centralised upgrading, Cheshire

CNG Services is planning to construct a distributed network of anaerobic digesters in Cheshire that feed dry biogas through underground pipelines into a central upgrading hub (Figure 13.2). At the hub, the biogas will be upgraded into biomethane and injected into the National Transmission System (NTS). All biogas CO_2 will be captured and taken to carbon storage facilities. Revenue will be generated for the project using a combination of the Green Gas Support Scheme and the Renewable Transport Fuel scheme. No biogas will be burned on site and all of the anaerobic digester heating will be provided by ground/water source heat pumps. Electricity will be supplied using a private electricity network including solar generation and batteries with SP Networks electricity supply. The hub will include a Bio-CNG Mother Station supplied from the NTS and this will allow farm tractors and trucks used in the area to be supplied with biomethane. The aim is to have no diesel vehicles on the farms from 2025. The hub will be designed with capacity to allow future AD facilities to be added to the network with a target of 50 miles of dry biogas pipelines and 10 AD plants by 2025.

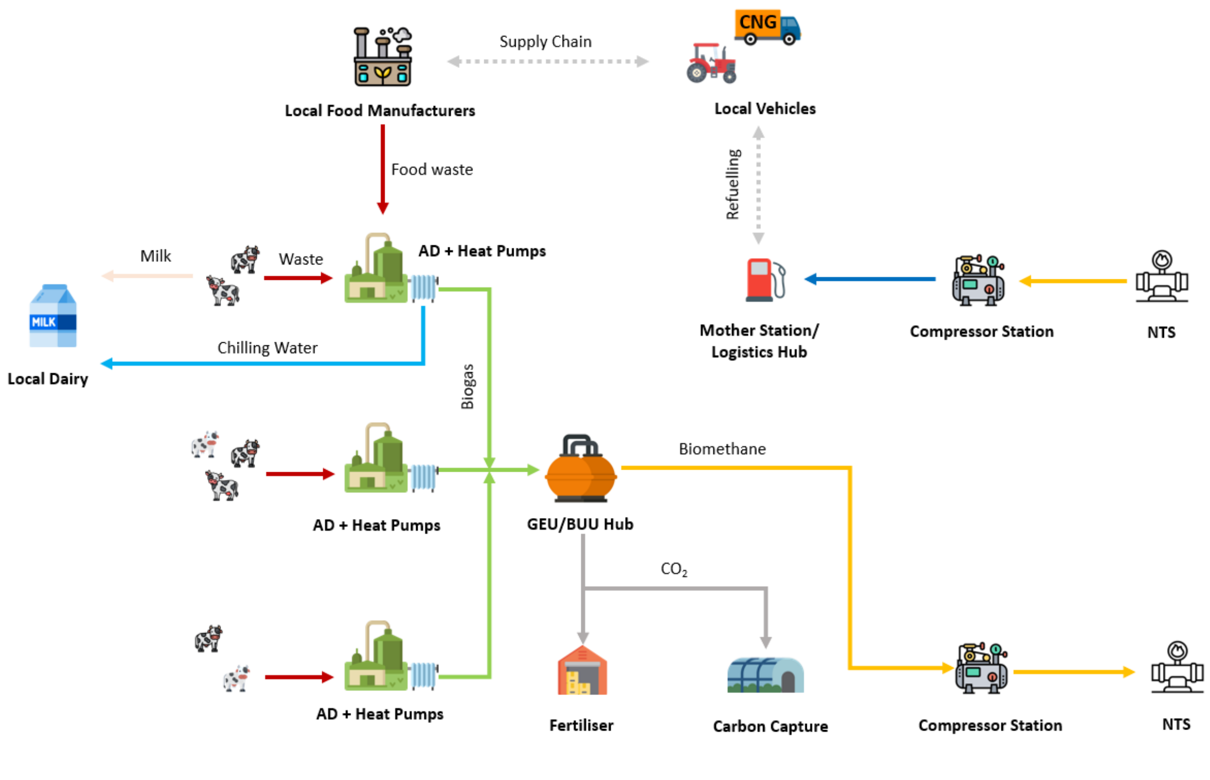

Figure 13.2. Schematic overview of the planned network for centralised biogas upgrading in Cheshire, UK

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