IEA Bioenergy Task 37

Country Report Summaries 2019

This publication contains a compilation of summaries of country reports from members 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 an annual update and is valid for information collected in 2019. Reference year for production and utilisation is as a rule 2018.

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IEA Bioenergy Task 37 – Country Reports Summaries 2019

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Front Cover Photo: Aben BV Biogas Plant, Westdorpe, Netherlands.

The digester at Westdorpe is of significant scale and has many innovative features facilitating a zero waste system. Aben BV is originally an agricultural company, which initiated renewable energy production in 2013 with a 230 kW CHP plant.

At the Westdorpe site, Aben BV can produce about 18 million m^3 green gas per year in a 22 MW installation. Due to the need to decarbonise natural gas, conversion of organic residues into green renewable gas is an advantageous circular bioeconomy system.

A lot of thought has gone into making the process circular, without any waste or emissions. This is also the reason that alongside the production of green gas, Aben annually produces 20,000 ton of liquid food grade CO_2. The process also produces heat, which can be used in internal processes.

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 29 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 39 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 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 the sixth annual summary of Task 37 country reports 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.

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

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 and energy crops)
- Industrial – digestion of waste stream from various industries (e.g. food industries)
- Landfill – landfills with collection of the landfill gas

2 Summary and Conclusions

The biogas production in the IEA Bioenergy Task 37-member countries is clearly dominated by Germany with more than 10,000 biogas plants, followed by UK with nearly 1,000 plants. None of the other member countries have more than 700 biogas plants (Figure 2.1). Austria and Canada have not reported their biogas production per feedstock, but present a total number of biogas plants.

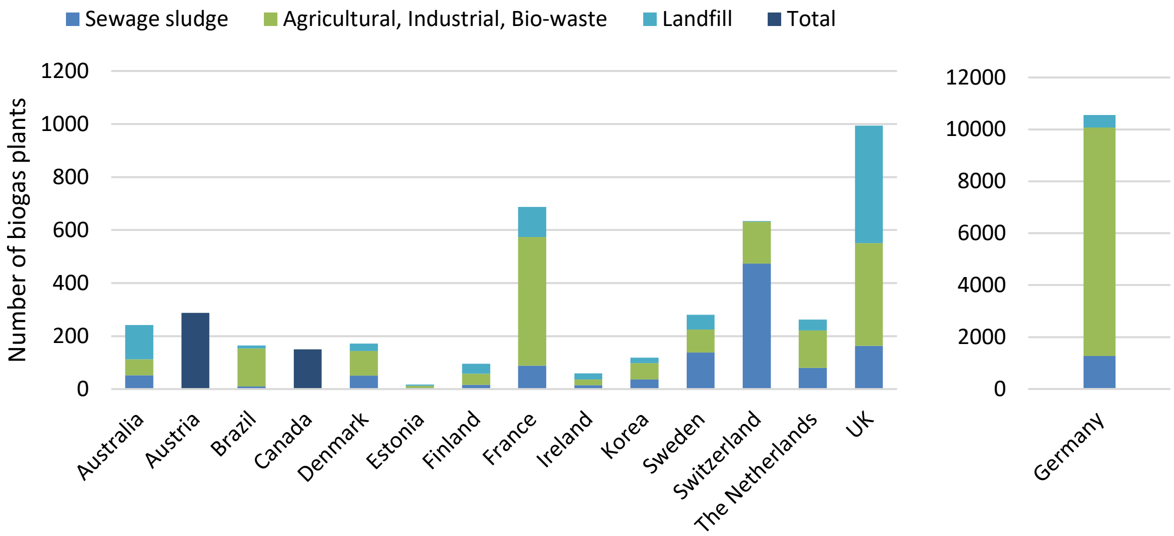

Figure 2.1. Number of biogas plants in operation in the IEA Bioenergy Task 37 member countries (2019)

The annual biogas production is around 120 TWh in Germany, 25 TWh in the UK[2], 9 TWh in France, 5 TWh in Brazil, and around 4 TWh in Denmark and the Netherlands. The remaining countries show production rates of less than 3 TWh (see Figure 17.2). In countries like Australia and UK, the biogas produced in landfills is the largest source, while landfill gas is only a minor contributor in countries like Germany, Switzerland and Denmark, 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.

The biogas produced is in most countries mainly used for generation of heat and electricity, except for Sweden where more than half of the produced biogas is used as vehicle fuel. Germany is second in absolute numbers in terms of biogas as a transport fuel. Many other countries, such as France, The Netherlands, Denmark and South Korea, have emerging markets for biomethane as a fuel for road transports.

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[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)

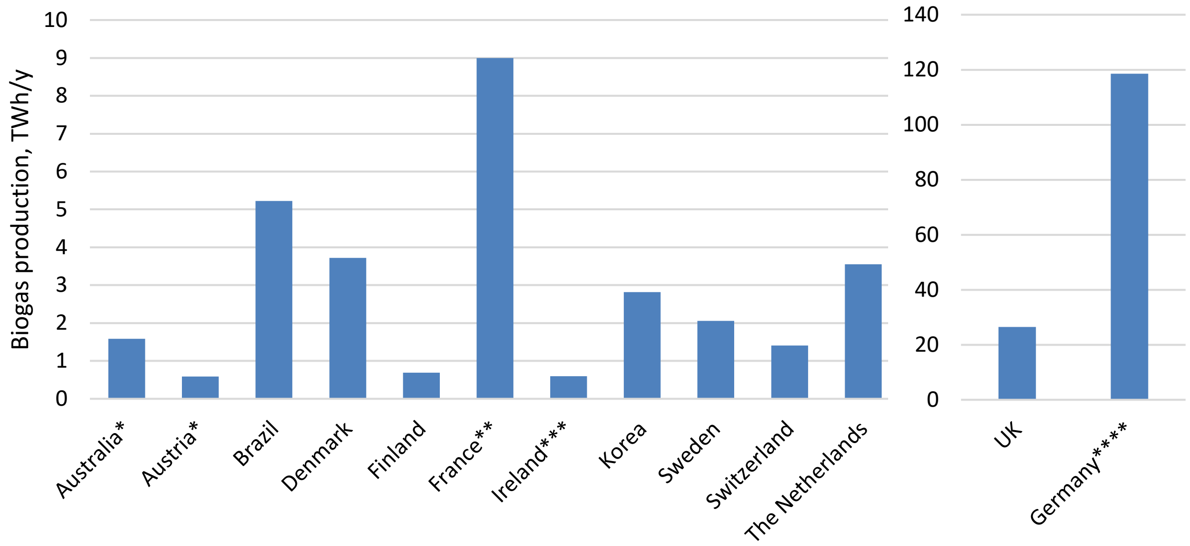

Figure 2.2. Annual biogas production in the IEA Bioenergy Task 37-member countries

**Calculated from installed capacity*

***Calculated from the reported heat and electricity production and an assumed efficiency of 35% for landfills, agricultural and bio-waste based plants and from the sum of reported heat and electricity production for industrial and waste water plants*

****Calculated from 80% of installed capacity for electricity production, assuming 35% efficiency*

The amount of biomethane produced and the number of biogas upgrading plants is increasing. In Figure 2.3 the distribution of the 577 biogas upgrading plants among the IEA Bioenergy Task 37-member countries is shown; the technologies used are indicated in Figure 2.4.

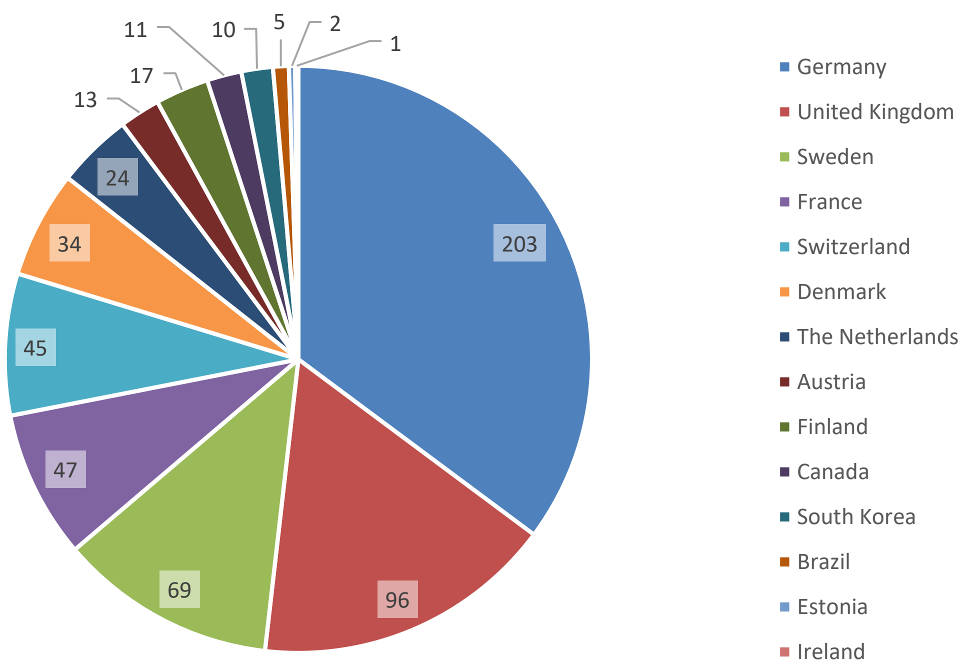

Figure 2.3. The distribution of the reported operational biogas upgrading units in the IEA Bioenergy Task 37-member countries (end 2019). The labels are in the order from the largest to the smallest. Data for Austria, Brazil, France, Netherlands and UK and are from 2016.

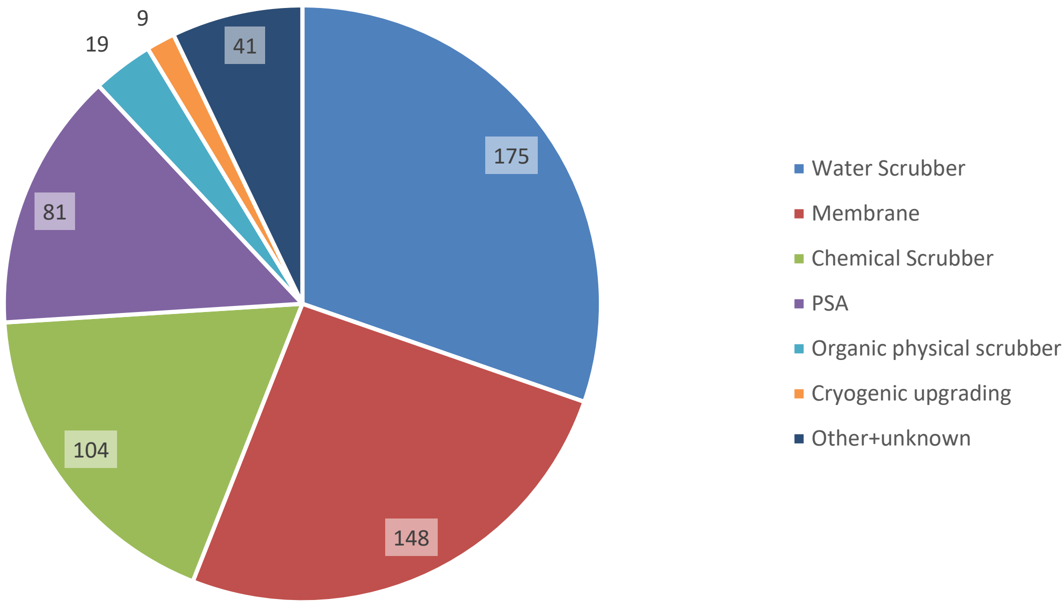

Figure 2.4. The distribution of upgrading technologies for the reported operational biogas upgrading units in the IEA Bioenergy Task 37-member countries. Data for Austria, Brazil, France, Netherlands and UK and are from 2016.

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. France and Switzerland are examples of other countries with significant growth.

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, including France, Denmark, Sweden and the UK, financial support systems have led to an increased share of biogas in the gas grids.

3 Australia

The Australian biogas industry is emerging. In 2016-2017, electricity generation from biogas was about 1,200 GWh (4,320 TJ), or 0.5% of the national electricity generation. Australia's biogas potential has been estimated as 103 TWh (371 PJ), which is equivalent to almost 9% of Australia's total energy consumption of 4,247 PJ in 2016-2017[3]. 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 242[4]. 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 18) 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 2017)

Plant type	Number of plants, estimated	Number of plants, from survey	Potential production (GWh/year)*
WWTP	52	22	381
Bio-waste	5	3	63
Agricultural	22	10	24
Industrial	34	14	44
Landfill	129**	73	1,075
Total	**242**	**122**	**1,587**

** Calculated from the installed capacity of the survey respondents.*
*** 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. The Clean Energy Finance Corporation (CEFC) projected 2020 target for agricultural biogas production is 791 GWh. The CEFC estimates a bioenergy investment opportunity of up to $5 billion by 2020, potentially doubling the current level of installed capacity[5].

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 of quantity of biogas produced and associated sizing of generators.

[3] http://s3-ap-southeast.amazonaws.com/piano.revolutionise.com.au/cups/bioenergy/files/2za1rgxbisjqxcme.pdf
[4] Ibid.
[5] http://www.cleanenergyfinancecorp.com.au/media/107567/the-australian-bioenergy-and-energy-from-waste-market-cefc-market-report.pdf

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 at end of 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 does not use biogas for vehicle fuel *per se* and there are no biogas upgrading facilities. However, the use of biogas as a vehicle fuel is currently being explored by some industries (see section 3.4).

3.3 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
  - Accessing private funding
- Lack of widespread industry experience, given the infancy of the biogas industry in Australia.

A recent 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[6]. 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

[6] Biogas opportunities for Australia. Available at: http://s3-ap-southeast.amazonaws.com/piano.revolutionise.com.au/cups/bioenergy/files/2za1rgxbisjqxcme.pdf

3.4 Innovative biogas projects

Goulburn Bioenergy Project at the Southern Meats Pty Ltd abattoir, Goulburn, NSW, Australia
The Goulburn Bioenergy Project at the Southern Meats abattoir commenced operation in February 2018.

- ReNu Energy is an Australian independent power producer (IPP) offering clean energy solutions ReNu Energy has provided a build, own, operate and maintain (BOOM) model for the Goulburn Bioenergy Project
- Southern Meats abattoir purchases the electricity via a 20-year power purchase agreement (PPA)

Plant capacity: The bioenergy plant includes a covered anaerobic lagoon for the treatment of wastewater from the abattoir, followed by a biogas treatment process. Produced biogas is then fed into 2 x 800 kW dual fuel Caterpillar generators that can run on dual fuel, blending biogas and natural gas.

Capital investment: A$5.75 million.

Government support and funding

- The project has received a A$2.1 million grant funding from ARENA
- The project is eligible to obtain approximately 2,500 Large-Scale Renewable Energy Certificates (LGCs) per year
- The project will also benefit from about 8,000 ACCUs per year via a contract with the Clean Energy Regulator

Revenues: The facility supplies approximately 4,200 MWh of energy for the abattoir during peak and shoulder periods, which help to reduce the facility's electricity bill by over 50% per year**.**

GHG savings: The plant is estimated to contribute to approximately 18,000 tonnes CO_2-eq. emission savings.

Figure 3.1. Anaerobic digester and flare of the Goulburn Bioenergy Project (photo: ReNu Energy)[7]

[7] https://bioenergyinternational.com/biogas/renu-energys-goulburn-bioenergy-project-commences-commercial-operation

4 Austria[8]

In the past few years prices for raw materials in Austria have increased tremendously and the plans to increase the amount of biogas plants have fallen behind schedule. Currently much effort is being invested to save existing biogas plants from bankruptcy. A new legislation is implementing a new framework. One aim is to reduce the amount of energy crops like maize and grain (maximum 30% of feed), plants shall be smaller than 150 kW, energy efficiency > 67.5% and remote controllable.

4.1 Production of biogas

Today the main production of biogas is derived from energy crops, sewage sludge and landfills. The annual biogas production corresponds to 1.5–2.5 TWh. Current trends are that high prices of biogas feedstock (e.g. maize) lead to severe difficulties to operate the plants economically. This has created a large interest to investigate the possibility to use alternative substrates. In total 394 approved biogas plants exist in Austria, but only 287 plants had a contract with OeMAG, the joint venture for the Austrian electricity grid, in 2016 (Table 4.1).

In Austria, the discussion about the efficiency lead to the classification of the biogas plants by average full load hours (Table 4.2). 69 biogas plants produced electricity during more than 8,499 hours per year.

Table 4.1. Status of biogas production in Austria, contract with OeMAG (Ökostrombericht 2017)

Number of plants with electricity generation	Energy production (GWh/year)*
287	**564.52**

** = Produced energy as electricity excluding efficiency losses.*
Source: Ökostrombericht 2017, Energie-Control Austria

Table 4.2. Average full load hours biogas (Ökostrombericht 2017)

Average full load hours biogas in 2016		
Classification	Full load hours	Number of plants
Best third	8,499	69
Middle third	7,753	86
Poor third	3,946	119
All plants	6,287	274

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). The amount of NGVs in Austria increased from 2013 to 2014 by 12.5% or 966 new vehicles. At the moment 172 compressed natural gas (CNG) filling stations. Three of the filling stations are situated at biogas upgrading plants.

Table 4.3. Utilisation of biogas in Austria (values from 2013)

Utilisation type	Utilisation (GWh)	Share (%)
Electricity	570	97
Vehicle fuel	7 *	1
Flaring	13 *	2
Total	**590**	

** = installed capacity*
Source: Ökostrombericht 2016; Franz Kirchmayr (Arge Kompost & Biogas)

[8] The information in this section is the same as in the 2017 report.

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 Financial support systems

Support is provided for electricity production via the Green Electricity Law (Ökostromgesetz 2012).

Feed-in tariffs for 2013 are:

- 0.1950 EUR/kWh up to 250 kW_e,
- 0.1693 EUR/kWh from 250 – 500 kW_e
- 0.1334 EUR/kWh from 500 – 750 kW_e
- 0.1293EUR/kWh for higher than 750 kW_e
- + 0.02 EUR/kWh if biogas is upgraded
- + 0.02 EUR/kWh if heat is used efficiently

It is required that a minimum of 30% manure is used as a substrate to qualify for the feed-in tariff. If organic wastes are used, the feed-in tariff is reduced by 20%.

Older biogas plants, when subsidies are running out, can apply for an extended period of subsidies, 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.

Some investment grants exist, but they are dependent on local conditions.

Figure 4.1. Biogas plant in Strem nearby Güssing

4.4 Innovative biogas projects

IEE project FABbiogas – Developing of a process to recover energy and materials via membranes from AD (NiMem)

Organic residues from the meat and poultry industry represent a largely untapped resource. With anaerobic digestion the inherent energy of the in-company wastes (chicken manure and slaughterhouse waste) can be recovered to a large extent. By means of anaerobic digestion of these substrates, however, the high nitrogen or sulphur concentrations in chicken manure or slaughterhouse waste lead to an inhibition of microbial flora thus to low methane yields. Mono-digestion of these residues, which is not yet established, is an excellent alternative to the use of specifically grown energy crops which lately has become the subject of intensive controversial discussion. The most common solution of this problem is the co-fermentation with renewable resources substrates that contain only low concentrations of interfering substances. However, this significantly reduces the economic and environmental benefit of the biogas process.

In the NiMEM project an innovative membrane technique for integrated nitrogen removal will allow anaerobic mono-digestion of chicken manure and slaughterhouse waste in combination with a reasonable recycling of nutrients as organic fertilizer.

The removal of the inhibiting substances leads to an energy efficient production of biogas and increases the methane yield. For this purpose, sulphur is recovered by microbiological oxidation of H_2S from the biogas to sulphuric acid. The highly concentrated acid is used as absorption liquid during nitrogen removal and is recycled as ammonium sulphate. Thus, a high-quality and marketable fertilizer can replace artificial fertilizers and therefore contributes to a reduced use of fossil fuels.

Chicken farms and slaughterhouses are ideally suited businesses for this innovative overall concept, since the energy and waste heat generated can be used on site. Increasing involvement of biogas technology within industrial process significantly increase the efficiency of biogas as energy carrier. An actual implementation of this project has the potential to increase the European power generation from biogas by 20%. Widely energy self-sufficient facilities can be established by an efficient utilisation of the biogas thus fossil fuels are replaced.

Safe Food and Feed through an Integrated Toolbox for Mycotoxin Management (MyToolbox)

MyToolBox mobilises a multi-actor partnership with 50% industry participation (farmers, technology SME, food/feed industry), as well as academia and policy stakeholders, to develop novel interventions aimed at achieving at least a 20% reduction in crop losses due to biological (fungal) and mycotoxin contamination. Cutting edge research will result in new interventions, which will be integrated together with existing measures (such as HACCP & GAP) in a web-based Toolbox that will guide the end-user as to the most effective measure(s) to be taken to reduce crop losses taking account of individual circumstances such as geographical location, climatic conditions, land-use, crop management & storage and intended end-use. We will focus on small grain cereals, maize, peanuts and dried fruit (figs), applicable to agricultural conditions in EU and China. Crop losses using existing practices will be compared with crop losses after novel pre-harvest interventions including investigation of genetic-resistance to fungal infection, cultural control, replacement of conventional fungicides with novel bio-pesticides (organic-farming compliant), competitive biocontrol treatment and development of forecasting models to predict mycotoxin contamination at an early stage. Research into post-harvest measures including real-time monitoring during storage, innovative sorting of crops using vision-technology and novel milling technology will enable cereals with higher levels of mycotoxin contamination to be processed without breaching regulatory limits in finished products. Research into the effects of baking on mycotoxin levels will provide better understanding of process factors used in mycotoxin risk assessment. Investigations will also extend to animal feed and novel uses of highly contaminated crops. Involvement of leading academic partners from China will aid in establishing international cooperation in mycotoxin research and, in particular, the initiation of a formal EU-China dialogue.

5 Brazil[9]

Brazil is recognised worldwide for the high share of renewable energy in its national energy matrix. In 2016, according to the 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.

Over the past years various plants for the production and utilisation of biogas have been established in the country. In fact, this sector has been growing steadily. Helping this progress is the 2015 regulation for biomethane. It establishes a standard definition (a Normative Resolution) for biomethane produced from biodegradable materials originating from agroforestry and organic waste and the regulation applies to nationwide use of biomethane as a fuel for vehicles, commercial shipping and for residential use. The standard 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, dated 29.6.2017, 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 the Biogas National Registry (*Cadastro Nacional de Biogás*), maintained by the International Center on Renewable Energies – Biogás (CIBiogas), there were 165 plants in operation in Brazil in 2016, with a total biogas production of around 2.2 million Nm^3/day, or 5,219 GWh/year in terms of energy (Table 5.1). The most utilised substrates were agricultural and industry residues, constituting 49% and 33% of the feedstock respectively. However, the highest share of the biogas (58%) was produced in sanitary landfills.

*Table 5.1. Current biogas production in Brazil (data from 2016)**

Plant type	Number of plants	Production (GWh/year)*	Share (%)
WWTP	10	210	4.0
Bio-waste	9	33	0.6
Agricultural	81	1,049	20.1
Industrial	54	877	16.8
Landfill	11	3,050	58.4
Total	**165**	**5,219**	

** = Produced energy as electricity, heat, mechanical energy and vehicle gas, excluding efficiency losses.*

The Energy Research Office - EPE (*Empresa de Pesquisa Energética*), an agency related to the Ministry of Mines and Energy of Brazil, has published studies regarding the technical potential of biogas in the

[9] The information in this section is the same as in the 2017 report.

country. In fact, the estimated biomethane production potential for 2014 was approximately 18.5 million Nm^3/day, and 4,346 MW of installed electrical capacity (from only agricultural residues and urban solids). Another study referred to a projection of their economic potential (including sanitary sewage and industrial residues). It indicated that, considering the baseline scenario, the installed capacity of the biogas-fuelled combined heat and power plants will amount to 458 MW in 2030 and 2,850 MW in 2050, corresponding to 2.33 million Nm^3/day and 15.25 million Nm^3/day of biomethane, respectively. The estimated production of biomethane points to 5.78 million Nm^3/day in 2030 and 36 million Nm^3/day in 2050.

5.2 Utilisation of biogas

In 2016[10], 37.6% of the biogas power plants used biogas to generate thermal energy, and 56.4% to generate electric energy (Table 5.2). In the meantime, only 21,9% of all biogas generated in Brazil was used for thermal energy. 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.

The use of biogas for the generation of mechanical energy is widespread in Brazil. This has to do with the necessity for pumping the liquid slurry originating from the pig production facilities for the purpose of crop fertilisation. Another important factor is the availability of biogas from bio-digesters installed in mid-2006 to provide for the Mechanism of Clean Development – a procedure contained in the Kyoto Protocol, which was abandoned after the fall of the of carbon credit price.

*Table 5.2. Utilisation of biogas in Brazil (data from 2016)[11]**

Utilisation type	Number of plants	Utilisation** (GWh/y)	Share (%)
Electricity	93	4,020	77.0
Heat	62	1,143	21.9
Mechanical	6	40	0.8
Vehicle fuel	4	20	0.4
Flaring	n.a.	n.d.	-
Total	**165**	**5,223**	

** = Categorised according to the main type of utilisation – a few cases of multiple applications*
*** = Calculated from the reported or estimated raw biogas production in volume (m^3/y) and an assumption of 64% CH_4 content.*

There are 5 upgrading plants in operation in Brazil, 2 use scrubber upgrading techniques and 3 uses PSA. The biomethane produced is utilised to generate electricity and vehicle fuel (Table 5.3).

There are three private filling stations for compressed biomethane, two in Parana and one in Rio Grande do Sul. There are 110 vehicles utilising biomethane in Brazil, 70 in Paraná and 40 in Rio Grande do Sul. The biomethane market in the country is still incipient, with some projects in planning or installation, but there is a great prospect of growth.

[10] In the updating of the quantitative data of this report for the year 2016, only the electric power plants and biomethane production were added, with no data available on the growth of the quantity of plants with thermal use.
[11] CIBiogas (2016) (https://cibiogas.org/biogasmap)

*Table 5.3. Biogas upgrading plants in Brazil (data from 2017)**

Location	Substrate/Plant type	Utilisation	% CH_4	Upgrading technology	Plant capacity (Nm³/h raw gas)	In operation since
Foz do Iguaçu, Paraná State	Organic residues	Vehicle fuels	96,5%	PSA	10	2017
Marechal Cândido Rondon, Paraná	Swine and dairy cattle wastewater	Electricity	> 96,5%	Water scrubber	50	2009
Montenegro, Rio Grande do Sul	Codigestion - Laying hens wastewater; dairy, cellulose and citrus juices industry wastewater; and slaughterhouse wastewater	Vehicle fuel	0,97	PSA	500	2012
Santa Helena, Paraná	Codigestion - Laying hens and beef cattle wastewater	Vehicle fuel	> 96,5%	PSA	42	2013
São Pedro da Aldeia, RJ	Landfill	Heat	97%	Water scrubber	1,200	2016

5.3 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 that changes 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 with biogas from landfill 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 Canada

In 2017, renewable energy technologies provided 2,120 PJ of energy, corresponding to 17% of Canada's total primary energy supply or 67% of its electricity production. Bioenergy currently contributes an estimated 26.7% of this renewable energy, with the majority being derived from the combustion of solid biomass (23.1%), followed by the combustion of liquid biofuels (2.4%) and biogas (1.2%)[12].

In Canada, biogas production takes place at landfills and in anaerobic digesters. Production, capture and use of biogas has been driven by waste management, energy and climate change policies that are largely provincially regulated. In the case of landfills, biogas capture has first been a safety and odour issue, and then a greenhouse gas mitigation measure. Anaerobic digesters have been constructed primarily to reduce the organic loading of waste streams, to stabilize bio-solids and to mitigate nutrient and pathogen impacts of livestock operations in certain parts of the country. Depending on the location of the landfill or digester and the energy demand of the facility, biogas is used internally for heat and power, piped to a nearby user, converted into power that is sold to the grid or upgraded to renewable natural gas (RNG).

Restrictions placed on the landfilling of organic materials and climate change mitigation measures, in particular, renewable fuel mandates and carbon pricing, are renewing interest in biogas RNG production. Two Canadian Provinces have set RNG targets and a new federal regulation (known as the Clean Fuel Standard) is under development that proposes natural gas fuel suppliers be required to reduce their carbon intensity as of 2023. Canadian producers of biogas and RNG can also take advantage of U.S. climate change policies and programs, with some facilities selling their RNG to the California's carbon market.

Going forward, it is expected that waste management, energy and climate change policies will continue to shape the development of the biogas and renewable gas industry. Both clean electricity and renewable gas policies will likely be needed to support the growth, build out and adoption in rural and urban areas of the country.

6.1 Production of biogas

The total number of landfills, with gas capture and use, and operating anaerobic digestion (AD) facilities is estimated to be around 150, with 6 to 10 facilities under construction. In addition, there exist close to 60 landfills where landfill gas is captured and flared. The types of AD facilities include wastewater treatment plants (WWTP) treating bio-solids, digesters treating source separated organics, industrial AD systems treating wastewater in agri-food processing plants and pulp mills, and on-farm digesters. The categories shown in Table 6.1 do have some overlap. That is, industrial wastewater, particularly from small operations, is often treated in municipal wastewater treatment systems and on-farm digesters almost always co-digest manure with local sources of organic material. At present, Canada does not grow, nor use energy crops for biogas production. The potential exists to co-digest crop residues, but this is not commonly practiced.

There is no official tracking of biogas production on a national basis. The facility numbers are taken from two recent surveys completed for the federal government departments of Environment and Climate Change Canada and Agriculture and Agri-Food Canada. Only partial information exists on total energy and biogas production.

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[12] Renewable Energy Facts. https://www.nrcan.gc.ca/science-data/data-analysis/energy-data-analysis/energy-facts/renewable-energy-facts/20069 Last accessed: January 15, 2020.

Table 6.1. Biogas production in Canada (2019).

Plant type	Number of plants	Share (%)*
WWTP	31	20.7
Bio-waste	12	8
Agricultural	37	24.7
Industrial	25	16.7
Landfill	45	30
Total	**150**	

**Referring to the number of plants, as the production is not reported.*

The Canadian Biogas Association estimates that biogas currently generates at least 195 MW of electricity and 400,000 GJ of renewable natural gas in Canada. These numbers are considered to be conservative as they do not include data from all biogas-generating facilities, including landfills. Work is underway to improve data collection. In 2018, Canada's landfills[13] generated 272 kilotons of methane that was used for energy, however 202 kt CH_4 was captured and flared.

6.2 Utilisation of biogas

Biogas use strongly depends on its own internal energy demand, its physical location (near users and infrastructure) and the policies that promote clean electricity, heat recovery, renewable natural gas, and GHG reduction in different sectors of the economy. Over the last few years, most electricity feed-in-tariff programs have closed and focus has shifted to the development of renewable natural gas.

Approximately half of the generated biogas is converted into electrical energy, with the remainder going to heat and electricity (25%); heat only (10%); RNG (4%); and electricity and RNG (1%)[14]. The main forms of biogas use are described qualitatively in Table 6.2 for the different types of biogas production facilities (XX = dominant use, X = secondary use). Again, there are too many data gaps to provide percentages.

Table 6.2. Utilisation of Biogas in Canada (2019). XX = dominant use, X = secondary use

Plant type	Biogas end-uses		
	Heat (boiler)	Power (co-generation)	Upgrading (number of facilities)
WWTP	XX	X	1
Bio-waste	X	XX	4
Agricultural		XX (35 facilities)	2
Industrial	XX	X	0
Landfill		XX	4

Landfill gas, for example, can be captured and flared or used for energy. Of the 105 recorded landfills, 26 use the landfill gas for energy, 60 flare the gas, and 19 use a portion of the gas and flare the rest. Approximately 8 facilities pipe their gas to a nearby industrial user such as a gypsum plant, greenhouse, forest products manufacturer or steel plant. However, as most landfills are located outside of communities, most captured landfill gas is converted into electricity via cogeneration units.

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13 Environment Canada - Waste Incineration in Canada 1990-2018 – A Summary of Findings from Surveys Conducted in 2006-2018; Kelleher Environment Biogas RNG Database May 2017 for ECCC; Agriculture and Agri-Food AD Facility Database (June 2019); Unpublished internal Environment Canada Report. Ottawa (ON): Pollutant Inventories and Reporting Division, Environment Canada.

14 Jain, S. Canada Market Report. World Biogas Association. https://www.worldbiogasassociation.org/canada-international-market-report/.

More and more municipalities are requiring separation of organics from the municipal solid waste stream, and some have implemented landfill bans. Consequently, anaerobic digestion of source-separated organics (SSO) is growing in Canada. The generated biogas is used to meet internal energy needs and, depending on its location, is either used directly by a nearby industrial facility, converted into clean power, or upgraded into RNG that is used by facility trucks, district energy systems or injected into the natural gas pipeline infrastructure. The end-use is influenced by the Province's clean energy direction with the Provinces of British Columbia and Quebec, that have RNG mandates, favouring RNG end-uses while electricity end-uses being more prevalent in the other provinces.

Wastewater treatment plants, with digesters in place to stabilize their bio-solids, mostly use the biogas to meet their internal energy needs via a boiler and/or cogeneration system. Similarly, industrial facilities in the agri-food processing and pulp and paper industries have significant energy requirements and use the biogas internally, typically burning it in a boiler to produce process steam and displace natural gas use.

In most cases, digesters on farms will not be able to use all of the energy produced by their AD systems. Most farms will have cogeneration systems in place and sell their electricity to the grid. Two farms in British Columbia are upgrading their biogas to RNG and selling it to the natural gas utility. A new biogas cooperative under development in Québec is also planning to upgrade its biogas to RNG for injection into the nearby natural gas pipeline.

At present, there are 11 biogas to RNG upgrading facilities operating in Canada, with most of the development concentrated in the Provinces of British Columbia and Quebec that have respective RNG mandates of 15% by 2030, and 5% by 2025. The RNG is usually injected into the natural gas pipeline and used wherever the natural gas is distributed. There are at least 2 facilities that use the RNG to fuel their truck fleets.

6.3 Financial support systems

Municipal landfill and AD projects have almost entirely been funded through public infrastructure, economic development or climate change program funds of regional, provincial and federal governments. They have included federal programs such as the Green Municipal Investment Fund, Innovative Clean Energy Fund, and Energy Cogeneration form Agriculture and Municipal Wastes. Over the past 2 decades, there have only been a handful of funding programs that have specifically funded AD projects. One of the most well-known programs was the Ontario Biogas Systems Financial Assistance Program that supported 25 projects in the agriculture and agri-food sectors with grants for capital costs and feasibility studies. Alberta's Bioenergy Infrastructure Development Fund also supported biogas projects, and today Quebec's PTMOBC (Program for Processing Organic Matter using Biomethanization and Composting) is supporting a number of SSO projects. Some of the programs are/were also open to industrial applicants and agriculture producers, but all non-municipal projects require private sector investment from internal funds and/or bank loans.

In addition to support for raising capital, revenues from tipping fees, premiums for renewable energy production and carbon credits are considered necessary for the financial viability of AD facilities. Provincial feed-in-tariff (FIT) programs were key to biogas to energy projects, providing biogas producers with the bankable security of a 15 to 20 year power purchase agreement. The Province of Ontario offered the highest FIT rates of 0.165 to 0.258 CAD/kWh for electricity from biogas, and not surprisingly has the largest number of biogas to power facilities in the country.

Today focus is being placed on the RNG market, and utilities in the Provinces of British Columbia and Quebec, respectively, can pay up to 30 CAD/GJ and 15 CAD/GJ for pipeline quality RNG. The new Clean Fuel Standard, currently under development, intends to create a GHG emission reduction requirement for natural gas and propane, and an opportunity for biogas producers and RNG suppliers to earn carbon credits.

6.4 Innovative biogas projects

Lethbridge BioGas[15] operates a high temperature, high-pressure thermal hydrolysis process ahead of its anaerobic digester. This technology, developed by the Canadian firm Biorefinex, destroys all infectious agents in the incoming biomass, allowing specified risk material to be treated in this AD system.

The digestion of SSO is growing in all parts of the country. In the Province of British Columbia, Surrey Biofuels (private-public partnership) can treat 115,000 tonnes of SSO per year and uses the resulting energy to fuel its waste collection trucks and supply energy to a local district heating system. In Québec, the biogas produced from digestion of SSO from three municipalities[16] is used by the Greenfield Global's ethanol plant in Varennes for process energy. The biogas displaces approximately 15% of the plant's natural gas use, and consequently lowers the carbon intensity (GHG footprint) of its ethanol product.

In the agriculture sector, farm size can limit the adoption of an AD system. That is, many livestock farms are too small to justify the capital investment – even with 50% co-digestion. Two new approaches are being tested, namely the installation of "package digesters" for small dairy farms, and the creation of farm cooperatives to collect manure from several farms with a third party operating the digester and upgrading the biogas. Harcolm Farms, a 75-cow dairy farm in Ontario, purchased a small-scale digester manufactured by Bioelectric (Belgium), installed the system within one week in January 2018, and has been successfully operating this unit, producing energy for its operations and for sale to the grid. In Québec, a cooperative has been set up in Warwick to collect feedstock from 10 dairy farms and a local food processing plant, and centrally digest this feedstock to produce 83,500 GJ of pipeline grade RNG and high quality digestate. Construction is expected to be completed in 2020.

Finally, on the digestate side, there are number of technologies being tested to concentrate nutrients from digestate streams. This work will be reported during 2020.

15 www.lethbridgebiogas.ca/technical/
16 www.ethanolproducer.com/articles/16272/waste-not

7 Denmark

The "Green Growth" initiative, which formed the basis for a political agreement in June 2009, includes the objective that 50% of the livestock manure is to be used for green energy in 2020. This requires a significant acceleration of biogas deployment in Demark. In March 2012, the Danish Government entered a broad energy policy agreement, valid for the period 2012–2020. The agreement calls for a significant enhancement of the share of renewables in the Danish energy supply. The main aim is to make Denmark free from fossil fuels by 2050. Biogas is a key element in the 2012 energy agreement, which is dominated by wind energy.

7.1 Production of biogas

172 biogas plants were in operation in Denmark in 2018, producing 13.4 PJ (3.7 TWh) energy (Table 7.1). The majority of the production, 85%, is from agricultural plants and feedstock, either based on single farms or centralised plants in clusters of farms. The overall role of biogas in the future Danish energy supply is to balance the wind-dominated electricity production. In the last years, biogas has also been seen as an important and economically advantageous tool for the mitigation of climate change and reduction of CO_2 emissions from the energy-, transport- and agricultural sectors. Thus, biogas will help convert the transport sector from fossil to "green" fuels.

Table 7.1. Biogas production in Denmark (2018)[17].

Plant type	Number of plants	Production (GWh/year)	Share (%)
WWTP	51	308	8.3
Bio-waste	-	-	-
Agricultural	86	3,175	85.3
Industrial	7	193	5.2
Landfill	28	47	1.2
Total	**172**	**3,723**	

A significant expansion of biogas capacity started with the 2012 Energy Agreement. Further expansion is forecasted for the next decades. This is a major challenge, as it requires availability of suitable biomass co-substrates, in sufficient amounts, to be co-digested with manure and slurry. The available co-substrates such as organic industrial waste is estimated to be depleted. The use of other co-substrates is challenging due to either low potential, relatively high costs, or technological challenges, related to their use in biogas plants. The potential of biomass to biogas is expected to be stable until 2020. The amounts of manure and slurries are expected to decrease by approximately 5%, while a slightly higher share of the total is expected to be supplied for biogas production. The available amounts of crop residues, especially straw, but also by-crops and crop silage are also expected to increase. The co-substrates with high potential are straw, deep litter, source separated household waste, industrial organic waste and grass cover from natural areas. The share of energy crops and by this their potential in the future deployment of biogas production in Denmark will be decreasing and eventually reduced to zero, due to sustainability considerations. The highest priority will be to use the waste materials easily available, as pointed out by the Danish government already in 2013, in the document "Resource strategy – Denmark without waste".

Phosphorus limits – more environmentally friendly consumption of phosphorus on the individual farms

The previous harmony rules were abolished from August 2017, after it was noticed that they would lead to accumulation of 250 kg P/ha over 25 years. The new rules give possibility of using a maximum of 170 kg

[17] Personal communication with Søren Tafdrup /Danish Energy Agency and Bruno Sander/ Danish Biogas Association-2019

N/ha from livestock manure (Nitrate Directive); with exemption for cattle farms with eco-friendly land use (230 kg N/ha from livestock manure). The new N-rules will worsen P-accumulation. The need to set up phosphorus limits for the supply of phosphorus by all kind of phosphorus fertilizers (commercial fertilizers, manure and other fertilizer types, such as sewage sludge) occurred. The new phosphorus limits vary between farms, depending on the type of farm, the crop rotation, the soil, the P-reserve on soils, the animal feeding practices, etc. This means that some farms will have higher limits than earlier, while others will have lower. The exemption for the cattle farms means that a specific farm can increase its harmonic demand from the normal 170 kg N/ha to 230 kg N/ha, given the fact that the cattle breeder grows its fields more environmentally friendly under certain strictly prescribed conditions. These conditions mean e.g. a crop rotation with a particularly high nitrogen uptake and a long growing season, for at least 70% of the farm's area. In addition, the farm must meet requirements of ploughing down the nitrogen rich crops (leguminous) and of making laboratory tests of nitrogen and phosphorus content of the soil, every 4 years. The main aim of the new P-regulation is to achieve an average decreasing P accumulation in soil (protection level) on long term.

7.2 Utilisation of biogas

In 2018, 54% of the produced biogas in Denmark was upgraded in the 34 upgrading units established at the AD plants. Furthermore, 17% of the biogas was used for power generation and 29% for heat production (Table 7.2 and Figure 7.1).

Some significant economic benefits are the drivers behind the great interest for biogas up-grading/grid injection. The first Danish biogas upgrading plant was established in Fredericia in 2011. Biomethane represents today more than 10% of the gas in the natural gas grid (18,6% in July 2018). The share of biomethane is expected to be 30% by 2023 and 100% green gas utilisation can be reached by 2035. Biomethane proves to be a major contributor to reach the national climate goals and the goals in the Paris Agreement. Biomethane can be stored in existing gas facilities, balancing other green energies (wind and solar) at no extra cost. New-built biogas plants have gas upgrading facilities, and most of the older ones have been refurbished, adding gas upgrading units. The cost of biogas upgrading is 3 EUR/GJ (Danish Energy Agency).

Use of compressed upgraded biogas (CNG) for city busses and trucks is also increasing. The main drivers for this are pollution avoidance and economic incentives, as biogas is cheaper than imported diesel. The main barrier is the high taxation of biofuels in Denmark, about 40% higher than of diesel. There is a political interest to remove this barrier, in order to promote use of biogas of biofuel for transport. The number of filling stations increased to 18 in 2018. There is no LNG used for transport in Denmark.

Table 7.2. Utilisation of biogas in Denmark (data from 2018)[18]

Utilisation type	Utilisation (GWh/y)	Share (%)
Electricity*	619	17
Heat	1,101	29
Upgraded	2,003	54
Flaring	3	< 1
Total	**3,723**	

** = including heat losses*

[18] Personal correspondence with Søren Tafdrup /Danish Energy Agency and Bruno Sander / Danish Biogas Association.

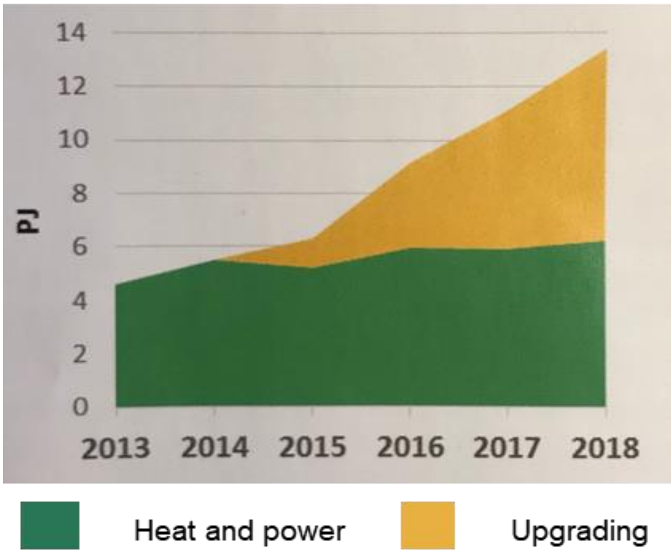

Figure 7.1. Evolution of biogas utilisation in Denmark, 2013-2018

7.3 Financial support systems

An improved financial support package for the biogas sector was adopted and approved by the EC in 2013. Removal of the restriction that the support cannot be given for both investments and operation was also approved by the EC in 2014.This consolidated the confidence in the future of biogas and consequently boosted the deployment of biogas in Denmark. The main elements of the Danish support system for biogas are:

- 0.056 EUR/kWh for biogas used in a CHP unit or injected into the grid (115 DKK/GJ)
- 0.037 EUR/kWh for direct usage for transport or industrial purposes (75 DKK/GJ)

These tariffs include natural gas price compensation of maximum 3.5 EUR/GJ (26 DKK/GJ) and temporary support of 1.34 EUR/GJ (10 DKK/GJ) up to 2016. It is also possible to apply for investment grants for plants digesting mainly manure. Support for upgraded biogas supplied to the natural gas network in calendar year 2013 was 111.6 DKK/GJ. The support is payable to upgraded biogas supplied to the natural gas grid and to purified biogas entering a town gas grid. This support is provided with effect from December 1st 2013. In the energy agreement, new support frames for biogas to transport and other applications were also agreed:

- 10.6 EUR/GJ in basis subsidy for combined heat and power heating (direct and indirect subsidies)
- 10.6 EUR/GJ in basis subsidy for upgrading and distribution via the natural gas grid
- 5.2 EUR/GJ in basis subsidy for industrial processes and transport

In addition:

- 3.5 EUR/GJ for all applications – scaled down with increasing price of natural gas. If the natural gas price the year before is higher than a basis price of 7.1 EUR/GJ the subsidy is reduced accordingly.
- 1.34 EUR/GJ for all applications – scaled down linearly every year from 2016 to 2020 when the subsidy expires.

A new energy agreement was signed in June 2018 and enforced in April 2019. The agreement intends to control the growing expenses for biogas production and includes a support of a total pool of EUR 32.2 million annually. The support will go to biogas and other green gases used for upgrading, transport and industrial processes, in the period 2021-2023. At the same time, the existing biogas support schemes will be closed for plants built after 2020.

The 2018 agreement stipulates:

- From January 1st 2020, no new built biogas plants are subsided (it was possible to get a dispensation, if you already have signed contracts for building a new plant)
- Biogas plants built before January 1st 2020 are subsidised through feed-in tariffs, until the end 2032. After this date, there will be no subsidies. The feed-in tariff is a combination between the gas price and a fixed price (government support). The fixed price is based on last year's gas price and is fixed ultimo January, for the coming year.
- Biogas plants build before January 1st 2020 are assigned a production maximum, in order to control the finances.

The new biogas production for electricity generation will in the future be supported through a comprehensive support scheme for biomass and biogas for cogeneration, while there will be no support for new biogas plants for heat production. The government estimate that the effect of these measures will be a total biogas production increase to around 23 PJ/year (6.4 TWh).

8 Estonia

The Estonian energy consumption has historically been mostly reliant on local woody biomass. During the industrial revolution it became highly concentrated and oriented towards one energy source – oil shale. The significance of other sources, including renewable sources, has been low, especially before the EU accession. However, Estonia's entry into the European Union influenced its emphasis on renewable energy and the share of renewable sources has been growing steadily ever since. While Estonia is producing nearly double the target of renewables, use in the transport sector is greatly lagging behind, barely reaching 3.4% in 2018.

However, Estonia has set ambitious targets for transitioning into a low-carbon economy. In 2017, the Estonian Parliament adopted the General Principles of Climate Policy until 2050, where they committed to reducing greenhouse gas emissions by at least 80% by 2050, compared to 1990. In October 2019, the Government of Estonia endorsed setting the climate neutrality target across the EU. This increased level of ambition can only be met by a combination of increased uptake of renewables, energy efficiency and innovative technologies. In Estonia – a country to 50% covered by forests – biomass will play a key role in transitioning towards climate neutrality.

Estonia's renewable energy share of gross final energy consumption was 29.2% in 2017, well above the country's mandatory EU 2020 target of 25%. Looking to 2030, Estonia has established goals for renewable energy shares of up to 50% in both gross final energy consumption and electricity generation, and renewable energy shares of 63% in heat production and 14% in transport.

Since 2017 the Estonian government launched additional support schemes to stimulate the uptake of renewable energies, especially biomethane, in the transport sector. It is estimated that Estonia has the resources to produce up to 4.2 TWh (450 million Nm^3) of biomethane per year, the raw materials for which would mainly be biomass from grasslands and waste from agricultural production. In addition, biodegradable waste from industry and landfills as well as sewage from wastewater treatment plants can be used for that purpose. Biomethane can also create synergies between the transport sector, the waste sector and agriculture. Biomethane will contribute to the reduction of CO_2 emissions in transport and agriculture, using e.g. silage and slurry to produce transport fuels would prevent emissions of agricultural greenhouse gases into the atmosphere. Instead, the technology would help to capture the harmful gases and convert them to fuels.

8.1 Production of biogas

The Estonian biogas sector took its first steps in the 1980s, when 2 piggeries built the biogas plants in Läänemaa and Pärnumaa. In the beginning of the 1990s the first landfill and wastewater based plants were constructed in Pääsküla and Tallinn, respectively. Many landfills followed this example (Jõelähtme, Väätsa, Pakre and Uikala). The first biogas plant based on agricultural residues was in built in Saaremaa (Saare Economics) in 2008 with support from Nordic environmental funding facilities (Nefco). The rest of the agricultural biogas plants were built with investment support from Estonian Environmental Investment Center (KIK) in order to convert local central district heating boiler-houses into co-production units based on renewable fuels.

Biogas production in Estonia has been considered as an efficient manure management method that produces electricity and heat for local consumption, but also for production of biomethane for the transport sector.

At the moment there are 17 active biogas plants in Estonia that can be divided into three types (Table 8.1):

a) Based on agricultural residue (5 plants)
b) Based on wastewater and industrial water treatment (7 plants, four and three respectively)

c) Based on landfill gas production (5 plants)

In addition, two of those biogas plants have invested in the hardware to purify biogas to biomethane. One, based on agricultural residues, is situated in Viljandimaa. The other, based on pulp production wastewater from Estonian Cell AS, is situated in Kunda. Both started operating in 2018.

Currently, a majority of the plants use biogas directly to power combined heat and power plants (CHP) to produce electricity and heat (Table 8.1).

Table 8.1. Biogas production and utilisation in Estonia in 2019, based on the production type.

Owner	Year	Substrate	Utilisation			
			Electricity (GWh)	Heat (GWh)	Methane (GWh)	Flaring
Aravete Biogaas OÜ	2008	Agricultural residue	6.6		-	+
Tartu Biogaas OÜ	2014	Agricultural residue	7.3	+	-	+
Oisu Biogaas OÜ	2013	Agricultural residue	9.0	2.3	-	+
Vinni Biogaas OÜ	2013	Agricultural residue	8.9	3.3	-	+
Saare Economics OÜ	2005-2018 (closed)	Agricultural residue	-	-	-	-
Biometaan OÜ	2018	Agricultural residue	-	-	12	-
Tallinna Vesi AS	1998	Sewage sludge	-	+	-	+
Tartu Vesi AS	2014	Sewage sludge	+	+	-	+
Narva Vesi AS	2005	Sewage sludge	-	-	-	+
Kuressaare Veevärk AS	2013	Sewage sludge	0.3	+	-	+
Rohegaas OÜ	2018	Pulp production waste	-	-	60	-
Eastman Specialities OÜ	1997	Toluene production waste	-	+	-	+
Salutaguse Pärmitehas OÜ	2002	Yeast production waste	-	+	-	+
Väätsa Prügila AS		Landfill	+	+	-	+
Tallinna Jäätmete Taaskasutuskeskus AS		Landfill	7.0	+	-	+
Paikre OÜ	Closed	Landfill	0.7	+	-	+
Uikala Prügila AS		Landfill	0.6	+	-	+
Aardlapalu prügila	Closed	Landfill	1.5	+	-	+

**all values are according to Estonian Biogas Association*

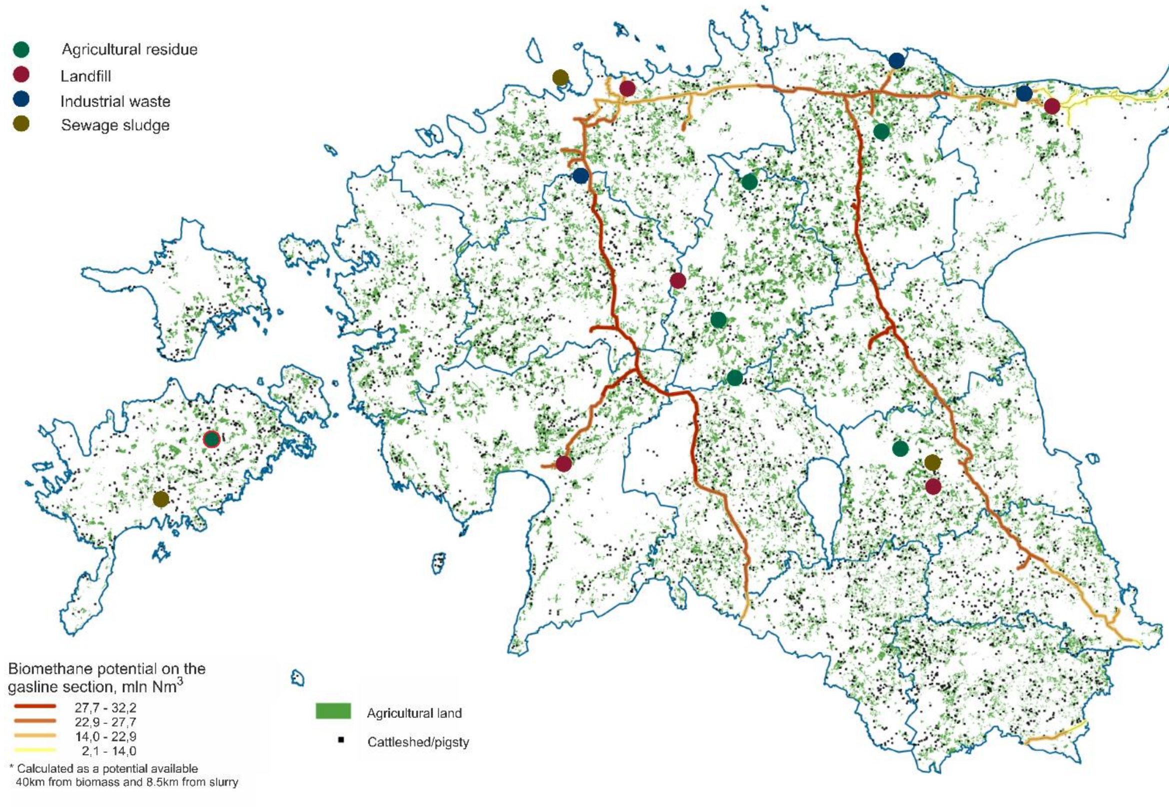

Figure 8.1. Estonian biogas plants in 2019

The biogas potential in Estonia was calculated with the preparation of the National Development Plan of the Energy Sector until 2030 and the accompanying action plans. The biogas potential for Estonia is estimated to 633 million Nm^3, of which 21 million Nm^3 would be from landfills. This includes a potential production of 450 million Nm^3 biomethane. The study concluded that biogas has large unused energy potential. In addition to operational heating installations and power plants that produce heat and electricity from biogas, biomethane produced from biogas can be an important resource for increasing the use of renewable energy in the transport sector. Additional utilisation of the biogas resources is currently not required to meet Estonia's overall target for renewable energy by 2020, but there is a need to identify cost-effective options for meeting the renewable energy target of the transport sector. Based on the experiences of neighbouring countries, the Renewable Energy Action Plan until 2020 includes measures for placing biomethane on the market and those measures are listed among the actions for the implementation of the NDPES 2030 measures.

8.2 Utilisation of biogas

Currently, a majority of the biogas producers use the biogas on site for heat and electricity production. However, measures have been taken in the past years to increase the use of biomethane in the transport sector. In 2018, two biomethane production units started working in Viljandimaa and Kunda.

The public transport in larger cities like Tallinn, Tartu and Pärnu is moving towards gas buses that would use biomethane as a fuel in the future. Tartu and Pärnu have already established full fleets of gas buses running on biomethane. The capital city, Tallinn, is planning to acquire 100 gas buses in the near future and expand this fleet to 300 later. In addition, the network of natural gas fuel stations is being developed all over Estonia that would be able to also distribute biomethane when the necessary production levels are reached in the upcoming years.

8.3 Financial support systems

In Estonia, the following support systems are currently in place:

- Biomethane refuelling station construction support – the measure is managed by Environmental Investment Centre (KIK) and its budget is 3 million euros. KIK covers up to 35% of the costs.
- Biomethane bus line kilometre subsidy for local governments – the measure is also managed by Environmental Investment Centre and its budget is 6 million euros. KIK covers up to 30% of the costs of one year line kilometre price.
- Sale of biomethane to the transport sector is managed by the Estonian grid operator Elering AS and is calculated as 100 €/MWh minus last month's natural gas average market price. The sale of biomethane to some other purposes (for example for heating) is calculated as 93 €/MWh minus last month's natural gas average market price. The whole budget for this measure is around 40 million EUR.

Additionally to the support schemes, Estonia has in place the GO (guarantees of origin) system for biomethane[19]. Through the GO system, it was recorded that last year the two biomethane producers in Estonia (Rohegaas OÜ and Biometaan OÜ) produced 40 GWh biomethane, which was all used in the transport sector. Moreover, Estonia has excise duty exemption on biomethane (excise duty is considered as zero).

Estonia's minimum 2030 target is to produce and consume 40 Mm³ (ca 375 GWh) of biomethane in the transport sector. Figure 8.2 shows the projected production of biomethane and the consumption of biomethane in the transport sector in Estonia until 2030 (calculated without multipliers).

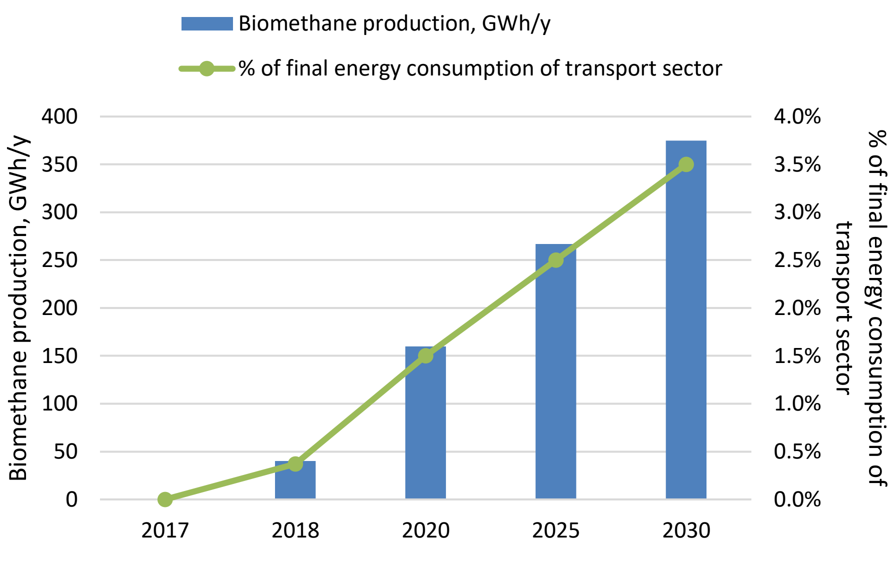

Figure 8.2. Planned development of total biomethane production and biomethane consumption in the transport sector

[19] https://biometaan.elering.ee/login

9 Finland

9.1 Production of biogas

In 2017, the total recovered energy production from biogas was 692 GWh from 96 different biogas production sites. Biogas production has increased (ca 11%) since 2016. For the first time landfills are not the major gas producers anymore, the amount of collected landfill gas as well as the utilisation of landfill gas decreased compared to 2016. About 30 GWh (109 TJ) biogas was used as vehicle fuel.

Table 9.1. Status of biogas production in Finland (data from 2017)

Plant type	Number of plants	Production* (GWh/year)	Share (%)
WWTP	16	162	23
Bio-waste	24	312	45
Agricultural	14	7	1
Industrial	4	15	2
Landfill	38	203	29
Total	**96**	**692**	

** = Produced energy as electricity, heat and mechanical energy, including efficiency losses. Huttunen et al, 2018, Suomen biokaasulaitosrekisteri n:o 21, University of Eastern Finland*

It has been estimated that theoretically up to 4–6 TWh/year biogas could be produced from waste and manure, but there are no official targets for biogas production. The potential biogas yield from grass silage is about the same amount, but present use is negligible. In addition, wood-based bio-SNG production by gasification could significantly add to the gas supply in the future.

9.2 Utilisation of biogas

Biogas is mainly used for heat and electricity production in CHP plants located at the biogas production sites or transported by pipelines for use in industrial processes. There are 17 biogas upgrading facilities, and upgraded biogas is used as vehicle fuel or injected into the natural gas grid. The usage of biogas as an automotive fuel has increased 41% compared to 2016. Vehicle fuel use has increased remarkably outside the natural gas grid.

Table 9.2. Utilisation of biogas in Finland (data from 2017)

Utilisation type	Utilisation (GWh/y)	Share (%)
Electricity*	178	21
Heat	505	60
Vehicle fuel**	30	3
Mechanical energy	15	2
Flaring**	121	14
Total	**849**	

** = excluding efficiency losses; **capacity, biomethane consumption as transport fuel 30 GWh, not included in the table. Source: Huttunen et al, 2018, Suomen biokaasulaitosrekisteri n:o 21, University of Eastern Finland*

The operational upgrading plants are in most cases using water scrubbing technology, but there are also a few using amine, membrane or PSA technology. There are 34 public filling stations for biomethane/CNG and 7 private fuelling stations in operation, mainly in the southern part of Finland. The most northern filling stations are located in Oulu. Most of the increase of biogas upgrading and filling stations has happened off grid. In total there are about 10,000 gas vehicles in operation in Finland. The first two public LNG stations were opened in Finland. On an energy basis, the prices of biomethane is about half that of petrol.

9.3 Financial support systems

The Energy Market Authority of Finland supports new biogas plants, which produce more than 100 kVA, with a feed-in tariff. It guarantees a minimum price of 83.5 EUR/MWh for electricity, but when the combined capacity of the generators exceeds 19 MVA no subsidy is paid. If the generated heat is utilised, 50 EUR/MWh heat premium on top of the basic subsidy is paid, provided that the total efficiency is at least 50% or at least 75% if nominal generator capacity exceeds 1 MVA.

In the feed-in tariff system, an electricity producer whose power plant is approved in the system will receive a subsidy (feed-in tariff) for a maximum of 12 years. The subsidy varies on the basis of a three-month electricity market price or the market price of emission allowances. These subsidies are paid up to the amount confirmed in the acceptance decision. When the price of electricity is below 30 EUR/MWh, the subsidy to be paid amounts to the target price less 30 EUR/MWh. A subsidy is not paid when the price of electricity is negative.

Feed-in-tariffs have been applied since March 2011 and since then 170,000 EUR has been paid for biogas production (two plants) while during the same period 84.4 million EUR has been used for wood-based bioenergy and 56.5 million EUR for wind energy.

Investment grants are paid by the Ministry of Employment and Economy to biogas plants which produce energy and do not meet the requirements of feed-in tariffs, but this kind of grant is not meant for residential buildings, farms or plants connected to the above-mentioned installations. A maximum of 30% of acceptable investment costs are supported provided that there is still money available in the budget for the investment year. The Ministry of Agriculture and Forestry supports biogas plants built on farms aiming at producing their own electricity and heat. More than half of the biomass must be from their own farm and more than 50% of the energy produced must be used on the farm. Part of the support is paid as a subsidy and part of it is a loan.

Finally, there is no excise tax on biogas.

9.4 Innovative biogas projects

Kalmari biogas plant has been in continuous operation since 1998. The plant has been updated during the years and the capacity has increased. Since 2015 the majority of the energy has come from the dry fermentation plant (batch process) which uses grass, silage, straw, horse manure and wood chips as biogas raw-material (Figure 9.1).

Figure 9.1. Dry fermentation process at Kalmari farm

10 France[20]

The vision of the French Environment and Energy Management Agency is to produce 70 TWh biogas annually by 2035 and that approximately 400 biogas plants are to be built every year. 60% of the biogas produced shall be injected into the grid, 40% shall be used to generate electricity and heat within CHP plants. In 2050, the aim is to produce 100 TWh/y.

10.1 Production of biogas

In France, at the end of 2017, there were almost 574 AD plants and 113 landfills producing biogas (Table 10.1).

Table 10.1. Status of biogas production in France (data from 2017)

Plant type	Number of plants	Electricity production (GWh/year)	Heat production (GWh/year)	Biomethane (GWh/year)
WWTP	88	41	401	
Bio-waste	16	67	22	
Agricultural	390	765	627	
Industrial	80	7	350	
Landfill*	113	953	294	
Total	**687**	**1,833**	**1,694**	**406****

** source ADEME : ITOM, les installations de traitement des ordures ménagères en France – Résultats 2010, octobre 2012; ** Renewable gas French panorama 2017 (in French), SER 2018.*

10.2 Utilisation of biogas

In France there is a strong development of on-farm and centralised biogas plants and for landfills to recover biogas for electricity generation (in 2017 only 113 out of 240 landfills utilised biogas). Around 390 on-farms AD plants were built by the end of 2017.

In addition, 88 WWT and 80 agri-food industry AD plants were operating in 2017. 16 MSW AD plants were always in operation in 2017. 47% of the energy recovered is transformed into electricity, 43% into heat and close to 10% into biomethane (Table 10.1).

At the end of 2017, 47 upgrading plants were in operation, of which 44 inject biomethane into the natural gas grid, producing 406 GWh of green gas. Today, all the biomethane produced is injected into the natural gas grid or sold in the compressed state as automotive fuel. There are 360 applications for injecting biomethane into the natural gas grid, which indicate an increase of the number of upgrading plants in the near future. The governmental plurennial energy programming (PPE) speaks of 8 TWh of biomethane injected into the natural gas grid by 2023.

10.3 Financial support systems

In France and its overseas territories, there is a feed-in-tariff system for electricity and biomethane. New tariffs for electricity have been published at the end of 2016 with some major changes and range from 150 to 225 EUR/MWh:

- Limit to 500 kW_e of maximum power to benefit from the purchase price
- The purchase electricity contract goes from 15 to 20 years
- The need to study the option of biomethane injection over 300 kW of electric power
- There is no more energy efficiency bonus

[20] The information in this section is the same as in the 2017 report.

- The rate is regressive from 2018 (0.5% per trimester)
- The bonus for manure is increasing by 10 EUR/MWh

Biomethane feed-in tariffs (values of 2018):

- Landfills (depending of volume): 47.7 to 100.7 EUR/MWh
- WWTP sludge (depending of the volume injected and the age of the plant): 55.1 to 142 EUR/MWh
- AD plants (depending of volume and the nature of the feedstock): 73.1 to 132.5 EUR/MWh

Some subsidies are possible via the French Agency for Environment and Energy Management through two financial funds: The Waste Fund and the Renewable Heat Fund. The subsidies depend on the nature of the investment and limited in amount or by the percentage of aid. Other subsidies can also be applied, including regional (Regional Councils) or European (FEDER) funds.

Figure 10.1. Collective unit in Mortagne sur Sèvre, west of France, owned by Agribiométhane Ltd. (picture: GRDF). The plant produces biomethane from manure and agri-food wastes. This is the first French plant that uses a PSA system to clean the biogas.

Figure 10.2. Collective unit in Vinzier, French Geneva Lake area, owned by Terragr'Eau Co (picture: GRDF). The plant uses various products from agro food biowaste and manure. This is the first French plant that uses an amine scrubber to clean the biogas.

11 Germany

In Germany, the share of renewable energies 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.

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. The annual available capacity for biomass including biogas is limited to a maximum of 150 MW_e compared to 2,800 MW_e for onshore wind and 2,500 MW_e for solar power, respectively.

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 potentials.

Furthermore, several regulations for biogas facilities are under revision or amendments are already enforced. The controversial safety regulation "Technische Regel für Anlagensicherheit (TRAS 120)" was published in 2019. The draft of the "Technical Instructions on Air Quality Control" (TA LUFT) was released in 2018 with its enforcement expected by 2020. 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 Immission Control Act) major changes are 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 2029 for existing plants.

In addition, there are further requirements for biogas plant operators resulting from the revised German fertilizer ordinance and the recast renewable energy directive (RED II), which entered into force in 2017 and 2018, respectively. The German fertilizer 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 fertilizers. Due to the revision of RED II, the 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 regards 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 agriculture sector.

11.1 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.

Regarding the energy provision, the 8,780 biogas plants in the agricultural sector made the biggest contribution to biogas production in 2018 with electricity and heat supplies of 31.5 TWh/year and 16.5 TWh/year, respectively (Table 11.1)

In 2018, a total number of 203 biogas upgrading plants were in operation with a feed-in capacity to the gas grid of more than 120,000 Nm^3/h biomethane (DBFZ, 2019) with a marginal increase in capacity of 2% compared to the previous year, delivered by 3 new plants.

Table 11.1. Status of biogas production in Germany (data from 2019, year of reference 2018)

Plant type	Number of plants	Energy production[21]* (GWh/year)	
		Gross electricity**	Gross heat[22]
WWTP	1,274[23]	1,490	2,167
Bio-waste	336 (136 + 200)[24]	865	392
Agricultural	8,270	27,978	12,677
Biomethane	203	2,712	3,455
Landfill	468[25]	300	122
Total	**10,551**	**33,345**	**18,813**

** = Fuel not included; ** = excluding efficiency losses*

The calculated total technical biogas potential available for energy provision varies between 155 and 265 TWh/year, in line with possible restrictions on usage of cultivated biomass for energy purposes in 2015. Around 30% of the calculated potential is currently used for biogas generation in Germany. Table 11.2 provides an overview of the total technical potential with respect to the substrates used for biogas production[26].

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[21] Federal Ministry for Economic Affairs and Energy (BMWi): Development of Renewable Energy Sources in Germany based on the data of the Working Group of Renewable Energy Statistics (AGEE-Stat), December 2016. (http://www.erneuerbare-energien.de/EE/Redaktion/DE/Downloads/zeitreihen-zur-entwicklung-der-erneuerbaren-energien-in-deutschland-1990-2015.pdf?__blob=publicationFile&v=11, accessed on 21.01.2017)

[22] Heat utilisation (external heat purposes excluding heat demand for biogas production); heat production from biogas and biomethane (without sewage sludge and landfills) in 2016 16.9 TWh_{th} in total (AGEE-Stat 2017); from biomethane-based CHP according to the Federal Network Agency (BNetzA); heat from biogas according to ratio of waste/agricultural plants

[23] Federal Statistical Office (destatis): https://www.destatis.de/DE/Presse/Pressemitteilungen/2019/09/PD19_340_433.html

[24] Substrate input of 136 plants ≥ 90% of bio-waste of the whole input amount per year (according to §27a EEG 2012, §45 EEG 2014); bio-waste is defined as separate collected municipal waste (e.g. kitchen waste, green waste); about 200 co-fermentation plants with substrate input < 90% of bio-waste including plants using agro-industrial residues.

[25] Federal Statistical Office (2019): Waste disposal, data for 2017 (https://www.destatis.de/DE/Themen/Gesellschaft-Umwelt/Umwelt/Abfallwirtschaft/_inhalt.html#sprg229182; including non-EEG landfills)

[26] Daniel-Gromke, J.; Rensberg, N.; Denysenko, V.; Erdmann, G.; Schmalfuß, T.; Hüttenrauch, J.; Schuhmann, E.; Erler, R.; Beil, M. (2017). Efficient small scale biogas upgrading plants: potential analysis & economic assessment. In: Ek, L.; Ehrnrooth, H.; Scarlat, N.; Grassi, A.; Helm, P. (Hrsg.) *Papers of the 25th European Biomass Conference*: *Setting the course for a bio-based economy*. *Extracted from the Proceedings of the International Conference held in Stockholm, Sweden*. Florence (Italy): ETA-Florence Renewable Energies. ISBN: 978-88-89407-17-2. pp. 1105–1109.

Table 11.2. Calculated total technical biogas potential in Germany in 2015 (data according to Daniel-Gromke et al. 2017[27])

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

11.2 Utilisation of biogas

According to information from the Federal Ministry for Economic Affairs and Energy (BMWi), in 2018 most of the biogas was used for electricity and heat production, while biomethane utilisation as a vehicle fuel dropped by 13% in comparison to 2017 (Table 11.3). The share of energy consumption from biogas incl. biomethane in Germany for electricity, heat and fuel amounted to 5.4%, 1.3% and 0.1%, respectively[28].

Table 11.3. Utilisation of biogas in Germany (data from 2019, year of reference 2018)

Utilisation type	Utilisation (GWh/y)	Share (%)
Electricity*	33,345	58
Heat	18,813	33
Vehicle fuel**	389	1
Flaring***	4,061	7
Total	**56,608**	

** = excluding efficiency losses*

*** = according to the Federal Ministry for Economic Affairs and Energy (BMWi), as to 08/2019*

**** = estimation, 5% flaring losses for all types of production but landfill (10%)*

According to the Federal Association of Energy and Water Industry (BDEW), the number of filling stations offering biomethane (partly up to 100%) remained at the lower level with 255 in 2018[29]. The amount of biomethane decreased to 389 GWh[30], which corresponds to 20.5% of the whole amount of natural gas sold in 2018 as a vehicle fuel[31].

11.3 Financial support systems

The amendment of the Renewable Energy Sources Act (EEG) 2017, which entered into the force on 1.1.2017, stands for the switch from feed-in tariffs models as applied in the previous EEG versions 2000 – 2014 to the auction models for renewable energies. Beside on- and off-shore wind and PV facilities the

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[27] Daniel-Gromke, J.; Rensberg, N.; Denysenko, V.; Erdmann, G.; Schmalfuß, T.; Hüttenrauch, J.; Schuhmann, E.; Erler, R.; Beil, M. (2017). Efficient small scale biogas upgrading plants: potential analysis & economic assessment. In: Ek, L.; Ehrnrooth, H.; Scarlat, N.; Grassi, A.; Helm, P. (Hrsg.) *Papers of the 25th European Biomass Conference*: *Setting the course for a bio-based economy*. *Extracted from the Proceedings of the International Conference held in Stockholm, Sweden*. Florence (Italy): ETA-Florence Renewable Energies. ISBN: 978-88-89407-17-2. pp. 1105–1109.

[28] Federal Ministry for Economic Affairs and Energy (BMWi): Time series for the development of renewable energy sources in Germany, based on statistical data from theWorking Group on Renewable Energy-Statistics (AGEE-Stat), as of 08/2019 (https://www.erneuerbare-energien.de/EE/Redaktion/DE/Downloads/zeitreihen-zur-entwicklung-der-erneuerbaren-energien-in-deutschland-1990-2018-en.pdf?__blob=publicationFile&v=8)

[29] Federal Association of Energy and Water Industry (BDEW): https://www.bdew.de/energie/erdgas/interaktive-karte-gas-kann-gruen/

[30] Federal Ministry for Economic Affairs and Energy (BMWi): Time series for the development of renewable energy sources in Germany, based on statistical data from theWorking Group on Renewable Energy-Statistics (AGEE-Stat), as of 08/2019 (https://www.erneuerbare-energien.de/EE/Redaktion/DE/Downloads/zeitreihen-zur-entwicklung-der-erneuerbaren-energien-in-deutschland-1990-2018-en.pdf?__blob=publicationFile&v=8)

[31] Federal Association of Energy and Water Industry (BDEW): Natural gas filling stations, as of 08/2019 (https://www.bdew.de/service/daten-und-grafiken/erdgastankstellen/)

newly built biogas plants with an installed electrical capacity of more than 150 kW_e as well as already existing biogas facilities can participate in auctions. In order to be able to participate, the biogas plants to be built should already have building permission and be registered with the Federal Network Agency (BNetzA). The existing biogas plants can bid in order to receive the follow-up 10-years funding only by compliance with flexible operation and only if they are entitled to a maximum of 8 years of further regular tariff payment. To further incentivize a demand-oriented generation of electricity from biogas, not more than a half of the maximum possible rated power will be remunerated for biogas and biomethane plants. Thus, it is necessary to install at least a twofold CHP overcapacity in relation to the average rated power output. The development corridor initially introduced within the EEG 2014 was further specified and is defined as following for two periods:

- from 2017 till 2019 – 150 MW_e of the installed biomass capacities
- from 2020 till 2022 – 200 MW_e of the installed biomass capacities can be auctioned each year.

The results of the auctions run in 2017 and 2018 are presented in Table 11.4. The maximum bidding value for new biomass plants in 2018 amounted to 14.73 c/kWh_e, whereas the maximum bidding value for existing biomass plants was 16.73 c/kWh_e with the regression of 1%/year (in comparison to the last auction round in 2018 with 6.26 c/kWh_e for onshore wind and 4.69 c/kWh_e for solar). It has to be stated that the result of the auctions run so far is that neither the auctioned volume for biomass was completely used nor were substantial cost reductions achieved. The reasons for that are challenging compliance requirements (technical requirements, permission for operation, new regulations) in particular for small installations and high costs of biomass installations, which are not covered by the available tariffs.

Table 11.4. Results of the biomass auctions in Germany in 2017-2018 (based on data of the The Bundesnetzagentur for Electricity, Gas, Telecommunications, Post and Railway (BNetzA), 2019)

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

The cap for maize input in biogas plants to be built is further specified within the EEG 2017. The utilisation of maize silage and corn (including whole crop silage, corn-cob-mix, grain maize and ground ear maize) is limited to maximum of 50% for the mass-based substrate input. The maize cap will be lowered in the future and thus will decrease to 47% in 2019-2020 and to 44% in 2021-2022[32]. Consequently, there are efforts towards further utilisation of alternative substrates such as wild plants (cup plants) and agricultural residues (straw, chaff, sugar beet leaves) for biogas and biomethane production due to their positive environmental effects and cost reduction potentials while using for biogas generation.

11.4 Innovative biogas projects

ELIRAS

In the sector of biogas production, substrate disintegration processes are key technologies for cost reduction, since they have an enormous potential for efficiency enhancement. However, the market for disintegration technologies is versatile and unclear. There are no objective and consistent criteria for evaluating disintegration effects on biogas production. The purpose of the project ELIRAS was to develop a guideline,

[32] Federal Ministry for Economic Affairs and Energy (BMWi): Renewable Energy Sources Act EEG 2017 (https://www.bmwi.de/Redaktion/DE/Gesetze/Energie/EEG.html, accessed on 14.02.2018)

which should examine the partial aspects of disintegration and as a result, provide recommendations concerning the principal introduction of disintegration on the particular biogas plant.

According to the approach elaborated within ELIRAS project, the impact of disintegration can be attributed to the following effects:

(1) increase of the digestable organic fraction
(2) increase of the reaction rate
(3) change in hydrodynamics

The experimental proof can be delivered within batch and continuous digestion tests on the lab scale. Here, a special attention should be paid to the fact, that an indication of a disintegration effect measured in a batch test is no valid basis for a prognosis of impacts in continuous processes, since the transferability of the results from batch to continuous mode is compromised[33.] A statistically and scientifically sound proof of effects from disintegration with semi-continuous digestion can be only done based on data retrieved from steady-state operation and under consideration of statistical aspects, such as the number of replicates.

BMP III

Within the Biogas monitoring program III (BMP III), 61 German biogas plants, including grid injection plants as well as small-scale manure plants (75 kW_e), were selected for detailed monitoring of process parameters with the aim to provide a comprehensive picture of the current state of the national portfolio. These data include, amongst others, substrate inputs, biogas production rates, heat flows, comprehensive lab analyses and economic data.

The methodological development will refer to the provisions in place for sampling and treatment, the process evaluation on mass and energy balances, assessments of the biological efficiency of the fermentation process as well as the evaluation of the fermentation process itself. On the commercial side, an assessment of economic conditions is carried out in order to shed light on relevant barriers to the development of the industry. Laboratory protocols and on-site sampling methods were harmonised amongst project partners and a round robin test was carried out to ensure that the acquired data is comparable.

The economic assessment reveals a broad range in terms of profitability of current biogas plants. Still being dependent on feed-in tariffs, premiums turn out to be an effective way of influencing the role of biogas plants in the energy system, e.g. by providing net stabilisation through flexible power provision or by stabilising manure. Further results will be the precise mass and energy balances of the selected biogas plants based on the acquired data in accordance with the available methods for balancing.

GAZELLE

An energy system based on renewable energies faces severe challenges such as fluctuating electrical power production from wind and sun; this has to be balanced in order to meet the power demand. Beside pumped storage hydro power stations and batteries, biogas con contribute to power on demand production. Time variable power production from biogas is possible, either by using gasholders to store surplus biogas or to vary the biogas production itself by substrate feeding management. Substrate feeding management for variable biogas production can be achieved using model predictive control strategies based on available biogas yields and substrate degradation kinetics. A demand oriented biogas production has the advantage of minimising the necessary gasholder volume and therefore, minimising costs. The project “GAZELLE – Integrated Control of Biogas Plants for Flexibilization and Energetic Optimization“ aims to combine substrate management, substrate pre-treatment, heat and gas management, process monitoring and model

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[33] Hofmann, J., Müller, L., Weinrich, S., Debeer, L., Schumacher, B., Velghe, F. and Liebetrau, J. (2019), Assessing the Effects of Substrate Disintegration on Methane Yield. Chem. Eng. Technol.. doi:10.1002/ceat.201900393

predictive control in order to reach a high level of process flexibility and economic efficiency of biogas plants. The overall objective of the project is to develop and test a biogas plant control-scheme based on stock exchange power tariffs (day-ahead-market) and substrate characteristics that includes meteorological data to calculate changes of the gasholder capacities as well as technological and economical restrictions (e.g. CHP start/stop frequencies and substrate prices).

EvEmBi

Within the research project "EvEmBi" - Evaluation and reduction of methane emission from different biogas plant concepts" (funded within the 11^{th} ERA-NET bioenergy call, started in April 2018), the existing technologies at biogas plants in the European countries represented by the project partners (Austria, Germany, Sweden, Denmark, Switzerland) were evaluated with regard to their methane emissions. Based on the quantified methane emissions at these different biogas plant concepts, strategies to reduce the emissions are deduced. A further objective of the "EvEmBi" project is the determination of emission factors (EFs) from individual biogas plant technologies and its transfer to EFs of the entire plant inventory of the particular countries. For that, an emission quantification model (EQM) was produced by using statistical information about the emissions from different plant components and about the distribution of certain technologies in the biogas plant inventory.

A large number of measurements have already been carried out in the participating countries and a number of individual mitigation measures have been implemented at some of the investigated biogas plants. For the determination of methane emissions in the particular countries, on-site approaches as well as remote sensing approaches were used.

A scheme for the determination of emissions by EQM was developed within the consortium. First EQM calculations to determine the emissions of different plant types have been carried out. From that, a comparison between individual biogas plant concepts is possible and enables the evaluation of the different plant concepts. As an example, Figure 1 depicts the EQM results of two real biogas plant types (where emission measurements were carried out during the earlier ERA-NET project MetHarmo).

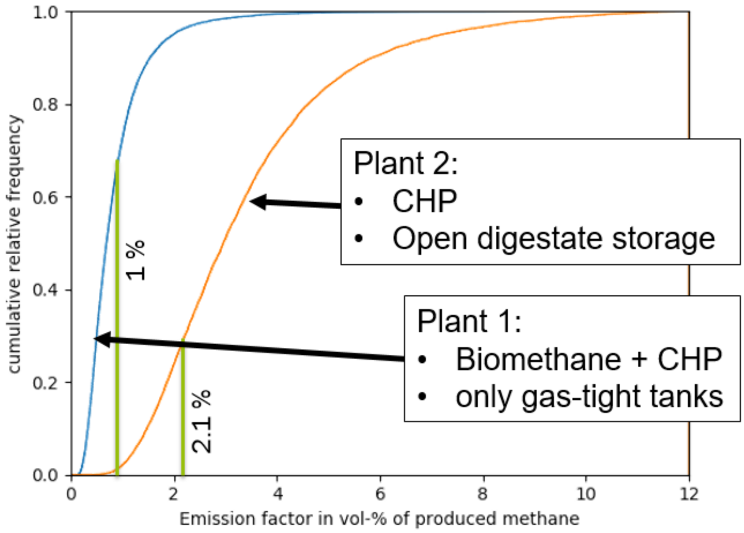

Figure 11.1. Cumulative distribution function of methane emission factor of two different biogas plant concepts. The green lines show the measurement results from measurement campaign at an individual biogas plant using this concept. Concept 1 uses only gas-tight tanks and uses a part of the gas in an upgrading unit. Plant concept two uses an open digestate storage tank and utilizes the gas via CHPs.

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.

SubEval - Evaluating substrates for biogas production from laboratory to industrial scale

Science and practice offer numerous investigation procedures and calculation methods for quality assessment of substrates and efficiency evaluation of their technological conversion to biogas. Up to now, a direct comparison of the different estimation procedures based on the dry matter content (DM, OM, FOM), caloric value, feed stuff or elemental analysis as well as the reference values of the KTBL is not possible. Thus, plant operators or financial service providers are not able to realistically evaluate the specific substrate utilisation (and process state) or the individual investment risk.

The main objective of the current project is to evaluate the different procedures in their significance, validity and practicality and to further advance the existing methods regarding a uniform and precise basis for substrate and process evaluation. Therefore, the individual theoretical and analytical procedures for the determination of the maximum biogas formation potential of common substrates need to be compared. Based on simplified kinetic models the results can then be used for mass or energy balancing and efficiency assessment of biogas plants. Furthermore, all analyses will be applied in laboratory, technical and full-scale digesters to evaluate the scalability of each individual method.

12 Ireland

The biogas industry has yet to take off in the Republic of Ireland despite a lot of studies on the potential of the industry. There are a number of reasons for this, including the relatively recent introduction of the support scheme for renewable heat. 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 heat demand due to need for pasteurisation of slurry imports and investment risk are some of the barriers mentioned. Gas Networks Ireland (GNI) the operator of the Gas Network have a strategy in place for 20% carbon neutral gas in the grid by 2030 rising to 50% by 2050. The remaining gas would be abated natural gas with carbon capture and storage.

12.1 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 wastewater 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 12.1 and Table 12.2.

Table 12.1. Biogas production in the Republic of Ireland (data from 2018)

Plant type	Number of plants	Installed capacity (MW_e)
WWTP	15*	n.d.
Bio-waste	3	3.5
Agricultural	12	6.4
Industrial	4	>8.7**
Biomethane	3	2.6
Landfill	22	64.7
Total	**59**	

Source: RGFI, Cre and IrBEA, nvpenergy, according to latest available data; n.d. = no data
** Data difficult to obtain ** data found for only output of 3 of 4 facilities*

Table 12.2. Biogas plants under construction in the Republic of Ireland (data assessed in 2019)

Plant type	Number of plants	Installed capacity (MW_e)
WWTP	n.d.	n.d.
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; n.d. = no data

SEAI commissioned a study on the economic potential for further development of biogas and biomethane in Ireland in 2017[34]. The report was overseen by a steering group, comprised of representatives from a range of relevant Government Departments, regulatory bodies and academic experts, and managed by SEAI. Stakeholder consultation, including a stakeholder workshop in September 2016 in Dublin, was an important component of the study. The report shows that the development of a sector focused on the use of food waste and animal manure can deliver societal benefits and increase biomethane and biogas production to a scale of approximately 12 PJ by 2050. Maximising the use of grass silage delivers a net benefit under favourable conditions. These include higher fossil fuel and carbon prices as well as lower silage production costs. Under these conditions, the equivalent of 28% (~34 PJ) of Ireland's current gas demand could come from biogas and biomethane by 2050. Grass silage is a resource with very large potential in Ireland but cultivation and supply chain emissions, as well as cost, may limit the accessible resource. Gasification with methanation for the production of green gas for gas grid injection needs to achieve significant cost reductions to deliver a net societal benefit but the study finds that power to gas has the potential to increase renewable gas production substantially.

12.2 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 m 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 released a strategy document in October 2019 entitled *Vision 2050: A net zero carbon gas network for Ireland*[35]. 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.

[34] Assessment of cost and benefits of biogas and biometane in Ireland, available in: https://www.seai.ie/resources/publications/
[35] https://www.gasnetworks.ie/vision-2050/net-zero-carbon/)

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.

12.3 Financial support systems

Support to biogas in the Republic of Ireland includes for REFIT, a support scheme for renewable heat, and landfill taxes.

REFIT closed to new applicants in 2017. The existing REFIT3 scheme offered tariffs in 2018/2019 as below:

- AD CHP equal to or less than 500 kW: 158.244 €/MWh_e (2018); 159.035 €/MWh_e (2019)
- AD CHP greater than 500 kW: 137.144€/MWh_e (2018); 137.83 €/MWh_e (2019)
- AD (non CHP) equal to or less than 500 kW: 116.045 €/MWh_e (2018); 116.626 €/MWh_e (2019)
- AD (non CHP) greater than 500 kW: 105.494 €/MWh_e (2018); 106.023 €/MWh_e (2019)

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 1000 MWh pa will be paid at 2.95 c/kWh of energy produced from anaerobic digestion heating systems. From 1000 to 2400 MWh pa will be paid at 0.5 c/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.

Figure 12.1. Biogas plant McDonnell Farms Limited. Primary Digester and first covered storage digester. David McDonnell milks 300 dairy cows in Limerick and also operates a free range poultry farm. In 2009/2010 he installed the most modern farm digester in Ireland which has a capacity of 250 kWe. (Source: SEAI (Sustainable Energy Authority of Ireland) Anaerobic Digestion: A case study – McDonnell Farms Biogas Limited, Shanagolden, Co. Limerick))

12.4 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:

- Development of policy and community based business model underpinning distributed energy recovery from residual biomass involving multiple stakeholder types
- ReBioGen - Development of policy and community based business model underpinning distributed energy recovery from residual biomass involving multiple stakeholder types
- Distribution System Optimisation & Mobile Pilot demonstration of Low temperature AD Technology
- SLURRES – a low cost technology and business model to mobilise livestock slurries for community based Anaerobic Digestion (AD)
- Development of a Syngas Conditioning System To Enable Use of Pyrolysis for Energy Recovery from Biomass Wastes and Residue (PYROPOWER)
- Micro scale Anaerobic Digester for digesting cooked and uncooked food waste from households and small food businesses
- Enabling the Bioenergy Sector to Understand and Assess Life Cycle Sustainability
- Planning Guidance Recommendations for the Bio Energy sector in Ireland

In 2018, the funding scale of the RD&D programme has increased and SEAI have partnered with 5 co-funding agencies. The 2018 Funding Programme provides the opportunity for applicants to submit proposals to either a thematic strand or open strand. The Open Strand provides an opportunity for applicants to propose projects within SEAI's legal remit, which directly address the aims and objectives of the SEAI RD&D Funding Programme Call. A number of the themes focus on biogas including a theme calling for demonstration of small-scale generation and aggregation of biogas suitable for grid injection

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

The SFI MaREI Centre[36] 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 12 Universities or research centres, and 50 industrial partners. MaREI includes for a number of research themes including for Bioenergy. The objectives of the bioenergy research include:

- Assessment of the financially feasible green gas resource in Ireland including for biogas production from organic residues and from grass
- Evaluation of the biomethane potential from various types of seaweed harvested at different times of year
- Interrogation of the optimum methods of generating biomethane from seaweed including co-digestion with suitable substrates
- Examination of cogeneration of hydrogen and methane from macro- and micro-algae
- Investigation of microbial ecology of algae digesters
- Design and fabrication of "in-situ" and "ex-situ" bio-methanation processes

[36] http://marei.ie/

- Optimal applications of Power to Gas systems

In 2017 a new spoke "Sustainable Energy and Fuel Efficiency" (SEFE) was added to MaREI. This includes for eight additional industry partners, €1m in industry contributions and adds €2,176,614 in direct funding from SFI. The academic partners added include for Prof Henry Curran, Prof Vincent O' Flaherty, Prof Xinmin Zhan, Dr Maria Tuohy and Dr Rory Monaghan from NUIG, Prof Stephen Dooley from TCD and Prof JJ Leahy from UL. The expertise in bioenergy is broadened including for world-class expertise across several technologies and disciplines.

The Causeway Project

The €25 million Causeway project won by Gas Networks Ireland (GNI) began construction of its first CNG filling station and its first biomethane grid injection plant. The demonstration work will be supplemented by academic input from Dr Rory Monaghan from the MaREI team in NUIG and Prof Murphy in UCC. This is an excellent example of commercialisation of innovative technologies and collaboration between industry and partner Universities.

Certification of Renewable Gas

The International Energy Research Centre (IERC) together with Deutsches Biomasseforschungszentrum (DBFZ), Deutsche Energie-Agentur GmbH (dena) - German Energy Agency and the MaREI Centre produced a report on Certification of Renewable Gas in Ireland.

GENCOMM

Dr Rory Monaghan (MaREI, NUIG) was a team leader that won EU InterReg NWE funding for the €9.34 million **GENCOMM** project that will demonstrate the use of hydrogen storage as a solution to renewable energy curtailment, and a means to integrate power, heat, transport and chemical sectors through hydrogen.

Marie Skłodowska-Curie Individual Fellowship on advanced anaerobic digestion systems for gaseous transport biofuel production

Dr Richen Lin (MaREI, UCC) won a Marie Skłodowska-Curie Individual Fellowship on the topic "**Direct Interspecies Electron Transfer** in advanced anaerobic digestion system for gaseous transport biofuel production". This is a €180k project from 2018 to 2020.

Irish Environmental Protection Agency Advanced Gaseous Methane

Dr Richen Lin (MaREI, UCC) was awarded a three-year project with funding for a senior post-doc and a PhD on the topic of "Advanced Gaseous Biomethane"

The Animal & Grassland Research and Innovation Centre Teagasc

The Animal & Grassland Research and Innovation Centre Teagasc, Ireland are investigating synergies from co-digestion of grass silage with other feedstock. Their objectives are to: identify the optimal growth stages of grass and legume silages and the optimal mixture with cattle slurry for biomethane production; identify the optimal slurry type and the optimal mixture with grass silages harvested at different growth stages for biomethane production; undertake a full cost analysis of biogas/biomethane production system. Teagasc now operate a 0.15 MW_e anaerobic digester at their facility in Grange, Co. Meath.

13 Korea

The total energy production in the Republic of Korea has steadily increased over the last years; renewable energy accounted for 3.5% (9.9 MTOE or 115 TWh) in 2012 of which 1.6 MTOE was bioenergy (8.9% from biogas plants and 6.2% from landfill gas). More recently renewable energy accounted for 5.45% (16.4 MTOE or 191 TWh) in 2017 of which 3.6 MTOE was bioenergy (2.7% from biogas plants and 2.1% from landfill gas). Landfill gas has dominated biogas production over the last decade while biogas plants have started to make a significant contribution ever since 2010. In 2017, biogas from bio-waste co-digestion constitute almost half (45.5%) of the biogas produced. This is the result of rapid change of sewage sludge digestion plants into bio-waste co-digestion plants (14 plants) and new construction of bio-waste digestion plants (9 plants). The "Bioenergy Strategy 2030" targets bioenergy production to increase by a factor of more than 4.

13.1 Production of biogas

A total of 119 biogas plants are now in operation and produce almost 2,815 GWh per year of biogas. Landfill gas contributes 31.8% (896 GWh/y), biogas from sewage sludge 22.4%, and bio-waste 45.5%. Bio-waste mainly consists of food waste, food waste leachate, and digestible co-substrates. Table 13.1 shows Korean biogas production from different types of plants. In 2017, 14 sewage sludge digestion plants were transformed into bio-waste co-digestion plants and 9 new bio-waste digestion plants started to run. Recently, bio-waste has become the most important source of biogas in Korea.

Table 13.1. Status of biogas production in Korea (data from 2017)

Plant type	Number of plants	Production* (GWh/year)	Share (%)
WWTP	36	630	22
Bio-waste	55	1,280	45
Agricultural	7	9	<1
Industrial	-	-	-
Landfill	21	896	32
Total	**119**	**2,815**	

** Produced raw biogas expressed as its energy content from the different plant types*

Electricity generation from biogas plants amounted to only 171 GWh in 2017. There are 5 new biogas plants under construction to treat 1,588 tons of food waste and food waste leachate daily to produce 151 GWh biogas by 2022. The electricity generated from landfill gas reached 256 GWh in 2017. The electricity production is expected to increase to 1,937 GWh in 2030.

13.2 Utilisation of biogas

About 39.5% (1,112 GWh) of the biogas is utilised for electricity production. The main part (23.7%, 667 GWh) of the remaining biogas is used for heat generation. This part is decreasing every year to meet the increasing demand for biogas in other sectors. Flaring biogas is still significant, but has decreased compared to the previous year (from 14.8% to 11.3%). The utilisation of biogas as vehicle fuel was only 4.2% of the total biogas production. The utilisation of biogas in Korea is summarised in Table 13.2.

The number of buses using CNG as a vehicle fuel reached 39,081 and the number of gas filling stations reached 201, including 6 biomethane filling stations. However, these biomethane filling stations only supply 0.2% of the total number of buses.

Table 13.2. Utilisation of biogas in Korea (data from 2016)

Utilisation type	Utilisation (GWh/y)	Share (%)
Electricity*	1,112	39.5
Heat	667	23.7
Vehicle fuel	118	4.2
Flaring	317	11.3
Biogas sale	601	21.3
Total	**2,815**	

* = *including efficiency losses.*

Biogas upgrading is carried out through water scrubbing, PSA and membrane separation at 5 wastewater treatment plants and 5 food waste leachate plants. One other food waste AD plant with biogas upgrading is now under construction. The biomethane is used mainly in city buses and municipal vehicles and grid injection. The standard for vehicle fuel and grid injection is similar to Swedish standards.

13.3 Financial support systems

There are no tariffs or subsidies for biogas. However, 10% VAT and a 2% tariff will be charged when the mixture of CNG and biomethane is sold. A feed-in-tariff system was implemented until 2011.

The RPS (Renewable Portfolio Standard) system has been enforced since 2012, requiring all power plants generating over 500 MW electricity to also supply a certain share of renewable energy. As "Mandatory Supply Quantity (MSQ)", 2% of the total power generation should be supplied using an appropriate kind of renewable energy. There is a governmental target to increase MSQ up to 10% of the total power generation in 2022. The REC price has been around KRW 58,980/MWh (44 EUR/MWh) in August 2019.

13.4 Innovative biogas projects

Animal Manure to Biogas Project

- The Ministry of Agriculture, Food, and Rural Affairs has financially supported enterprisers with 70% of the total construction cost of AD plants treating 70-100 m^3 of manure per day.
- 6 AD plants are now under construction and 4 more AD plants will be built by 2020.

Organic Wastes to Energy Project

- The Ministry of Environment (MOE) established a centre for Organic Wastes to Energy
- The total budget for the research project 2013-2020 (7 years) is 74 million US Dollars (MOE: $56.5 million; private: $17.5 million) and the following research results are expected:
    - Construction of an AD plant for food waste with a volume of 1,800 m^3. Research on biogas upgrading, system development for odour control, O/M manual development for the AD plant and application of digestate.
- Development and demonstration of an hydrogen station using biogas
    - Hydrogen (500 kg/day) station with reformer for biogas from food waste of Choongju city, 2019-2021, budget $10.3 million

Figure 13.1. Chungyang Biogas Power Plant that is producing 8.16 GWh electricity (3,900,000 Nm^3 biogas) annually. Source: Chilsung Energy Farming Association, Chungnam, Korea

14 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, Sweden have some very ambitious long-term climate and energy goals that were adopted by the parliament in 2017:

- 63% GHG emission reduction in non-EU 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[37]. 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 to be used in the transport sector and 3 TWh in industry[38]. 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.[39]

In Sweden only 3% (20 TWh) of the total energy supply (including imported energy) of 566 TWh was from gas (predominantly natural gas) in 2017 (Figure 14.1), which is rather low compared to many other countries in EU. Of these gases, 62% (12.1 TWh) was natural gas, 23% (4.6 TWh) was LPG and 15% (2.9 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.

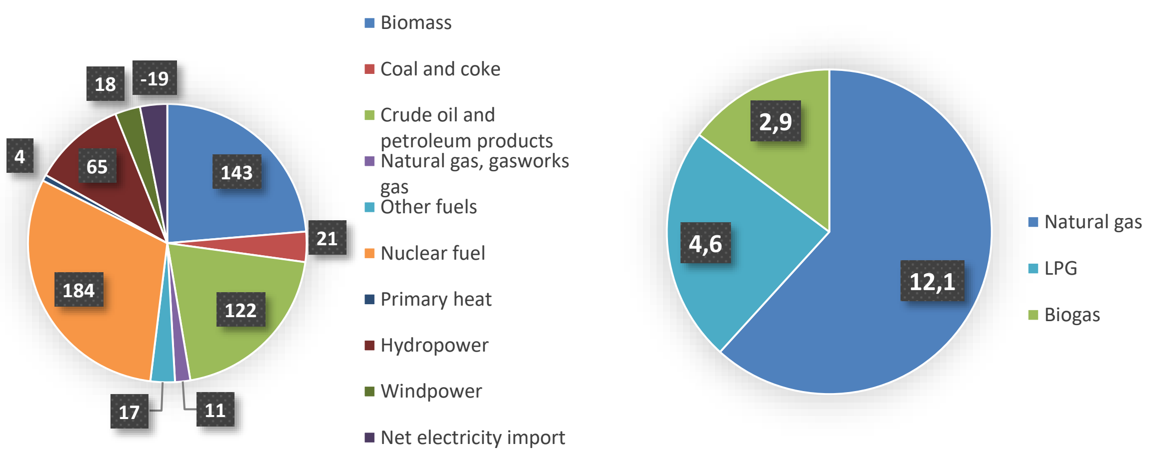

Figure 14.1. Total energy supply and deliveries (TWh) of energy (left) and gas (right) in Sweden 2017, including imports. Source: Statistics Sweden (SCB) and Swedish Gas Association.

[37] Swedish Gas Association, Green Gas 2050 (Energigas Sverige, Grön Gas 2050)

[38] Proposal for a National Biogas Strategy 2.0 (Förslag till Nationell Biogasstrategi 2.0), 2018

[39] Westlund et al. (2019), More biogas! For a sustainable Sweden (Mer biogas! För ett hållbart Sverige), report SOU 2019:63

14.1 Production of biogas

There were 280 biogas plants in Sweden 2018, producing in total 2 TWh of biogas. Most of the biogas was produced from different types of bio-waste and residues in co-digestion plants (47%) and from sewage sludge in wastewater treatment plants (35%) as shown in Table 14.1.

Table 14.1. Biogas plants and distribution of biogas production in Sweden 2018. Source: Swedish Gas Association.

Plant type	Number of plants	Production (GWh/y)	Share (%)
WWTP	138	715	35
Bio-waste	36	961	47
Agricultural	44	61	3
Industrial	6	143	7
Landfill	55	143	7
Biomethane (gasification)	1	20	1
Total	**280**	**2,044**	

There were 69 biomethane upgrading plants producing more than 1.2 TWh biomethane (2018). 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 was also one biomethane liquefaction plant producing 44 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[40]. 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[41], 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[42]. Aquatic substrates are usually omitted or estimated to have a very low potential in all of these studies.

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[40] Dahlgren (2013). Realisable biogas potential in Sweden 2030 through anaerobic digestion and gasification (Realiserbar biogaspotential i Sverige 2030 genom rötning och förgasning).

[41] Avfall Sverige (2008). The Swedish biogas potential from indigenous feedstock (Den svenska biogaspotentialen från inhemska råvaror), Report 2008:02.

[42] Westlund et al. (2019). More biogas! For a sustainable Sweden (Mer biogas! För ett hållbart Sverige), report SOU 2019:63

14.2 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 2018, 63% of the produced biogas was upgraded and mainly used as transportation fuel, due to a favourable support system. Table 14.2 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 14.2). The use of biomethane has however continued to increase and accounted for more than 90% of the vehicle gas use in 2018.

Table 14.2. Utilisation of domestically produced biogas in Sweden (2018). Source: Swedish Energy Agency and Swedish Gas Association

Utilisation type	Utilisation (GWh/y)	Share (%)
Electricity	41	2
Heat	409	20
Vehicle fuel	1,124	55
Other biomethane	164	8
Industry	61	3
Other	20	1
Flaring	204	10
Losses/n.d.	20	1
Total	**2,044**	

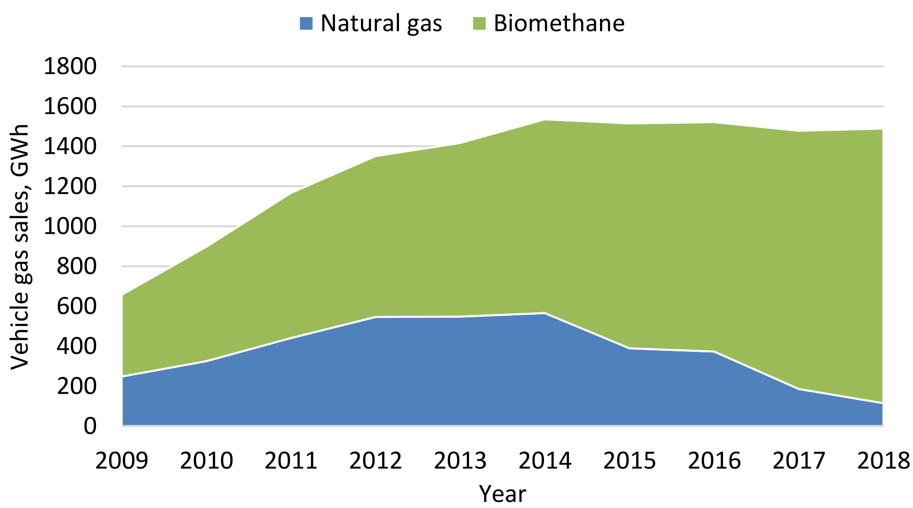


Figure 14.2. Sales of vehicle gas in Sweden 2009-2018 (Statistics Sweden)

In addition to the domestically produced biogas and biomethane, Sweden also used around 1.7 TWh of imported biomethane in 2018, giving a total utilisation of 3.7 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. Around 1/3 of the imported gas was used as vehicle fuel, and the rest was used in industries and for heating.[43]

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

[43] https://www.energigas.se/om-oss/nyheter-och-press/nyheter/anvaendningen-av-biogas-oekar-kraftigt-nu-maaste-svensk-produktion-stimuleras/

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 14.3). There is also a gas grid in Stockholm, fuelled with locally injected biogas and shipped LNG.

Figure 14.3. 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.

The number of gas filling stations has increased from less than 20 in 2000 to about 190 stations by the end of 2019, plus 60 non-public stations. New filling stations for LNG are being built on several locations in Sweden. There are currently 15 filling stations for LNG, and three more are under construction. The number of gas vehicles has during the same period increased from just a few hundred to in total 54,352 by the end of 2018; 2,522 of these were buses (about 15% of all buses) and 920 trucks (incl. approx. 50 LNG trucks) and the rest passenger cars and other light vehicles. However, although sales have increased, the number of gas vehicles has not increased in the last two years, due to exports of gas vehicles.

Liquefied biomethane for industry and heavy transports

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 transports, that require a fuel with a high volumetric energy content. Currently, there is only one biogas plant producing bio-LNG in Sweden (Lidköping), but new facilities are being built in Linköping and Nymölla. 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, 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*, is hosted by the Swedish Gas Association, and will "act to collect, demonstrate and increase the knowledge, innovation and development opportunities in sustainable solutions for LBG in national as well as international level" [44], during a period of three years. As a part of this work, the cluster will give financial support to companies and organisations who choose to invest in heavy vehicles with LNG propulsion rather than diesel. New filling stations and bio-LNG production plants will also be supported with money from Drive LBG.

[44] https://www.energigas.se/om-oss/nationella-samarbeten/drive-lbg/

Increased import puts pressure on Swedish biomethane producers but opens up for increased market

Most of the biogas 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 have increased from 155 GWh in 2016 to more than 1 TWh in 2018.

14.3 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 has been conducted to investigate most suitable long-term policies for biogas and biomethane after 2020, when the current EC state aid approval for tax exemption expires. 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[45].

Existing policies:

- CO_2 tax and energy tax exemption for biomethane as transportation fuel until the end of 2020. CO_2 tax and energy tax for petrol of about 0.72 SEK/kWh (~69 €/MWh) and 2.4 SEK/Nm^3 (~23 €/MWh).
- No CO_2 tax or energy tax on biogas for heating (including industry use) until end of 2020. Corresponding tax on natural gas is 3.4 SEK/Nm^3 (~29 €/MWh).
- 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).
- 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 1.5 billion SEK/year (~0.14 billion €), which is proposed to increase to 2.3 billion SEK/year from 2020. A large part of the over 2 billion SEK investment support that has been granted since 2015 so far has been given to biomethane investments and EV charging infrastructure.
- 40% reduction of income tax for use of company gas vehicles until end of 2019 (max 10,000 SEK, ~950 €)
- A national innovation cluster, Drive LBG, will contribute to financing infrastructure and projects for bio-LNG in transport. Companies buying LNG trucks instead of diesel can receive a subsidy of up to 40% of the extra investment cost compared to a diesel truck.
- A “Bonus-Malus” taxation system for light vehicles from July 1st 2018. Bonus up to 60,000 SEK (~5700 €) for new low emission cars. Gas vehicles get a bonus of 10,000 SEK (~950 €).

[45] Westlund et al. (2019). More biogas! For a sustainable Sweden (Mer biogas! För ett hållbart Sverige), report SOU 2019:63

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% 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 until end of 2020.
- New legislation for environmental zones in cities, implemented from January 1st 2020. Cities should be 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.

New but not yet implemented policies:

- The Swedish Energy Agency investigates a national biogas/biomethane register (guarantees of origin or certificates, etc.) to facilitate off-grid distribution.
- Production support package proposed in a national enquiry: continued support for biogas from manure (0.04 EUR/kWh), new supports for upgraded biogas (0.02-0.03 EUR/kWh) and liquefied biogas (0.01-0.015 EUR/kWh)[46]. There was also a suggestion for a new support for renewable energy gases produced with other technologies than AD, such as thermal gasification, but the rate was not specified in the proposal.

Uncertainties for the future biogas/biomethane market development

- Long-term conditions and a biogas strategy from the government are missing. It is still not clear what the support system for biomethane will be after 2020.
- 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.

14.4 Innovative biogas projects

The Swedish Biogas Research Center released a book in 2019 on the role of biogas in a sustainable society, comprising examples of innovative biogas projects in Sweden and in Norway[47]. Here follows a brief presentation of some of those projects.

Linköping

Linköping has been a leader in the Swedish development of biogas solutions since the 1990s. By 1999, Linköping had the largest fleet of biogas buses in the world. Born from challenges with air pollution and waste management, the municipal biogas plant in Linköping now handles 100,000 tonnes of organic waste per year, producing 120 GWh of biogas. The basis for their production is food waste from households, complemented with waste from a local slaughterhouse and a dairy factory. The digestate from the plant is taken care of as biofertiliser by another company in the region, thus recirculating 58 tonnes of phosphorus and 644 tonnes of nitrogen per year. In 2019, the construction started of a new liquefaction plant, which

[46] Westlund et al. (2019). More biogas! For a sustainable Sweden (Mer biogas! För ett hållbart Sverige), report SOU 2019:63

[47] Biogas Research Center (2019). Biogas in the sustainable society – The Nordic way.

will allow the biogas company Svensk Biogas to deliver bio-LNG to Toyota's forklift manufacturing industry in Mjölby, where the gas will replace fossil LPG. They will also provide bio-LNG for road transports via the new fuelling stations built around Linköping.

Sotenäs

In Sotenäs, biogas production is a key part in a symbiotic web built around the local fish industry. Process water from the fisheries and fish farms is cleaned through anaerobic digestion. Heat and CO_2 from the biogas plant are used in algae cultivation, which produces fodder for the fish farms. Nutrients in the digestate are recirculated as biofertiliser in local agriculture, and residues from agriculture are also used for fish fodder. By setting up this cluster, the fish industry has been able to stay and to grow in Sotenäs, whilst also becoming more sustainable from an environmental point of view.

Nymölla

During 2020, a new biogas production plant will start its operation in Nymölla. The plant is built in collaboration between Stora Enso and Gasum and includes a high-rate reactor with short retention time. Wastewater from Stora Enso's pulp- and paper mill will be treated in the reactor to produce 220 GWh biogas, which will then be upgraded and liquefied to bio-LNG for use in road transports and shipping. The project has received financial support through *Klimatklivet*.

15 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 835 GWh in 2018.

In order to promote this development, various instruments are planned or already introduced. For biogas plants with electricity and heat production, the previous feed-in tariff will be replaced by new financing options. In addition to one-off investment contributions, large plants are given the task of directly marketing the energy produced. 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. The existing transitional situation is characterised by investment uncertainty and a slightly sluggish development and implementation of new biogas projects.

15.1 Production of biogas

In the three main AD sectors – sludge digestion, bio-waste treatment and agriculture – the number of biogas plants has stabilised at 634 installations. A slight reduction in sludge digesters and industrial AD plants outbalance the small growth in numbers of agricultural plants. The volume of biogas produced has increased by 4% since 2017. Biogas from landfills is marginal and continues to lose importance. The table below presents the state of the current biogas production in Switzerland including the shares of biomethane upgrading installations and biomethane fed to the gas grid (Table 15.1).

Table 15.1. Status of biogas production in Switzerland (data from 2018)

Plant type	Number of plants	Production* (GWh/year)	Share (%)
WWTP	473 (28)	633 (177)	43.5
Bio-waste	28 (12)	345 (118)	23.5
Agricultural	111 (2)	400 (10)	28
Industrial	20 (2)	75 (20)	5
Landfill	2 (0)	2 (0)	<1
Total	**634 (44)**	**1,454 (325)**	

** = produced raw biogas expressed as its energy content from the different plant types*
Numbers in parentheses indicate share of biomethane upgrading.

The trend of slightly increasing biogas production from existing municipal wastewater treatment plants continues. This is largely due to the still slightly increasing amount of co-substrates which are fermented here. This trend will weaken in the next few years due to market saturation. Two-stage mesophilic stirred tank cascades with hydraulic retention times of 20-60 days are still representing the dominant technology for sludge digestion. The actual production in 2018 (633 GWh/y) represents 79% of the estimated sustainable potential (800 GWh/y) or 32% of the theoretical potential (2,000 GWh/y) from sewage sludge respectively. Digested sludge is predominately dewatered and dried before incineration. Disposal in dedicated sludge incinerators is gaining ground due to the future requirement for phosphorous recovery from domestic sewage sludge.

A slight growth in numbers can be observed for biogas plants for the digestion of source separated household waste and industrial organic residues. As the foreseeable extensive coverage of separate collection of green waste will be reached soon, it's mainly the diversion of existing flows of green waste from composting to biogas plants that drives growth in this sector. The actual production of biogas including biomethane (345 GWh/y) represents 63% of the estimated sustainable potential (550 GWh/y) from bio-wastes.

The highest sustainably usable biogas potential is clearly located in the agricultural sector. As a result of the emerging clarification of future financing models, a slight trend towards implementing planned biogas plants is discernible. In this regard, preference continues to be given to medium-sized plants and it remains unclear how the considerable potential of decentralised biogas production from manure can be exploited. The actual production of biogas and biomethane of the 111 agricultural AD plants in operation (400 GWh/y) represents 10% of the estimated sustainable potential (4,000 GWh/y) from agricultural residues and manure.

The utilisation of the remaining potential of industrial wastewater through anaerobic digestion is progressing only slowly. Apart from the food industry sector, a certain potential has been identified within the chemical and pharmaceutical industries. The actual production (75 GWh/y) however already covers 90% of the estimated sustainable potential from industrial wastewaters.

The phasing-out of landfill biogas is still in progress with only 2 installations running, both expected to shut down within the next decades.

In total, the actual production of biogas (1,454 GWh/y) still represents only <30% of the estimated sustainable potential (5,300 GWh/y) or 4% of the theoretical potential (39,000 GWh/y) for biogas or biomethane production, not accounting for any future power-to-gas options.

15.2 Utilisation of biogas

Domestic biogas continues to follow the trend, which has been ongoing for years, away from the direct on-site production of heat and electricity towards biomethane upgrading and feeding into the gas grid with over 40 upgrading plants in operation. Sales of biomethane as a vehicle fuel remain at a low level, accounting for only 14% of domestic biomethane or 3% of the total biogas production. However, local off-grid solutions to produce 100% biomethane as fuel are increasingly being implemented. Biomethane accounts for around 25% of total sales of vehicle gas, a number which is stagnant over the last decade. On the other hand, sales of biomethane for domestic heating (comfort heat) have developed strongly, which is clearly reflected in the increasing quantities of imported biomethane. The total biomethane production equals 325 GWh/y or 22% of the total biogas produced. This represents an 8% growth of this sector. Table 15.2 gives an overview of biogas utilisation in 2018.

Table 15.2. Utilisation of biogas in Switzerland (data from 2018)

Utilisation type	Utilisation (GWh/y)	Share (%)
Electricity*	351	24
Heat	340	23
Grid injection	325	22
Thereof vehicle fuel	*45*	*3*
Parasitic (heat, electr.)	438	30
Flaring	n.d.	<1
Total	**1,454**	

**excluding efficiency losses, which are listed separately*

15.3 Innovative biogas projects

Biological methanation on demonstrator scale

The development of the production of renewable gases using methanation technologies (power-to-gas) is making only slow progress in Switzerland. In 2015, a catalytic demonstration plant proved the suitability of this technology and in 2018 long-term trials with real biogas were carried out in a likewise catalytic pilot plant. In 2018 and 2019, the Aarmatt microbiological demonstrator achieved very good and reliable results in the European Store&Go project. The biological methanisation with a capacity of 30 m^3 CH_4/h or 30 MW capacity processes renewable CO_2 from the biomethane treatment of a nearby wastewater treatment plant plus PV-based H_2 and is fully integrated into existing heat, electricity, H_2, O_2 and CH_4 grids (Figure 15.1).

Figure 15.1. Aarmatt Biomethanation plant, Store&Go Project

Anaerobic digestion as an energy add-on to composting

Traditionally, considerable quantities of organic waste and green waste are processed in technical composting plants to produce high-quality organic fertilisers and soil improvers. Some of this waste can be used to produce energy in biogas plants without any loss of quality before composting. After a sustainably usable potential of 170 GWh/year of waste that has so far been used in composting but is suitable for fermentation was identified in 2017, the first expansions of composting plants were tackled in the last two years. The use of dry fermentation processes without liquid digestates is in the foreground (Figure 15.2). As an additional tool to ease the penetration of AD into the compost market and to bring operators of different technologies closer to each other, a coherent and combined education and training of AD and composting operators was initiated in 2018.

Figure 15.2. Expansion of an existing composting facility (rear) by Dry AD (centre)

Plastics in bio-waste

Due to the high proportion of separately collected green waste and packaged organic waste from the food industry and retail trade, waste management is increasingly confronted with the problem of rising plastic contents in digestate and compost. As a reaction to the criticism on digestate quality with respect to macro-plastics, even without exceeding limiting legal values, different measures to raise public awareness as well as to prevent plastics in bio-waste and organic fertilisers by technical solutions have been taken. Several municipalities and collection-services initiated campaigns to inform and educate the broad public about plastic waste sorting mistakes (Figure 15.3). Image detection systems for on-truck identification of plastics in collected waste and subsequent refusal of low quality OFMSW have been tested with promising results. Quality assurance in digestate and compost is supported by means of detection and sorting of macro-plastics in final compost.

Figure 15.3. Example of an Awareness Rising Campaign to prevent plastic waste sorting mistakes.

16 The Netherlands

To meet the European Union 20-20-20 goals, the Netherlands has to increase the amount of renewable energy to 14%. In 2018 6,6% was reached, which can be compared to 2% achieved in 2005. The ambitions of the Netherlands to increase the amount of renewable energy are expressed in the Climate Agreement in which the ambition for 2030 will be 70 PJ for green gas or 2 billion m³. A roadmap for green gas, initiated in 2019 will chart the course for this industry.

16.1 Production of biogas

In the Netherlands, there are around 262 biogas plants, including approximately 41 landfills, producing around 3.5 TWh biogas (Table 16.1). The total installed capacity for electricity production from biogas is 133 MW_e, assuming 4100/y average full load hours for agricultural production plants. The capacity for biogas upgrading to biomethane, with subsequent gas grid injection, is around 107 million Nm³/y, corresponding to approximately 1000 GWh.

Table 16.1. Status of biogas production in The Netherlands (data from 2018)

Plant type	Number of plants	Electricity production* (GWh/y)	Heat production* (GWh/y)	Vehicle fuel (GWh/y)
WWTP	80	220	420	
Bio-waste + Industrial	50	311	1,018	
Agricultural	91	581	808	
Landfill	41**	41	66	
Total	**262**	**1,153**	**2,312**	**Approx. 90**

**not including efficiency losses*

***assumed number, not reported*

The development of biogas in the Netherlands has not been very strong during recent years, mainly due to the increasing costs of feedstock. The development has been focused on energy utilisation of industrial and municipal bio-waste while the development in the agricultural sector has been slow. Due to changes in the feed-in tariff system (no extra money for CHP), more projects for green gas are expected in the future.

The Climate agreement published in 2018 includes the ambition to produce 2 billion m³ green gas in 2030, which corresponds to 70 PJ. As the production in 2018 was only 107 million m³, this will only be possible by developing several big gasification and digestion plants in the future.

16.2 Utilisation of biogas

Around 80% of the biogas produced in the Netherlands is utilised as either heat, electricity or automotive fuel (Table 16.1), with heat being the main area of use (twice as large as electricity). Only 3% of the biogas is used in road transports. That is half of the amount of 2017. The main reason for that is the high price for green certificates which makes putting the gas on the gas grid very lucrative. In 2012, the first biogas upgrading unit using cryogenic separation was taken into operation in the Netherlands. In 2018 there were 38 green gas producing installations using 3 different types of upgrading. Data from May 2014 show that 7,500 vehicles were running on methane with 175 filling stations available (2018)[48].

[48] http://www.ngvaeurope.eu/european-ngv-statistics

16.3 Financial support systems

In the Netherlands financial support is offered by the *SDE+ scheme the feed-in-tariff* support system for renewable energy. The interesting concept of the scheme is that it forces all renewables to compete with each other. The support system opens twice a year and in a staged application process with 3 closing dates in which the opening projects can apply when the tariff fits their business plan. Since the tariff gradually increases during the opening the scheme favours large scale facilities (with lower cost prize). The tariffs are guaranteed minimum income, which means that the scheme only pays out if energy prices are lower than the prices in the feed in tariff for a certain category. In 2017 there was 12 billion EUR available in this system. In 2018 the available budget was again 12 billion EUR. In 2019 there will be a different SDE++ system in which CO_2 emission reduction will be important for getting money out of it. Further on the system stays the same.

16.4 Innovative biogas projects

Aben Green Energy

The Aben biogas plant in Westdorpe (Figure 16.1) is of an innovative great scale, with a zero waste principle. Aben BV is originally an agricultural company, founded by the two brothers Jan and Toine Aben. The company took a rather natural step in 2013 and started producing renewable energy. Many agricultural businesses have these sorts of installations, but on a smaller scale. Aben BV too started with a small CHP plant, which produced around 230 kW.

Over the years, the company expanded its production of renewable energy and at its location in Wanroij, it now produces green electricity for around 13,000 households. The company has already built another plant almost 200 km away in the heart of North Sea Port, named Aben Green Energy.

Figure 16.1. Aben BV biogas plant in Westdorpe

Early on, Aben BV had the ambition to build an even bigger plant. They ended up in Westdorpe in North Sea Port by chance but at the same time very logical because Aben uses organic residual goods to produce green gas, of which a large quantity passes through North Sea Port. These organic residual goods are usually rejected for consumption for people and animals. Examples are moulded food, goods that were dropped on the floor, or rejected for reasons. They also noticed that several companies in North Sea Port have residual goods that they cannot use. They take these goods and use it to produce renewable energy.

The zero-waste principle does play a part in this. If these residual goods were not used, they would be disposed of, which is a costly operation for some of the suppliers. Aben Green Energy instead takes this ‘trash’ and turns it into enough green gas to heat around 12,000 households. This process of course also has a residual product of its own, which can be used as an organic fertiliser, which results in a complete zero-waste process.

Another important value is sustainability. A lot of thought has gone into making the process circular, without any waste or emissions. This is also the reason that alongside the production of green gas, Aben annually purifies and converts CO_2 to approximately 20,000 ton of liquid food grade CO_2 that is useable for technical applications. The process also produces heat, which can be used in their own processes. And so nothing goes to waste.

At the Westdorpe site, Aben BV can produce about 18 million m^3 green gas per year in a 22 MW installation. With the problems surrounding natural gas, turning organic residues into green gas is a great industry for a sustainable future.

Even though the company had already chosen the location at North Sea Port in 2014, the construction of the plant took some years to realise. The construction depended on receiving subsidy for Renewable Energy (SDE+) which they got in 2016, and construction then started in May 2017. The plant was finalised in January 2019 and currently consists of thirteen silos: four fermentation silos in which biogas is produced, one validation silo, four silos for the storage of residual goods, and four smaller storage silos for storing substrates for production.

Now that the plant is up and running, the company notices even more opportunities and advantages offered by North Sea Port. Good cooperation, like going to neighbours for questions, residual goods, and even transportation, is very common.

Furthermore there is a broad infrastructure in this area. They have a perfect location for inland shipping and truck transportation for the supply and disposal in North Sea Port. After already benefitting from the perfect opportunities that North Sea Port has to offer, they believe in uncovering even more opportunities and new collaborations, like the search for residual goods and other partnerships to enhance a sustainable industry.

17 United Kingdom

There are 660 AD plants (WWTP, bio-waste, agricultural and industrial) in the UK of which 103 produce biomethane for injection into the gas distribution network. In all, this amounts to a capacity of 955 MW_e. The main stimulus has been and continues to be the UK Government's low carbon policies. In 2016, renewable energy produced 25% share of the electricity generation with the present aim to increase this further to 30% by 2020-2021. A succession of tariff supports have been introduced to encourage the construction of renewable energy projects generally and AD in particular. This policy had led to a tripling of the growth rate since 2012 in the production of AD renewable energy capacity. However, as such supports have been reduced the rate of construction has dropped dramatically from 109 a year in 2014 to 20 in 2018 and to just one plant in 2019. The latest tariff changes have shifted the emphasis from electricity/CHP to biomethane with injection into the gas distribution network and the production of compressed biomethane.

Three new policy initiatives in the government's *Clean Air Strategy, the Resources and Waste Strategy* and the announcement of Greening the Gas grid in the Spring Statement by the Chancellor of the Exchequer, may lay the foundations for future growth. 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 recognising 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 energy and the output of nutrient rich digestate to avoid GHG emissions from manure storage and landfill and the need to accelerate the decarbonisation of the gas grid. The new measures include:

- Requiring all slurry/digestate stores to be covered by 2027 and the use of low emission digestate spreading equipment by 2025
- Universal food waste collections with a potential to redirect to AD more than 4 million tonnes away from landfill and lower GHG reducing alternatives with the potential of 187 MW_e of new capacity
- The Department of Transport's *Transport Energy Model* to reduce tail pipe emissions of air pollutants and GHG emissions from cars, vans, buses and heavy goods vehicles
- The use of spare AD capacity at wastewater treatment plants to become the hub of a national AD infrastructure to process other waste sources such as food waste and that from the agri-industrial sector.

The government has continued to implement feedstock sustainability criteria with regulatory control:

- No more than 50% of feedstock from crops
- Have life cycle GHG emission saving of at least 60%
- Not come from land with a high biodiversity level
- Not be taken from land with a high carbon stock value, e.g. wetlands, forest or peat

Feedstock made wholly of waste or animal manure /slurry will not be required to demonstrate minimum GHG emissions of 240 g CO_2-eq/MWh. These requirements were introduced in advance of the sustainable requirements of the European union's Renewable Energy Directive recast.

17.1 Production of biogas

The production of biogas in the UK is summarised in Table 17.1. Apart from landfills, the greatest number of biogas plants are in the agricultural sector, but when compared with those in other sectors they are significantly smaller in terms of capacity. Although the total electricity generation is similar between the respective sectors, the output from agricultural plants is secured from a much larger number of smaller installations. This sector has been most successful in the development of the industry.

Table 17.1. Status of biogas production in the UK (2018)

Plant type	Number of plants	Electricity production (GWh/y)	Capacity (MW_e)	Average plant capacity (MW_e)
WWTP[1]	163	1,280	203	1.2
Bio-waste[1]	91	1,261	200	2.2
Agricultural[1]	261	1,205	191	0.7
Industrial[1]	36	271	43	1.2
Landfill[2]	443	4,300	874	2.0
Total	**994**	**8,317**	**1,511**	**1.5**

Sources: [1]Derived from ADBA (2019) Annual Report; [2]Department of Business, Energy & Industrial Strategy (2019) UK Energy in Brief.

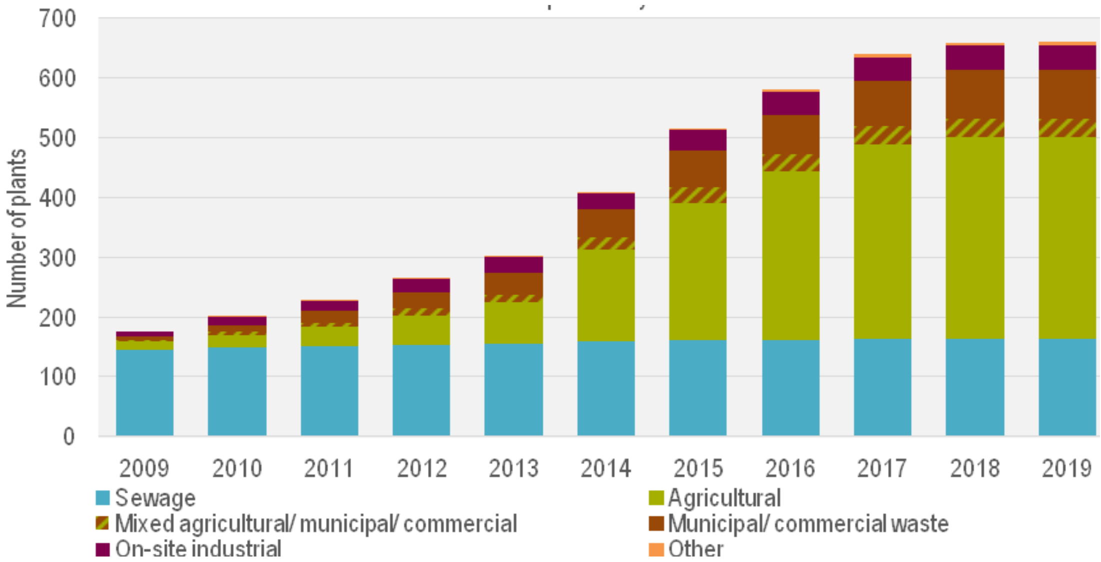


Figure 17.1. Number of biogas plants by feedstock sector. Source: ADBA Annual Report 2019.

There appears to be some discrepancy in the totals above but when the volume of gas used for biomethane is also taken into account there is a total 955 MWh_e capacity in the UK.

The annual increase in capacity and number of AD plants so far peaked around 2014-2016. Until the reduction of the tariff the number of projected plants each year matched the number of plants built but this changed dramatically in 2019 when just 1 out of 14 plants with planning permission was built (Figure 17.2).

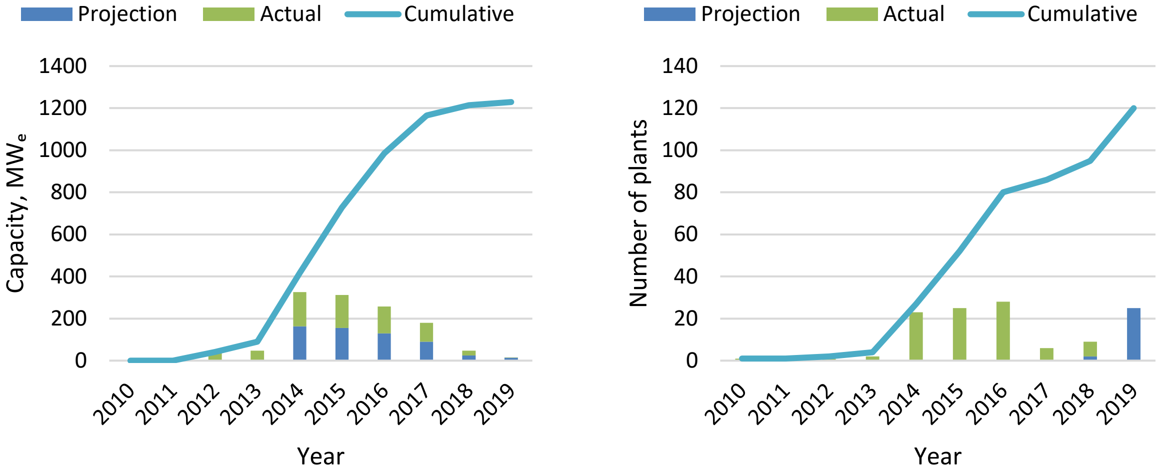


Figure 17.2. Annual increase in production capacity and number of AD plants 2010-2019[49]

17.2 Utilisation of biogas

In 2018, a total of 37,948 GWh of renewable heat was produced in the UK from all the technologies eligible to receive payment from the Renewable Heat Initiative (RHI), of which 32% was from anaerobic digestion (Table 17.2).

Table 17.2. Proportion of UK renewable heat produced from anaerobic digestion[50]

Energy	GWh /y	% total renewable heat
Biomethane	9,003	24
Biogas	2,095	6
CHP	918	2
Total	**12,016**	**32**

By the end of 2018, there was a total of 955 MW capacity of operational AD plants for the combined production of electricity and biomethane (Table 17.3). The sector produced 2,681 GWh of electricity.

[49] ADBA annual report 2019.
[50] Ibid.

Table 17.3. Number and output of operational plants in 2018[51]

Electricity/heat/biomethane	Number of operational plants	Capacity of operational plants	
Excluding sewage plants			
Electricity/CHP plants	398	434	MW_e
Heat-only plants	6	0.4	MW_{th}
Biomethane plants	93	72,773	m^3/h
Total	**497**	**712**	**MW**
Sewage sludge plants			
Sewage sludge CHP plants (number of plants does not include CHPs on biomethane sites)	153	203	MW_e
Biomethane sewage plants	10	8,720	m^3/h
Total	**163**	**237**	**MW**
Total (all sectors)			
Electricity/CHP	551	637	MW_e
Heat-only	6	0.4	MW_{th}
Biomethane	103	81,493	m^3/h
Total	**660**	**955**	**MW**
Other			
Landfill gas plants (BEIS 2019)	443	874	MW_e

Fuelling stations

This section presents information from CNG Fuels and CNG Services Ltd.

The UK network of public access CNG fuelling stations is currently limited, but this is changing quickly. CNG Fuels and CNG Services Ltd. currently have nearly 20 CNG stations between them running or in development. The stations are categorised into "mother stations" and "daughter stations". A mother station is a fuelling station located near the production site or connected via the gas grid, while the daughter stations receive their gas via trailer transports from the mother stations. The daughter stations are thus more flexible in terms of location; up to 150 miles (240 km) from a mother station is deemed economically feasible. The mother stations are generally much larger, with dispensing capacities of up to over 30,000,000 kg/y. The gas is stored in buffer tanks at 300 bar and fuelled into trucks and busses at 250 bar. CNG Fuels' stations have two compressors with a combined capacity >90,000 kg/day and dedicated CNG trailer loading bays, which allow high-capacity CNH trailers (>4,000 kg) to be filled in a couple of hours). The CNG delivered by CNG Fuels consists of 100% biomethane.

17.3 Financial support systems

A range of support mechanisms have been used to encourage the development of renewable electricity production generally and claimable for AD in particular for nearly 20 years. These have been very successful in stimulating the development of the biogas industry, which has grown by over 600 plants in just eight years. The feed-in-tariffs (FIT) provided a guaranteed price for a fixed period to small-scale electricity generators (Figure 17.3). FITs were intended to encourage the provision of small-scale low carbon electricity. Only AD facilities with less than 5 MW_e capacity and completed after 15th July 2009 were eligible for the FIT. As from 31st March 2018 all support for any new electricity generation has ceased.

51 ADBA annual report 2019.

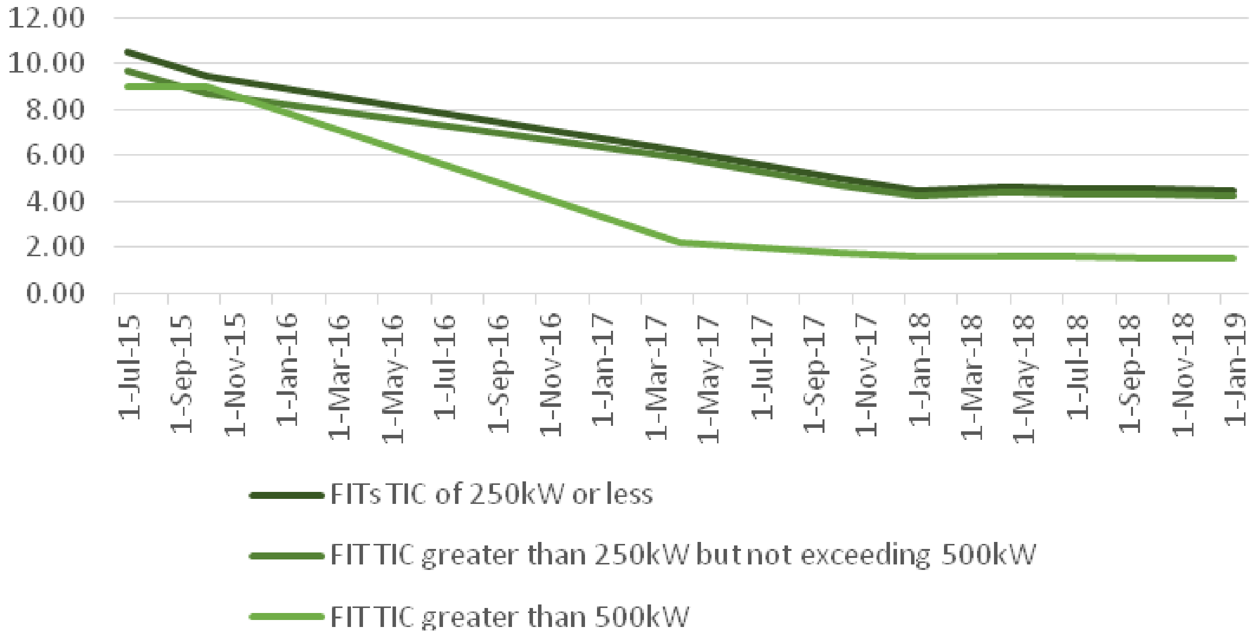
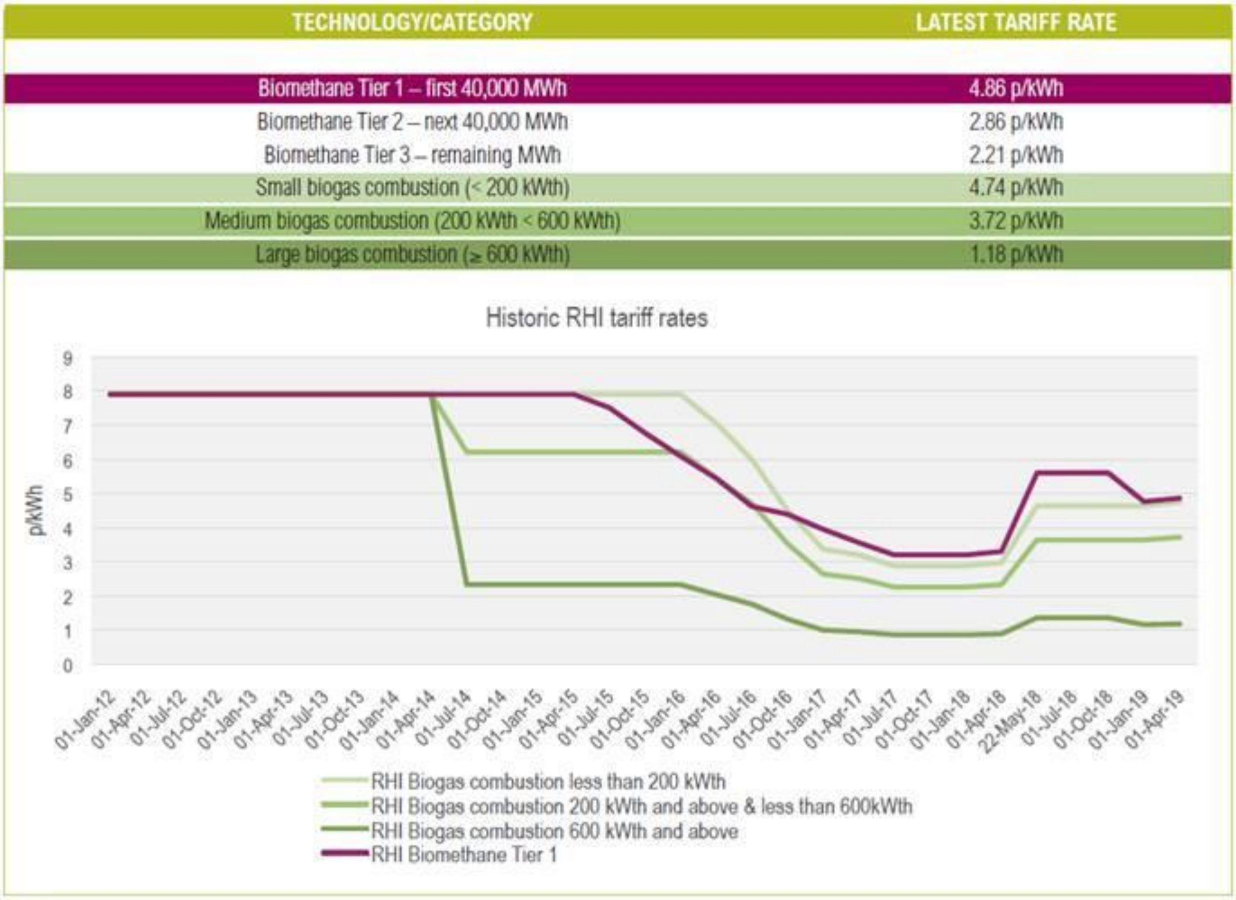


Figure 17.3. UK feed-in-tariff rates (pence/kWh) for renewable electricity 2015-2019[52]

The Renewable Heat Incentive (RHI) was introduced in April 2014 to provide a fixed income (pence/kWh) to generators/users of renewable heat and also benefited renewable biogas and biomethane producers (Figure 17.4). Prior to 1st July 2015 the RHI for biogas/biomethane was set at 7.9 p/kWh but was reduced to 3.2 p/kWh on 1st January 2018 for the first 40,000 kWh produced and to lesser rates as the output of the plant increased. This had a catastrophic effect on the UK biogas industry. Until the reduction of the tariff the number of projected plants each year matched the number of plants built but this changed dramatically with just one out of fourteen of the plants with planning permission going into construction.

[52] ADBA annual report 2019.



TECHNOLOGY/CATEGORY	LATEST TARIFF RATE
Biomethane Tier 1 – first 40,000 MWh	4.86 p/kWh
Biomethane Tier 2 – next 40,000 MWh	2.86 p/kWh
Biomethane Tier 3 – remaining MWh	2.21 p/kWh
Small biogas combustion (< 200 kWth)	4.74 p/kWh
Medium biogas combustion (200 kWth < 600 kWth)	3.72 p/kWh
Large biogas combustion (≥ 600 kWth)	1.18 p/kWh

Figure 17.4. Renewable heat incentive rates (p/kWh) in UK 2012-2019[53]

After more than a year of delays, new RHI regulations finally came into force on the 22nd May 2018. These raised the tariffs back to 5.6 p/kWh as at the start of 2016. Currently there are 313 plants with planning permission already granted and a further 77 in preparation (Table 17.4).

Table 17.4. Number or electricity, CHP and biomethane plants in the planning stages 2018[54].

	Number of electricity/CHP plants	Potential installed capacity (MW_e)	Number of biomethane plants	Potential installed capacity (m^3/h)	Total number of plants	Total capacity (MW)
Plants with planning application approved	251	295	62	40,029	313	353
Plants with planning applications submitted	66	65	11	5,960	77	85
Total	**317**	**260**	**73**	**46,389**	**390**	**441**

The Renewable Transport Fuel Obligation (RTFO) also benefits biomethane producers. It places an obligation on fuel suppliers that supply more than 450,000 litres per year to ensure that a set percentage of this is from renewable and sustainable sources (either through their own supply or through the purchase of Renewable Transport Fuel Certificates, RTFCs). The Renewable Transport Fuels and Greenhouse Gas

53 ADBA annual report, 2019.
54 Ibid.

Emissions Regulations 2018 came into force on 15th April 2018 and have extended the RTFO to 2032. The percentage of renewable fuel which suppliers must provide has been increased from 4.5% to 9.75% by 2020. This doubles the size of the market in just two years.

Despite the slowdown almost to a halt when the tariff supports were stopped or reduced, there is a more positive note on which to end this report. There appears to be a growing confidence in the industry from investors. One environmental infrastructure investment fund, just as an example, has acquired a portfolio worth £69 million with an AD combined capacity of 270 MW during the past two years.

17.4 Innovative biogas projects

Allpress Farms Ltd Charteris Norfolk

This is a large family owned business with 1,220 hectares of some of the best quality arable land in the UK, of which 1,052 ha is devoted to crop production (Table 17.5). Its farms are located in the Fens (polders) in East Anglia. The business is one of the country's largest producers of leeks and onions, which are harvested, packed and dispatched ready for sale in the major supermarkets. Like its neighbours, it is at the forefront of innovation in seeking the optimum financial and environmental solutions, in this case to the management of the large 3,000 tonnes/year of trimmings from the vegetable production (Figure 17.5).

Figure 17.5. Onion waste

Table 17.5. Areas and yield of cultivated crops

Crop	Area (ha)	Yield (tonnes/y)
Leeks	390	8,000
Onions	180	9,000
Wheat	182	1,700
Maize	205	9,000
Sugar beet	95	7,000

In 2013, the Nick and Patrick Allpress commissioned a feasibility study into the possibility of installing a biogas plant that could fulfil five functions:

- Convert the vegetable trimmings into an income earning enterprise
- Produce a digestate with the potential to replace mineral fertiliser and restore organic matter to the soil
- Remove any risk of recycling plant disease through the ploughing in of the raw trimmings
- Reduce overhead costs by the replacement of grid electricity for the operation of the plant, pack house, etc. and an extra income from sales of surplus to the grid
- Reduce the farm's carbon footprint

Characteristics of the plant

<u>500 kW anaerobic digester</u>

Inputs:	Leek and onion trimmings, 3,000 tonnes per year
	Maize, 9,000 tonnes per year
Outputs:	Electricity, 4,400,000 kWh per year
	Digestate, 11,500 tonnes per year

A pre-mixer has been incorporated into the plant design in order to dissolve and aid the removal of stones.

Agri-Tech Innovatory Farmers' Network

Allpress Farms together with five other large farms in this part of eastern England have each provided two 24.5 ha fields where the Agri-Tech Innovatory Farmers Network has set up a field laboratory in conjunction with the National Institute of Agricultural Botany and Cranfield University. The objective is to measure the impact on crop nutrition from liquid and fibre digestate, with the aim to:

- Ensure maximum N available to feed the crops
- Minimise N leaching through the soil, diffuse pollution or valorisation as ammonia gas
- Impact of digestate on soil microbiology
- Influence of cover crops on digestate impact.

The field trials on each farm replicate the same approach:

- Cover crop with no digestate
- No cover crop digestate only
- Cover crop with digestate
- A control fallow treatment area
- A personal plot on Allpress Farms with a cover crop and an inoculant to help root growth.

The cover crops include vetches, black oats, fodder radish and buckwheat.

The digestate is an integral part of the fertiliser management schemes, which makes full use of technology including GPS equipment to permit variable application of fertiliser to pinpoint the exact amount for each part of the field. The ultimate aim is to save money and reduce environmental impact. The AD plant plays an innovative and key role in this forward-looking farm business.

A considered approach to maximising gas yields and environmental impact at six biomethane plants

This short case study explains how the Foresight Groups plants at Grange Farm, Vulcan Renewables, Merlin Renewables, Egmere Energy, Warren Energy and Biogas Meden work with farmers to accomplish this in conjunction with the operator Future Biogas to maximise the many benefits from crop fed biogas production.

Figure 17.6. Maize harvest.

Sustainable maize

With its consistently high yields, both per hectare as a crop and per cubic metre of biogas, maize has become the core feedstock of these AD plants. The Future Biogas' farming team has disproved common claims that maize needs too much fertiliser to grow in the UK and that its late growing season results in fields being left bare for too long – leading to soil erosion, water run-off and, potentially, flooding. They have shown it's entirely possible to grow sustainable British maize. The key is to plant and tend it correctly.

Natural fertiliser

When maize is grown as a feedstock for an AD plant, a large percentage – or indeed all – of its chemical fertilisers can be replaced with the eco-friendly natural fertilisers made from the plant waste leftover from the AD process. Known as 'digestate', this is what the farmers of these sites use, both on their energy crops and other crops too. Using digestate also improves the sustainability of farming by reducing the emissions associated with fertiliser manufacture. This way, it can help farmers meet a carbon target of net zero. One of their Norfolk farming partners saw an 11% increase in yield when digestate was used as part of the fertiliser programme for sugar beet.

Rotational Farming

Maize has a short growing period. Typically, it's on the land for five or six months, which means the land can lie fallow for a long time. To retain soil moisture and nutrients, the farmers working with Future Biogas are encouraged to plant it as part of a traditional rotational farming pattern. This is of huge benefit to both them and the environment. In practice, it means they plant green cover crops over winter. Such crops help prevent soil erosion, because their root biomass holds onto the soil. They also capture residual nitrogen and prevent other pollutants reaching watercourses. Even better, increasing crop diversity enhances the soil's microbial biomass and, thereby, improves its organic matter content and, so, its fertility.

Scientific Efficiency
The AD plants in partnership with Future Biogas use the latest science to make sure their agricultural practice is extremely efficient. They meticulously record all harvest data. This informs their planning for the next year. It helps them decide which maize varieties should be grown where, as well as the amount of digestate that should be spread on specific fields. Future Biogas is also one of the only British biogas producers to have its own dedicated laboratory, with a team of biologists analysing digester samples to ensure things are running efficiently. They regularly balance out the content of a digester tank with natural additives using their in-house additive, 'T16', which is proven to maximise biogas yields.

Effective Clamping
Before they can be fed into an AD site, crops must be turned into silage, by preserving them through fermentation. Failing to clamp silage properly is damaging to a biogas plant's output and bottom line. The contractors who work on these sites are all trained in expert ensiling. They know it's vital to chop feedstock to the right size, ensure the silage is at the right dry matter and clamp so no pockets of oxygen remain. The farming team also believe it's vital to invest in quality silage sheeting, to minimise plastic use and reducing clamp losses which can be damaging to the bottom line.

Wildlife Preservation
Even though it's not required by government regulations, all these sites have established wildlife areas. In partnership with biodiversity consultants Cambridge Eco Ltd and Norfolk Wildlife Services, the farming team has helped farmer partners plant over 50 km of wildflower margins, designed to attract wild birds and pollinators, like bees.

Conclusion
Over the last decade the sites in conjunction with their farming partners have blended the latest science with traditional farming techniques to hone an ultra-efficient and eco-friendly method of creating green energy from crops. The focus is not only on attaining the highest possible gas yields, but also on boosting overall productivity for farmers and creating numerous environmental benefits.

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