

## Biogas: Developments and perspectives in Europe

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### ABSTRACT

This paper presents an overview of the development and perspectives of biogas in and its use for electricity, heat and in transport in the European Union (EU) and its Member States. Biogas production has increased in the EU, encouraged by the renewable energy policies, in addition to economic, environmental and climate benefits, to reach 18 billion m<sup>3</sup> methane (654 PJ) in 2015, representing half of the global biogas production. The EU is the world leader in biogas electricity production, with more than 10 GW installed and a number of 17,400 biogas plants, in comparison to the global biogas capacity of 15 GW in 2015. In the EU, biogas delivered 127 TJ of heat and 61 TWh of electricity in 2015; about 50% of total biogas consumption in Europe was destined to heat generation. Europe is the world's leading producer of biomethane for the use as a vehicle fuel or for injection into the natural gas grid, with 459 plants in 2015 producing 1.2 billion m<sup>3</sup> and 340 plants feeding into the gas grid, with a capacity of 1.5 million m<sup>3</sup>. About 697 biomethane filling stations ensured the use 160 million m<sup>3</sup> of biomethane as a transport fuel in 2015.

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## 1. Introduction

### 1.1. Biogas as a sustainable fuel for heat, power and transport

Natural degradation of organic material results in the production of biogas by microorganisms under anaerobic conditions. Anaerobic digestion convert organic material into biogas, a renewable fuel that could be used to produce electricity, heat or as vehicle fuel. In recent years, Anaerobic Digestion (AD) of waste and residues from agriculture and industry, municipal organic waste, sewage sludge, etc. has become as one of the most attractive renewable energy pathway.

The energy and climate policies in the EU and the introduction of various support schemes for promoting the utilization of renewable resources have encouraged the development of biogas plants for energy production. Anaerobic digestion provides opportunities for biogas to be used for generating energy, such as electricity, heat and fuel with additional economic, environmental and climate benefits. In Europe, most of the modern anaerobic digestors provide electricity and heat in electricity only plants, heat only or Combined Heat and Power (CHP) plants. Anaerobic digestors are mostly connected to gas-fired engines for heat and power generation with electrical capacity ranging from tens of kWe up to a few MWe. The heat generated can also be used to meet the local heat demand on farm, or delivered to external users. Biogas can be upgraded to biomethane and injected into natural gas network or use it in transport vehicles, with proper purification to remove trace gases such as H<sub>2</sub>S and water and CO<sub>2</sub>.

In addition to economic benefits from energy and fuel generation, AD plants provide additional environmental benefits (e.g. decrease in water, soil and air pollution, etc.). Traditionally, manure is directly used as fertiliser in agriculture, which could cause environmental problems, water contamination and pollution. Natural degradation of manure leads to emissions of methane and carbon dioxide during storage [1–3]. Anaerobic digestion contributes to mitigate odours associated with manure storage and decomposition and removes pathogens that can pose significant risk to human and animal health. Digestate from biogas production can still be used as fertiliser, just like manure, having the same content of nutrients as manure. This brings additional economic benefits by reducing the use of chemical fertilizers in farms, and reduces nutrient runoff and avoids methane emissions [1–4].

Anaerobic digestion of manure reduces GreenHouse Gas (GHG) emissions released into the atmosphere by avoiding methane emissions from natural decomposition during storage. The use of manure to produce biogas for energy generation displaces the use of fossil fuels and thus contributes to emission reductions of GHG emissions and other pollutants.

### 1.2. Renewable energy policies in the EU

In the European Union (EU), the basis of a European Union policy on renewable energy was made in 1997 when the European Council and the European Parliament have adopted the “White Paper for a Community Strategy and Action Plan” and when the share of renewable energy was 6% of gross internal energy consumption [5]. In 2007, the European Commission proposed an integrated *Energy and Climate Change* package on the EU’s commitment to change (*Energy policy for Europe* (COM(2007) 1 final) [6] and *Limiting Global Climate Change to 2 degrees Celsius - The way ahead for 2020 and beyond* (COM(2007) 2 final) [7]. This includes an EU commitment to achieve at least a 20% reduction of GHG emissions by 2020 compared to 1990 levels and a mandatory EU target of 20% renewable energy [8].

The *Renewable Energy Directive* (RED) 2009/28/EC on the

promotion of renewable energy sources [9] requires the MS to increase the share of renewable energy to 20% of gross final energy consumption at EU level and a contribution of 10% of the renewable energy in the energy use in transport in each MS by 2020. The RED specifies national objectives and legally binding targets for the share of renewable energy. In addition, the *Fuel Quality Directive* (FQD) 2009/30/EC [10] sets a target of a 6% GHG emission reduction for fuels used in transport in 2020. The RED and FQD include criteria for sustainable biofuels and procedures for verifying that these criteria are met. The RED includes provisions to facilitate the development of renewable energy, such as detailed roadmaps and measures taken to reach the RES targets and develop energy infrastructure [8].

On a longer term, the European Union has established the ambitious goal of building a competitive low carbon economy in 2050 and to reach 80%–95% GHG emission reduction by 2050 (COM(2011) 112 final) [11]. The share of renewable energy could reach between 55% and 75% of gross final energy consumption in the European Union in 2050 (COM (2011) 885 final) [12]. The *Energy Roadmap 2050* investigated possible pathways for a transition towards a decarbonisation of the energy system and the associated impacts, challenges and opportunities [8].

A bioeconomy strategy (COM(2012) 60) was set to develop an “innovative, resource efficient and competitive society that reconciles food security with the sustainable use of renewable resources for industrial purposes” [13]. The bio-based economy plays a key role, as part of a green economy, to replace fossil fuels on a large scale, not only for energy applications, but also for chemicals and materials applications [8].

The Directive 2015/1513 has set a limit of 7% of the final consumption of energy in transport in the Member States in 2020 for the biofuels produced from food or feed crops grown for energy purposes on agricultural land [14]. A target of 0.5% points has been set for 2020 for the share of energy from renewable sources in transport, to be achieved by biofuels produced from feedstocks that are not in competition with food crops and biofuels made from feedstocks such as wastes, residues, non-food cellulosic material or ligno-cellulosic material.

In 2015, 195 countries agreed at the United Nations Framework Convention on Climate Change (UNFCCC) 21st Conference of the Parties (COP21) in Paris on a long-term goal of limiting the increase of global average temperature to well below 2 °C above pre-industrial levels. The agreement sets out a legally binding global climate deal and a global action plan to limit the increase to 1.5 °C in order to reduce risks and the impacts of climate change. The countries submitted comprehensive national climate action plans and their Intended Nationally Determined Contributions (INDCs) mainly through renewable energy and energy efficiency measures. These are not yet enough to keep global warming below 2 °C, but the agreement traces the way to achieving this target, but high-income countries intend to make available USD 100 billion per year by 2020 to support low-income countries [15,16].

The EU has already adopted a 2030 Framework for climate and energy and has set EU-wide targets and policy objectives for 2030 (COM(2014) 15 final): a 40% reduction in GHG emissions compared to 1990 levels, at least a 27% share of renewable energy consumption and at least 27% energy savings compared with the business-as-usual scenario [17]. The 27% target set for 2030 is an important intermediary milestone toward the targets set for 2050. The European Commission has published at the end of 2016 a proposal for a revised Renewable Energy Directive (COM(2016) 767 final/2) to make the EU a global leader in renewable energy, to ensure that the 27% target for the share of renewable energy consumed in the EU in 2030 is met, as a milestone for its long-term 2050 greenhouse gas reductions target [18]. The limit for the use of

biofuels used in land transport, produced from food or feed crops, shall be reduced to 3.8% in 2030. The European Parliament is currently discussing an increase of the European Union's renewable energy target to 35% by 2030. These favourable framework conditions and the significant benefits biogas production create good perspective for further biogas development and its use in various sectors.

## 2. Bioenergy and biogas markets

### 2.1. Global bioenergy market

The use of renewable energy sources experienced a significant growth worldwide, providing 19.2% of global final energy consumption in 2014 [16]. The use of renewable energy has increased significantly in the European Union from 8.5% in 2005 to almost 17% in 2015 in the gross final energy consumption. The global primary energy supply from biomass has reached about 60 EJ in 2015, representing a share of the total global primary energy consumption of 10% and a share in the final energy consumption of 14%. The traditional use of biomass, primarily for cooking and heating, has an important contribution, accounting for about 9% of the global final energy consumption. The modern use of biomass is increasing rapidly, particularly across Asia. The bioenergy share in total global primary energy consumption has remained steady since before the year 2000, at around 10% [16]. Bioenergy is likely to keep its major role in the European Union as renewable energy source in the energy mix until 2020 with a share above 60% of renewable energy. Overall, the share of bioenergy in the final energy consumption is projected to increase from 5.0% in 2005 and 9.6% in 2015 to almost 12% in 2020 [8].

Most biogas production occurs in the United States and Europe, although other regions increasingly are deploying the technology as well. Global biogas production increased from 0.28 EJ in 2000 to 1.28 EJ in 2014, with a global volume of 59 billion m<sup>3</sup> biogas (35 billion m<sup>3</sup> methane equivalent) [19]. In the European Union, primary energy production from biogas production has increased in the last decade from just 167 PJ in 2005 to 654 PJ in 2015, with a biogas volume increasing from 2.5 billion m<sup>3</sup> in 2000, to 18 billion m<sup>3</sup> methane equivalent in 2015, representing half of the global biogas production [19,20].

### 2.2. Biopower production

The installed power capacity of renewable energy reached 1699 GW worldwide in 2015 [21], driven by sustained policy support and continuous cost reductions, especially for wind and solar technologies. The installed capacity of renewable energy in the European Union reached 374 GW in 2014 and 397 GW in 2015 [16,20]. The annual growth of the renewable energy has decreased lately in the EU due to the shift in support policies, uncertainties of post 2020 renewable energy policies and challenges related to higher renewable energies integration into energy systems. Thus, although Europe remained an important market for renewable energy, progresses continued to shift toward other regions [16].

Bio-power production reached an installed capacity of about 106 GW worldwide in 2015. The EU is a world leader for bio-power generation and capacity, with an installed capacity of 30 GW in operation in 2015 [20], followed by the United States, with 16.7 GW, China with 10.3 GW, Brazil with 9.7 GW, India with 4.7 GW and Japan with 4.7 GW. The global biomass electricity generation also increased from 429 TWh in 2014 to 474 GWh in 2015, with major production occurring in the EU (178 TWh), United States (69.1 TWh), China (41.6 TWh), Brazil (32.9 TWh), and Japan (30.2 TWh) [16,21].

Biogas electricity has a share of about 20% in total biopower production and 4% in global heat generation worldwide (REN 21 2016). The European Union is the world leader in biogas electricity production. Thus, the global installed biogas capacity reached in 15 GW in 2015, with 10.4 GW in Europe only, 2.4 GW in North America, 711 MW in Asia, 147 MW in South America and 33 MW in Africa. Europe is also leading in electricity production from biogas, with 58 TWh electricity generated only in the European Union, out of the global electricity production of 80 TWh in 2014, while other major producing countries including United States (14 GWh), Australia (1.6 TWh) and Thailand (1.5 TWh) [20,22].

### 2.3. Bioheat market

The use of energy for heat accounted for about half of total world final energy consumption in 2015, with renewable energy supplying more than 25% of the energy use in the heating sector worldwide and 19% of the energy use for heating in the European Union. More than two-thirds of the use of renewable energy worldwide in the heating sector came from traditional biomass use (firewood, charcoal, manure and crop residues) [23,16]. Biomass use for heat represented 45 EJ worldwide in 2014, having a share of 75% of total global biomass demand, of which about 70% (31.5 EJ) was produced from traditional biomass, mainly in Asia (19.1 EJ) and Africa (11.6 EJ). Biomass accounted for over 90% of modern renewable heat generation in 2015. The heat production from biomass in the EU reached 3.5 EJ in 2015, representing about 90% of the renewable heat production. Modern biomass heat generation occurs mainly in Europe (3.1 EJ), developing countries in Asia (2.7 EJ), and North America (2.6 EJ) [20,23].

Most bio-heat is derived from solid biomass resources, but biogas is becoming a more important source of heat, reaching about 4% of the bioheat worldwide in 2015. In high-income countries, biogas is used primarily in electricity-only and CHP plants, with small amounts used in heat-only plants, while in low income countries biogas is mostly used for cooking of lighting. In Europe, biogas produced 127 TJ of heat and 61 TWh of electricity in 2015. About 50% of total biogas consumption in Europe (more than 330 PJ), was used for heat production.

### 2.4. Biofuels in transport

The use of biofuels for transport started in Brazil at the beginning of the twentieth century and boosted in the 1970s after the first oil crisis to ensure energy security. Biofuels later emerged as an alternative to fossil fuels to reduce GHG emissions from the transport sector. Biofuel mandates were in place in 66 countries at the national or state/provincial level in 2015, meeting about 4% of global road transport fuel, while support is being shifted towards the promotion of advanced biofuels in some countries [16]. The use of biofuels in transport reached about 132 billion litres worldwide in 2015, of which 98 billion litres of ethanol, 30 billion litres biodiesel and 5 billion litres of Hydrogenated Vegetable Oils (HVO), although the debate over sustainability and the reduced support for first-generation biofuels has decreased the growth [16,21]. European Union is the world leader in the use of biodiesel in transport, with about 12 billion litres used in 2015; in addition 5 billion litres of bioethanol were used in the same year [20,24].

Biogas upgrading to biomethane has started as an alternative to the direct use of biogas for heat and power generation due to low demand for the heat generated. Biogas can be upgraded to biomethane through different technologies to be used directly as a transport fuel in engines in Natural Gas Vehicles (NGV) that are widely available. Given the very low GHG emissions from the use of biomethane in vehicles over the whole supply chain, this is among

the best options as renewable fuel in transport and thus biomethane could contribute to the renewable energy targets in this sector. In this context, the use of gaseous biofuels in transport, including biomethane is increasing, in several EU countries (Sweden, Germany, Finland, etc.), in China, United States and other countries. The largest market for the use of biomethane as a transport fuel is the European Union, with a combined 160 million m<sup>3</sup> of biomethane in 2015 [20].

The number of Compressed Natural Gas (CNG) vehicles (18 million worldwide) and fuelling stations (22000 filling stations worldwide) create good opportunities for the use of gaseous biofuels, such as biomethane, in transport. The infrastructure for delivering natural gas as transport fuel is available, with about 3500 CNG vehicle filling stations in Europe and about 1400 in the United States, of which about 700 vehicle filling stations in Europe in 2015 offering biomethane [25,26].

### 3. Biogas production and trends

#### 3.1. Biogas developments worldwide

Biogas production plants for the treatment of wet-waste biomass, from wastewater treatment plants and landfill gas recovery is expanding in a number of countries. Biogas upgrading to higher-quality biomethane is also increasing, for use as a vehicle fuel or for injection into the natural gas grid.

In developing countries, biogas is mainly produced in small, domestic-scale digesters to provide a fuel for cooking or even lighting, in comparison to developed countries, where biogas developments focussed on larger scale, farm based and commercial, electricity and heat biogas plants. Different biogas support programmes have been carried out to develop household biogas systems to provide people with biogas for cooking, as an alternative energy source, to reduce firewood consumption and avoid deforestation, decrease indoor air pollution and improve soil fertility. Several countries in Asia (China, Thailand, India, Nepal, Vietnam, Bangladesh, Sri Lanka and Pakistan) have large programmes for domestic biogas production [20,23,27,28].

China had an estimated 100,000 modern biogas plants and 43 million residential-scale digesters in 2014, generating about 15 billion m<sup>3</sup> of biogas, equivalent to 9 billion m<sup>3</sup> biomethane (324 Tj primary energy). The Medium-and-Long Term Development Plan for Renewable Energy requires reaching by 2020 about 80 million household biogas plants, 8000 large-scale biogas projects with an installed capacity of 3000 MW and an annual biogas production of 50 billion m<sup>3</sup>. The biogas potential was estimated at 200–250 billion m<sup>3</sup> annually [23,29]. In the last years, modern biogas plants have been built, with the installed electricity capacity of biogas plants reaching 330 MW in 2015 and 350 MW in 2016 [30].

In India, the National Biogas and Manure Management Programme (NBMMMP) promotes the construction of family size biogas plants for producing fuel for cooking and organic manure. In 2014, there were about 4.75 million farm size biogas plants, in comparison to a potential to build about 12 million biogas plants, which could generate more than 10 billion m<sup>3</sup> biogas/year (about 30 million m<sup>3</sup>/day) [31]. India plans to install 110,000 biogas plants from 2014 to 2019. So far, the installed electricity capacity of biogas plants reached 179 MW in 2015 and 187 MW in 2016 [30]. Nepal has one of the most successful biogas programmes in the world, with more than 330,000 household biogas plants installed under the Biogas Support Program and providing fuel for cooking purposes [23].

In Vietnam, the Biogas Program for the Animal Husbandry Sector started in 2003 aiming at developing commercial biogas plants, which led to 183,000 biogas plants at the end of 2014

[23,28,32]. A National Domestic Biogas and Manure Program opened in 2006 for rural and off-grid areas of Bangladesh, that resulted in about 36000 domestic biogas digesters installed by the end of 2014, primarily for generating cooking gas. It is estimated that about 500–600 commercial biogas units are currently operational in the country in medium-to large-sized animal farms and generate electricity. There is a plan to build 100,000 small biogas plants by 2020 and to install at least 130 commercial biogas digesters by 2017, with an average capacity of 50 kW. About 6000 domestic biogas plants have been installed in Sri Lanka and 4000 biogas plants in Pakistan [27,33].

Large volumes of waste are available in Africa, but biogas production is still less developed than in other regions. Biogas digesters are being installed in several countries (Burundi, Botswana, Burkina Faso, Cote d'Ivoire, Ethiopia, Ghana, Guinea, Lesotho, Kenya, Namibia, Nigeria, Rwanda, Senegal, South Africa, Uganda and Zimbabwe). National programs are currently implemented in Rwanda, Tanzania, Kenya, Uganda, Ethiopia, Cameroon, Benin, and Burkina Faso [34]. In Africa, a Biogas Partnership Programme (ABPP), supported by the Ministry of Foreign Affairs of the Netherlands and Netherlands Development Organisation aimed at developing national biogas programmes in five African countries (Ethiopia, Kenya, Tanzania, Uganda and Burkina Faso) for building 100,000 domestic digesters to provide access to energy for a half million people by 2017. The programme has led to the installation of almost 16000 biogas plans in these five countries (16,419 in Kenya, 13,584 in Ethiopia, 13,037 in Tanzania, 6504 in Uganda and 7518 in Burkina Faso) [35]. The African "Biogas for Better Life" initiative aims to provide two million household biogas digesters by 2020 to substitute traditional cooking fuels (wood fuel and charcoal) and provide clean energy for cooking for at 10 million Africans [36]. The technical biogas potential in Africa has been estimated to allow the construction of 18.5 million household biogas plants [37].

In Latin America, several agricultural and domestic biogas plants have been set up for rural households and biogas has also being extracted from several landfills [28]. The Network for Biodigesters in Latin America and the Caribbean (RedBioLAC) promotes the development of small bio-digesters in Bolivia, Costa Rica, Ecuador, Mexico, Nicaragua and Peru. Bolivia is the leader with over 1000 domestic biogas plants installed. Large-scale biogas plants have been built to use effluents from palm oil mills and large farms in Colombia, Honduras and Argentina [27]. Brazil had 127 biogas plants using agricultural and industry residues, biowaste, sewage sludge, and landfill gas, which produced about 1.6 million Nm<sup>3</sup>/day, (584 billion m<sup>3</sup> biogas/year) representing 3835 GWh of energy in 2015 [23,38]. The installed biogas electricity capacity has increased significantly in the last years, reaching 196 MW in 2015 and 450 MW in 2016 [30].

In the United States, there were more than 2100 biogas plants in 2017, of which 250 farm-based digestion plants using livestock manure [39], 654 biogas recovery plants from landfills [40]. From a number of 15,000 Waste Water Treatment Plants (WWTPs), there were about 1240 WWTPs operating anaerobic digesters producing biogas. Almost all of wastewater biogas plants are installed at large scale facilities, treating from one to several hundred million gallons per day of wastewater [41]. Biogas plants had an installed electricity capacity of 2400 MW in 2015 and 2438 MW in 2016 and generated 1030 GWh electricity [30,40,41]. The energy potential of biogas in the United States was assessed at 18.5 billion m<sup>3</sup> of biogas/year, of which 7.3 billion m<sup>3</sup> from manure, 8.0 billion m<sup>3</sup> from landfill sites and 3.2 billion m<sup>3</sup> from WWTPs, that could generate about 41.2 TWh of electricity. It was estimated that about 13,000 biogas plants could be built, 8241 anaerobic digestion plants in farms, 1086 plants at landfill sites 3681 plants at WWTPs [41]. For comparison, the evolution of global installed biogas electricity plant capacity in

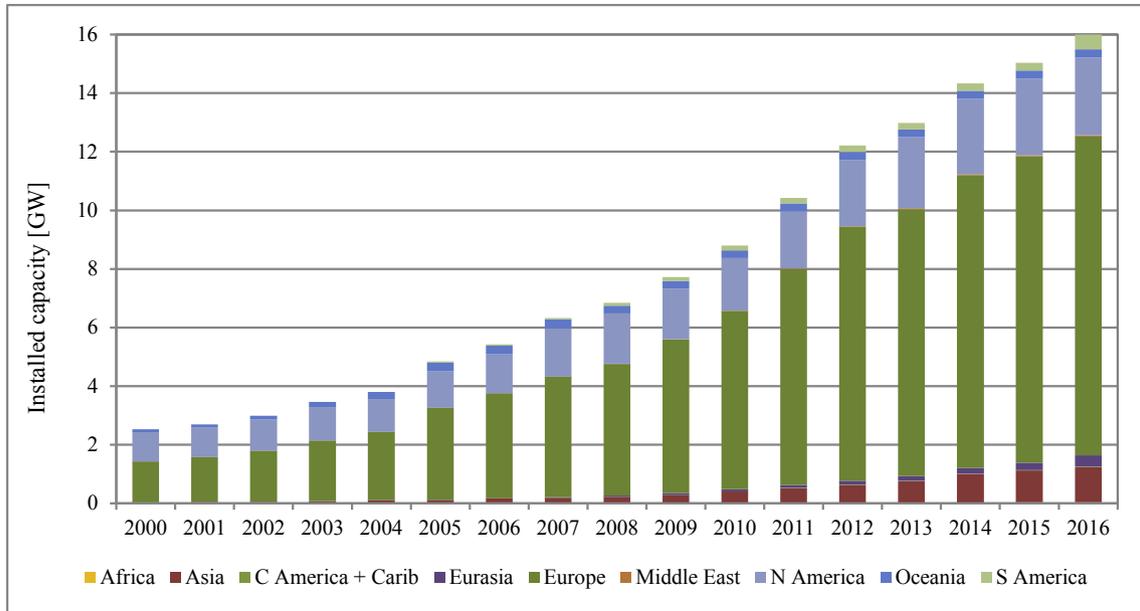


Fig. 1. Evolution of global installed electricity biogas plant capacity [30].

different regions of the world is given in Fig. 1.

### 3.2. Biogas production in Europe

Biogas production has seen a significant growth in the last years in Europe, mainly driven by the favourable support schemes in place in several European Union Member States (Fig. 2). In 2015, the total biogas production in the European Union reached 654 PJ of primary energy or more than 18 billion m<sup>3</sup> natural gas equivalent [20], as result of a long term development, with 92 PJ biogas produced in 2000, 167 PJ in 2005 and 357 PJ in 2010 (Fig. 2). While the contribution of landfill gas recovery to biogas production has been almost constant over the last decade, the major contribution to this growth came from Anaerobic Digestion (AD) plants and to lower

extent as sewage gas from wastewater treatment.

Most of the biogas in the EU is used as a fuel for electricity generation, in electricity only or combined heat and power plants with the effort toward the maximum use of heat aiming to increase the income and to improve the economics of the biogas plants. Gas engines are most commonly used, which can reach electrical efficiency of 35–40%, depending on gas engine type and size [42]. Biogas was used in the European Union to produce 61 TWh (219 PJ) of electricity, and 26.6 PJ heat was sold to district heating networks in 2015 [20].

The situation of biogas production is very different between different countries, both in terms of the biogas production (Table 1) and the source of biogas (landfill gas, sewage sludge, anaerobic digestion or thermochemical processes). The contribution of biogas

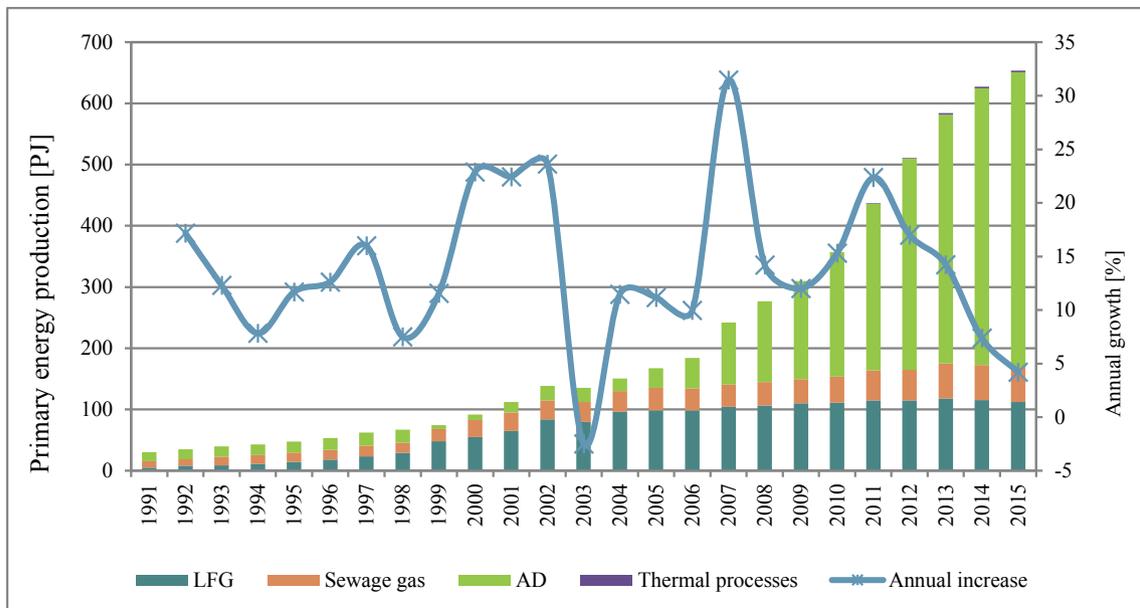


Fig. 2. Evolution of primary energy biogas production in the EU [20].

**Table 1**  
Biogas production in Europe in 2015.

	Biogas production	Biogas production	Natural gas use	Biogas share in natural gas use
	TJ	mil m <sup>3</sup>	mil m <sup>3</sup>	%
Belgium	9492	264	16,244	1.6
Bulgaria	820	23	3018	0.8
Czech Republic	25,681	715	7539	9.5
Denmark	6347	177	3317	5.3
Germany	328,840	9160	75,775	12.1
Estonia	550	15	454	3.4
Ireland	2287	64	4364	1.5
Greece	3826	107	3113	3.4
Spain	10,954	305	28,538	1.1
France	22,549	628	40,759	1.5
Croatia	1507	42	2421	1.7
Italy	78,355	2183	64,316	3.4
Cyprus	471	13	0	N/A
Latvia	3674	102	1277	8.0
Lithuania	981	27	2404	1.1
Luxembourg	739	21	900	2.3
Hungary	3335	93	8712	1.1
Malta	69	2	0	N/A
Netherlands	13,693	381	33,932	1.1
Austria	12,563	350	7998	4.4
Poland	9581	267	16,021	1.7
Portugal	3457	96	4738	2.0
Romania	767	21	10,380	0.2
Slovenia	1242	35	773	4.5
Slovakia	6223	173	4512	3.8
Finland	4321	120	2608	4.6
Sweden	7009	195	842	23.2
UK	94,303	2627	71,268	3.7
Switzerland	4591	128	3341	3.8
Iceland	69	2	0	N/A
Norway	1866	52	6268	0.8
FYROM	206	6	130	4.4
Serbia	242	7	2036	0.3
Moldova	401	11	855	1.3
Ukraine	600	17	30,311	0.1
<b>EU</b>	<b>653,636</b>	<b>18,207</b>	<b>416,223</b>	<b>4.4</b>
<b>Europe</b>	<b>661,611</b>	<b>18,429</b>	<b>459,195</b>	<b>4.0</b>

Source [20].

to the national natural gas consumption is very diverse, at about 4% on average, but it reached 12% in Germany, a country with a very large natural gas consumption. The leading countries in the biogas production in the EU are Germany, UK, Italy, Czech Republic and France. Germany is the European leader with a biogas production of 329 PJ and a share of 50% of total biogas production in the EU in 2015.

Looking at the sources of biogas (landfill gas, sewage sludge, anaerobic digestion or thermochemical processes), Fig. 3 shows a complex situation. The highest amount of biogas comes from anaerobic digestion in Germany, Italy, Czech Republic and France, followed by biogas from landfill gas recovery in UK, Italy, France and Spain. The biogas from anaerobic digesters predominates in Germany, Italy, Denmark, Czech Republic and Austria. Landfill biogas also dominates the market in the Portugal, Estonia, Ireland or Greece and UK, while biogas from wastewater treatment prevails in few countries, such as Sweden, Poland and Lithuania [20].

There were more than 17,400 biogas plants in Europe in 2015 [25] of different types and sizes, ranging from small anaerobic digesters on farms to large co-digestion plants (Fig. 4). There were 16,606 biogas plants in the EU with total electricity installed capacity surpassing 10,100 MW in the EU in 2015 [20]. Most of the biogas plants are in the size range 100–500 kW (electrical output). A small part of the biogas is being used in boilers to produce heat only for farm use or in industrial applications for steam generation.

### 3.3. Biogas upgrading and biomethane market

A combination of factors, including the advancement of biogas upgrading technology, poor economics of electricity biogas plants and the new opportunities for the use in the transport sector, has resulted in a shift from electricity and heat production to upgrading biogas to biomethane. This has created new opportunities and opened the competition as well between various biogas uses. Biogas upgraded into biomethane, which has a similar quality to natural gas with respect to methane, trace gases content, etc., could be used as fuel in Natural Gas-powered Vehicles (NGVs) or injected into the natural gas grid as a substitute for natural gas to supply traditional end-users (power plants, industries and households).

Grid injection enables the biomethane to be stored at lower cost and allows its use at the places where it is needed. Grid injection requires the biogas facility be sited close to a low-pressure natural gas grid. In comparison with the biogas produced, relatively small, but increasing quantities of biomethane are being used to fuel vehicles. The biomethane injected into the grid has to meet national quality standards. The European Committee for Standardisation (CEN) has set up in 2014 a Technical Committee (TC408) to formulate harmonised standards for the use of biomethane in transport and for injection in the natural gas grid to support the development of the use of biomethane. The Committee published the standard EN 16723–1:2016 - Part 1: Specifications for

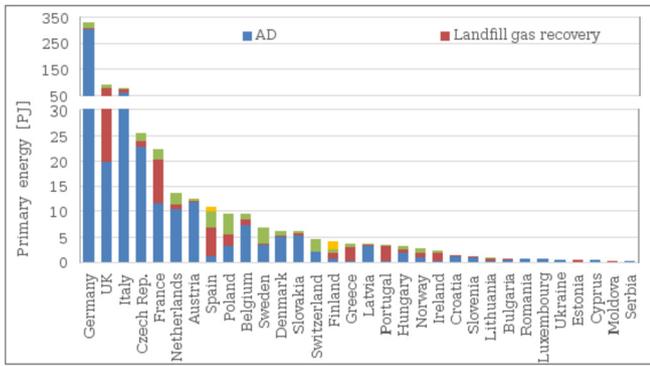


Fig. 3. Primary energy production from biogas in European countries in 2015 [20].

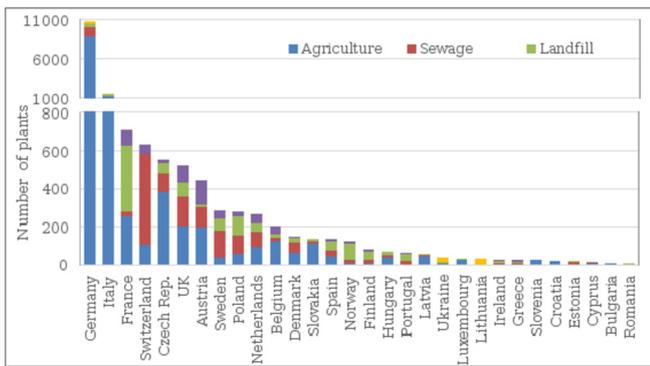


Fig. 4. Number of biogas plants in Europe in 2015 [25].

biomethane for injection in the natural gas network and EN 16723–2:2017 - Part 2: Automotive fuels specification. The European Standard specifies the requirements and test methods for biomethane at the point of entry into natural gas networks as well as the requirements and test methods for the use of natural gas, biomethane and their blends as automotive fuels [43].

Europe is the world's leading producer of biomethane, with 459 plants in 2015 producing an estimated 1.23 billion m<sup>3</sup> annually and 414 plants in the EU and 1.2 billion m<sup>3</sup> annually, in comparison with total biogas production of about 18 billion m<sup>3</sup> in the same year

(Table 2). Biogas upgrading to biomethane takes place in 15 European countries and injected into the natural gas grid in 10 countries [20,25,44]. Most biomethane production plants are in Germany (185 plants), UK (80 plants) and Sweden (61 plants). In the other countries the biomethane production volumes are still marginal [25,45].

There were 340 plants feeding into the natural gas grid across Europe of which 305 plants in the European Union, in 2015, with 165 plants in Germany, 80 plants in the UK and 35 feeding plants in Switzerland. The capacity of the plants feeding biomethane into the natural gas network reached 1.459 million m<sup>3</sup> in 2015, with the majority being injected into the gas grid in Netherlands and marginal volumes in other countries [20,25]. More than half of the biogas produced in Sweden is been upgraded to biomethane and the share of upgrading biogas has increased slightly, while the biogas used for electricity production was quite marginal and the share that goes to heat production has decreased [46].

### 3.4. Biogas feedstock and potential in Europe

Biogas is produced in anaerobic digestion plants, from wastewater treatment and from recovery from landfill sites. In Europe, biogas is mainly produced from anaerobic fermentation in anaerobic digesters using agricultural waste, manure, and energy crops, with about 74% of the primary biogas energy output. A significant share of biogas is derived from landfill gas recovery (17%) and to a smaller extent from sewage sludge treatment plants and other sources, with 9% in 2015 [20]. The picture of biogas production shows significant differences between European countries (Fig. 5).

Anaerobic digesters use different types of organic feedstock, including farm manure, slurry, food-processing waste and farm crops (grasses, maize, etc.). Anaerobic co-digestion of manure with various substrates increases the biogas yield and energy output, provides significant improvements to the economy of the biogas plants, improves the fertiliser value of digestate and the mitigation of GHG emissions.

In the past decade, there has been a significant development towards the use energy crops, industrial and municipal waste for anaerobic digestion. The use of energy crops (grasses, silage maize, etc.) for biogas production has increased significantly, especially in Germany, due to high biogas yields and favourable support schemes (Table 3). Biogas thus originates in different European countries from a wide range of diverse feedstocks: agricultural

Table 2  
Biomethane production in Europe in 2015.

	Number of biomethane plants	Biomethane production million m <sup>3</sup>	Biomethane filling stations	Plants feeding into grid	Biomethane fed into the grid thousands m <sup>3</sup>
Denmark	12	n/a	–	12	
Germany	185	898	288	165	
Spain	1	n/a	–	0	
France	20	9	4	17	146
Italy	6	n/a	2	N/A	
Luxembourg	3	3	–	N/A	110
Hungary	2	0	1	1	
Netherlands	21	72	–	N/A	1105
Austria	13	8	3	13	
Finland	10	10	22	4	98
Sweden	61	129	205	13	
UK	80	74	8	80	
Switzerland	35	28	140	35	
Iceland	2	n/a	–	N/A	
Norway	8	n/a	24	N/A	
<b>EU</b>	<b>414</b>	<b>1203</b>	<b>525</b>	<b>305</b>	<b>1459</b>
<b>Europe</b>	<b>459</b>	<b>1231</b>	<b>697</b>	<b>340</b>	<b>1459</b>

Source: [21], [26].

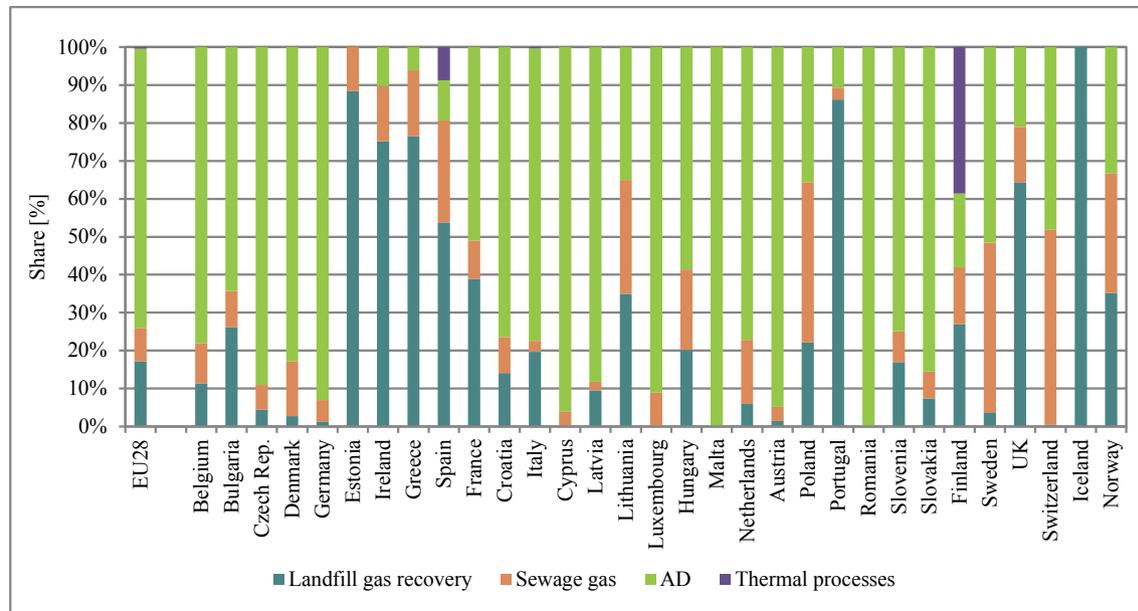


Fig. 5. Share of different processes for biogas in Europe in 2015 [20].

**Table 3**  
Biomethane yield from selected feedstocks.

	DM	VS	methane yield	methane yield
	%	% Of DM	l CH <sub>4</sub> /kg VS	l CH <sub>4</sub> /kg fresh
pig slurry	3–8%	70–80%	250–350	6–22
cattle slurry	6–12%	70–85%	200–250	8–25
poultry manure	10–30%	70–80%	300–350	21–84
maize sillage	30–40%	90–95%	250–450	68–170
grass	20–30%	90–95%	300–450	55–128
alfaalfa	20–25%	90–95%	300–500	57–118
potatoes	20–30%	90–95%	280–400	54–128
sugar beet	15–20%	90–95%	230–380	31–72
straw	85–90%	80–90%	200–250	136–202
vegetable waste	85–90%	80–90%	200–251	136–203
organic waste	10–40%	75–90%	350–450	26–180
sloutherhouse residues	35%	90–95%	550–650	173–216
sewage sludge	5–10%	75%	300–400	11–30

DM- Dry Matter; VS - Volatile Solids.

Source: [46–53].

residues (livestock manure, crop residues and energy crops), industrial residues from food and beverage industry, biowaste and municipal organic waste, sewage sludge, etc. (Fig. 6). Various concerns related to the use of energy crops have already lead to changes in the legislations in Germany and Austria, capping the use of land for biogas production.

Some estimations of the potential of biogas production are available in the European Union based on statistical data on various feedstocks. The technical potential of biogas in the EU was assessed by the German Biomass Research Centre (DBFZ) to be in the range of 151–246 billion Nm<sup>3</sup> biomethane from anaerobic digestion and bio-SNG (Synthetic Natural Gas) produced via gasification, including 66 billion Nm<sup>3</sup> from woody biomass, 11 billion Nm<sup>3</sup> from herbaceous biomass, 48–143 billion Nm<sup>3</sup> from energy crops and 26 billion Nm<sup>3</sup> from wet biomass [52]. The Green Gas Grids Project estimated that a production of 48–50 billion Nm<sup>3</sup>/year of biomethane (including raw biogas, upgraded biogas and syngas) could be achieved by 2030 out of the technical potential of 151 billion Nm<sup>3</sup>. The use of upgraded biomethane for grid injection and as gaseous biofuel in transport could reach 18–20 billion Nm<sup>3</sup> in 2030

[8,30].

The European Biomass Association (AEBIOM) estimated a biogas potential at about 78 billion m<sup>3</sup> biomethane (2.8 EJ), of which 58.9 billion m<sup>3</sup> from agriculture (27.2 billion m<sup>3</sup> from crops, 10.0 billion m<sup>3</sup> from straw, 20.5 billion m<sup>3</sup> from manure and 1.2 billion m<sup>3</sup> from landscape management) and 19 billion m<sup>3</sup> from waste (10 m<sup>3</sup> from municipal solid waste, 3.0 billion m<sup>3</sup> from industrial waste and 6.0 billion m<sup>3</sup> from sewage sludge). From this potential, 46 billion m<sup>3</sup> could be used until 2020. The biogas potential from manure was estimated by AEBIOM at about 20.5 billion m<sup>3</sup> (736 PJ), of which about 35% (253 PJ) could actually be used in 2020 [53].

The comparison of existing potential with current biogas production of 18 billion m<sup>3</sup> shows that the European biogas potential could contribute significantly to higher deployment of biogas plants, especially considering the fact that about half of biogas is produced in Germany and the potential in other countries is only marginally used. The estimates of the National Renewable Energy Action Plans (NREAPs) show that the use of biogas/biomethane estimated for electricity, heating and in transport in 2020 could reach 20–22 billion Nm<sup>3</sup> methane equivalent, which represents about 5% of the 500 billion Nm<sup>3</sup> EU natural gas consumption [8].

#### 4. Biogas contribution to renewable energy generation and targets

The use of renewable energy has reached a share of 17% in the gross final energy consumption in 2015 in the European Union and the projections show that it will exceed the target of 20% in 2020. The use of renewable energy increased from 4.2 EJ in the EU in 2005 to 7.8 EJ in 2015 and it is expected to reach 10.3 EJ in 2020, according to the aggregated data from the National Renewable Energy Action Plans (NREAPs). Bioenergy is expected to maintain its major role as renewable energy in the EU until 2020, despite the increased contribution of other renewables. So far, the share of bioenergy in the gross final energy consumption increased from 5.0% in 2005, to 9.6% in 2015 and is projected to reach about 12% in 2020 [8]. Biogas has still a small contribution to bioenergy production across the EU, but increasing from 71 PJ in 2005 to 352 PJ in 2015, with a share of 2.7% in 2005 to 7.8% in 2015, having the

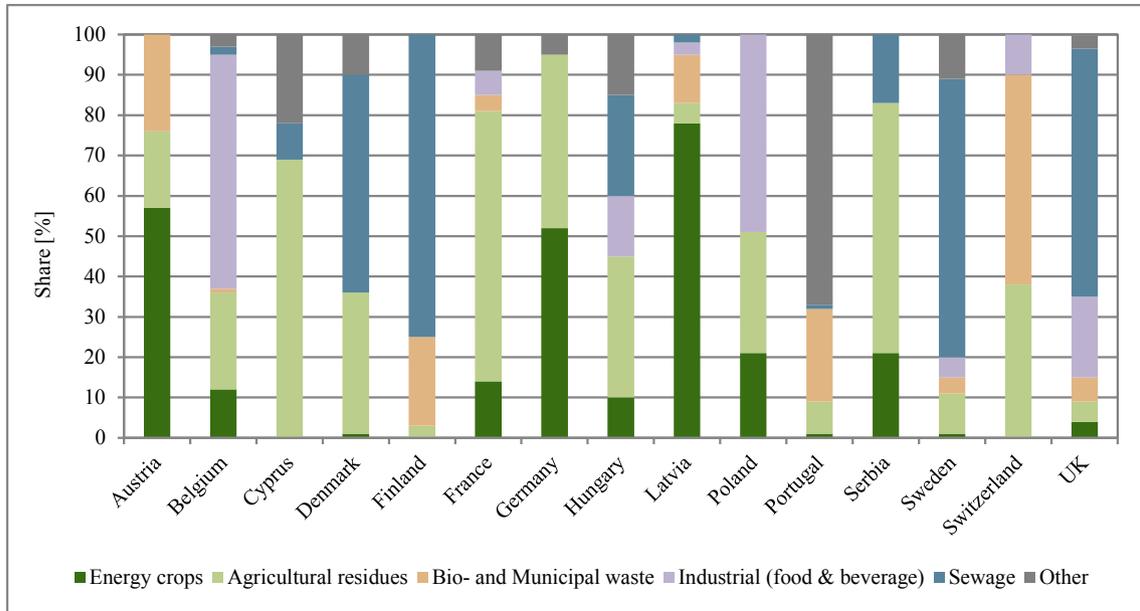


Fig. 6. Feedstock use in biogas plants in European countries [25].

highest growth within the bioenergy sector in the last decade.

Until 2020, the use of biogas is projected to reach 420 PJ, including 189 PJ of heat and 63.9 TWh (230 PJ) of electricity. In addition, based on NREAPs predictions, up to 13.9 PJ of biogas (386 million m<sup>3</sup> biomethane) could be used as a fuel in transport. The developments in biogas production that led to significant higher levels in comparison with Member States projections (Fig. 7) provides good opportunities for exceeding the expected levels for 2020. In comparison with current biogas production of 18 billion m<sup>3</sup> CH<sub>4</sub> equivalent in 2015, we estimate that reaching the biogas energy targets for 2020 would require the production of 20–22 billion Nm<sup>3</sup> CH<sub>4</sub> equivalent, depending on the electricity and heating production and biogas plant configurations (heat only, electricity only or CHP) and energy conversion efficiencies [8].

#### 4.1. Biogas electricity

While the installed capacity of renewable electricity plants increased in the European Union from 170 GW in 2005 to 397 GW in 2015, the installed bioenergy power capacity in the EU almost doubled from 16 GW in 2005 to 30 GW in 2015. Biogas electricity capacity has experienced the highest growth in the bioenergy sector in the EU, with an increase from 3 GW in 2005 to 10 GW in 2015, close to the expected 11.2 GW installed capacity for 2020 (Fig. 8) [8,20].

The biogas capacity represents today a share of 34% in total biomass power capacity in the EU. However, the uncertainties related to sustainability of bioenergy and the reductions in support for biogas in European countries have led to a decrease of the

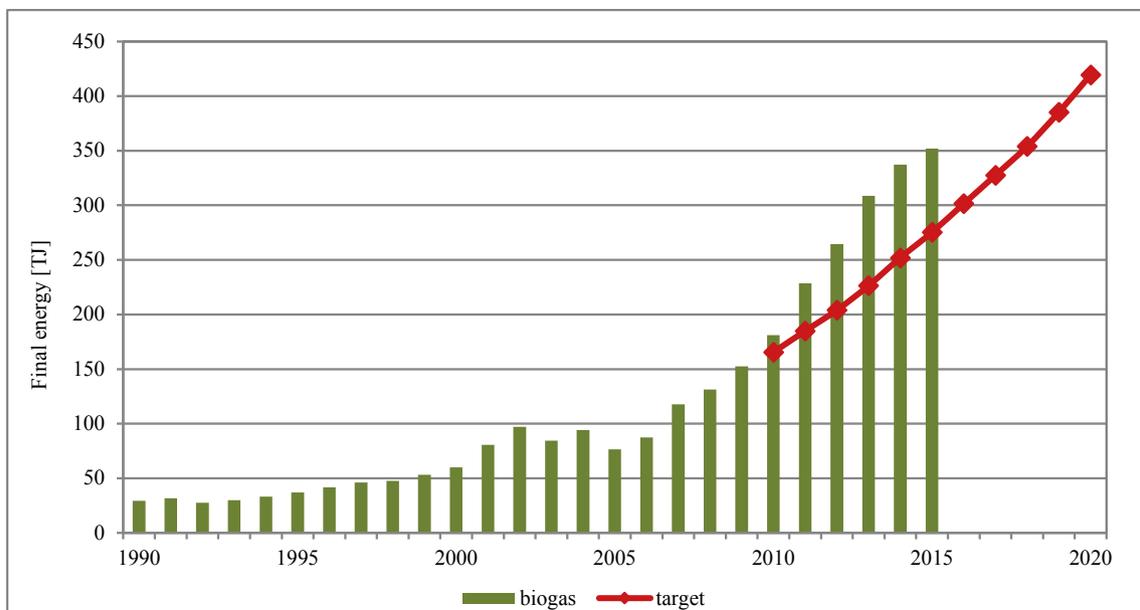


Fig. 7. Evolution of final energy production and biogas targets in the EU [20,24,54].

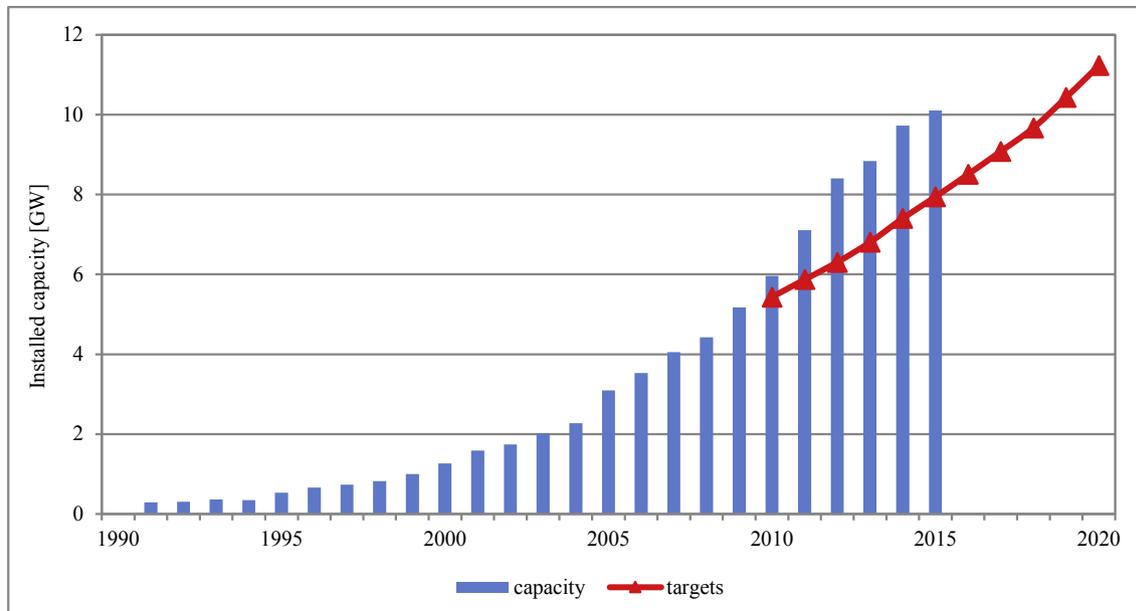


Fig. 8. Evolution of installed biogas electricity capacity and targets in the EU [20,24,54].

growth rate between 2012 and 2015 [8,20].

Significant progress in installed electric capacity of biogas plants has been made in most countries, but especially in Germany, UK, Italy and Czech Republic (Table 4) that became European leaders in

biogas production. In particular, the installed biogas capacity has reached 4.8 GW in Germany (almost half of the EU biogas capacity), in comparison to a total biomass capacity of 7.3 GW in 2015 (two thirds of total biomass capacity). The entire electricity capacity

**Table 4**  
Energy production from biogas in Europe in 2015.

	Electricity capacity	Average capacity	Electricity production	Heat production	Derived heat
EU	MW	kW	GWh	TJ	TJ
Belgium	183	897	955	4272	388
Bulgaria	20	1818	120	182	24
Czech Republic	368	664	2611	6491	623
Denmark	102	671	485	3265	2099
Germany	4803	443	33,073	69,047	9285
Estonia	11	611	50	286	112
Ireland	53	1828	202	370	0
Greece	49	1750	230	661	0
Spain	224	1612	982	2474	0
France	320	446	1783	6859	1432
Croatia	28	1217	177	219	219
Italy	1336	859	8212	10,469	8604
Cyprus	10	769	51	214	51
Latvia	60	1017	391	1256	892
Lithuania	21	583	86	403	91
Luxembourg	12	400	62	390	80
Hungary	69	972	293	667	131
Malta	3	1500	7	30	6
Netherlands	239	892	1036	0	48
Austria	194	437	624	2036	145
Poland	216	780	906	3703	436
Portugal	66	1031	294	336	0
Romania	14	1273	61	303	156
Slovenia	32	1231	132	383	304
Slovakia	91	650	541	2122	473
Finland	0	0	358	1600	763
Sweden	95	337	62	2150	274
UK	1488	2845	7189	6641	0
Switzerland	74	116	303	1342	1199
Iceland	0	0	0	37	0
Norway	17	138	7	834	118
FYROM	4	1333	20	37	0
Serbia	5	714	23	45	0
Moldova	3	750	15	159	11
Ukraine	18	1125	10	282	360
<b>EU</b>	<b>10,107</b>	<b>609</b>	<b>60,973</b>	<b>126,829</b>	<b>26,636</b>
<b>Europe</b>	<b>10,228</b>	<b>588</b>	<b>61,351</b>	<b>129,565</b>	<b>28,324</b>

Source [21].

comes from biogas in Cyprus and Malta, in few countries (Ireland and Greece) biogas capacity represents more than 90%, while in other countries (Czech Republic, Croatia, Slovenia) this represents about 50%.

The renewable electricity production in the EU increased by almost 75% since 2005 to 927 TWh in 2015, on a trajectory that is likely to lead to 1210 TWh renewable electricity in 2020. The renewable electricity share in the final electricity consumption almost doubled from 2005 to reach almost 29% in 2015. In parallel with the increasing installed capacity, the electricity generation from biomass has increased from 69 TWh in 2005 to 178 TWh in 2015 on the target to reach 233 TWh in 2020. The contribution of biomass to electricity generation will remain at around 19% of total renewable electricity generation until 2020. Following high growth in biogas capacity, high progress has been recorded in biogas electricity production, with an increase from 12.5 TWh 2005 to 61 TWh in 2015 (Fig. 9). The recent developments on biogas electricity production brought the electricity production from biogas at 40% above the projections for 2015 and close to the expected level of 63.9 TWh biogas electricity in 2020. The investments in biogas electricity capacity, in comparison to whole biomass sector, have brought the share of biogas in the biomass electricity to more than 34% in 2015, in comparison to 18% in 2015 [8,20].

The production of electricity from biogas looks very different among different MS, as well as the progress made in comparison to the targets set by the different Member States (Fig. 10). The leading countries in biogas electricity generation in 2015 are well above their targets for 2020 (Germany, Italy, UK), with other countries have already reached the projected level for 2020 (Czech Republic, Finland, Austria). Higher progress is needed in other MS that are still well below their projected growth. With an electricity production from biogas accounting for more than 50% of the EU biogas electricity production, Germany would still hold this position until 2020, when its share in total EU biogas electricity would decrease due to the progress made in other MS [8,24].

#### 4.2. Biogas heat

The use of renewable energy in the heating sector is expected to

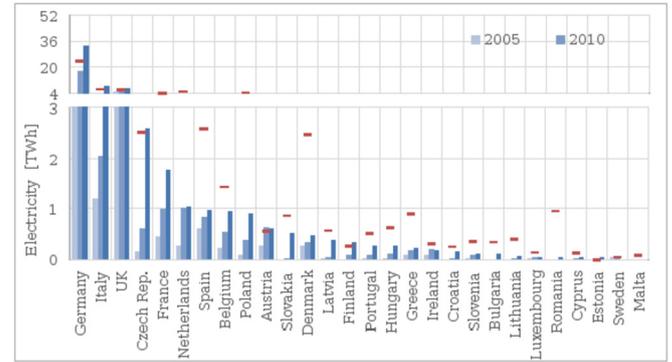


Fig. 10. Progress made and targets for 2020 for biogas electricity production in the EU MS [20,24,54].

double between 2005 and 2020 and to reach 4.7 EJ in the EU in 2020. The contribution of renewable energy in heating and cooling sector has already increased from about 9% in 2005 to almost 19% (4.5 EJ) in 2015 on the path to reach 21% until 2020. Biomass is the largest contributor in renewable heating and cooling and the use of biomass in heating and cooling should increase from 2.2 EJ in 2005 and 3.5 EJ in 2015 to 3.8 EJ in 2020 [8].

While the main contributor of biomass in renewable heating in 2005 was solid biomass (forest and agricultural residues, wood pellets and various waste), the biogas share in biomass heating was limited to only 1% in 2005, which increased to about 3.7% in 2015, as most of the biogas plants used the heat to a low extent. With a slower progress in biogas heat than in electricity generation, the use of heat from biogas increased from 26 PJ in 2005 to 127 PJ in 2015, which is however about 10% above the level forecasted for 2015. The current levels for heat generation from biogas offer good prospects for reaching the forecasted level for 2020 (Fig. 11) [8].

The biogas heat use also shows large differences across the EU, as well as the progress made in comparison to the targets set by the Member States (Fig. 12). The leading countries in the use of biogas heat in 2014 were Germany, Italy and Denmark, while important growth is still expected in France, Poland, UK and the Netherlands.

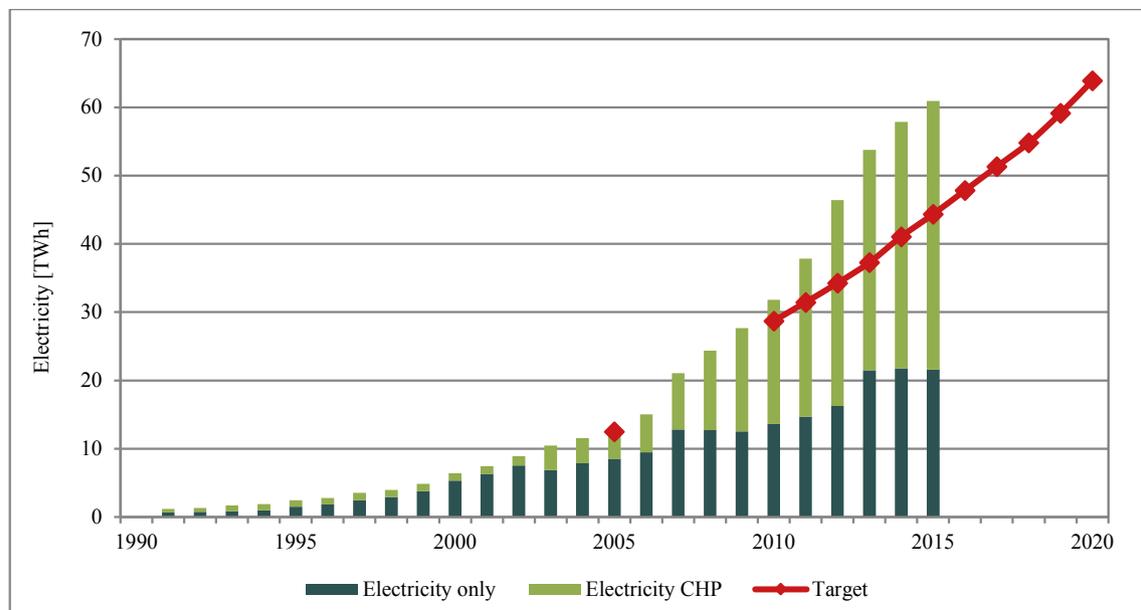


Fig. 9. Evolution of electricity production from biogas in the EU and targets [20,24,54].

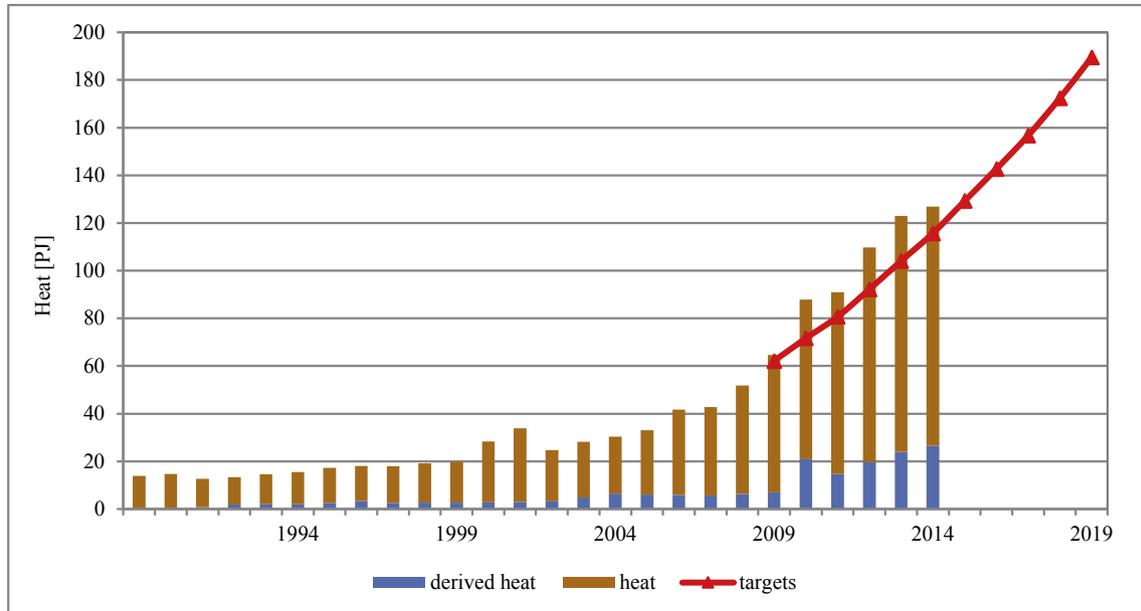


Fig. 11. Evolution of biogas heat generation and targets in the EU [20,24,54].

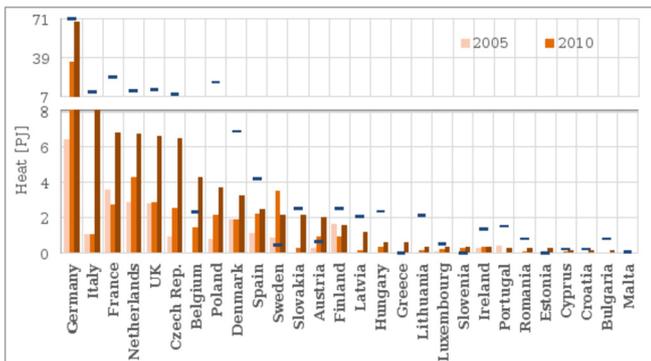


Fig. 12. Progress made and targets for 2020 for the use of biogas heat in MS [20,24,54].

Germany also dominated the biogas heat market in the EU with a share of about 50%. The highest growth in the use of heat from biogas has been achieved in Germany, which has now more than 50% of the biogas heat market in the EU. While Germany almost reached its 2020 projections, Belgium and Sweden surpassed their targets and large growth has been recorded in Italy. Higher progress is needed in other MS that are still well below their projected growth.

#### 4.3. Biogas use in transport

The share of renewable energy in the energy used in transport in the EU has increased from 1.3% in 2005 to 6.7% (13.2 Mtoe) in 2015, with first-generation biofuels providing more than 80% of all biofuels used in the EU. The growth of biofuel use in transport has been slowed down due to debates surrounding the various concerns related to sustainability issues (GHG emissions, Indirect Land Use Changes - ILUC, impacts on food security, etc.) and the perspectives of reducing support for biofuels causing a considerable degree of uncertainty in the market.

The National Renewable Action Plans (NREAPs) defines different biofuels categories that could be used in transport. Although the NREAPs do not provide detailed info on the expected contribution

of biogas in transport, a category was defined as other biofuels and includes biogas, vegetable oils, etc., that was expected to provide maximum 13.9 PJ (1% of the biofuels expected to be used in transport) in 2020 [8]. As already observed, a small part of biomethane obtained through biogas upgrading is being used in transport in several European countries (Fig. 13). The latest data show that the use of biomethane as a transport fuel in the Europe, has achieved 160 million m<sup>3</sup> of biomethane in 2015, of which 113 million m<sup>3</sup> in Sweden, 35 million m<sup>3</sup> in Germany, 10 million m<sup>3</sup> in Norway, 2 million m<sup>3</sup> of in Iceland, 0.2 million m<sup>3</sup> of in Finland and 28000 m<sup>3</sup> in Italy [20]. Although biomethane use in transport is still low and confined to a small number of countries, the high rate of development offers good perspectives for the biomethane market development in transport.

Biomethane can be used in present combustion engines and existing Compressed Natural Gas (CNG) and Liquefied Natural Gas (LNG) refuelling infrastructure. Biomethane is currently supplied in Europe as compressed gas from dedicated filling stations, for city public transport applications and other Natural Gas Vehicles (NGV). Liquefied methane, suitable for large engines and heavy duty and commercial vehicles started to be provided from landfill gas recovery and biogas upgrading to fuel commercial vehicles in the UK. The further use of biomethane in transport depends on the support schemes and progress made in terms of technical advancements and cost developments. The proposal to cap the use of food-based biofuels to a share of 7% of the energy use in transport in 2020 and furthermore to decrease progressively to 3.8% in 2030 will influence significantly the contribution of (first generation) biofuels in transport that will differ substantially from the NREAPs projections and potentially favour the use of biomethane in transport.

Natural gas engine technology is already well established and millions of vehicles using natural gas are in operation worldwide. Natural gas engines have low-NO<sub>x</sub>, around 24% lower CO<sub>2</sub> emissions, and low particulates emissions. Infrastructure for compressed natural gas vehicles and fuelling stations is widely available and provides opportunities for biogas upgrading and use in transport [16,55,56]. The consumption of natural gas as vehicle fuel was estimated to be in the EU at 5 billion m<sup>3</sup> in 2015 and the amount of gas has been increasing rapidly in the last 15 years. There are about

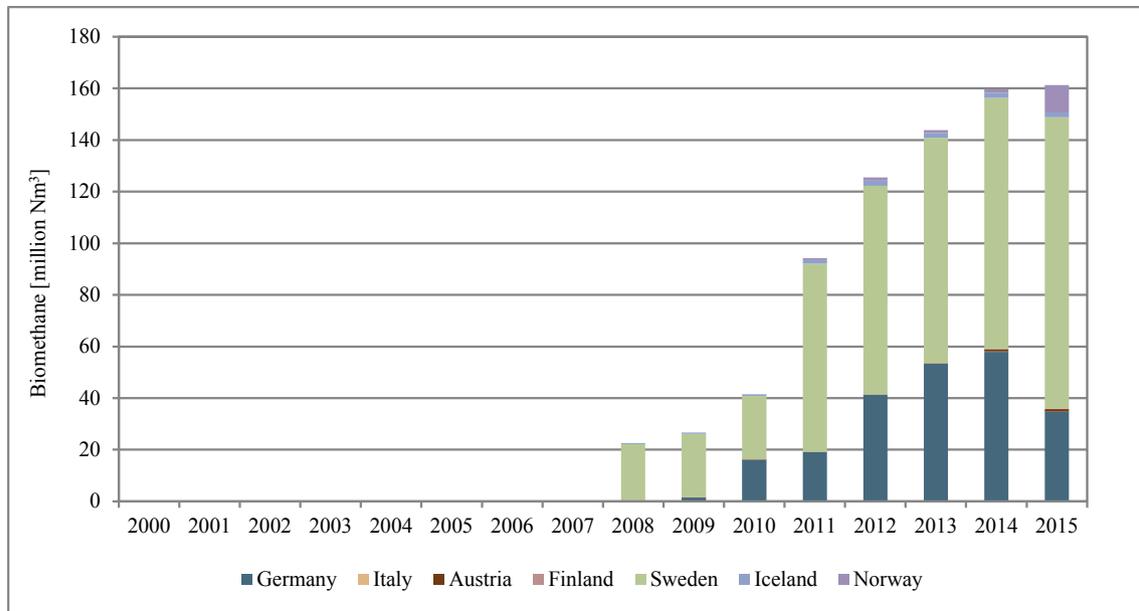


Fig. 13. Biomethane use in transport in European countries [20].

3345 Compressed Natural Gas filling stations in the EU feeding about 1.3 million Natural Gas Vehicles. In the selected European countries, there are almost 3800 filling stations for 1.6 million NGVs, as shown in Table 5. The use of natural gas as vehicle fuel could increase to 10–15 billion m<sup>3</sup> by 2020, reaching 5% market share in the transport sector; biomethane from biogas upgrading can have a contribution to this [20,26].

Currently, there were 697 biomethane filling stations in European countries, with 288 filling stations in Germany, 140 biomethane stations in Switzerland and 24 in Norway (see Table 2 above). Sweden is the world leader in the use of biomethane in transport, with a share of 75% of the biomethane used in the European Union in transport and with 205 biomethane filling stations [20,25]. CNG filling stations provide in Sweden nowadays mixtures of at least 50% biogas with natural gas, but it may also provide 100% biogas (Energy in Sweden 2015).

## 5. Discussion and conclusions

### 5.1. Contribution to the energy and climate targets

Bioenergy production, as part of a bio-based economy, has the potential to contribute significantly to the development of a green, low carbon economy. Biogas production can significantly contribute to the development of rural areas and encourage creating new supply chains for biomass feedstock, especially based on the use of waste and residues from agriculture. The potential of biogas contribution to renewable energy generation with various waste and residues is significant, both in terms of energy supply and in terms of the GHG emission reduction potential. In particular, biogas production from various waste and residues has no side-effects (such as land use/land use change, ILUC, food security, etc.) and provides the highest GHG emission reductions among many bioenergy supply chains.

This paper shows that significant progress has been made worldwide on biogas production both in small scale household digestors in developing countries, as well as in larger scale, commercial electricity biogas plants. Europe is a leader in biogas production, with a large, increasing number of commercial biogas

plants (more than 17,000 plants) installed and a total electricity capacity of over 10 GW, as compared to a global electricity capacity of 16 GW. Anaerobic digestion provides energy (electricity, heat or fuels) for local farm use or to external users, delivered through the electricity, district heating or natural gas grids. However, despite a high existing potential, biogas production is still low in many European countries and the potential largely unused.

Biogas market development has been favoured in several countries by positive policy framework conditions, programmes, administrative procedures and financial support (feed-in tariffs, investment support, etc.) mainly for electricity generated from biogas. The use of heat from biogas, especially the use of derived heat are still limited, although some heat is used for own purposes and internal processes. However, the commercial use of heat from biogas has generally increased as result of the need to improve the economics of biogas plants through additional income, and as result of heat use obligations or measures to promote the use of heat from CHP plants.

Biogas upgrading and biomethane production offer new opportunities for the use of biogas and for the substitution of fossil fuels in transport sector, overcoming the limitations for the use of heat and for improving the economics of biogas plants.

The potential of biogas for grid balancing, either for electricity or natural gas grid, is substantial, allowing the integration of higher shares of variable renewable energy sources, such as solar and wind, in the electricity grid. Hybrid systems are being currently developed worldwide by combining biogas plants with solar or wind for balancing the grids.

Biogas support underwent some changes in the last few years in many European countries, following a decreasing trend. For example, the Renewable Energy Act 2017 (*EEG 2017*) in Germany introduced a technology-specific tendering system for renewable energy sources, with a maximum market premium set and up to a maximum capacity set for each source [57]. The Feed-in Tariff (FiT) still applies for biogas production, depending on feedstock used and plant capacity, but with a decrease amount. Feed-in Tariff system in the UK provides a guaranteed price for 20 years to small-scale biogas electricity plants (less than 5 MW) and receives additional support in the form of multiple Renewables Obligation

**Table 5**  
Annual gas consumption in transport.

	Total NGVs	CNG stations	LNG stations	Natural gas consumption million Nm <sup>3</sup>	Biogas in transport million Nm <sup>3</sup>
	–	–			
Belgium	5365	78	2	61.83	0
Bulgaria	69,820	125		308.14	0
Czech Republic	15,500	143		85.78	0
Denmark	327	15		0	0
Germany	93,964	885	2	737.25	34.8
Estonia	1504	6		3.58	0
Ireland	8	1		0.03	0
Greece	2210	10		19.53	0
Spain	5797	66	22	402.89	0
France	14,548	60	9	192.89	0
Croatia	329	2		4.28	0
Italy	1,001,614	1186	10	1405.19	0.03
Latvia	–	–		0	0
Lithuania	343	3		38.58	0
Luxembourg	306	7		0	0
Hungary	6314	10		40.81	0
Netherlands	11,020	183	21	47.06	0
Austria	7084	172		346.78	1
Poland	3600	28	1	464.42	0
Portugal	570	19	7	16.86	0
Romania	1390	1		1.53	0
Slovenia	335	4		2.72	0
Slovakia	1893	11		119.22	0
Finland	2375	29	2	8.69	0.2
Sweden	54,379	173	6	746.83	112.8
UK	310	38	18	0	0
Switzerland	12,912	141		0	0
Iceland	1236	5		0	1.9
Norway	745	7		148.94	10.5
Serbia	878	10		N/A	0
Moldova	2200	24		N/A	0
Ukraine	388,000	324		N/A	0
<b>EU</b>	<b>1,300,905</b>	<b>3255</b>	<b>100</b>	<b>5055</b>	<b>149</b>
<b>Europe</b>	<b>1,706,876</b>	<b>3766</b>	<b>100</b>	<b>5204</b>	<b>161</b>

Source: [21,26,27].

Certificates. Biogas also receives support for heat use, under the Renewable Heat Incentive in the UK, while in Austria, a premium is granted for biogas electricity from CHP-plants. In Austria, FiT for biogas plants is provided if a minimum share of 30% manure is used as a substrate, depending on feedstock used, plant capacity and the plant efficiency. Biogas from manure receives higher support in Germany for plants smaller than 75 kW and the proportion of manure excluding poultry manure must be of at least 80%. Premiums are granted in Austria and in the UK for the biogas fed into the grid that has been upgraded to natural gas quality. After the eligibility period for the feed-in tariff expires, biogas plants will be eligible for financial support provided that the plant has efficiency higher than 60% and the share of food crops used as substrate is below 60% [58]. All these changes in the legislation for biogas show a trend toward the reduction of support for biogas plants that might lead to a slower development in the biogas sector due to unfavourable economics.

## 5.2. Sustainability issues

The European Commission proposal for a revised Renewable Energy Directive released in November 2016 includes updated sustainability criteria for biofuels used in transport and bioliquids, and solid and gaseous biomass fuels used for heat and power with updated greenhouse gas emission accounting rules and default values.

In order to foster the decarbonisation and energy diversification of the EU transport sector, the revised renewable energy Directive introduce an obligation on fuel suppliers to provide an increasing

share of renewable and low-carbon fuels (advanced biofuels, renewable fuels of non-biological origin, e.g. hydrogen, biogas produced from various waste and residues, waste-based fuels and renewable electricity). The level of this obligation is progressively increasing from 1.5% in 2021 to 6.8% in 2030. Within this total share, the contribution of advanced biofuels and biogas produced from feedstock listed in part A of Annex IX shall be at least 0.5% of the transport fuels in 2021, increasing up to at least 3.6% by 2030. In order to minimize the Indirect Land-Use Change (ILUC) impacts, the revised Renewable Energy Directive introduces a cap on the contribution of food-based biofuels towards the EU renewable energy target, starting at 7% in 2021 and decreasing progressively to 3.8% in 2030. These provisions provide good opportunities for the increased use of biomethane in transport, acting as an incentive for technology improvements and cost reductions.

The Directive reinforces the existing EU sustainability criteria for bioenergy and extends their scope to cover biomass and biogas for heating and cooling and electricity generation to deliver high greenhouse gas (GHG) savings compared to fossil fuels, and to ensure that bioenergy is produced in a way that does not cause deforestation or degradation of habitats or loss of biodiversity. The Directive aims to ensure high conversion efficiency into energy, promoting efficient use of limited resources and avoid unintended impacts on other (competitive) uses, which would thus promote the use of various waste and residues. The GHG emission saving requirements for biofuels increased to 70% for new plants and an 80% saving requirement applies to biomass-based heating/cooling and electricity; the criteria do not apply to small biomass-based heating/cooling and electricity installations, with a fuel capacity

below 20 MW. Biogas production mainly from various waste and residues (including manure) are favoured, due to its high capacity to deliver high GHG emission reductions.

### 5.3. Biomethane as transport fuel

Biomethane is an energy carrier with a special value because it is flexible in use and offers additional storage advantages. Various biomethane support schemes in European countries has led to significant improvements in biogas upgrading technology and market development in Sweden, Germany, Finland, etc.

Upgraded biogas to biomethane has emerged as a good alternative to the use of food-based crops biofuels to replace fossil fuels for transport, due to reduced environmental impact, reduced indirect effects and lower GHG emissions. Thus, the use of biomethane as a transport fuel in the Europe has increased significantly in a few years to reach 160 million m<sup>3</sup> in 2015 (5.4 PJ). This trend is likely to continue due to multiple environmental and climate benefits and the opportunities offered by the transport sector.

The use of biomethane will imply very low GHG emissions if compared to food-based crops biofuels or advanced biofuels. Biomethane could even result in negative GHG emissions when produced from feedstocks which otherwise would emit methane during decomposition, such as manure. The use of biomethane as transport fuel and biomethane as an additive to natural gas provide additional potential for reduction in carbon emissions.

Biomethane and natural gas can be distributed through the existing natural gas pipeline infrastructure as compressed natural gas (CNG) or can be delivered using tankers as Liquefied Natural Gas (LNG) and sourced from LNG terminals for fuelling heavy duty engines in transport sector (buses, trucks, ships, etc.). Increased use of biomethane would require the expansion of the already existing CNG filling stations network, benefitting from the experience achieved so far with the Natural Gas Vehicles (NGV) [55].

Various support measures included priority grid access and transport for biomethane, FIT for electricity from CHP, biofuel quota, renewable heat quota (Germany), tax reduction for biomethane as a fuel, investment programmes, specific aid for farm based biogas from manure, tax exemption from vehicle tax, tax exemption for biomethane application from CO<sub>2</sub> tax and energy tax (Sweden).

### 5.4. Future prospects

Economics are the key determining factor affecting the development of biogas production. The use of heat has emerged as an opportunity to increase the income and thus the profitability of biogas plants. The use of upgraded biogas in transport applications has increased as result of the new opportunities for the use of biogas and benefited from various support schemes and programmes. Technological improvements in biogas upgrading technologies to biomethane could lead to lower energy intensity and improved cost performance that could make biomethane cost competitive with fossil fuel use in transport.

Biomethane can play a high role in the future as energy carrier because it is flexible in use and it is storable, which makes it highly valuable for balancing the energy grids. Biomethane has been obtained almost exclusively using a biological process (anaerobic digestion) involving sewage sludge or agricultural and industrial waste. Several projects rely on the gasification of ligno-cellulosic biomass developing technology to produce Synthetic Natural Gas (SNG) or biomethane (such as BioGas Max, GasHighWay and MADEGASCAR and the plant project developed by Göteborg Energi

in Gothenburg, Sweden). Depending on the technology improvements, future cost reductions and support schemes, the volume of biomethane production will dramatically increase and this increase will facilitate rapid growth of its use in the transport sector.

The use of energy crops (such as silage maize) in particular has increased in several countries (such as Germany and Austria) used due to its exceptionally high methane yields which increased the profitability of biogas production. Co-digestion of various substrates also contributes significantly to the improvement of the digestion process, the improvement of biogas yield and biogas plant performances. However, the sustainability debated on the use of energy crops and their impact on land use changes and on food security has led to limitations for the share of energy crops used for biogas production (Germany, Austria, Denmark). Thus, it is expected that the use of energy crops and their potential in the future biogas production in the EU will be increasingly limited, due to sustainability considerations and support directed only to the use of waste and residues.

Biogas production could increase from the extended use of various organic waste streams, such as food waste, crop residues, sewage sludge from waste water treatment or micro and macro algae (freshwater and marine). Although anaerobic digestion is well established and to an extent demonstrated technology, some improvements and cost reduction could be expected from improved biological processes (optimisation, improving design and process integration), dry fermentation and thermophilic processes that increase biological efficiency and biogas yield.

Improved pre-treatment technologies (such as hydrolysis, etc.) aiming at increasing feedstock biodegradability can be expected, opening the possibility to use more feedstock types, including materials with high cellulose content. New techniques to improve the biological digestion process through ultrasonic treatment or enzymatic reactions, the use of new enzymes and substrates, the use bacterial strains with a greater tolerance to process changes and feedstock type can also contribute to the advancement in biogas production. Process improvements could result in a reduced need to clean the gas and removing contaminants [59].

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