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Research paper

Support for biogas in the EU electricity sector – A comparative analysis

Manjola Banja[a,*], Martin Jégard[b], Vincenzo Motola[c], Richard Sikkema[d]

[a] Directorate C - Energy, Transport and Climate, Air and Climate Unit Joint Research Centre, European Commission, Ispra, Italy
[b] Paris School of Economics, Former Trainee, Directorate C-Energy, Transport and Climate, Joint Research Centre, European Commission, Ispra, Italy
[c] Italian National Agency for New Technologies, Energy and Sustainable Economic Development, Italy
[d] WUR/ Environmental Science Group, Netherlands

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ABSTRACT

This paper aims to present a comparative analysis of biogas electricity deployment in EU countries over the period of 2010–2017. The analysis shows that the deployment of biogas electricity is mainly linked to the moment of the shift in the support framework, the maturity of tenders and the feasibility of long-term objectives. With 200 incentives in place the EU has created favourable conditions to support biogas electricity. Manure and waste are the main feedstocks of biogas electricity in the EU that receive the highest incentives. However, the recent shift towards capacity market mechanism has had an adverse effect in the deployment of biogas electricity. The way in which the biogas is currently valorised, has not been very effective in some EU countries. We found that the EU average growth rate of biogas electricity over 2016–2017 dropped 4 times compared with 2014–2016. Plans/targets have been very supportive in the fast deployment of biogas electricity. Nevertheless, a clear post 2020 picture for renewables is still missing in several EU countries that are risking lagging in biogas electricity deployment. The future of biogas is been seen promising on the upgrade to biomethane as a sustainable input for environment and economy.

1. Introduction

One of key pillars of the European Union energy strategy of the last 25 years has been the focus on the promotion of renewable energy sources. In its Green Paper (1996) [1] "Energy for the Future" the European Commission (EC) noted that "*while some (EU countries) have completely integrated favourable policies towards renewable sources into their general energy policy and planning framework, others have not adopted the use of renewable energy sources into their strategies for meeting global environmental targets*". The adoption of the "White Paper for a Community Strategy and Action Plan" in 1997 [2] created the basis of a European Union policy on renewable energy. In 2000 the EC planned to elaborate a proposal for the harmonised support mechanism, which had "*to be compatible with the principles of the internal electricity market*" [3] (EC, 2000). The Directive 2001/77/EC [4] accepted the heterogeneity of support instruments in the short term fixing indicative renewable electricity targets for the EU Member States' – in line with the principle of subsidiarity – for which they were free to choose any support instrument to achieve these targets.

The process culminated in 2009 with the Directive 2009/28/EC (RED-1) [5], when it set the target of a 20% share of renewable energy in its gross final energy consumption (GFEC) by 2020 and a 10% share of renewable energy in transport energy consumption by the same year. In 2013 the EU adopted the guidance document for the designing and reforming of renewable energy support schemes [6]. In 2014 the EC's *Guidelines on State Aid for Environmental Protection and Energy* [7] allowed Member States to support renewable energy sources, subject to certain conditions. The EU has established the ambitious goal to reach 80%–95% GHG emission reduction by 2050 [8]. According to Ref. [9] the share of renewable energy could reach between 55% and 75% of gross final energy consumption in the European Union in 2050. In utilizing 32% from renewable energy sources for its gross final energy consumption by 2030 the EU does not differentiate between the types of renewable energy sources (RED-2) [10]. EU's Renewable Energy Policy only prescribes the individual country shares of all renewable energy sources to be attained as a share of the total gross energy consumption. The bio-economy strategy [11] defined the key role of bioenergy replacing fossil fuels on a large scale and not only for energy purposes. Modern bioenergy is the overlooked giant within renewable energy. Modern bioenergy (excluding the traditional use of biomass) was responsible for half of all renewable energy consumed in 2017 (in global scale) – it provided four times the contribution of solar photovoltaic (PV) and wind combined. The forecast for bioenergy in the European Union has been lowered, although the United Kingdom and

* Corresponding author.
E-mail address: m.banja@yahoo.com (M. Banja).

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the Netherlands remain major markets [12].

The EU countries in accordance to these guidelines have implemented several different policies to increase the production of energy from renewable sources. Such support schemes are now being progressively phased out, due to the rising policy costs and to the significant reduction in renewable investment costs, which has also occurred thanks to these policies [13]. The cost-reductions in renewable energy technologies over the last couple of years are enabling consumers to increasingly produce their own energy and encouraging greater uptake [14].

A large literature exists on the role and effects of policies on the development of renewable electricity, but the most of the literature is qualitative and descriptive [15]. In Del Río, P., & Mir-Artigues, P [16], the authors explain that most support scheme combinations across Europe concern feed-in systems, mixing tariffs and premiums, and are applied simultaneously to the same technologies. Nicolini & Tavoni [13] test if policy support for renewable electricity has been efficient in its promotion of RE sources. Their analysis focuses on the five largest EU countries from 2000 to 2010. The data consists of the level of applied tariffs and the amount of incentives granted. The authors find a positive correlation between the amount of support and the production of the incentivized energy (1% increase in the tariff leads to 0.4%–1% increase of renewable electricity generation). The results also point towards better performance of feed-in-tariffs in comparison to green certificates system. In Banja & Jégard [17] it was found that 1% increase in the amount of support for solar photovoltaics in France during period 2005–2016 has contributed to an increase by 0.6% in the installed capacity of this technology. In the Council of European Energy Regulators 2017 Report [18], a document focusing on support schemes for 2014 and 2015, it is shown that European countries are adapting their support schemes to allow for more market integration of renewable electricity. It also brings out the fact that basic features of the main support schemes in Europe have not been modified in recent years (funding remains mainly non-tax levies, renewable energy plants continue to be given priority in terms of network connection and electricity dispatching). Furthermore, plants using renewable energy have increasingly the same level of financial responsibility as other plants concerning electricity balancing.

This paper aims to present the most recent data and information, having in focus the support given for the deployment of biogas within EU countries electricity sector. The paper presents a comparative analysis of dynamism of biogas electricity markets in EU investigating the relationship “support scheme – deployment”. The paper is structured to provide a (i) brief update of biogas progress in the EU; (ii) overall measures to support biogas for energy; (iii) support schemes and incentives for biogas electricity; (iv) an overview of the current situation regarding the regulatory and non-regulatory barriers for a biogas project, (v) a comparative analysis of capacity market mechanism for biogas deployment in EU countries electricity sector.

2. Biogas for energy in the EU – state of the art

The growth in bioenergy in the EU over the period 2005–2017 was mainly due to biogas rather than solid biomass. The share of biogas used for both electricity and heating/cooling purposes reached 8.3% (394.5 PJ) of bioenergy in 2017. This source saw the fastest increase until 2017, more than 5-fold (+318 PJ) the level of 2005. The majority of biogas (58%) was used to generate electricity in 2017. The range of this share among the EU countries is very broad from 2% in Sweden to 77% in Croatia. The share of biogas in renewable electricity consumption increased from 2.2% in 2005 to 6.3% in 2017. The contribution in the heating/cooling sector was marginal in 2005, at 30.5 PJ, whereas in 2017 this contribution reached 163.7 PJ.

As shown in Table 1 the installed biogas capacity tripled since 2005 exceeding in 2017 the planned capacity for 2020. Although the number of biogas plants in Europe has been stabilising since 2015 [19], the total biogas installed capacity is on the rise. Growth in biogas installed capacity since 2011 has been mainly due to the building of plants running on agricultural substrates: such plants went from 3408 MW in 2011 to 6348 MW in 2016 (56.5% of the total increase) [19] (see Table 2).

The number of biogas plants in Europe has greatly increased; between 2009 and 2017, the total number of biogas plants rose from 6227 to 17 783 installations. Growth was significant from 2010 to 2012, reaching double figures every year. Most of that growth derives from the increase in plants using agricultural substrates: these went from 4797 units in 2009 to 12496 installations in 2016 (67% of the total increase). Agricultural plants are followed by biogas plants running on sewage sludge (2838 plants), landfill waste (1604 units) and various other types of waste (688 plants). In 2016, the most dynamic countries in Europe for biogas plant construction were France (+93 units) and the United Kingdom (+41 units).

Since 2005, Germany has been the largest mature European market of biogas for electricity purposes having used nearly 126 PJ in 2017, almost 10-fold increase, representing 53% of the whole EU's biogas electricity. Italy and the United Kingdom shared a contribution, at nearly 13% each. The final consumption of biogas for electricity in Italy saw a fast increase until 2014, 7-fold the level of 2004; then this consumption remained almost constant. In the United Kingdom the consumption of biogas for heating/cooling purposes tripled between 2014 and 2017. The biogas from anaerobic digesters predominates in Czech Republic, Denmark, Germany, Italy, Austria and Greece. Landfill biogas also dominates the market in Estonia, Ireland, Portugal, and United Kingdom, while biogas from wastewater treatment prevails in few countries, such as Lithuania, Poland and Sweden.

More than 70% of the EU biogas plants for electricity operates on agriculture feedstock [20]. Energy crops (mainly maize) provide about half of the biogas production, followed by landfill, organic waste (including municipal waste), sewage sludge and manure. Based on the number of biogas plants installed, the mature biogas electricity markets cover the main players in biogas production in the EU [21]. Moderate markets include EU countries with a moderate number of biogas plants installed. Immature markets cover EU countries where biogas production is low. The main biogas feedstocks for these markets are presented in Fig. 1, together with the valorisation these markets are currently giving to these feedstocks. As shown in this figure the main valorisation for biogas feedstocks is currently given in the form of CHP and electricity.

Fig. 2 shows the employment and the turnover in the EU biogas sector in 2017. The estimated overall total EU employment in the biogas sector decreased from 83700 jobs in 2015–76000 in 2017 (−9.2%). The estimated turnover decreased from €8.7 billion to €7.5 billion (−13.7%) over the same period. Germany represented 48% of the total EU biogas employment in 2017, with an estimated labour force of 35000 workers (down from 43400 in 2015, -19%). In the same year Germany accounted for more than 55% of the overall EU biogas sector turnover. However, over the 2015–2017 period biogas sector turnover in Germany decreased from € 5.1 billion to 4.2 billion. In the United Kingdom, the employment level in 2017 was rated at around 8400 workers (−29% compared to 2016) and a €0.8 billion turnover, a 28% decrease from €1.1 billion in 2016. The Italian biogas sector size reached in 2017 an estimate of 8100 workers (1.2% increase from 2015) and a €840 million turnover (5.6% decrease from 2015). The contribution of France in the total number of workers and in the overall turnover in the EU biogas sector accounted respectively for 3.3% and 3.9% in 2017 [22].

3. Overall measures to promote biogas for energy in the EU

By the end of 2017 almost 700 measures (economic, financial, regulatory, administrative, support) for the deployment of bioenergy were in place in the EU countries since 2005; Fig. 3 two-thirds of which were financial measures. Over a decade nearly 20% of these measures

Table 1
Progress of biogas for energy in the EU (2005-2017) and the 2020 plans (in PJ and MW)
Source: [88], [89]

	2005	2010	2011	2012	2013	2014	2015	2016	2017	2020
Biogas-el (PJ)	46.2	115.8	138.0	169.4	194.0	208.7	220.5	227.0	230.9	229.5
Biogas-th (PJ)	30.5	64.9	88.0	90.7	109.6	124.2	137.1	150.5	163.7	188.4
Biogas-el capacity (MW)	3 113	6 711	8 289	9 560	9 883	10 456	10 986	11 410	11821	11 128

Table 2
Number of biogas plants in EU, (2009 – 2017)
Source: [78]

	2009	2010	2011	2012	2013	2014	2015	2016	2017
Biogas plants	6 227	10 508	12 397	13 812	14 661	16 834	17 439	17 432	17 783

were dedicated to biomass used for electricity production; 24% to the biomass in the heating/cooling sector; 38% to the biofuels used in the transport sector; the rest were measures dedicated to biomass used in one of these 3 sectors[1] Almost 150 measures exist to support the deployment of biogas in the electricity, the heating/cooling and transport sectors. More than 72% of these measures are financial, representing 23% of total financial measures for bioenergy.

Biogas has seen the largest number of measures (financial and regulatory) applied over the period of 2005–2017 for bioenergy in the electricity sector, 42% of the total. In the heating/cooling sector almost 60% of the total measures implemented were dedicated to biomass. The rest were dedicated to biogas (17%), solid biomass (8%), bioliquids (8%) and cogeneration (8%). In the transport sector more than 95% of the total measures implemented were dedicated to biofuels and the rest to biogas (mainly biomethane). The largest share of financial measures (36%) implemented was dedicated to biomass for electricity and heating/cooling purposes. Biogas and biofuels received nearly the same number of financial measures, at 23%. Among regulatory measures biofuels have received the largest share, at 66%. Biomass shared 19.5% of the regulatory measures and the rest was dedicated to biogas for electricity and heating/cooling, at 12.7%. Regulatory measures related to biogas are applied in countries such as France (in relation to new biogas plants), Poland (on generators of the agricultural biogas integrated into the gas distribution grid), Germany (on simplification of the granting of approvals for biogas plants), Italy (on conditions for connecting biomethane systems to the natural gas network), Croatia (on higher energy efficiency requirement for biomass and biogas plants), Slovakia (on facilitation of access to gas network for biomethane), Belgium (on biogas plant construction in a circular economy).

France is applying financial measures through calls for tender (2018) in the electricity sector to support the development of 1000 biogas plants by 2020. It also provides an addition to the purchase price for biomethane injected into grids allowing the dual utilization of the biogas produced, through injection and electricity generation [23]. In *Germany* in addition to the market premium, a “flexibility premium” shall be paid to support targeted investment in demand-orientated capacity of power generation by biogas systems. This premium will enable additional investment to be made in larger gas storage tanks and generators, which would not be covered by the market premium alone [24]. *Italy* is incentivizing the production of biomethane to be injected into the natural gas transportation and distribution grids [25]. *Malta* is promoting auto-gas in road transport through capital grant scheme for the conversion of vehicles to run on gas [26]. *Czech Republic* provides financial measures for small biogas stations with installed capacity of up to 500 kW [27]. *Cyprus* provides subsidy to support electricity generation from landfill biogas [28]. In *Latvia* the financial measures are applied for producers generating electricity in power plants with installed electrical capacity above 1 MW, utilizing biomass or biogas [29]. *Poland* exempts generators that produce electricity in micro-and small-scale installations as well as from agricultural biogas from the obligation to obtain a license in accordance with the Energy Law Act [30]. In *Slovakia* financial measures are applied to support FIT and guarantee the mandatory purchase of electricity from biomethane [31]. *Finland's* financial measures are related to the production aid for biogas [32].

4. Support schemes and incentives for biogas electricity in the EU

As reported in the EU countries National Renewable Energy Action Plans (NREAPs) and the respective 4 sets of Progress Reports, the current main support schemes used to promote the deployment of biogas for electricity are feed-in tariff (FIT), feed-in premium (FIP), Quotas combined with Tradable Green Certificates (TGC) systems and Tenders. As shown in Fig. 4 eighteen EU countries (Bulgaria, Czech Republic, Germany, Ireland, Greece, France, Croatia, Italy, Cyprus, Latvia, Luxembourg, Hungary, Austria, Poland, Portugal, Slovenia, Slovakia and United Kingdom) apply a feed-in tariff scheme for biogas electricity. Constant FIP is applied in twelve EU countries (Czech Republic, Denmark, Germany, Estonia, Greece, France, Italy, Luxembourg, Hungary, Netherlands, Poland, Finland). Germany, Croatia, Lithuania and Slovenia apply sliding FIP; Belgium, Romania and Sweden apply GC. The period after 2014 saw a shift towards the capacity market mechanism through the combination of FIT, FIP and tenders (Germany, France, Italy, United Kingdom) and combination of FIT and FIP (Bulgaria, Ireland, Latvia, Croatia) to support biomass in this sector. This combination is being applied mainly for large-scale installations. Auctions for renewables (including biomass) are now or planned to be, part of the support framework in Germany, France, Italy, Belgium, Lithuania, Croatia, Hungary, Poland, Portugal, Slovenia, Finland and United Kingdom.

Comparing the average level of support given for biogas and other biomass in the electricity sector through the above-mentioned support schemes we found that the average level of support for biogas through sliding feed-in premium is double that of other biomass. The average level of support through other support schemes is comparable between each other (Fig. 5).

Almost 400 incentives given through FIT, FIP, Tender, Contracts for Difference (CfD), Subsidy and Tax exemption are in place to enable the use of biomass for electricity in the EU. Half of these incentives[2] are

[1] In this category were included all measures dedicated to biomass for energy without any specification about the sector in which were implemented.

[2] Shares reported here are related to the number of the incentives in place through FIT, FIP, tax mechanism and tenders in the EU electricity sector.

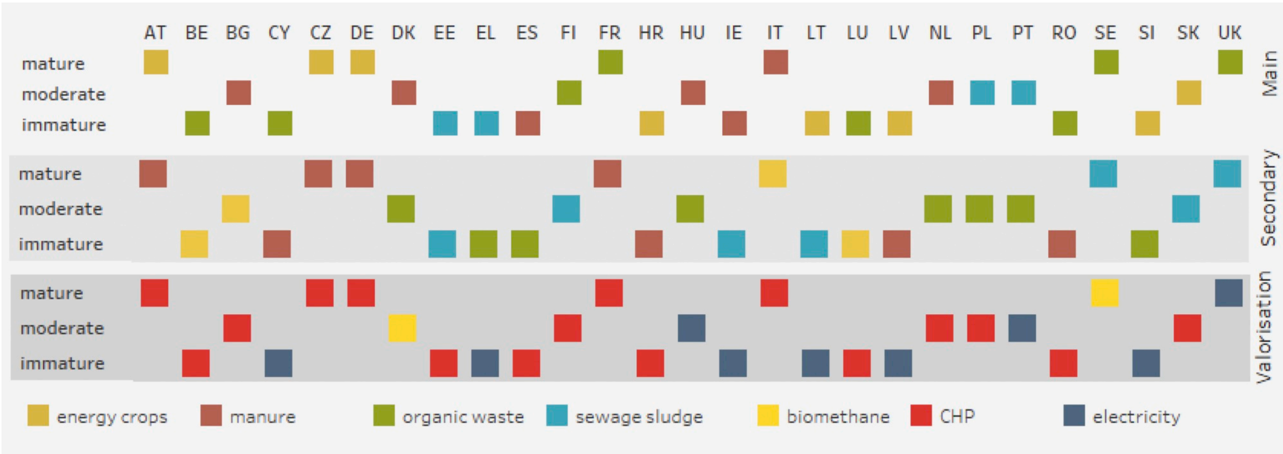

Fig. 1. Feedstocks for biogas for energy & biogas valorisation in EU countries markets (mature, moderate, immature).
Source [21].

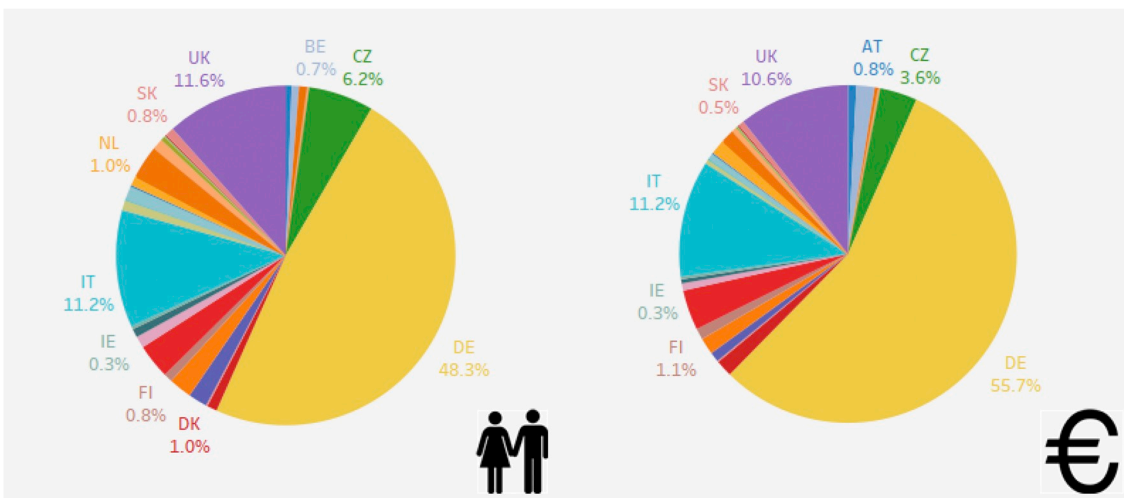

Fig. 2. Employment (left) and turnover (right) of biogas sector in EU countries, 2017.
Source [22].

dedicated to biogas: biogas (90), landfill & sewage gas (42), waste (10), anaerobic digestion (15), manure (6), fermentation (9), anaerobic fermentation (4), gasification (6). Fig. 6 illustrates the average incentives currently in place in EU countries to support the use of biogas in the electricity sector after2014[3] Germany has the highest number of incentives for biogas in electricity sector (21) followed by Netherlands (18), Czech Republic (18), Greece (14) and Poland (14).

Manure receives the highest incentives in minimum, average and maximum terms (see Fig. 7). This support is given through feed-in tariff and feed-in premium schemes. After 2014 the main support for manure is found in Bulgaria, France, Germany, Netherlands and Belgium under the feed-in tariff scheme. The highest incentive (248 €/MWh) is found in Bulgaria for plants working with indirect use of biomass from plant and animal substances (total weight manure not less than 50%). In France the biogas plants that use 60% of livestock manure receive an incentive at maximum level of 225 €/MWh. In Germany the support for biogas plants using manure with a capacity of up to 75 kW reaches a maximum of 231 €/MWh. The premium applied in Netherlands for fermentation of manure in CHP (co-fermentation) reaches 85 €/MWh [60].

5. Regulatory and non-regulatory barriers for biogas deployment in EU countries

Authorization procedures play a crucial role for the development of RES plants. Article 15(1), (d) of the RED-2 [10] states "*simplified and less burdensome authorization procedures, including a simple-notification procedure, are established for decentralised devices, and for producing and storing energy from renewable sources*".

In their NREAPs and respective progress reports the EU countries have reported on the progress made in evaluating and improving administrative procedures to remove regulatory and non-regulatory barriers to the development of energy from renewable sources. Based on the analysis of these official documents we found that currently 13 EU countries apply specific administrative procedures to support the deployment of biomass for energy (Table 3). Only few countries have implemented specific administrative procedures for biogas. *Germany* applies privileged treatment of biogas production plants in rural areas no longer linked to combustion heat output but only to capacity to generate a max of 2.3 Mm^3 of biogas/year (allow more flexible operation of plants to compensate for fluctuations in other RES). In Lithuania the biogas production is promoted by distributing connection costs of

[3] For information on support schemes to promote biomass for energy over period 2010–2014 see the JRC Science for Policy report [59].

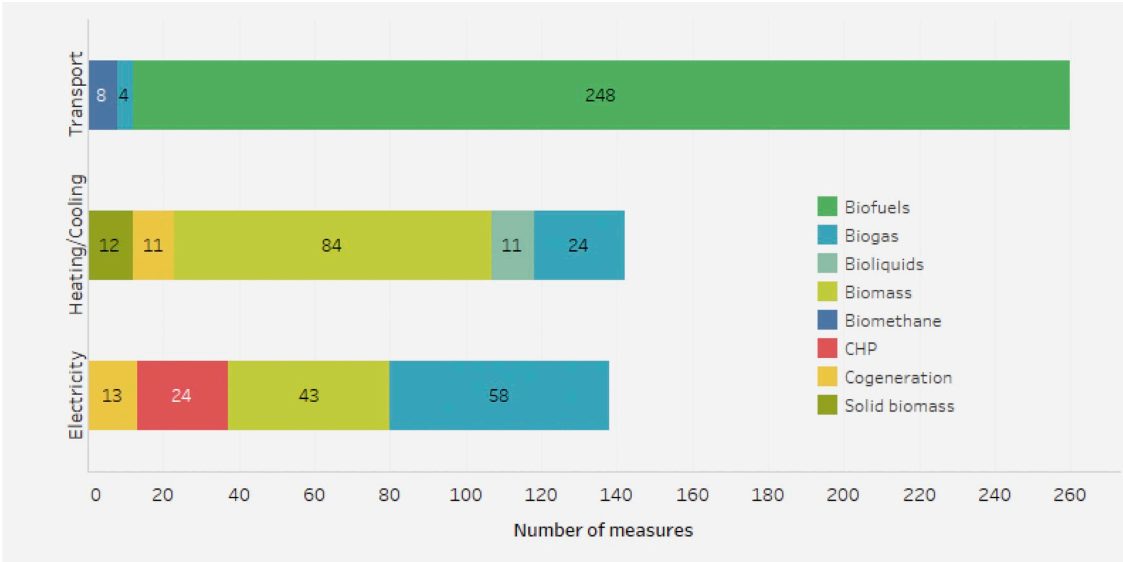

Fig. 3. Number of measures (financial, regulatory, soft) to promote bioenergy in the EU, (2005–2017).
Source [87].

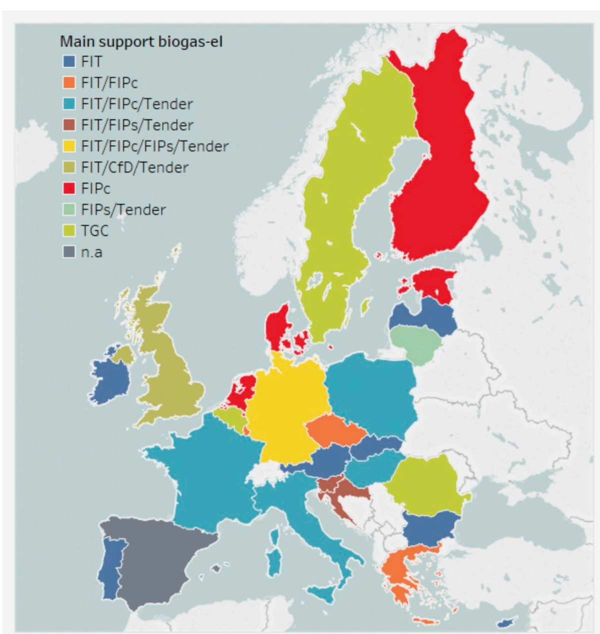

Fig. 4. Main support schemes to support biogas in EU countries electricity sector after 2014.
Source [87].

biogas production facilities to the gas system between the biogas producer and the gas system operator. No detailed plan is required in this EU country for biogas production installations with total capacities of up to 1 MW to be constructed within land plots of existing livestock farming buildings. In Cyprus no environmental impact assessments are required for electricity generation plants using biomass with installed capacity less than 20 kW. Cyprus Transmission System Operator does not request town planning permits/any other permits, in addition to the building permit at the stage where connection applications are submitted.

BiogasIn project [33] provided an overview of administrative barriers both during the permitting and the financing phases of a biogas project in Central and Eastern Europe (CEE). Biogas3 project [34] presented an overview of European legislative and financial frameworks for the implementation of small-scale biogas plants in agro-food and beverage companies. in EU countries such as France, Germany, Italy, Sweden, Ireland, Spain and Poland. The EC study [21] published in March 2017 showed an analysis of key barriers for biogas growth in each EU country identifying the five main barriers per sector (electricity, heating and transport), distinguishing between the three different types of markets (i.e. mature, moderate and immature market). According to this study the main barriers for mature biogas electricity markets are the ILUC & sustainability criteria, the stability of support schemes and the public awareness. For the moderate biogas electricity markets the main barriers are linked with the stability of support schemes, complexity and duration of administrative procedures and

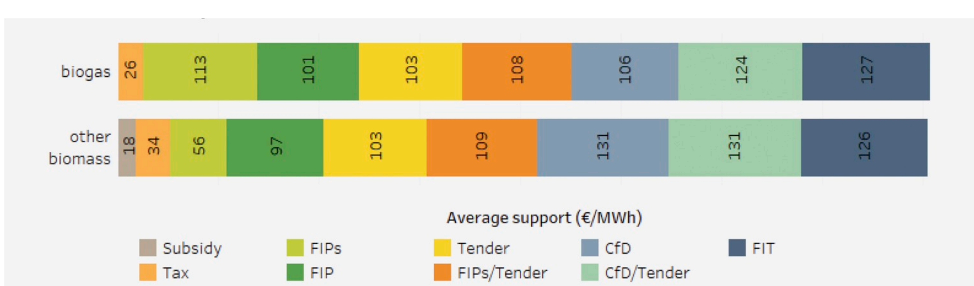

Fig. 5. Average support for the use of biogas and other biomass in electricity sector.
Source [47].

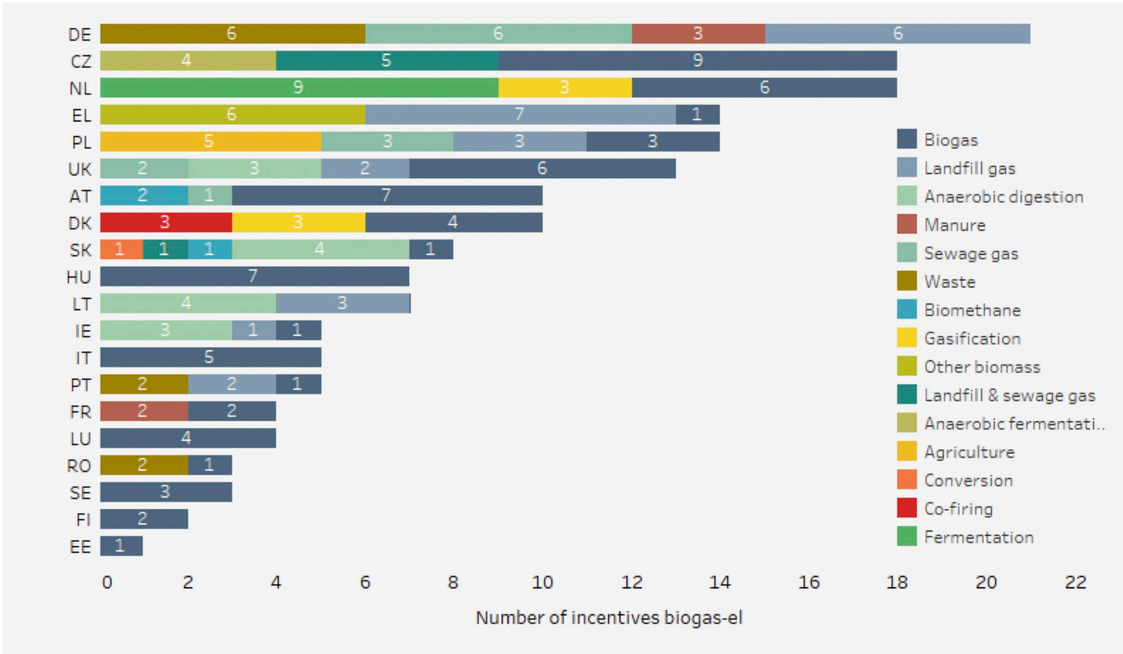

Fig. 6. Current number of incentives in EU countries to support biogas in electricity sector.[1].
Source [47].
(1) Countries are ranked in descending mode. The incentive for biogas.

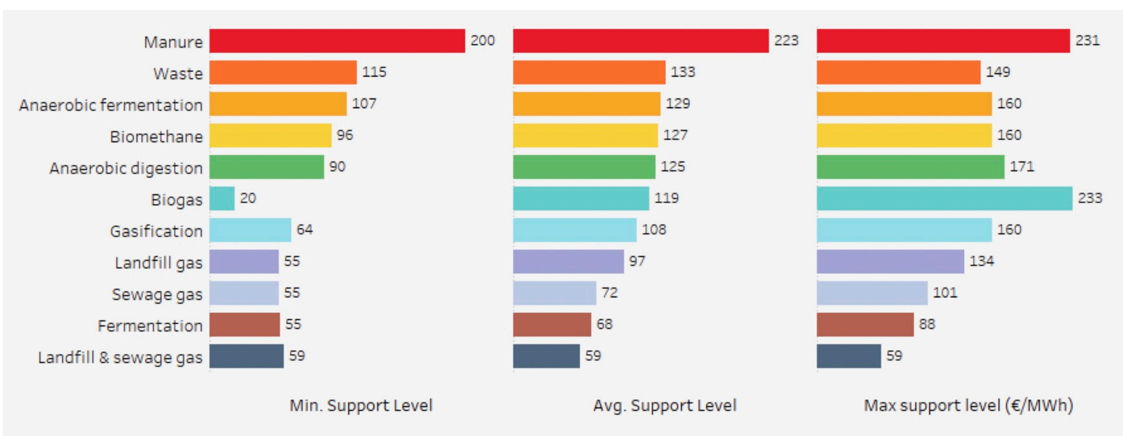

Fig. 7. Current incentives' level to support biogas for electricity in EU (minimum, average, maximum), FIT & Tender.
Source [47].

financing of a biogas project. For immature biogas electricity markets the main barriers are the financing and the existence, the stability and the reliability of support schemes. The Kreeft G.J. 2018 [35] study aimed to identify legal and regulatory challenges for the deployment of power-to-gas at the European Union (EU) and national level. This work done under the EU founded Horizon 2020 STORE&GO project [36], analysed the national legal framework applicable to power-to-gas in Germany, Italy, and Switzerland.

Table 3 shows a summary of the permits needed in each EU country to build a biogas plant. The authorization procedure for a biogas plant may depend on the project size (small or large scale) and if necessary, on obtaining an Environmental Impact Assessment permit. This is the case in Austria, Italy, Malta, The Netherlands, Germany and Sweden. On the other hand, other EU countries such as Croatia, Lithuania, Portugal, Spain, Slovenia, Greece, Bulgaria, Cyprus, Estonia, Finland, Poland and Czech Republic have set up an authorization process with a plurality of permits. The permits are issued to applicants based on plant size and territorial competences [37].

In *Italy* Simplified Authorization and Single Authorization procedures for biomethane plants (Legislative Decree No 28/11, amended by Law No 116/14) are in place since 2014. A regulatory measure was introduced in 2017 regarding the approval of single forms for installing, connecting and operating high efficiency micro-CHP plants and CHP plants using renewable sources [38]. In the *United Kingdom* all anaerobic digester operators must comply with regulations concerning environmental protection, animal by-products, duty of care, health and safety and waste handling. In *Poland* the construction and operation of bioenergy plants requires obtaining several permissions. Some of them are common for biogas and wood combustion plants, whilst some refer to a specific type of plant. A permission it is needed on the environmental conditions, a permission to release gases or dust in air, the permission for waste recovery in case of biogas plants where waste is spreading on the ground for fertilization or soil improvers, concession for electricity and heat production. In *the Netherlands* for the approval of

Table 3
Administrative measures for biomass for energy & Authorization procedures for biogas in EU countries
Source: [87]

	Specific measures	Authorization procedures for biogas[a]
BE	Specific for biomass	EA, Building Permit
BG	Not specific	Building Permit, Grid Permit,
CZ	Not specific	EA, Feasibility Study, Building Permit, Implementation Structure
DK	Not specific	EA, Land zone approval, Local Plan, Building permit
DE	Specific for biogas	EA, Spatial Planning & Construction, Building Permit
EE	Specific for biomethane	Activity Licence, Building Permit, Permit for Use, Urban Planning Permit,
IE	Not specific	EA, Power Purchase Agreement, Planning Permit, Waste licence, Acceptance to REFIT, Soil Stability Report, Grid Permit
EL	Specific for biomass	EA, Electricity Generation License, Grid Access, Installation License, Operation License
ES	Not specific	EA, Operation Permit, Status under the Special Regime,
FR	Specific for biomass	EA, Building Permit, Sanitary Approval, Grid Permit,
HR	Specific for biomass	EA (> 10 MW), Location, Construction, Operation Permits, Energy Permit (Grid & Building Permits)
IT	Specific for biogas	EA, Spatial Planning & Construction, Fire Prevention Permit, Single Authorization (P > 200 kWh)
CY	Specific for biomass	EA, Manage & Discard Waste Permit, Building Permit, Air Emission Permit for biomass plants,
LV	Not specific	EA, Electricity Generation, Transmission, Distribution Licence, Grid, Air Pollution, GHG & Construction Permits
LT	Specific for biogas	
LU	Not specific	EA, Safety Work Authorization, Building Permit,
HU	Not specific	EA, Construction Permit, Energy Licence, Grid Permit
MT	Not specific	EA, Energy Licence, Construction Authorization,
NL	Not specific	EA, Building Permit, Planning Permit, Activity Permit, Manure use accredited,
AT	Specific for biomass	EA, Building Permit, Authorization under Electricity Law, Grid Access Contract, Green Electricity System Recognition
PL	Specific for biofuel	EA, Building Permit, Waste Recovery Permit, Release of Pollutants Permit, Concession for El & Heat
PT	Not specific	Installation Contract, Operating Licence,
RO	Specific for biomass	EA, Construction Permit, Planning Certificate, Electricity Supply Licence, Site Approval, Connection Approval
SI	Not specific	EA, Building, Operating, Grid & Energy Permit, Energy Licence, Veterinary Consent
SK	Not specific	EA, Building Permit, Business Licence,
FI	Not specific	EA, Land use and Building Permit
SE	Not specific	EA, Building Permit,
UK	Specific for biomass	EA, Permits for Spreading Digestate, Animal By-Products Regulation

[a] In Table 3 the acronym EA comprises the Environmental Approval or Permits procedures that are part of the authorization procedures for a biogas plant. This type of approval or permit is defined by different names in the EU countries. The requirement of this approval depends on the specific legislation in each country and on the project planned capacity.

the permit for a biogas plants a lot of laws and orders must be considered. To be able to build a biogas installation a planning permit is needed, which includes permits for spatial planning, environment, construction, water protection, ammonia emissions etc. Next to the planning permit, the installation needs to be accredited by the Netherlands Food and Consumer Product Safety Authority (NVWA) for the use of animal by-product. Further, (co-) digestion of manure is also part of the manure law, which regulates, among other things, which co-substrates can be used in the process. In *Belgium* every project for building a business premise of noisy or noxious trade must obtain two important permits: an environmental permit and a building permit.

In *Denmark* local municipalities form the authority if farmers or companies apply for approval of installation of micro scale biogas plants. For large-scale plants a so-called screening for optional environmental impacts must be carried out and a specific estimation of environmental impacts must be elaborated. In *France* according to the impact intensity on the environment, three regimes can apply: Declaration, Recording and Authorization. An aerobic digestion plant can be considered as an agricultural plant or as an industrial plant. The delivery of the building permit is the Mayor's competence, if the municipality has a land use plan or a Local Urbanism Plan. Otherwise, the building permit is instructed by the state. A sanitary approval is required for all the anaerobic digestion plants using animal by-products, including manure. In *Germany* before the approval of biogas plants several laws and orders must be considered. These legal demands consider various regulations such as project planning rights, building regulations, protection against pollution regulations, water, nature, waste, fertilizer and hygiene regulations and laws to examine their environmental compatibility. Beside this, the epizootic diseases act laws could play a roll, if animal by-products are used in the plant. It must be considered that the action of approval is different creating criteria for rent for each federal state [37].

In its proposal for a "National Biogas Strategy" Sweden opts for more efficient permit procedures for new biogas plants [39]. Since 2017 Lithuania has simplified the building permit issuance procedures for installations generating energy from renewable energy sources [40]. Hungary issues a combined small power plant licence (an establishment and generation licence in one) for power plants with a rated capacity of between 0.5 MW and 50 MW in a simplified licensing procedure. Environmental and construction permits must be obtained in addition to the energy licence and construction permit. A network connection agreement must be concluded [41]. Portugal has simplified the authorization procedure for RES plants especially for micro-production and mini production. A simplified licensing regime for connecting to an existing consumer installation in the distribution network has been put in place [42].

6. Biogas electricity capacity market mechanism in EU countries – a comparative analysis

6.1. Auctions for biomass in EU countries

Germany, France, Italy, Belgium, Lithuania, Croatia, Hungary, Poland, Portugal, Slovenia, Finland and United Kingdom have already undertaken or expected to recently implement, competitive auctions for renewables (including biomass). These auctions are revealed up to now a mix of different experiences being implemented as a technology-specific process. As such, the shift towards capacity market mechanism is giving complete control on the support framework and high certainties to the project developers.

In France the tendering procedures have been applied for wood-energy projects (in 2003, 2006, 2009 and 2010) as well as for wood-energy and methanisation (2016, 2017). Fourteen were the winning projects in the 2016 first round of biomass-fired electricity generation tender. The number of dossiers submitted was 41 for a total installed capacity of 156 MW. The bid volume was 50 MW for wood fire projects and 10 MW for biogas projects. Twelve projects relied on wood as a feedstock and 2 were biogas-fed. In total, these projects represent an investment of 170 M€ which with a 480 MWh of renewable-sourced electricity per year. On average, the winning projects benefit a feed-in tariff of 122 €/MWh over a period of 20 years. In the second tranche of 2017 a cumulative power of 176.8 MW was submitted through 45 dossiers. Eleven winning projects were selected from which 9 projects for wood energy and 2 for methanization. The average price, weighted by the power of the winners' facilities for wood energy installations of less than 3 MW, was equal to 137 €/MWh, lower than the price of the winners of the previous tranche, in the same category, which was equal to 149 €/MWh. For all the winners, the average price, weighted by the power of the facilities of all the laureates, was 122.5 €/MWh [43].

Lithuania has also organised four call for tenders for biomass and biogas, in accordance to their installed capacity and it is now preparing to launch a technology-neutral tender in 2019 [44]. Biomass tenders in Germany are held once per year with a total volume of 150 MW. The first biomass tender in Germany was launched in 2017. The tendering process left almost 95 MW of unsubscribed capacity because the response was very weak. In the first round, the winners of which were revealed in September 2018, only 27.5 MW out of a potential 122 MW of capacity was awarded, with just 24 bidders sharing potential financial support. The average value of awards was at 2017 level, when an average of 141.6 €/MWh was awarded. In the second call for tender only a capacity of 76.5 MW was reached comparing with the total volume of 225.8 MW (including the unused volume from the previous tender). The average value of all bids was 147.3 €/MWh. For new plants up to 147.3 €/MWh was on offer, while the maximum for existing plants was 167.3 €/MWh [45].

In the United Kingdom the calls for tender are organised under the Contracts for Difference (CfD) allocations. In the second auction (2017) six waste-processing and two biomass-fired facilities won the auction, as strike prices drop dramatically compared with CfD's first round. The new efficiency standards for biomass will mean that such projects will need to be able to prove a 70% overall efficiency (net calorific value), a primary energy saving of 10% (gross calorific value), and the unchanged 10% heat efficiency rating (gross calorific value).

In Poland the 2018 Renewable Energy Act (REA) introduced the subsidy auction system for all power plants with capacity larger than 40 kWh. The support is given to agricultural biogas, landfill gas and sewage gas. An auction for small agricultural biogas plants below 1 MW was developed by the end of 2018, awarding 29 offers from 23 companies, ranging from PLN 538.86/MWh to PLN 569.69/MWh. Since 2016, a new annual call for projects (for 3 subsequent years) for electricity produced from biomass is in place. These apply to vegetable and animal agricultural waste, algae and some industrial biomass waste (pulp and paper, wood industries). A single bid emerged as winning in the auction for biomass or non-agricultural biogas projects larger than 1 MW [46].

In Hungary as of 1 January 2017, plants with installed capacity higher than 1 MW (including wind power plants regardless their capacity) are subject to tendering procedures. The winner projects will be part of the premium tariff system which is available to installations up to 1 MW without the obligation to participate in tendering procedures. Projects for biogas and biomass plants are eligible to participate in calls for tender [47].

In Portugal since 2015 a remuneration regime came into force for new small production installations. This remuneration regime is based on a bidding model in which producers offer discounts to a reference tariff [47]. The first renewable energy tender is planned in the second quarter of 2019, but it will include only the bid for solar photovoltaics.

In Croatia the support in the form of the premium-tariff and guaranteed tariff (for capacity less than 500 kW) is planned to be allocated through tenders [47]. Due to the delays in adopting the necessary secondary legislation still no tender is organised [48]. In Belgium tendering has been used to set the reference banding factor for support certificates, which can be converted in a Feed-in Premium equivalent [45]. In Slovenia the move towards tendering system is already approved.

Pay-as-bid is found to be the general price awarding mechanism in current biomass tendering procedures. Only Germany used a hybrid approach: (i) pay-as-bid for new biomass projects and existing larger ones (installed capacity $>$ 150 kW) and (ii) uniform pricing for smaller biomass installations already in operation. The minimum size for participation varies between countries and tendering procedures. In Italy the minimum capacity is 5 MW, in France 0.3–12 MW. The auctioned volume for biomass projects tends to be rather small, ranging between 50 MW (Italy) up to 60 MW (currently in France) while in the past, most tenders covered approximately 200 MW. In Germany no minimum threshold has been defined for existing plants (bidding for a prolongation of support) and a threshold of 150 kW is set for new projects. For wood-energy and methanisation, France also opted for covering small project sizes (300 kW) [45].

Price-based scheme is used in Germany, Lithuania and France (for its most recent tender), as the only relevant criteria for selection of successful projects. Volume criteria was used in case of price equality. Germany gives priority to the small projects while Lithuania to the large projects. Belgium and France (between 2003 and 2011) opted for multi-criteria selection processes in their biomass tenders, covering price, volume, sustainability aspects, supply plans and the localisation, attributing them different weight factors. 20 years of support time is allocated to the biomass projects. In Lithuania support is granted for 12 years, while in France, in the tendering procedures carried out in 2003 support time was limited to 17 years. In Germany, already installed biomass installation successfully participating in a tender can extend their support period by 10 years [45]. In Poland the contracts for biogas are valid for a period of 13 years.

Level of competition in the tendering system for biomass projects ranges between 1.3 and 3 (in France). On contrary Italy and Germany experienced low levels of participation in the biomass tenders. In Germany, the level of competition in the first tender carried out in September 2017 was rather low, as only bids for a third (41 MW) of the tendered volume (122 MW) had been submitted. As a result, all biomass projects qualifying for the tender (27,5 MW) won a support entitlement. In addition to new biomass projects, the existing biomass installations could bid for a prolongation of their support beyond 20 years. Many bids submitted, and support entitlements awarded, were for existing installed biomass capacity. The results of the tender show that the conditions defined, i.e. the ceiling price, were not attractive for new biomass projects. However, all planned projects with an installed capacity greater 150 KW had to successfully participate in the tender in order to be entitled for a support payment.

6.2. Dynamism of the EU biogas electricity markets

The aim of this section is to assess if some biogas electricity markets have similarities in terms of dynamics of development. The main interest is to put in evidence the biogas electricity markets that moves towards higher dynamism. The comparison is based on the correlation analysis in Compound Annual Growth Rate (CAGR) terms, between biogas electricity deployment in EU countries:

1. Over period 2010–2014 (second period) versus period 2005–2010 (first period).
2. Over period 2014–2016 (second period) versus period 2010–2014 (first period);
3. Over period 2016–2017 (second period) versus period 2014–2016 (first period).

In order to develop this comparison, the CAGRs of the EU biogas electricity in the two periods under comparison are used as benchmarks. Four clusters of this deployment are created representing EU countries biogas deployment compared with the benchmarks:

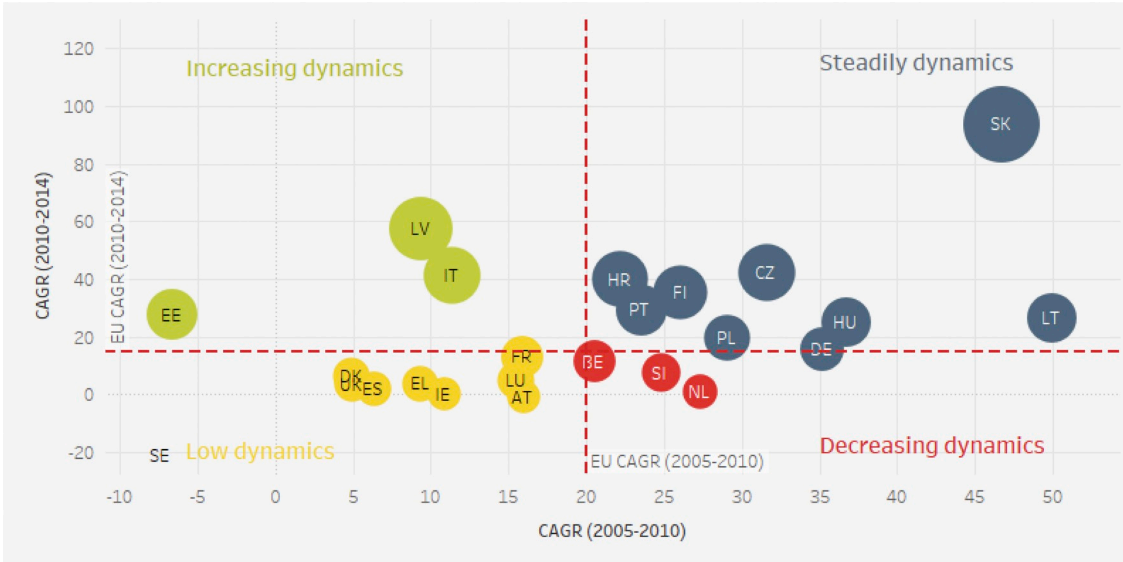

Fig. 8. Biogas electricity growth rate in EU countries: (2010–2014) vs (2005–2010)[2].
Source [88].
(2) Adopted from Ref. [49].

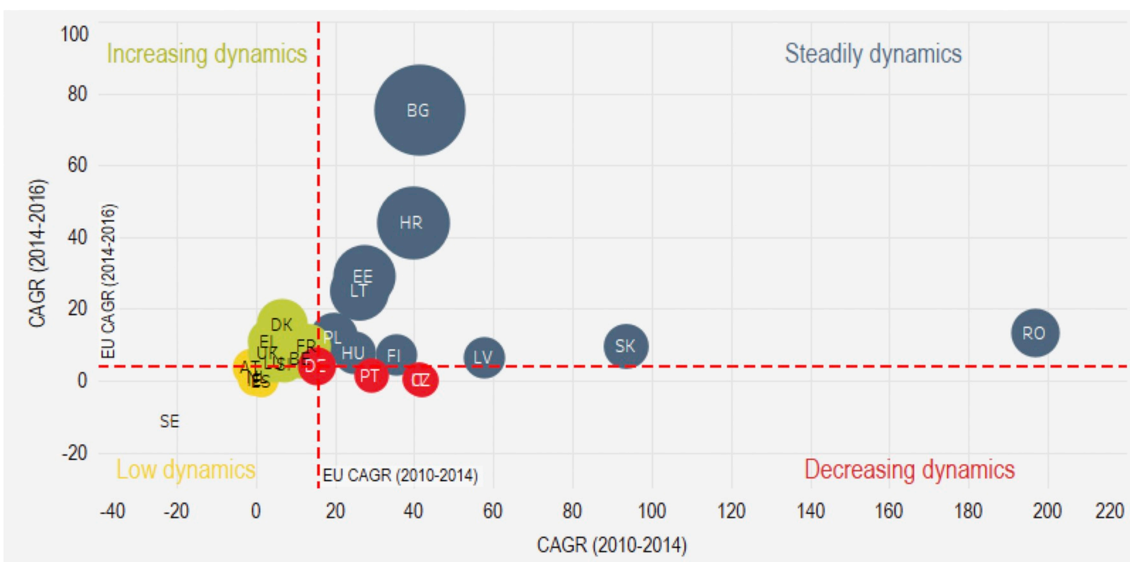

Fig. 9. Biogas electricity growth rate in EU countries: (2014–2016) vs (2010–2014) NOTEREF _Ref533790234 \h * MERGEFORMAT 2.
Source [88].

- Steadily dynamics (upper right of the graph) – including EU countries that have deployed biogas electricity faster than the EU biogas electricity in both periods;
- Increasing dynamics (upper left of the graph) – including EU countries that deployed biogas electricity faster than the EU biogas electricity over second period (ex. 2010–2014) but slower over first period (ex. 2005–2010);
- Low dynamics (lower left of the graph) – including EU countries that lag the EU biogas electricity deployment in both periods; and
- Decreasing dynamics (lower right of the graph) – including EU countries that deployed faster than the EU biogas electricity over first period (ex. 2005–2010) but lag in second period (ex. 2010–2014)

Fig. 8 illustrates this comparison for period (2010–2014) versus period (2010–2010). The EU CAGRs for periods 2005–2010 and 2010–2014 were respectively 20% and 16%.

As shown in Fig. 8 until 2014 the main dominant patterns of biogas electricity market were the steadily dynamics in countries as Germany, Poland, Czech Republic, Portugal, Croatia, Hungary, Lithuania, Finland and Slovakia and the low dynamics in countries as Austria, Denmark, Greece, Spain, France, Ireland, Luxembourg, Sweden and United Kingdom. The increasing dynamic pattern has been observed in few countries as Estonia, Latvia and Italy. Countries as Netherlands, Belgium and Slovenia have shown a decreasing in the dynamics of this market over period 2010–2014.

Fig. 9 illustrates the comparison of biogas electricity growth rate in period 2014–2016 versus period 2010–2014. Again, the two dot lines represent the EU growth of the biogas electricity for each period. As shown in the figure the EU growth rate of biogas electricity slowed down after 2014, at 4.5%.

The dominant pattern in this comparison is the steady dynamics of

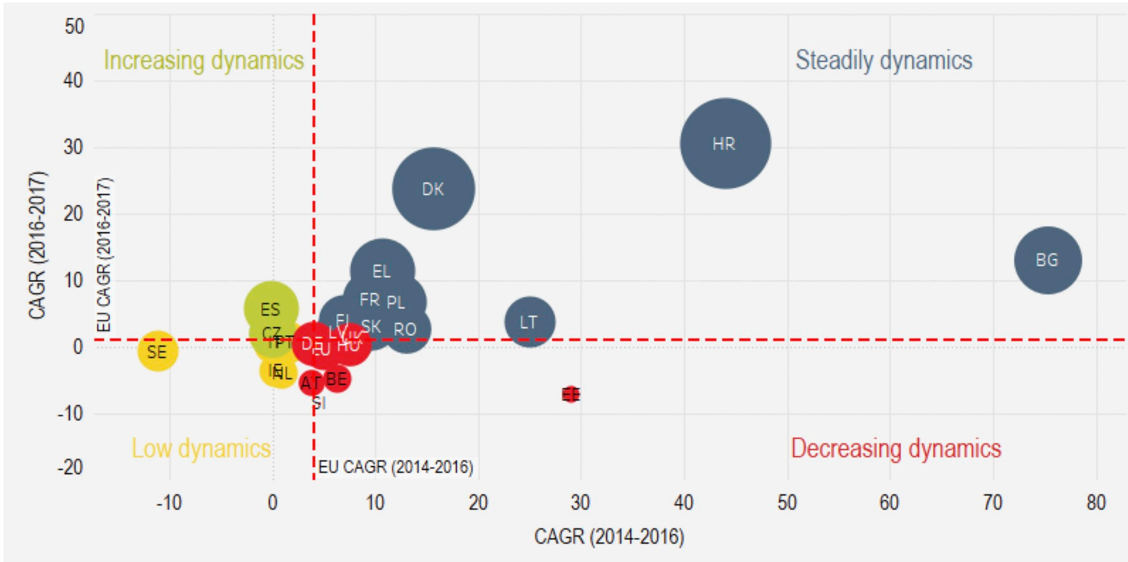

Fig. 10. Biogas electricity CAGR in EU countries: (2014–2016) vs (2016–2017). Source [88,89].

biogas electricity market in Estonia, Finland, Croatia, Hungary, Latvia, Lithuania, Poland and Slovakia. Bulgaria[4] continued to keep the increasing trend reached over 2010–2014 for biogas electricity even in period 2014–2016. Whilst in Romania[5] the deployment of biogas electricity has seen a very fast increase over 2010–2014, this deployment has been slower in period 2014–2016. The steady dynamics for countries as Poland, Hungary, Finland, Lithuania, Croatia and Slovakia continued also even after 2014. Germany, the main biogas electricity market in EU, is now situated in the pattern of decreasing dynamics together with Portugal, Czech Republic and Italy. The CAGR rate of biogas electricity in Germany after 2014 dropped 3-fold. For Italy and Czech Republic this drop has been more significant: from a CAGR of more than 40% before 2014, the deployment of biogas electricity in these two countries had after 2014 a CAGR of less than 1%. The increasing dynamic pattern, even that with a low speed, has seen countries as France, United Kingdom, Denmark, Greece, Luxembourg, Slovenia and Belgium. Countries as Austria, Spain and Sweden remained still in the low dynamic pattern. Despite that Netherlands has moved out from the decreasing dynamic pattern it remain as a low dynamic market in relation to biogas electricity.

Fig. 10 illustrates the comparison of biogas growth rates in EU countries with the EU growth rates over periods 2014–2016 and 2016–2017. As shown in Fig. 10 the EU growth rate for biogas electricity over 2016–2017 decreased further at only 1.3%. The comparison showed that still the steady dynamism is the main pattern found in Bulgaria, Denmark, Greece, France, Croatia, Latvia, Lithuania, Poland, Romania, Slovakia, Finland and United Kingdom. The decreasing dynamics pattern are now found in Austria, Belgium, Germany, Estonia, Hungary, Luxembourg and Slovenia. Netherlands and Sweden remain still in the low dynamics pattern of biogas electricity deployment, now together with Ireland, Italy and Portugal. Czech Republic and Spain increased their biogas electricity deployment after 2016 after the decrease they saw in period 2014–2016.

Even though the above analysis gives a flavour of the changes in the EU biogas electricity market dynamics, this comparison is not able to present the similarities/diversities of support for biogas electricity markets among EU countries. For this reason, an analysis based on the effectiveness of support schemes for biogas electricity and the average support applied, is done to effectively describe the biogas electricity market trends. The effectiveness of support is calculated as an Effectiveness Indicator (EI). This indicator is expressed as a percentage of the remaining production potential that can be realized by the end of the pre-defined medium-term period as measured at the start of that period. The effectiveness indicator is assessed for biogas electricity deployment over period 2010–2016 towards 2020 projections based on actual rates of deployment and the expected plans as they are reported in the EU countries NREAPs.

$$EI = \frac{G_n - G_{n-1}}{G_{2020} - G_{n-1}}$$

G_n – Energy generation from technology "i" in year "n"

The advantage of the effectiveness indicator is that it considers the country-specific factors whereas the disadvantage is that it is difficult to identify additional mid-term potential. It is important to know that the EI measures only the effectiveness of *overall renewables policy* in increasing the production or consumption of renewables. It *does not measure the impact of individual policies or measures, nor does* it provide any insights into why a national policy is effective or in effective relative to the potential or to performance in other sectors or countries [50].

Fig. 11 illustrates the relation “average support – average effectiveness indicator” for biomass electricity over period 2010–2016 under feed-in tariff, feed-in premium, CfD and tender schemes. The average effectiveness indicator as well as the average support level show a broad spectrum in quantitative terms for the EU countries under consideration[6] As shown in Fig. 11, in two biogas electricity mature markets, Germany and Italy, the effectiveness indicator has reached different values.

In Germany, a country with feed-in-tariff scheme for biogas electricity before 2014, the support has been more effective compared to Italy, despite a significantly lower average support level. Nevertheless, the increase of biogas electricity in Germany was relatively low in 2016

[4] The introduction of biogas in Bulgaria's electricity sector has started in 2010. Bulgaria has not been included in the analysis presented in Fig. 8.

[5] The introduction of biogas in Romania's electricity sector has started after 2008. Romania has not been included in the analysis presented in Fig. 8.

[6] The effectiveness indicator for biogas electricity gets negative values since most EU countries have now exceeded the 2020 plans reported in their NREAPs. In Fig. 10 “more negative the effectiveness indicator more effective has been the support”.

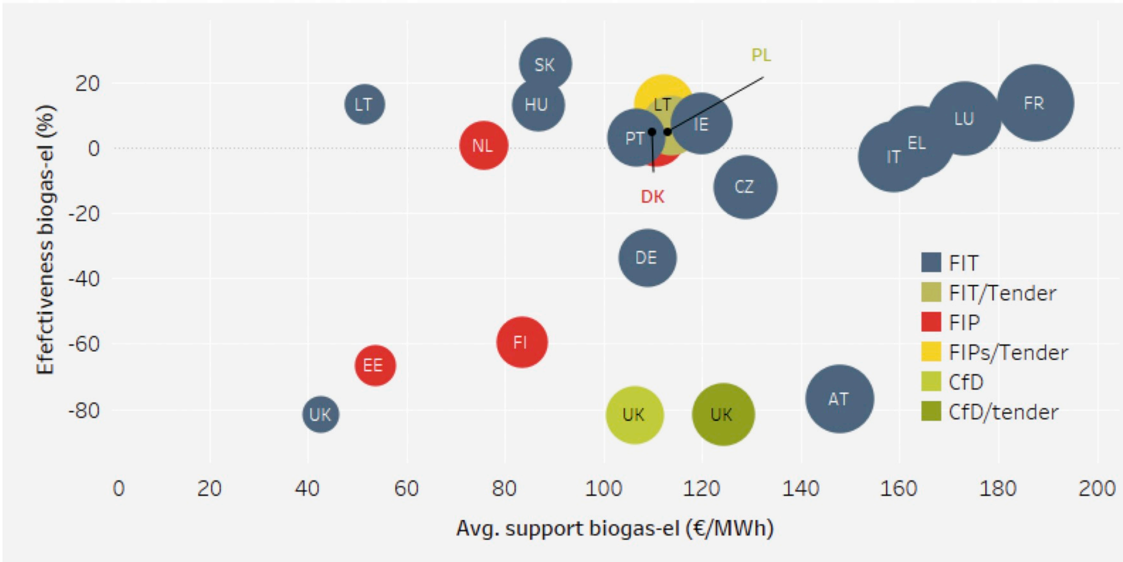

Fig. 11. Biogas electricity: effectiveness indicator vs average support level in EU countries (2010–2016).
Source [87].

due to the shift in the support scheme (a process that was completed in 2017). Under the new scheme that supports the calls for tender, the biogas facilities with a capacity larger than 100 kW are not anymore eligible for a simple FIT. In Italy the support scheme for biogas changed in 2013 supporting mainly the small-scale projects. Moreover, it is up to the producer to ask for the incentive following a certain procedure. This change had an adverse effect on the number of new biogas projects. Due to lack of technical rules of the gas grid operators, it is not yet administratively possible to inject renewable gas into the natural grid [51].

Despite that the United Kingdom has applied different average support levels through different support schemes, this support has produced almost the same level of effectiveness. The same happened for Lithuania that applies both FIT and calls for tender schemes. Austria experience nearly the same effectiveness of support as in the case of the United Kingdom even though the average level of support is higher. The country amended its renewable energy law in June 2017. France has not been as effective as Italy, despite it applied a higher average level of support for biogas electricity. The effectiveness of support for immature biogas markets as in Greece and Luxembourg has been slightly higher compared with France even for lower average support levels. This result is also linked with the plans each country has set for 2020. In the last case both Greece and Luxembourg expect to reach low levels of biogas electricity in 2020 compared with the plan of France. The support for biogas in Netherlands has produces a nearly zero effective indicator showing the low level of dynamism of the biogas electricity market in this country. The support for biogas in Finland has been more effective under the FIP scheme compared with the support given to this source under FIT in Hungary and Slovakia. In moderate markets as Poland (FIT/Tender) and Portugal (FIT) that both uses the same type of primary and secondary feedstock for biogas, the application of almost the same support level has produced an almost equal level of effectiveness indicator.

The range of biogas electricity deployment in EU countries is very broad. To compare this broad range the adjusted “per capita” biogas electricity indicator is introduced. Fig. 12 illustrates the relationship between the capita indicator of expected additional electricity from biogas over period 2017–2020 with the current biogas per capita deployment. The comparison is based on the following clusters:

- Countries situated at the upper left side of the graph have currently high momentum for biogas electricity – these countries have a higher gap towards their 2020 plans;
- Countries situated at the lower right side of the graph have currently low momentum for biogas electricity – these countries have already reached their 2020 plans;
- Countries in between have both maturity and momentum for biogas electricity – these countries have advanced in the deployment of biogas electricity having now a moderate gap towards their 2020 plans

With the current deployment rhythm, the planned 2020 figures for biogas use in electricity sector are now out-dated for some countries as Germany, Italy, United Kingdom, Czech Republic, Austria, Finland and Estonia. These countries are in risk of losing their momentum for biogas electricity mainly due to changes in their support schemes, due to missing of a clear post 2020 picture or due to a lower projeced biomass electricity for post 2020. Italy has planned a lower contribution of bioenergy in electricity sector at 15.7 TWh by 2030 compared with the 2017 deployment of 19.3 TWh [52]. Germany's biomass electricity share is planned to decrease from 7.5% in 2021 to 6.4% in 2030 [53]. In Czech Republic the contribution of biogas in final renewable electricity is expected to decrease by 40% in 2030 compared with the current deployment [54]. No information is currently provided on 2030 bioenergy consumption in electricity, heating/cooling and transport sectors for Austria [55]. Finland has planned to increase biomass for electricity from 14 TWh in 2020 to 17 TWh in 2030. However, there are no detail data on biogas deployment up to 2030 [56]. Countries as Denmark are already in the way of increasing their momentum for biogas deployment. Since 2005 biogas electricity deployment in Denmark passed from low dynamics to increasing dynamics and steady dynamics. The deployment of biogas is also part of Denmark ambitious plans towards 2030. According to Denmark NECP-draft report [57] the support for biogas and other types of green gas is planned to be with 32 M€/year over a period of 20 years.

7. Biogas valorisation in competing markets – challenges and future perspectives

Almost 90% of biogas for energy in the EU is valorised in the process of heat and power production. In 2015 electricity production accounted for 62% of this valorisation and heat for 27%. Direct use of biomethane

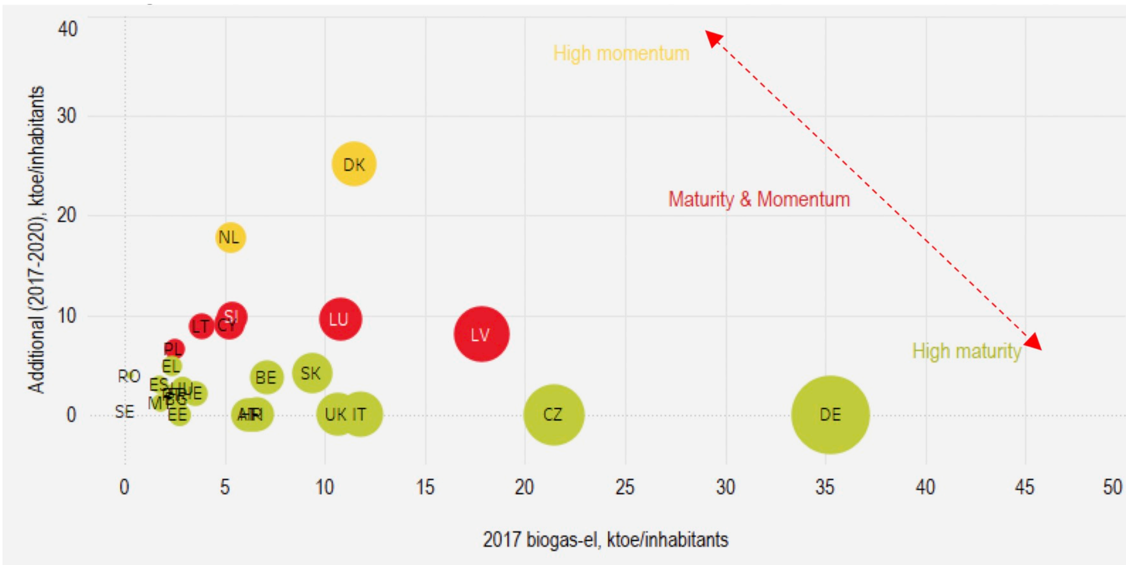

Fig. 12. Maturity & momentum in the EU countries biogas electricity market vs 2020 plans.
Source [66,87].

in transport sector or injected into the grid accounted for the rest, 11% [21].

One of the most important factors that considerably has contributed to the largest fraction of biogas valorisation is the application of feed-in tariffs for the sale of electricity generated by biogas production [58]. In the heating/cooling sector, subsidy is the main support scheme for biomass (biogas included), being applied in 18 EU countries (Belgium, Bulgaria, Czech Republic, Germany, Estonia, Ireland, Greece, France, Lithuania, Luxembourg, Hungary, Austria, Poland, Romania, Slovenia, Slovakia, Finland and United Kingdom). Nine EU countries (Czech Republic, Denmark, Ireland, Greece, France, Latvia, Lithuania, Netherlands and Sweden) are applying tax mechanism (tax relief, tax reduction etc.). FIP scheme is used only in Denmark and Netherlands. Lithuania is the only country that applies even a FIT scheme. Tendering system is used only in Hungary and Netherlands. A production-based incentive (Renewable Heat Incentive) like a FIT scheme is applied in United Kingdom [59].

Currently, the EU countries encourage heat and power conversion instead of electricity only, sometimes by putting minimum efficiency ratios. In Germany a "thermal efficiency" (+25%) and an "electrical efficiency" (+60%) bonus is introduced to improve the overall efficiency of CHP plants [24]. The higher energy conversion efficiency rates are applied also in Austria ($\eta \geq 60\%$) and France ($\geq 75\%$) [60].

Within electricity sector the use of biogas goes along with the use of other renewable technologies as wind and solar photovoltaics. The significant cost reductions for wind and solar photovoltaics as well as the environmental constrains, is affecting the choice for biogas use in electricity sector. The recent developments are showing that the LCOE for technologies as solar photovoltaics have decreased significantly over years, 73% since 2010, reaching 100 $/MWh in 2017 [61]. In Germany the LCOE of biogas power plants (specific plant costs between 2000 and 4000 €/kW) ranges between 101.4 €/MWh (7000 full load hours) and 147.4 €/MWh (5000 full load hours). In meanwhile the solar PV systems have a LCOE between 37.1 €/MWh and 115.4 €/MWh [62]. According to Ref. [63] the 2015 LCOE of anaerobic digestion process for biogas production is less than 100 €/MWh composed by feedstocks costs (11 €/MWh), operation and maintenance (O & M) costs (44 €/MWh) and capital expenditure (CAPEX) costs (41 €/MWh).

Fig. 13 illustrates the levelized costs of electricity (LCOE) of biomass-power projects by capacity factors over period 2000–2016. Projects based on biogas and other agriculture residues come with lower capacity factors, due to the seasonality of the available feedstock. The LCOE of these projects, however, is comparable to projects relying on more generic wood biomass feedstocks, such as wood pellets and wood waste that can be more readily purchased year-round [64]. As shown in this figure the landfill gas projects are characterised by a large capacity, higher capacity factors and low LCOE levels. The typical range of LCOE of biogas-power projects fall between 40 and 190 $/MWh.

One of the ways the biogas for heat production can be valorised is the replace of the natural gas in district heating (DH) systems. However, this substitution depends on factors such the position of DH systems, flexibility of the systems, status of developments of supply chains, the heating demand, biogas plants capacity, fossil fuels prices, the other biomass feedstocks prices and costs, stable policy framework and relevant tax incentives [65]. The position of DH systems, based on traditional differences and infrastructure design, varies between countries. In parts of northern and eastern Europe, approximately 50% of all households are currently heated by DH. It is the dominant heating method in all Nordic countries and is prominent in Germany and the Netherlands [65]. More than 70% of Denmark's district heating is produced in CHP plants. Biogas is used mainly for decentralised cogeneration plants in which biogas replaces natural gas and the heat is used in district heating systems. Although the electricity production from biogas in CHP systems is almost 9-fold of the heat production from this source in DH systems [66], it is remarkable that all centralized biogas plants in Denmark are connected to DH systems and sell the heat to them [58]. In Germany there is a variety of heating systems, which date back to different phases of the energy market. There are more than 3300 DH plants that in 2016 were run with CHP plants (83%). The electricity production from biogas in CHP systems was 34-fold the heat production in DH systems [66].

In Netherlands some 400 000 homes are connected to a heat grid, which corresponds to 5.5% of the number of homes in the country. Due to the extensive gas infrastructure, natural gas is the most common form of heating for buildings in Netherlands. The heat and electricity supplied is produced from natural gas to an amount of approximately 60%. At present, the government does not have a specific incentive policy for CHP. Nevertheless, CHP is supported by the Energy-saving Investment Credit (EIA). Furthermore, the use of natural gas for CHP units is exempt from energy tax. The Sustainable Energy Production Incentive (SDE+) grant scheme provides an operating grant for CHP units with a renewable source, such as biomass CHP or biogas CHP

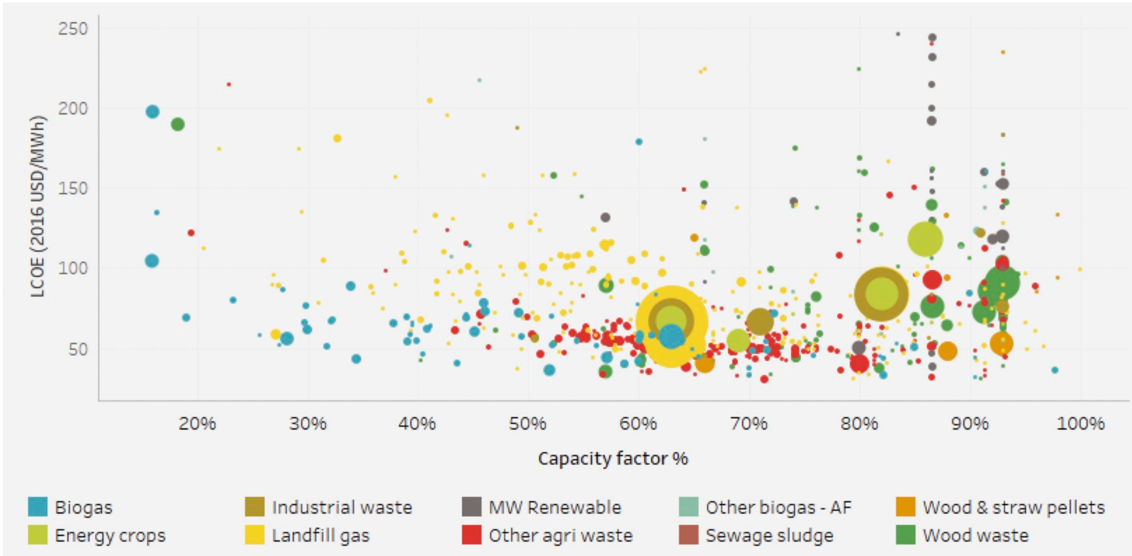

Fig. 13. Levelised cost of electricity (LCOE) by capacity factors of biomass-fired projects, (2000–2016)[3].
Source [64].
[(3)] Size of bubbles is set upon projects capacity.

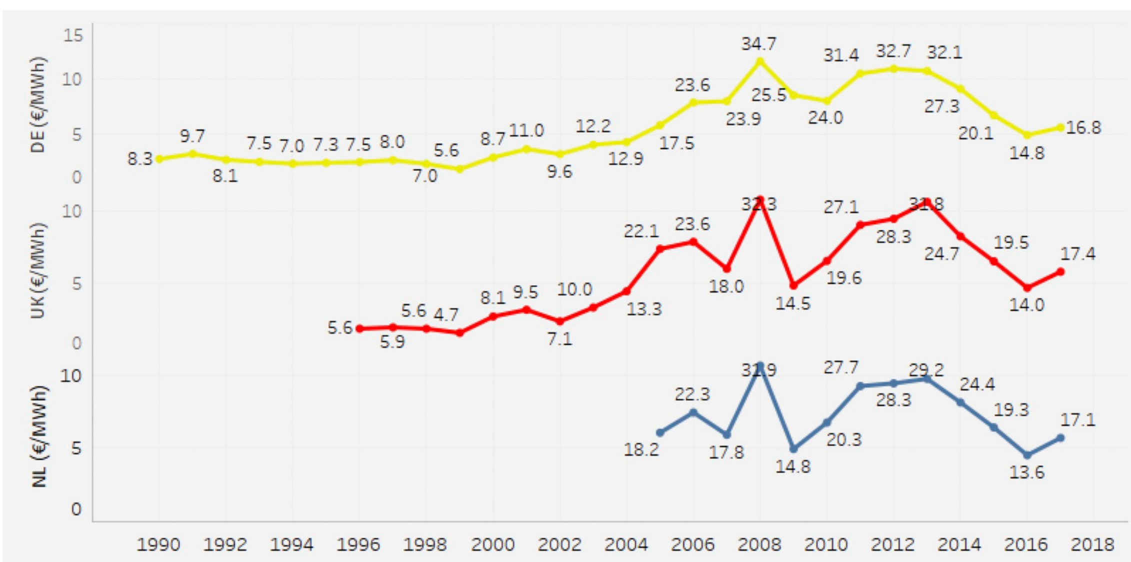

Fig. 14. Evolution of natural gas prices in Europe over period 1990–2017.
Source [86].

[67].

In 2016 nine EU countries (Germany, Finland, Denmark, Sweden, France, Austria, Italy, Romania, Poland and Hungary) have used biogas to produce heat in their district heating systems. The average EU ratio of biogas used in CHP systems versus the use in DH systems (CHP/DH) is nearly 50. The highest ratio CHP/DH is found in Italy, more than 3500 time-fold [66]. According to the [68], the lowest shares of CHP in district heating generation are found in Romania (7%), Poland (19%), France (23%), Slovakia (27%) and Slovenia (32%).

Biogas for heating purposes is currently suffering in the low-priced natural gas environment since the cost of its production are higher. However, natural gas prices have been rising recently and biogas producers may yet benefit from technology that improves their operation profile [69]. As shown in Fig. 14 natural gas prices in the EU start falling only after 2013, experiencing in 2016 a drop by more than 55% of the 2013 figure. Natural gas prices have seen an increase after 2016 which has continued even in the years after. Within heat market biogas must goes along with the use of other biomass feedstocks such as wood. However, the wood chips and pellets combustion in district heating systems and largescale cofiring power plants are the economically and environmentally preferred options [70]. The differences in prices among these sources and their trend over time differs among countries.

Fig. 15 illustrates the trend of prices for some cereal crops (useable for biogas) in Italy, Germany, France and Netherlands over period May 2014–February 2019. In Italy the indicative prices for wood (firewood, wood chips) that can be used in the wood-energy supply chain range between 40 and 73 €/t. whereas the indicative prices of feedstocks for biogas production (cereal crops) range between 160 and 301 €/t [25]. In EU countries as Germany, France, Netherlands, Austria, Spain and United Kingdom the prices of cereal crops that can be used for biogas production ranged between 100 and 200 €/t over the above-mentioned period [71].

Fig. 16 illustrates the trend of wood chips and wood pellets prices in Germany. As shown in this figure the prices of wood chips (water

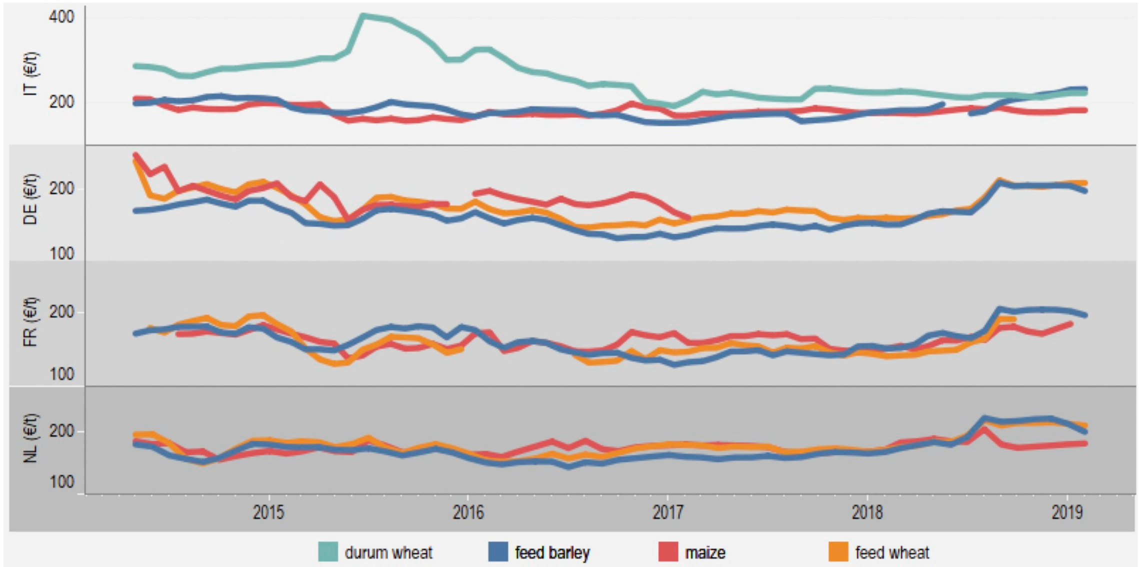

Fig. 15. Trend of cereal crops prices in Italy, Germany, France and Netherlands (May 2014–February 2019)[4].
Source [71].
(4) For Italy the cereal crops prices refer to the delivery to first customer – silo or processing plant – on truck or other transport means; For Germany the cereal crops prices refer to the prices on the departure from silo – after some storage – on truck or other transport means; For France the cereal crops prices refer to the prices on delivering to port – French definition: "marchandise livrée dans un silo portuaire par train ou camion ou péniche", "grain delivered to a port silo by train or truck or barge"; For Netherlands the cereal crops prices includes cost, insurance and freigt [71].

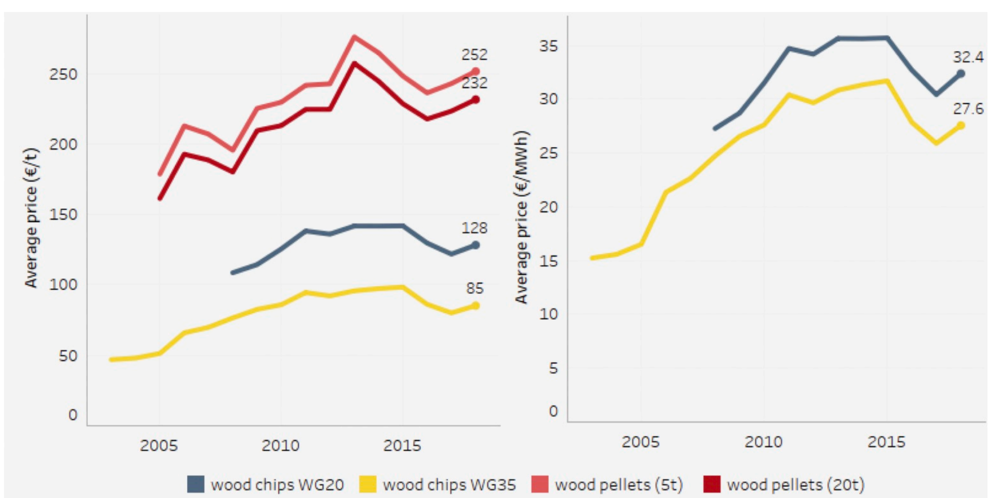

Figure 16. Trend of wood chips and wood pellets prices in Germany (2003–2018)[5].
Source [72].
(5) Prices of wood chips and wood pellets are price indices in the context of supply contracts.

content 35%) for energy in Germany decreased from 95 €/t in July 2011 to 85 €/t in July 2018 [72]. In meanwhile the prices of wood pellets in Germany increased from 236 €/t to 245 €/t over the same period [73,74]. In Slovenia the prices of wood chips changed from 68.4 €/t in October 2011 to 90.85 €/t in November 2018. Over the same period the price of wood pellets (packed) decreased from 300.96 €/t to 283.05 €/t [75]. In Austria, after an increase in 2016, the wood chips prices have fallen due to an oversupply in the market [76]. In Spain the price of biomass for heat was characterised by a prolonged fall over period 2015–2016, which was strongly influenced by the low prices of alternative fossil fuels (heating oil and natural gas) and by unusually mild average temperatures [77]. In France an upward trend in the price indices for wood energy was observed between 2011 and 2014, stagnation between 2014 and 2015, and a downward trend after 2016 [23].

Biogas has more potential for upgrading into biomethane. Biomethane can replace natural gas in the grid with no competition or can be used for the transport sector. Like raw biogas production, however, the extent of biomethane upgrading has also varied significantly by country and can grow rapidly depending on government policy. Development of the biomethane sector in certain EU countries has played a central role in the fast deployment of biogas.

According to Ref. [78] biomethane production has greatly increased from 752 GWh in 2011 to 19 352 GWh in 2017 (+17 264 GWh). In 2017 alone, biomethane production in Europe increased by 2087 GWh (+12%). The countries which saw the most significant development in biomethane production in 2016 were Germany (+900 GWh), France (+133 GWh) and Sweden (+78 GWh). In France the total annual production of biomethane increased from 3 GWh in 2011 to 215 GWh in 2016 (+212 GWh) [19].

In 2017 there were in total 540 biomethane plants in EU, a growth

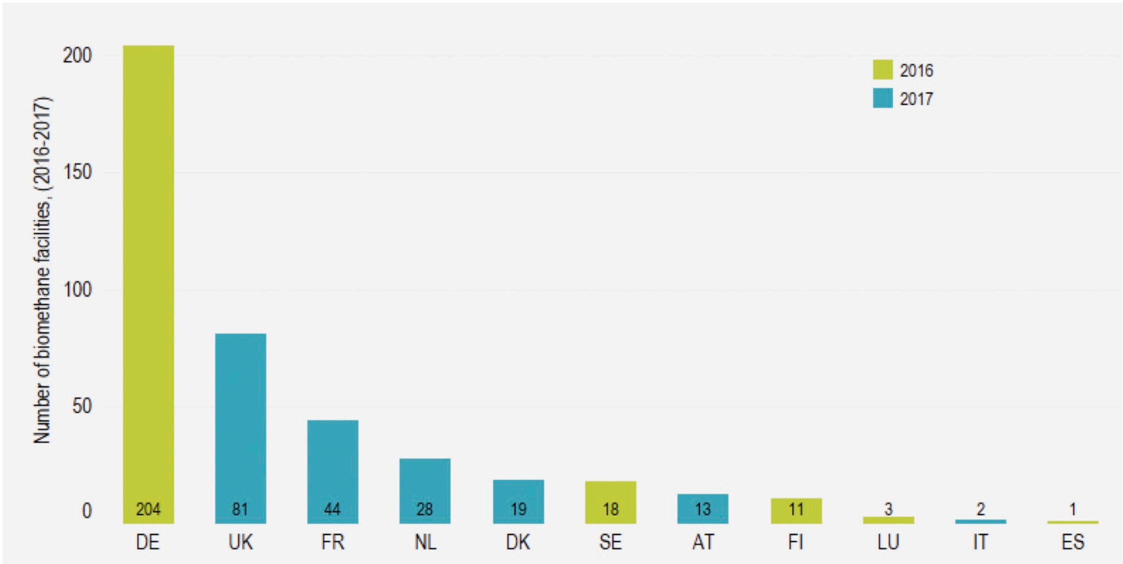

Fig. 17. Number of biomethane facilities that injects to the natural gas distribution networks in EU, (2016–2017).
Source [84].

by 8% compared with 2016 [78]. According to Ref. [74] in Germany there are 212 the plants for biomethane which have an upgrading capacity of more than 132000 Nm^3/h in 2018.

Upgrading of biogas to biomethane has a substantial percentage of the use of biogas in Sweden, the Netherlands and Germany [21]. Currently there is no correlation between the number of plants producing raw biogas and those upgrading to biomethane. Italy is second country in terms of raw biogas, but it has very little upgrading capacity. Meanwhile in Sweden some 57% of raw biogas production is upgraded to biomethane, primarily for road transport [79].

Biomethane can be a greater player in the transport sector replacing natural gas in Natural Gas Vehicles (NGVs). In 2016, the total number of NGVs in the EU amounts to 1.3 million, a rise of 3% compared with 2015 [80]. The reduction of GHG emissions from the use of biomethane in road transport compared with gasoline is estimated to range between 60% when being produced from maize, 70% when produced from waste and 80% when produced from manure [81]. Nevertheless, the biomethane impact in NGVs market still faces different challenges. In 2016 the share of NGV technology in the Europe commercial vehicle fleet stated at 1.9%, slightly higher that the share of hybrid electric vehicles that stood at only 0.4% [82]. However, due to the need for initial investment in building the gas-filling stations and the fact that the NGVs vehicle still emit CO_2 (24% reduction of GHG emissions compared with gasoline [81], the push goes more in favour of electric vehicles. This push aims the replacement of millions petrol and diesel vehicles with electric ones which means placing a bigger load on the electrical network, that is already under pressure at certain times of the day in some areas, and the increase of some electricity grid reinforcements, especially for high-power recharging points [83]. In 2016 the market penetration for small NGVs passengers' cars was the highest only in Sweden, Bulgaria and Italy with a share above 0.4%. Sweden outperforms all other countries on the bus market share with 16%, other well performing countries were Czech Republic and the Netherlands. In 2016 Italy counted more than 1 million NGV vehicles followed by Germany with almost 94 000 NGV vehicles and France with more than 14500 NGV vehicles [80]. However, the number of NGVs cars registered in Italy in 2016 almost halved compared with registered NGVs cars in 2013 [82]. In 2017 over 11% of the fleet in France runs on gas that expects a consumption of 0.7 TWh by 2018 and 2 TWh by 2023 for biomethane replacing natural gas in NGVs. This contribution will represent 20% of French consumption of natural gas for vehicles by 2023 across segments supplementing electric vehicles and rechargeable hybrid vehicles [23].

Italy plans to reach a contribution of biomethane in transport sector at 5.9 TWh in 2025 and 9.2 TWh in 2030. The incentives for biomethane are now given as defined by the Ministerial Decision of 02.03.2018 [52]. The decree provides new incentive schemes for constructing biomethane liquefaction plants, in order to promote the widespread use of biomethane also in liquid form [25]. Advanced biofuels are planned to cover 8% of transport sector demand in 2030 in Italy. Biomethane will cover 75% of advanced biofuel for transport supply, with a planned production of 1.1 BNm^3 in 2030.

Biomethane for grid injection probably is now seeing more increasing support. In 2016, several countries injected particularly high shares of renewable gas into their grid, as Sweden (75%), the Netherlands (55%) and Finland (50%) [80]. The total number of facilities in service for biomethane injection into grid in 2016 have reached to around 450 with an annual production of around 18 TWh [84].

In Germany the market of biomethane injection into the grid is still young. Indeed in 2016 nearly 90% of biomethane is used in the cogeneration process whereas the share of biomethane in the final use of renewables in transport sector accounted for only 0.012% [24]. In France the biomethane injection into grid can be considered now a mature market that has found the support through the French Multi-annual Energy Programme (PPE) and the application of a FIT scheme. The total maximum injection capacity of biomethane in France at the end of 2016 was estimated at 410 GWh, with the largest share (199 GWh) being produced by agricultural plants. The production objectives for France in terms of injecting biomethane into the gas network are 1.7 TWh by 2018 and 8 TWh by 2023. Support for biomethane injection is financed by the Energy Transition special account. The scheme under which natural gas suppliers purchase biomethane from producers is designed to ensure that they are compensated for the difference between the purchase price of methane and the wholesale market price of natural gas. The compensation was 7.1 M€ for 2015 and 18.6 M€ for 2016. This compensation is estimated to have a significant increase at 37.3 M€ for 2017 and 99.56 M€ for 2018 [23]. The use of biomethane in Portugal for heating purposes is expected to reach 3.4 PJ in 2030 [85].

The United Kingdom provides a good example of how government policy can stimulate rapid growth in biomethane upgrading. In 2011, there was just one biomethane plant in the country. The introduction of Carbon Price Support from 2013, as well as a FIT for biomethane injected into the grid under the Renewable Heat Incentive, resulted in 20–30 new plants per year coming onstream between 2014 and 2016, and it is estimated that around 100 new plants could be in operation before 2018 [79]. However, after 2016, the United Kingdom has reduced subsidies for biomethane and biogas injection into the grid under the non-domestic Renewable Heat Incentive (RHI). The most recent cut saw a 10% reduction to the biomethane for injection tariff, and a 5% reduction to the small, medium and large biogas tariffs, effective from April 2017 [69].

Fig. 17 shows the number of biomethane facilities that injects to the EU countries natural gas distribution networks in 2016–2017. In Netherlands biomethane has been being injected into the distribution network for over 20 years, including biogas from landfills. There were 28 sites in 2017 that injected more than 900 GWh/year biomethane. In Finland 11 sites were injecting in 2016 more than 100 GWh/year into the natural gas distribution network. In Sweden 18 sites were injecting in this year biomethane into the natural gas distribution network at an amount of more than 470 GWh/year. In Luxembourg 3 sites were injecting 62 GWh/year biomethane into the natural gas network in 2016. In Austria 13 sites injected more than 250 GWh/year in 2017. In Italy by end of 2017 there were only 2 sites that injected biomethane into the networks. In Germany the 204 biomethane plants injected in 2016 more than 10000 GWh into the natural gas network. In United Kingdom there were 81 facilities injecting biomethane into the natural gas network in 2017. By end of the same year there were 44 facilities that injected biomethane into French natural gas network. In Denmark this number was 19 with an injected capacity of more than 1700 GWh/year [84].

8. Conclusions

In this paper a comparative analysis of biogas electricity deployment in EU countries has been carried out to assess the links with the support frameworks, the dynamics of markets and the feasibility of long-term objectives. This analysis shows that an increasing number of EU countries is currently moving towards capacity market mechanism to support the deployment of biogas in electricity sector, a shift that has seen a slowdown in the pace of biogas in the EU mature biomass electricity markets. Despite of the downward trend several EU countries continues to keep the dynamics of their biogas electricity markets.

The role of targets/plans has been important in the fast deployment of biogas over the last years, but now they are outdated in several EU countries and do not cope more with this pace. Moreover, these targets/plans do not provide a clear goal for post 2020 and in some EU countries the biomass contribution is projected to be decreased.

The valorisation choices for biogas face the stiff competition with solar and wind due to the continues drop in the costs of. these technologies. Biogas (or biomethane) faces also the abundant and low-cost natural gas and in some cases with the competitive prices of biomass feedstocks as wood, mainly wood chips.

Recent developments have shown that biogas upgrading and biomethane can be a sustainable input for the environment, especially when the main supported biomass feedstocks, manure and waste, are available. The grid injection of biomethane is the future direction that the leading economies in Europe are currently promoting.

Disclaimer

The views expressed are purely those of the authors and may not in any circumstances be regarded as stating an official position of the European Commission.

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