European Commission

LOW CARBON ENERGY OBSERVATORY

HEAT AND POWER FROM BIOMASS

Market development report

Joint Research Centre

EUR 29934 EN

Contact information

Name: Nicolae SCARLAT
Address: European Commission, Joint Research Centre, Ispra, Italy
Email: Nicolae.SCARLAT@ec.europa.eu

Name: Maria GEORGIADOU
Address: European Commission DG Research and Innovation, Brussels, Belgium
Email: Maria.GEORGIADOU@ec.europa.eu

Name: Thomas SCHLEKER
Address: European Commission DG Research and Innovation, Brussels, Belgium
Email: Thomas.SCHLEKER@ec.europa.eu

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Foreword on the Low Carbon Energy Observatory

The Low Carbon Energy Observatory (LCEO) is an Administrative Arrangement being executed by DG-JRC for DG-RTD, to provide top-class data, analysis and intelligence on developments in low carbon energy supply technologies. Its reports give a neutral assessment on the state of the art, identification of development trends and market barriers, as well as best practices regarding use private and public funds and policy measures. The LCEO started in April 2015 and runs to 2020.

Which technologies are covered?

- Wind Energy
- Photovoltaics
- Solar Thermal Electricity
- Solar Thermal Heating and Cooling
- Ocean Energy
- Geothermal Energy
- Hydropower
- Heat and Power from Biomass
- Carbon Capture, Utilisation and Storage
- Sustainable advanced biofuels
- Battery Storage
- Advanced Alternative Fuels

In addition, the LCEO monitors future emerging concepts relevant to these technologies.

How is the analysis done?

JRC experts use a broad range of sources to ensure a robust analysis. This includes data and results from EU-funded projects, from selected international, national and regional projects and from patents filings. External experts may also be contacted on specific topics. The project also uses the JRC-EU-TIMES energy system model to explore the impact of technology and market developments on future scenarios up to 2050.

What are the main deliverables?

The project produces the following generic reports:

- Technology Development Reports for each technology sector
- Technology Market Reports for each technology sector
- Report on Synergies for Clean Energy Technologies
- Annual Report on Future and Emerging Technologies (information is also systematically updated and disseminated on the online FET Database).

Techno-economic modelling results are also made available via dedicated review reports of global energy scenarios and of EU deployment scenarios.

What's the timeline?

The LCEO produces its main reports on a two-year cycle. The first set was published in 2016 and the second will be available in 2018. A final set will be released in spring 2020.

How to access the deliverables

Commission staff can access all reports on the Connected LCEO page. These are restricted to internal distribution as they may contain confidential information and/or assessments intended for in-house use only. Redacted versions will also be distributed publicly on the SETIS website.

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Thanks also to Maria Georgiadou and Thomas Schleker (DG Research and Innovation) for their review and comments.

Acronyms and Abbreviations

AD	Anaerobic digestion
BBI	Bio-based Industries
BETO	DOE Bioenergy Technologies Office
BIGCC	Biomass Integrated Gasification Combined Cycle
BIG-GT	Biomass Integrated Gas Turbine
BtL	Biomass to liquid
CAPEX	Capital expenditure
CCS	Carbon Capture and Storage
CCU	Carbon Capture and Utilisation
CCUS	Carbon Capture, Utilisation and Storage
CFBC	Circulating Fluidised Bed Combustion
CFD	Computational Fluid Dynamics
CHP	Combined Heat and Power
CP	Collaborative project
CPI	Current Policy Initiative Scenario
CPC	Coordinated Patent Classification
DH	District Heating
EC	European Commission
EIBI	European Industrial Bioenergy Initiative
ERC	European Research Council
EU	European Union
FBC	Fluidised Bed Combustion
FP7	Seventh Framework Programme for Research and Technological Development
FT	Fischer-Tropsch
GHG	GreenHouse Gas
HTC	HydroThermal Carbonization
HTG	Hydrothermal Gasification
HTL	HydroThermal Liquefaction
IEA	International Energy Agency
IED	Industrial Emissions Directive
IGCC	Integrated Gasification Combined Cycle
IPC	International Patent Classification
IPCC	Intergovernmental Panel on Climate Change
IRENA	International Renewable Energy Agency

KPI	Key Performance Indicators
LCA	Life Cycle Analysis
LCEO	Low Carbon Energy Observatory
LCOE	Levelised Cost Of Electricity
LFG	LandFill Gas
LHV	Lower Heating Value
MRL	Manufacturing Readiness Level
MS	Member State
MSW	Municipal Solid Waste
NER	New Entrants' Reserve
NREAP	National Renewable Energy Action Plan
NREL	National Renewable Energy Laboratory
OPEX	Operational expenditure
ORC	Organic Rankine Cycles
PWS	Pressurised Water Scrubbing
PSA	Pressure Swing Adsorption
RED	Renewable Energy Directive
REN21	Renewable Energy Policy Network for the 21st Century
R&D	Research and Development
RIA	Research and Innovation action
SCR	Selective Catalytic Reduction
SET Plan	Strategic Energy Technology Plan
SETIS	Strategic Energy Technologies Information System
SNG	Synthetic Natural Gas
TDR	Technology Development Report
TRL	Technology Readiness Level
US	United States
US EPA	United States Environmental Protection Agency
US DOE	United States Department Of Energy
WID	Waste Incineration Directive
WtE	Waste-to-Energy

Executive summary

This Technology Market Report provides an analysis of the market status of bioenergy and an insight into future technology development in the European Union and provides a global perspective at global scale. This report aims to highlights recent technology market trends and developments in the field of heat and power from biomass and to explore the medium and long-term perspective of the global bioenergy technology markets, with a focus on European Union. The report also provides an outlook for future deployment of bioenergy through modelling and analysis of key sensitivities and barriers to market expansion.

The report firstly provides an evaluation of the historical technology trends and future prospects for development, exploring in detail the global deployment trends for bioenergy production. Specific attention has been paid on the current status and progress made against the deployment targets in the European Union. The report also discussed the policy context relevant to the development of the sector and the support policies as a key mechanism to facilitate investment in bioenergy, as well as the well trends in R&D investment and patenting activity. This report provides a market overview of the market structure and market shares in the global bioenergy sector. In order to provide an outlook on future developments this chapter also identifies emerging markets, players and trends.

An overview on the mid- and long-term deployment of bioenergy is provided based on different major energy system studies. A special focus was put on a global outlook for future bioenergy developments, derived from the IEA Bioenergy Roadmap, as part of the future global energy system that would be able to deliver the carbon emission reductions necessary to achieve the long-time goal of limiting climate change. In the European Union, the potential role of bioenergy in the future energy system is highlighted, in various possible pathways for a transition towards a low-carbon energy system until 2050, according to the EC 2050 long-term strategy, as derived from the Energy Roadmap 2050.

An outlook for future developments under different scenarios, as provided by the JRC-EU-TIMES model, is presented for analysing the role of the biomass up to 2060 in the energy system for meeting the EU's energy and climate change policy objectives. The JRC-EU-TIMES scenarios are also used to provide the market outlook and deployment trends as well as capacity additions and investments per Member States. Through a sensitivity analysis, model results from are used to estimate to which extent investment costs, fossil fuel prices or energy policies impact bioenergy deployment and the associated market size.

1. Introduction

1.1 Scope and basis of the report

The Technology Market Report Heat and Power from Biomass is produced within the LCEO project by the JRC for DG RTD. The present report provides an insight into the current status and recent developments of the heat and power production from biomass in the European Union and at the global scale. The report offers information, analysis and insight on market status and trends, as well as expected developments in heat and power from biomass technologies. The report provides an assessment on the state of the art, development trends and market barriers, as well as the status of private and public R&D investments and policy support measures. The main actors involved in bioenergy production and their role in the value chain are identified. Modelled projections on the future role and development of heat and power production from biomass for the mid- and long-term deployment in the EU and at worldwide level are also provided. The report made use of different data sources, such as IEA, IRENA Eurostat and existing JRC analyses, scientific studies, statistical reports etc.

1.2 Current market penetration

The global use of biomass for energy production for heat, electricity and in transport has increased significantly in the last decade to reach about 56 EJ in 2016, representing a share of the total global primary energy consumption of 10% and a share in the final energy consumption of 12%. The use of renewable energy and of biomass for energy increased significantly since 2000 (Figure 1), simultaneously with a large growth in energy supply. Thus, the contribution of all renewables has increased from only 54 EJ in 2000 to 79 EJ in 2016, while the primary energy supply increased from 420 EJ in 2000 to 576 EJ in 2016.

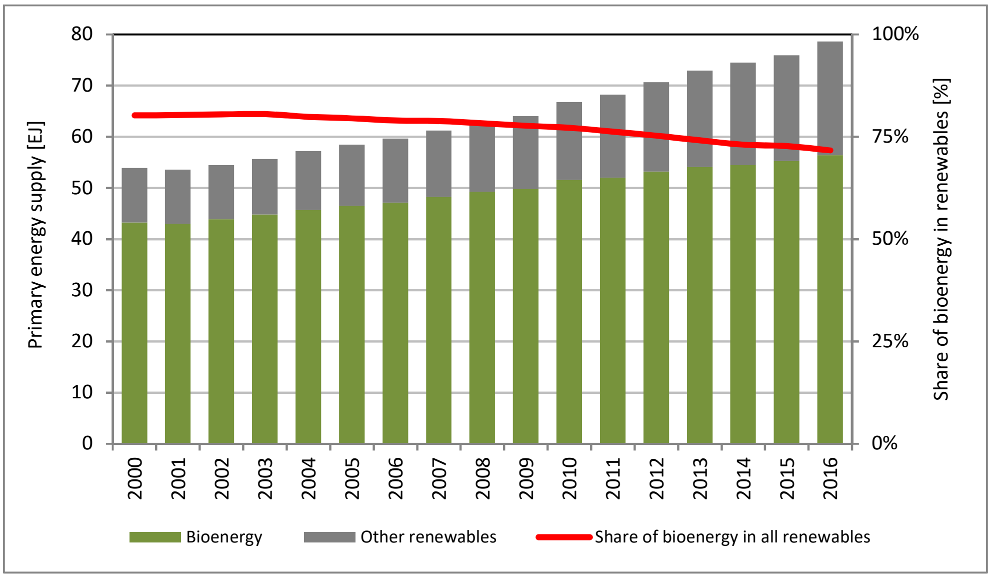

Figure 1 Contribution of bioenergy and other renewables to the global primary energy supply

Source: IEA 2019

As shown in Figure 1, the bioenergy supply increased also significantly during this period from 43 EJ to 56 EJ. Bioenergy thus represents the major component of the renewable energy portfolio, although its share decreased from 80 % to about 70 % between 2000 and 2017, due to the large growth in other renewables, in particular in the solar and wind sectors.

In the European Union, the use of the renewable energy has seen a much larger increase (

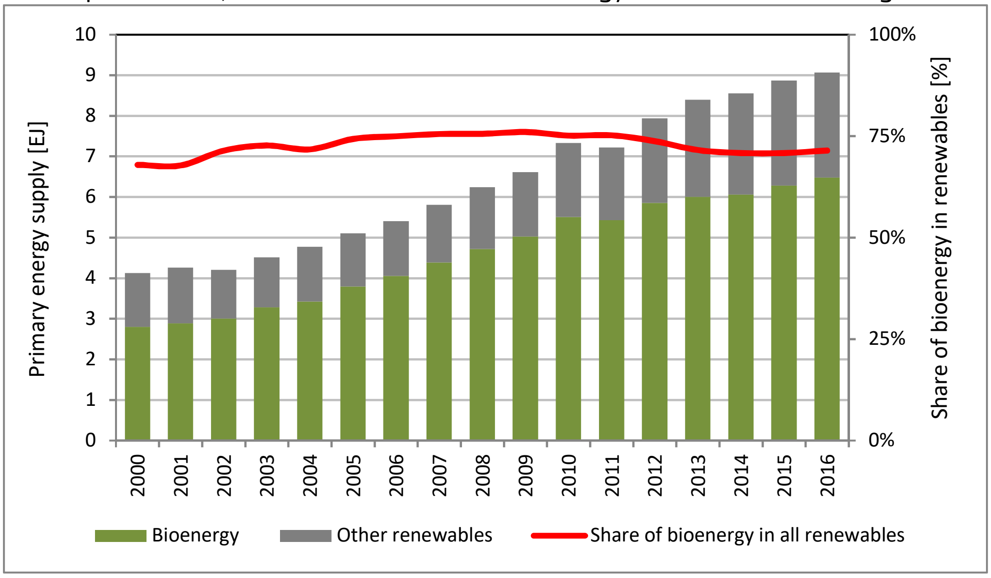

Figure 2), from just above 4 EJ in 2000 to more than 9 EJ in 2016, with a share in the primary energy supply increasing from almost 6% in 2000 to almost 14% in 2016. Bioenergy has maintained and it is likely to keep its major role as renewable energy source in the energy mix in the next period, with a share above 70 % of renewable energy supply. The share of bioenergy in primary energy supply increased in the European Union from 4% in 2000 to almost 10% in 2017. Bioenergy is also expected to have a share in the gross final energy use of about 12 % in 2020 (Scarlat et al. 2018).

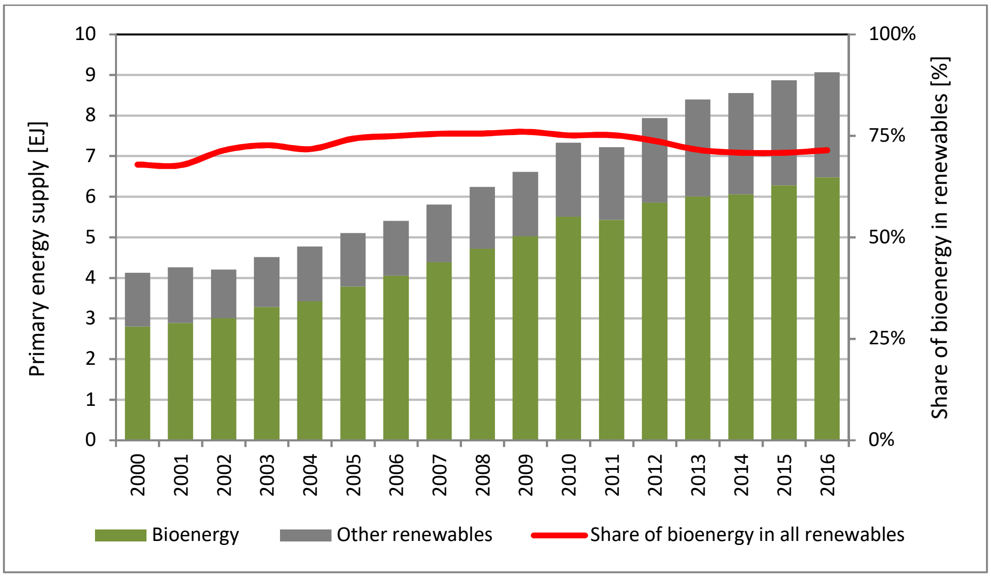

Figure 2. Contribution of bioenergy and renewables to the primary energy supply in the European Union

Due to the continued growth in overall energy demand, which counteracts the increase in renewable energy production, the share of bioenergy in primary energy supply decreased slightly from 10.3 % in 2000 to 9.8 % in 2016, despite significant increase in bioenergy supply (Figure 3). Looking at different world regions, the contribution of bioenergy to primary energy supply is quite different. The share of bioenergy in total primary energy supply is very high in Africa with a contribution of above 50 % in 2016, mostly due to the traditional use of biomass for energy production (cooking, lightning). High share of biomass into energy supply is also noticed in Central and South America with a contribution between 21 % and 24 %. Important growth has been registered in particular in the European Union, North America and South America, due to considerable developments in the modern bioenergy. Among all world regions, important decrease of bioenergy share into the primary energy supply has been registered in Asia (from 20.6 % to 9.6 %), followed by Africa, from 58.5 % to 53.8 %) between 2000 and 2016 due to the decrease in the traditional use of biomass. The availability of biomass feedstock in sub-Saharan Africa and Asia provided much needed energy to rural areas and led to a large dependence on biomass. In some cases, the unsustainable use of fuelwood and charcoal along with ineffective forest and land management has led to large-scale deforestation, forest degradation and associated environmental impacts (WEC 2016).

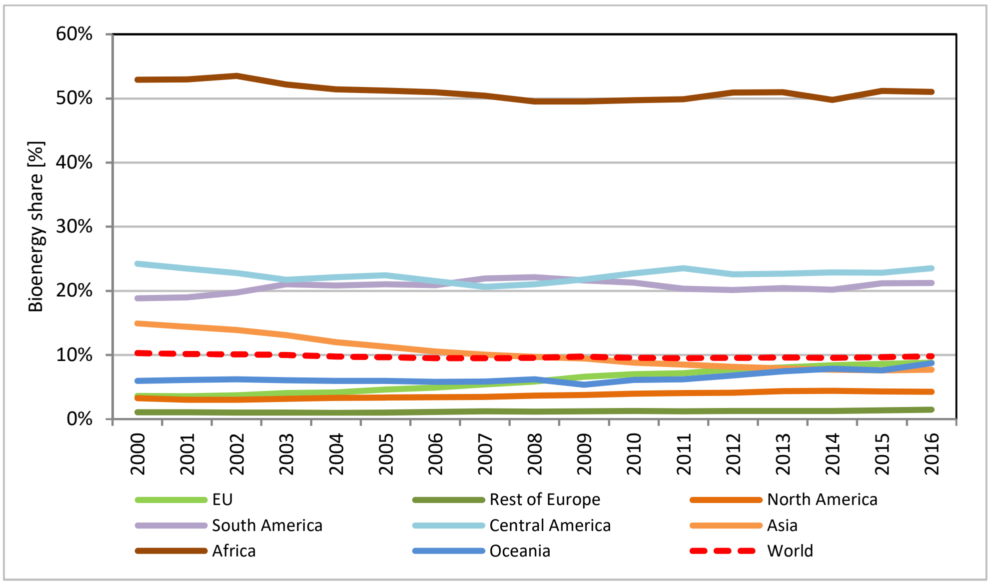

Figure 3. Share of bioenergy in total primary energy supply in world regions
Source: IEA 2019

The overall share of renewable energy in total final energy supply has also decreased to a small extent in recent years, despite significant growth in all renewable energy sectors (Figure 4). Bioenergy is the largest renewable contributor to global final energy consumption, providing 43.4 EJ in 2000, with a share in total final energy consumption showing a decrease from 14.1% to 11.9% since 2000, despite the increase of the use of biomass, linked to a higher increase of final energy consumption. Among all world regions, the most important decreases of bioenergy share into the final energy supply, Asia registered the most important decrease (from 20.6 % to 9.6 %) followed by Africa, from 58.5 % to 53.8 %) between 2000 and 2016.

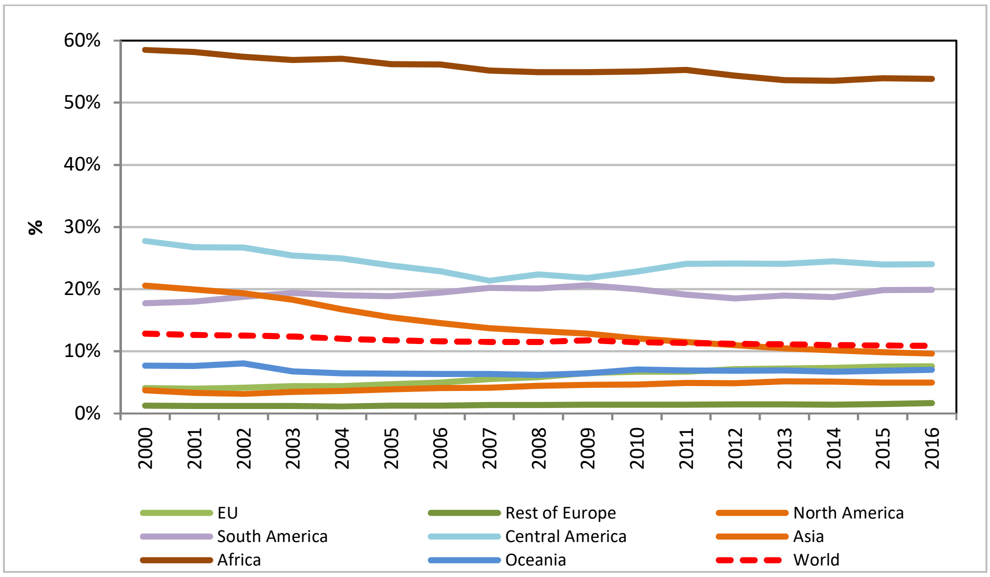

Figure 4. Share of bioenergy in final energy consumption in world regions

Source: IEA 2019

Bioenergy production includes traditional use of biomass for cooking and heating but also modern bioenergy production of electricity heat and biofuels in high efficiency applications. Traditional use of biomass for cooking and heating in residential applications relies mainly in fuelwood, charcoal, manure and agricultural residues burned in open fires, stoves and ovens. Modern biomass energy is widely used for the production of electricity, heat and liquid and gaseous fuels in modern, high efficiency conversion facilities. Biomass used worldwide for energy consists mainly in solid biomass and includes fuel wood, charcoal, crop residues, organic municipal solid waste, wood pellets, and wood chips in modern, small and large-scale facilities (Scarlat et al. 2018).

The use of biomass for heat production plays a key role to renewable heat supply worldwide, with 45 EJ in 2014, a share of 80 % of total global biomass demand. Almost two third of biomass use for heat production was traditional biomass use, mainly in rural areas in low-income areas in Asia and Africa. Biomass accounted for over 90% of modern renewable heat generation in 2016 at large scale in households in stoves, using fuelwood, wood residues or wood pellets, or in small boilers using wood pellets. Biomass heat is also is produced in large-scale boilers using wood chips or wood pellets or in district heating. Biomass power generation has a major role in the renewable electricity generation worldwide, reaching almost 500 TWh in 2016, the biomass electricity capacity having an installed capacity in 2016 of about 109 GW (IEA 2019, REN21 2018, Eurostat 2019). Thus electricity production from biomass represented globally 8% of total renewable electricity production in 2016, while this share was about 19 % in the European Union.

Biogas is used on large scale in modern and small-scale household systems as well for cooking, lighting and heat generation. Modern biogas plants produce electricity and heat in Combined Heat and Power (CHP) plants, electricity-only and heat only plants. About 50% of total biogas consumption in Europe was used for heat production. Small biogas amounts upgraded to biomethane were used in the transport sector; limited volumes of biogas upgraded to natural gas quality are now being injected into the natural gas grids. Biogas is also produced in a very large number of small, domestic-scale digesters, mainly in developing countries in Asia and Africa and is used as a cooking fuel, a number of large-scale plants that run on biogas are also operating across Asia and Africa (REN21 2019).

Among others, bioenergy deployment is constrained by the available local biomass resources and a number of sustainability limitations. A major barrier for deployment of bioenergy technologies is the cost competitiveness in comparison to fossil energy, depending on the technology and process configuration (capital and operating costs, conversion efficiency, process reliability), plant capacity, feedstock (supply chain, type, quality, and cost), competitive uses (e.g. pulp and paper, wood processing industry etc.). Bioenergy technologies still need the improvement of the conversion efficiency, improving reliability, scale-up to benefit from the economies of scale, reduction of investment costs and improving the ability to use low-cost feedstock (agri- and forest residues, municipal solid waste, sewage sludge, food waste, industrial waste etc.). Cost reduction depends on the maturity and advancement of technology. Biomass is, in many cases, a difficult feedstock that requires higher capital and operating costs, extensive effort for pre-treatment, gas cleaning, more expensive equipment etc.

Furthermore, biomass can be used not only for electricity, heat and transport fuels but increasingly more for bio-based materials and bio-chemicals. Available biomass resources could allow the expansion of current 56 EJ bioenergy to 145 EJ worldwide by 2060, and up to between 10-12.6 EJ in the European Union in 2050 (Scarlat and Dallemand 2019).

2. Technology trends and prospects

2.1 Global technology deployment and market trends

2.1.1 Bioenergy supply

Various biomass feedstocks (oil crops, starch and sugar crops, waste oil, as well as lignocellulosic biomass) are used for liquid biofuels production for the use in transport sector or even for electricity and heat production.

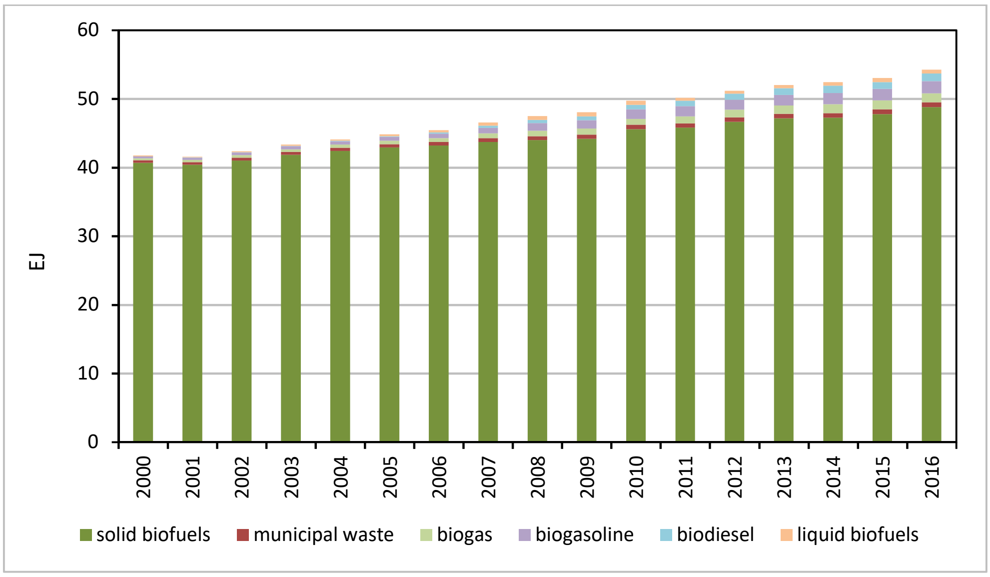

Figure 5. Evolution of primary energy production from biomass in the world by feedstock
Source: IEA 2019

Since 2000, the global biomass supply for energy has increased from 42.4 EJ to 56.4 EJ in 2016 (Figure 5). The evolution of primary energy production from biomass shows an increase of more than 30 % globally in the use of biomass during this period. The major feedstock used for bioenergy production are been solid fuels (fuelwood, charcoal, wood chips, wood and forestry residues, etc.) with a marginal contribution comes from the use of renewable municipal waste, biogas, biogasoline, biodiesel or other liquid biofuels.

In particular, in recent years, biogas production from the treatment of wet-waste biomass, from wastewater treatment plants and landfill gas recovery is expanding worldwide. Biogas is produced primarily by landfill based plants or small-scale family digesters, mainly in small, domestic-scale digesters to provide a fuel for cooking or even lighting in developing countries. Biogas is produced from a variety of wet waste and residues from agriculture and industry, municipal organic waste, sewage sludge, etc., as anaerobic digestion converts organic material into biogas, a renewable fuel that could be used to produce electricity, heat or biofuels (Scarlat et al 2018).

The analysis of the evolution of the contribution of biomass to primary energy supply by world regions (Figure 6) shows clearly the major share of Asia or Africa in the global use of biomass for energy supply since 2000. However, while the use of biomass was almost constant during the analysed period in Asia for example, significant increase in biomass use came from the European Union (130 % increase), South America (65 % increase) and Africa (58 % increase).

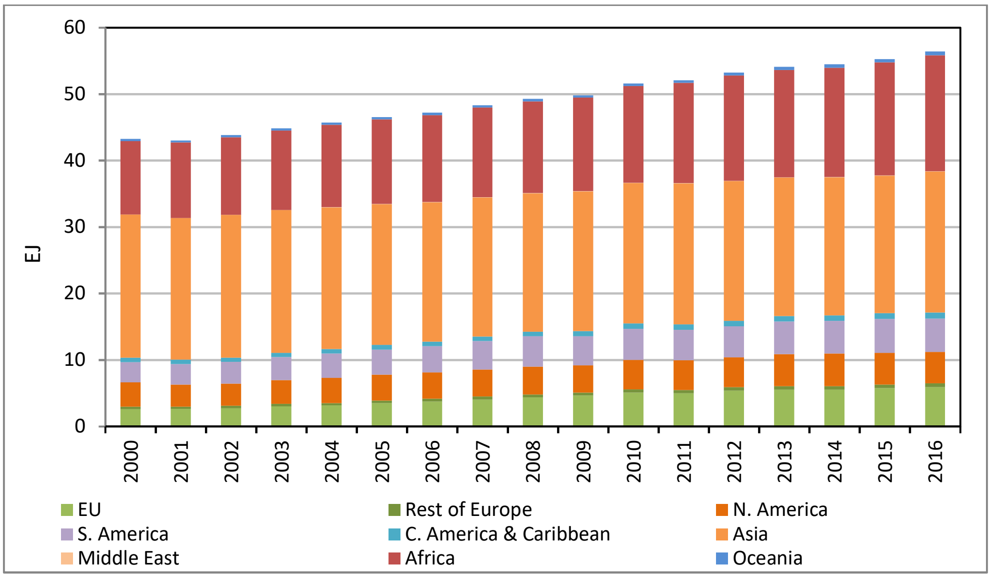

Figure 6. Evolution of the contribution of solid biofuels to primary energy supply by world regions
Source: IEA 2019

An important share of bioenergy supply is provided by the traditional use of biomass (mostly as fuelwood, charcoal, agricultural residues, dung, etc.) for cooking and heating in developing countries and emerging economies. The traditional use of biomass for cooking and heating often relies on the use of very inefficient devices, open fires or low efficiency stoves with very low efficiency (5 % - 15 %), associated to high particulate matter emissions and other air pollutants with severe consequences on (indoor) air pollution and health hazards.

Traditional biomass use remains for many people across the world the only viable energy option readily available, free, simple and easy to use. The unsustainable nature of some biomass supply and serious negative environmental and health impacts, require actions for reducing traditional biomass uses. This requires actions for the transition from traditional use of biomass to more modern, more advanced heating and cooking solutions, with significantly higher efficiency and lower solid and gaseous pollutant emissions, as part of the efforts to improve access to clean energy for all.

Figure 7 shows that while the amount of biomass used in traditional applications remained at about the same level since 2000 (27. EJ in 2016), the modern bioenergy supply almost doubled, reaching about 29 EJ in 2016. Thus, the share of traditional biomass in total global energy consumption has been declining gradually for several years, from 9.3 % in 2000 of total final energy consumption (TFEC) in 2005 to 7.5 % of global final energy demand (400 EJ) in 2016. Due to a sustained global effort, the traditional use of biomass has even declined in some countries (REN21 2018).

Modern biomass energy is widely used in many developing and industrialised countries for the production of electricity, heat and liquid and gaseous fuels in modern, high efficiency conversion facilities. Modern biomass boilers and stoves better options for energy supply at small-scale, with high energy conversion efficiencies and low gaseous and particulate emissions, but they are is relatively more expensive. Large scale facilities provides even better options for electricity and heat supply from biomass with high efficiency, while complying with the most stringent standards for pollutant emissions.

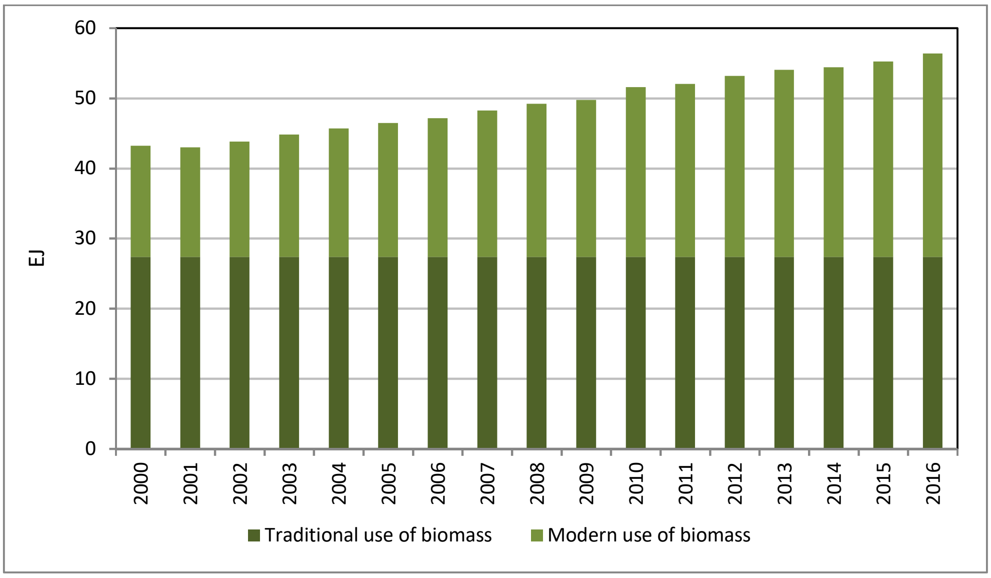

Figure 7. Biomass use worldwide for modern bioenergy and traditional use of biomass
Source: IEA 2019

Looking at the contribution of bioenergy to final energy supply in the world in 2016, the major source of biomass comes from the use of solid biofuels (forestry residues, wood residues, crop residues) with a share of 87% in biomass use, followed by the use of charcoal with 4 % (the feedstock associated mostly with traditional use of biomass for heating and cooking), bioethanol with 4 %, biodiesel with 3 %, and biogas and other liquid biofuels with 1% each. The major source for biomass comes from Asia with 41 %, followed by Africa with 31 %, North America with 9 % and South America and the European Union with 8 % each (Figure 8).

The analysis of the sources of biomass into the final energy supply shows significant differences between different world regions (Figure 8). Thus, for Africa, the major sources of biomass come from the use of solid biofuels with a share of 91.5 % followed by the use of charcoal with 8.5 %, which reflects the contribution of the traditional use of biomass for cooking, lighting and heating. In Asia, solid biofuels are the dominant feedstocks, but other sources also contribute to final bioenergy supply: charcoal (2 %), biogas (2 %) and biogas and biodiesel. Other regions of the world show a more balanced distribution of biomass feedstock that include solid biofuels, biogasoline, biodiesels, biogas and other liquid biofuels, with different proportions. In general, the most important feedstock is represented by the solid biofuels in all world regions as well as at global level.

Figure 8. Contribution of biomass feedstock to final energy supply in world regions in 2016
Source: IEA 2019

2.1.2 Biomass electricity production

Total global electricity generation from biomass increased significantly worldwide from 131 TWh in 2000 to 499 TWh in 2016 (Figure 9). In particular, significant increase in bioelectricity production, in absolute terms, has been registered in the EU and Asia, followed by South America. This chart shows that the European Union has become the world leading region in bioelectricity generation in 2016, while the growth rate in Asia is significantly higher in the last decade. Bioelectricity production increased at a high pace in the European Union in the first decade, but the growth rate decreased in the last years due to policy uncertainties about debates about biomass sustainability.

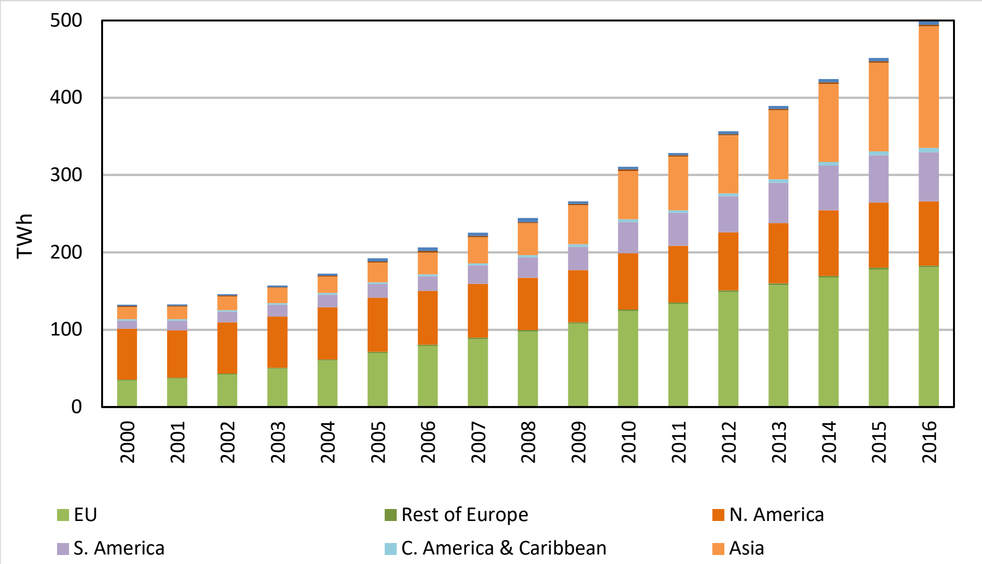

Figure 9. Trends in bioelectricity production in world regions

Source: OECD

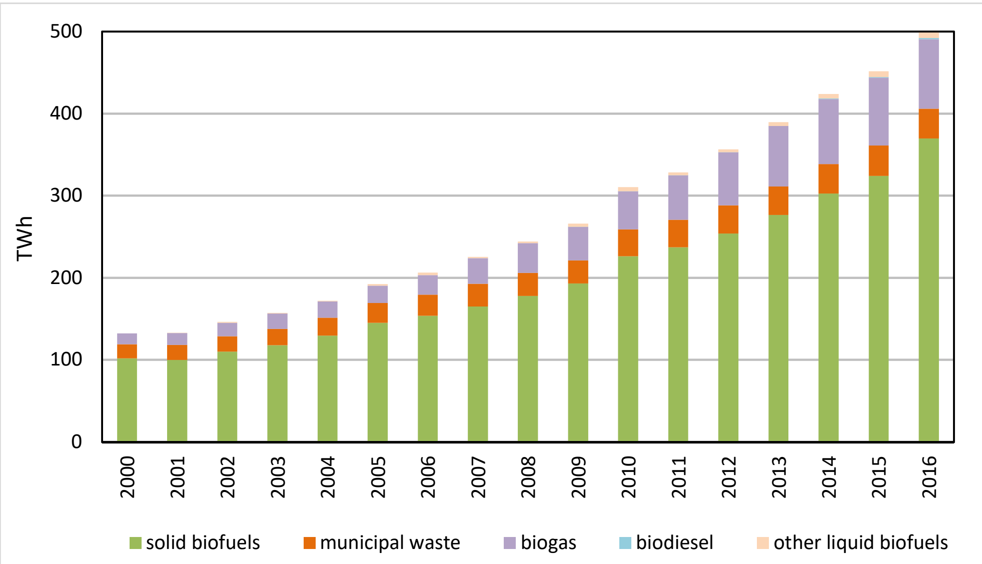

Figure 10. Trends in bioelectricity production in world regions by feedstock

Source: IEA 2019

The main feedstock for electricity generation from biomass (Figure 10) comes from solid biofuels (wood and forestry residues, bagasse, crop residues, etc.) that reached 369 TWh in 2016, followed by municipal renewable waste with 36 TWh, biogas with 85 TWh and other liquid biofuels with 7 TWh. All different feedstocks have seen a significant increase in their contribution, in particular the use of solid biofuels with an increase of 268 TWh between 2000 and 2016 and biogas with an increase of 72 TWh during the same period. In relative term, the contribution of biogas to electricity production increased much faster (more than five times) since 2000.

Electricity production from biogas has increased significantly worldwide from 13 TWh in 2000 to 85 TWh in 2016 (Figure 11), favoured by the possibility of various wet biomass feedstocks. Biogas electricity has a share of about 17% in total biomass power production worldwide, increasing from a share of 10 % in 2000. Most of the growth in biogas electricity generation originates in the European Union that is nowadays the world leader in biogas electricity production. In the European Union, electricity generation from biogas increased from 6 TWh in 2000 to 63 TWh in 2016. Other world regions have also seen an important growth including North America with a growth from 6 TWh in 2000 to 15 TWh in 2016 and Asia with a growth from 32 GWh in 2000 to 4.4 TWh in 2016. The analysis of biogas electricity production shows a clear decrease in the growth rates in the European Union due to the changes in the support policies and sustainability debates.

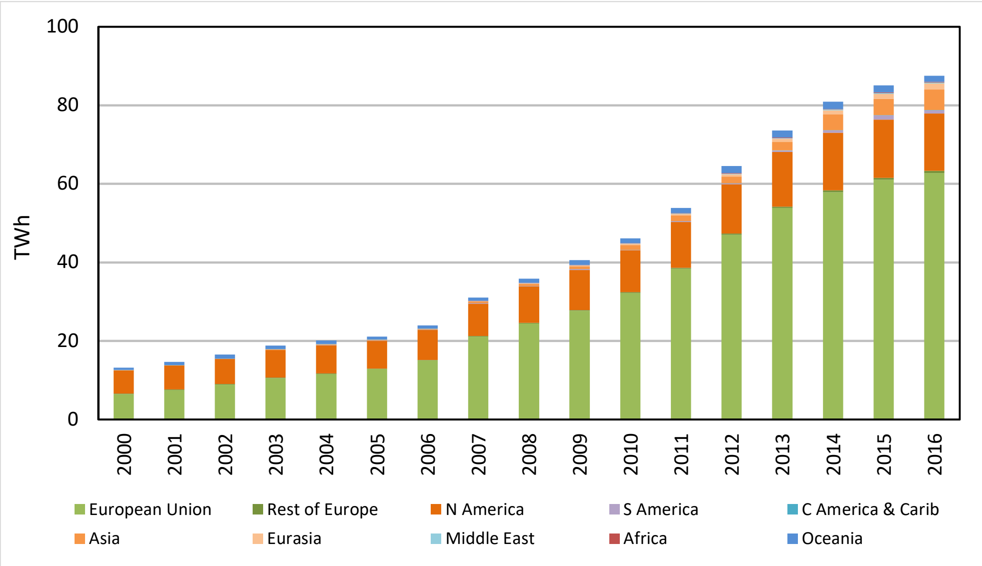

Figure 11. Increase of biogas electricity production in world regions

Source: IEA 2019

Global bioelectricity capacity increased from 29 GW in 2000 to 109 GW in 2016 (Figure 12). Significant increase in biomass installed power capacity has been noticed in all world regions. The European Union has become the world leading region in biomass power capacity overpassing North America. Major growth has been noticed in the European Union with a capacity addition in this period of 28 GW followed closely by Asia, with an increase of 27 GW and South America with a growth of 14 GW. However, the market in Asia seems to be much more dynamic compared to all world regions, while the increase of power capacity seems to be levelled up lately in the European Union. The European Union is the leading region with respect to the installed biomass electricity capacity with 32 GW, followed by Asia with 32 GW, South America with 17 GW and North America with 16 GW. Africa, despite the high share of biomass in the primary energy supply had only 1.3 GW installed capacity due to the fact that most of the biomass is used for producing heat for cooking.

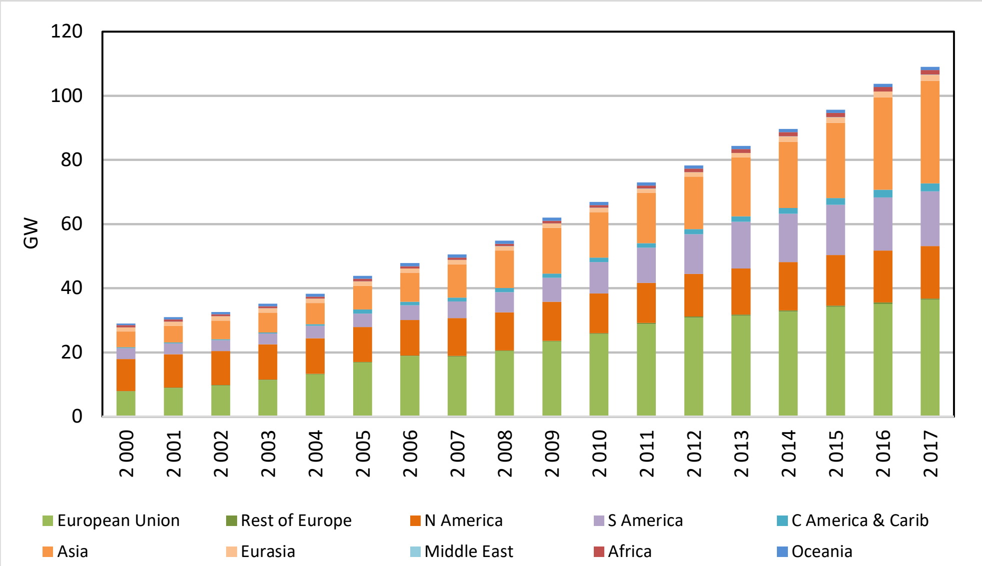

Figure 12. Evolution of installed biomass electricity capacity in world regions
Source: IRENA 2018

Figure 13 shows the evolution of the installed biomass electricity capacity by feedstock at global level. The installed capacity of plants using other solid biofuels increased from 19 GW in 2000 to 60 GW in 2016, the installed capacity of plants using bagasse increased from 4 GW to 18 GW and the installed capacity of biogas plants increased from 2.4 GW to 17 GW. An important increase was also registered in the installed capacity of energy recovery plants from renewable municipal waste, from 3.6 GW to 11.4 GW in 2016. This figure shows that the total solid biofuels electricity plants dominated the market in 2016, with 60 GW installed worldwide, followed by bagasse plants with 18 GW and biogas plants with 17 GW installed capacity worldwide.

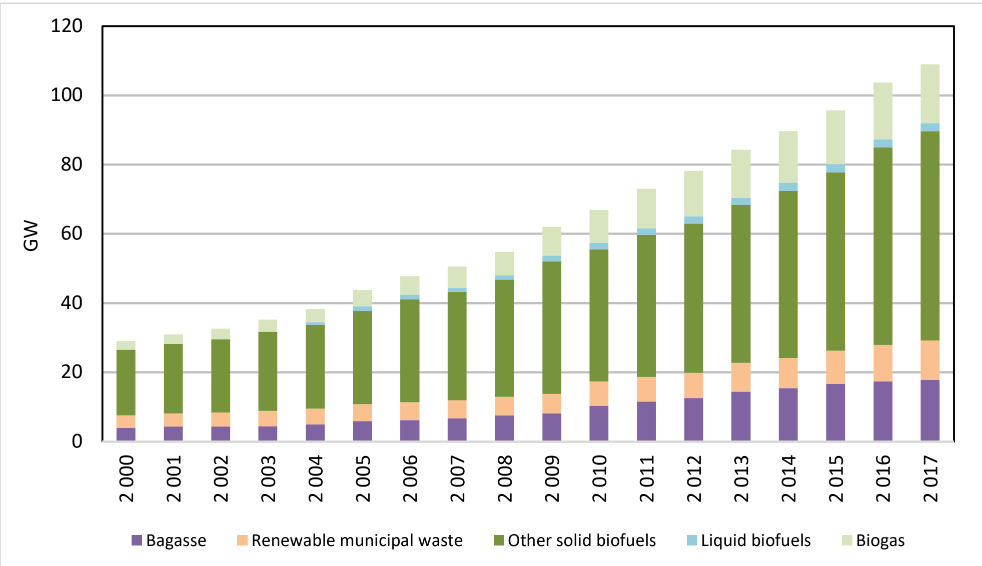

Figure 13. Evolution of installed biomass electricity capacity in the world by feedstock
Source: IRENA 2018

The global installed biogas capacity reached in 17 GW in 2016, from only 2.4 GW in 2000 (Figure 14). The European Union is by far the leading region in terms of biogas installed electricity capacity with 12 GW in 2016 followed by North America with 2.6 GW and Asia with 1.2 GW. While the annual growth rate in the biogas installed capacity decreased in the European Union since 2011, the annual increase in installed capacity is significantly higher in Asia. The observed trend in installed capacity shows a decreasing growth in the annual installed capacity determined largely by the European Union trend.

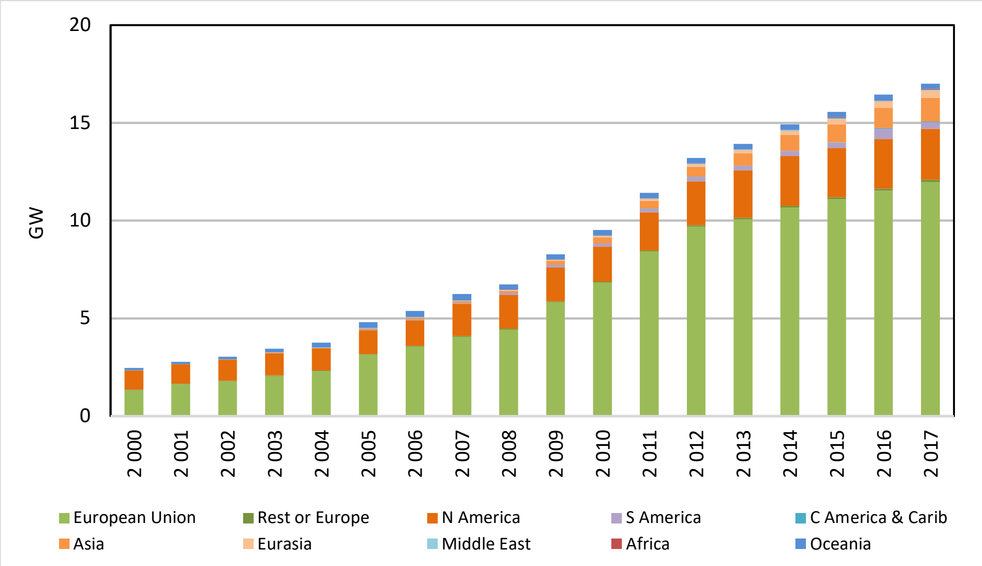

Figure 14. Evolution of biogas electricity capacity in world regions

Source: IRENA 2018

2.2 Current status and deployment targets in the EU

2.2.1 Progress and current status in the EU

2.2.1.1 Bioenergy supply in the EU

The analysis of the gross inland consumption of bioenergy and other renewables (Figure 15) shows a significant and continuous progress in bioenergy (for electricity, heat and biofuels), which increased from 2.5 EJ in 2000 to 5.8 EJ in 2016. A similar trend can be noticed for the deployment of all renewables: hydro, solar wind, geothermal, heat pumps. The share of bioenergy in renewable energy supply in the European Union in general increased from 61.8 % in 2000 to 64.8 % in 2016 with some variations during this period reaching a maximum share of bioenergy of 69.4 % in 2009. The growth trend seems to be levelling out in the last years both in bioenergy and in other renewables due to the uncertainties in supporting policies and decrease in oil prices.

Figure 16 shows the contribution of bioenergy and other renewables to gross inland consumption in the Member States of the European Union in 2016. The leading Member States both in bioenergy and renewable energy supply include Germany, Italy France Sweden and Spain and shows a good correlation between renewable energy support and bioenergy support throughout all Member States. Significant variation in the share of bioenergy to renewable energy supply is obvious varying from below 40 % in some southern countries (Spain, Greece, Cyprus, Malta) to above 90 % (Estonia, Lithuania, Hungary, Czech Republic, Finland).

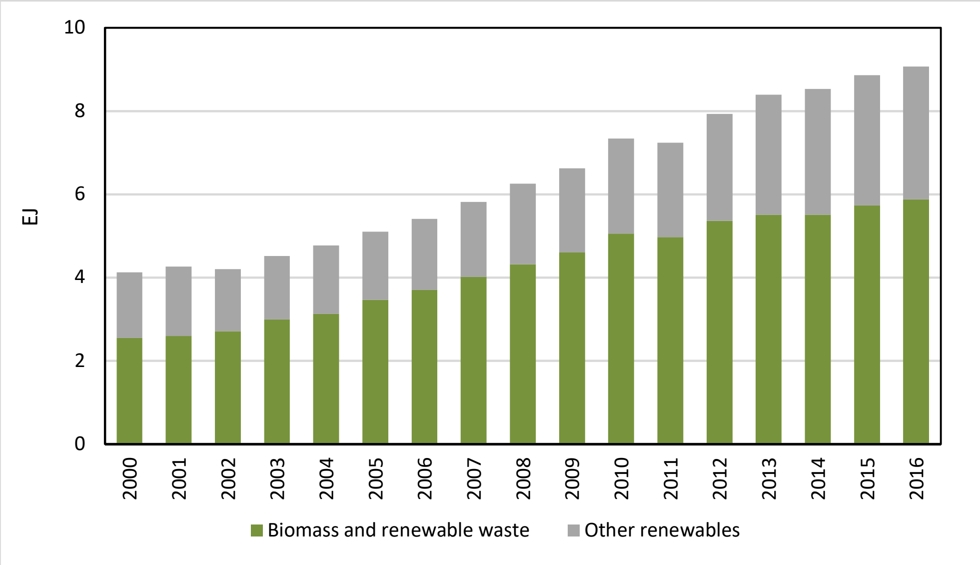

Figure 15. Evolution of bioenergy and other renewables supply in the European Union
Source: Eurostat 2019a

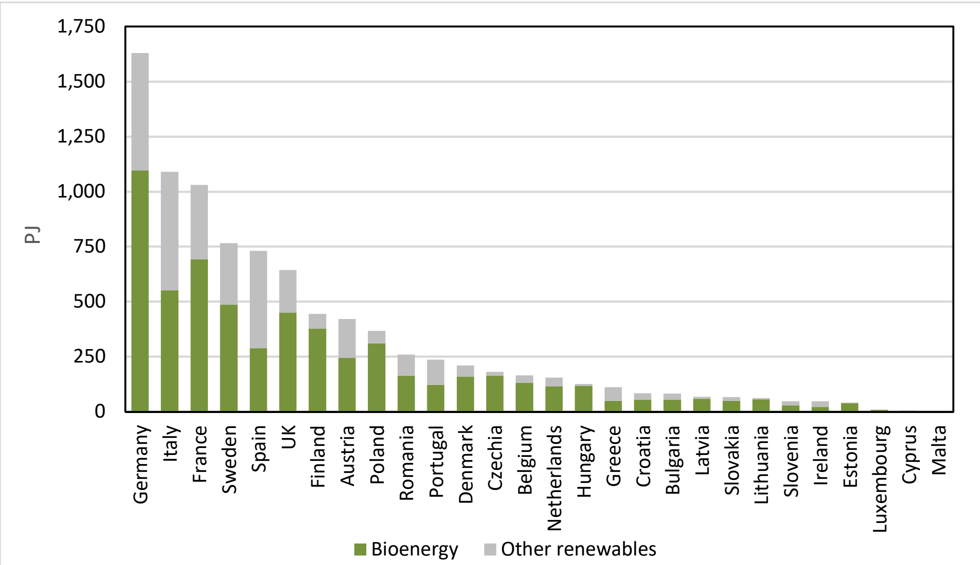

Figure 16. Gross inland consumption of bioenergy and other renewables in EU Member States in 2016
Source: Eurostat 2019a

The major feedstocks used for bioenergy production in the European Union are solid biofuels, municipal renewable waste, biogas and liquid biofuels (biogasoline, biodiesel, other liquid biofuels and bio jet). Since 2000 the primary energy supply biomass has increased from 2.5 EJ to 5.8 EJ in 2016 (Figure 17). Solid biofuels are the most common biomass feedstock used in the European Union with an increase from 2.3 EJ in 2000 to 4.1 EJ in 2016. Solid biofuels include a range of wood, wood wastes and residues either from energy crops (poplar, willow, energy grasses, etc.), as woody materials generated from wood processing and paper industry, or provided directly by forestry and agriculture (firewood, wood chips, bark, sawdust, shavings, chips, black liquor, etc.) as well as wastes such as straw, rice husks, nut shells, livestock manure, etc. Although the share of solid biofuels in primary bioenergy supply decreased from almost 90 % of the primary energy supply from biomass in 2000, they still representing about 70 % in 2016. The contribution of biogas shows a significant increase in this period from 92 PJ to 695 PJ. Liquid biofuels have also seen a large growth from 30 PJ in 2000 to 631 PJ in 2016, mostly for the use in the transport sector (biogasoline, biodiesel other biofuels) or as liquid biofuels for heat and power. Another component of biomass feedstock, renewable municipal waste is being also increasingly used for energy recovery, although with a progress at lower rates, increasing from 160 PJ to 432 PJ in 2016.

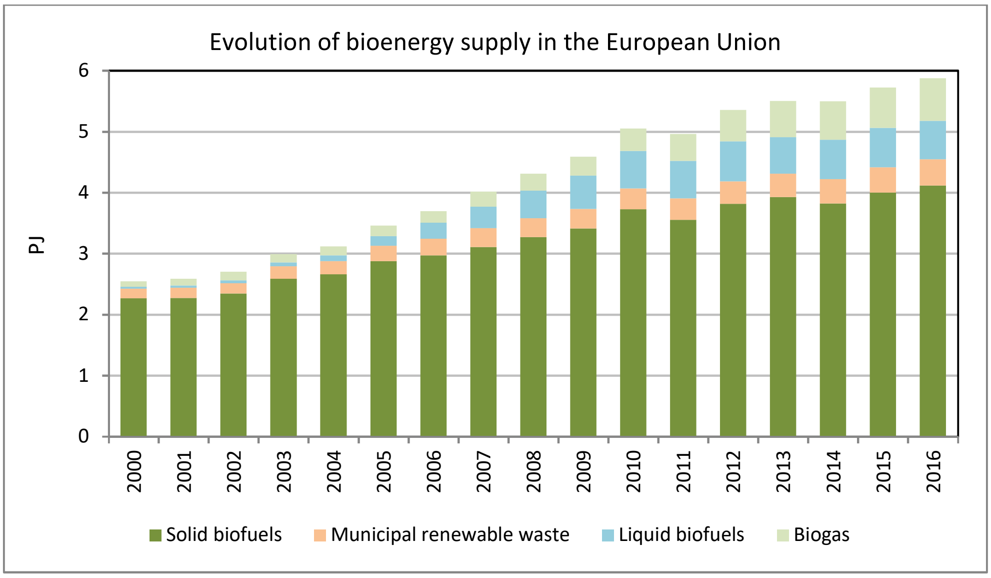

Figure 17. Evolution of bioenergy supply in the European Union by feedstock
Source: Eurostat 2019a

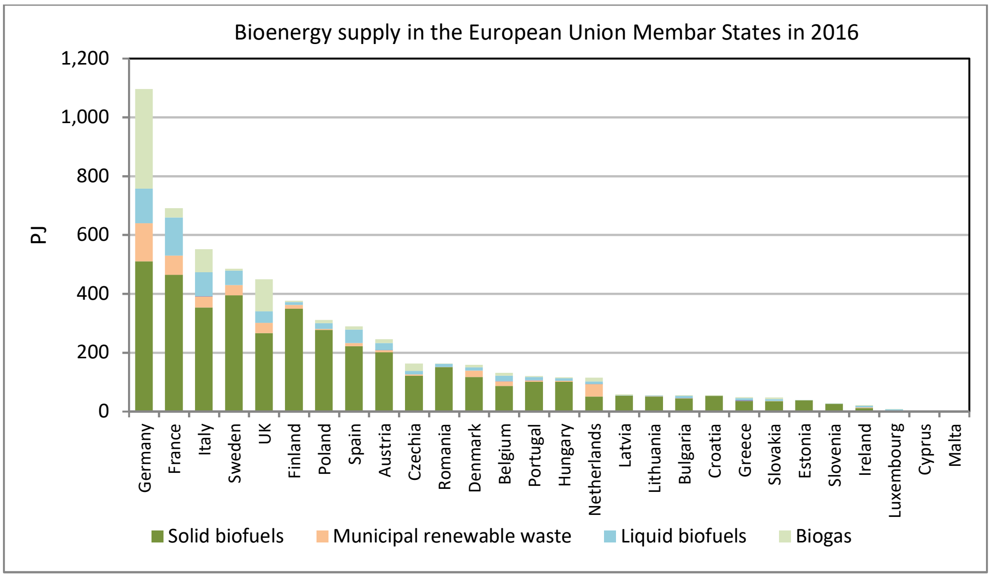

Figure 18. Bioenergy supply in the European Union Member States in 2016
Source: Eurostat 2019a

Figure 18 shows the contribution of different feedstock (solid biofuels municipal renewable waste, liquid biofuels and biogas) in the Member States in 2016. It is obvious that the main feedstock used for bioenergy comes from solid biofuels in most Member States. Thus the share of solid biofuels in total biomass supply could be as high as above 90 % in several Member States including Finland, Romania, Latvia Croatia, Estonia and Slovenia. In some other Member States the contribution of solid biofuels could be below 50 % in Cyprus Malta, Germany, the Netherlands and UK. In some leading Member States, such as Germany, France, Italy and UK, biogas municipal renewable waste and liquid biofuels play, besides solid biofuels, an increased role in bioenergy supply.

In the primary energy production from solid biomass, the main feedstock comes from the use of fuelwood, wood residues and by-products, with a contribution doubling since 2000 from 1.5 EJ to 2.9 EJ in 2016 (Figure 19). A lower growth has been registered from the use of black liquor from the pulp and paper industry with an increase from 378 PJ to 532 PJ. On the contrary, the use of other vegetal and residues has seen a small decrease from 337 PJ to 294 PJ. Although still small the use of wood pellets has increased severely from only 3 PJ in 2000 to 149 PJ in 2016, the European Union being the major market for the use of wood pellets for energy supply.

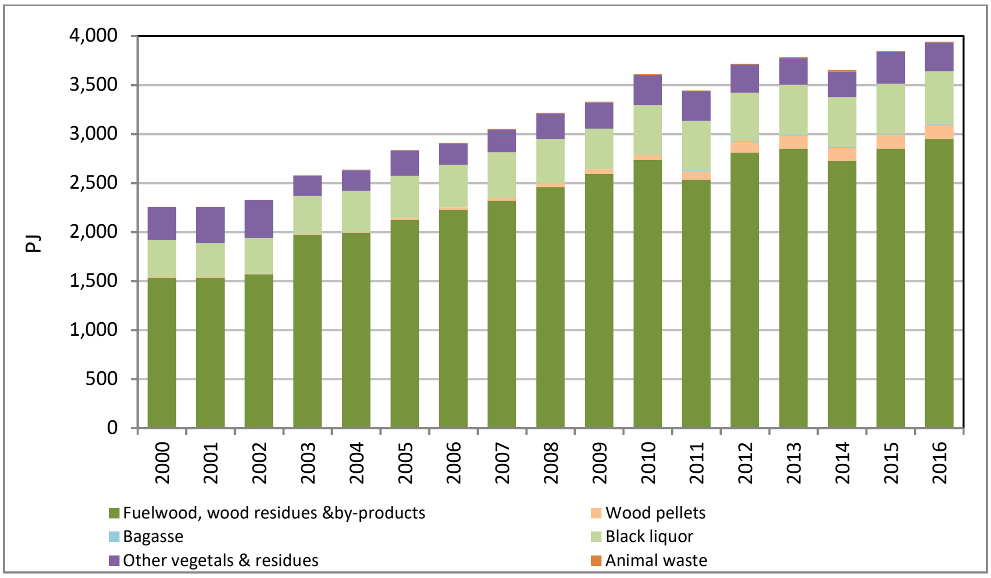

Figure 19. Evolution of primary energy production from solid biomass in the European Union
Source: IRENA 2018

In most Member States, the main solid biomass feedstock used for bioenergy supply comes from fuelwood, wood residues and by-products (Figure 20). The share of fuelwood, wood residues and by-products in the total solid biofuels use could be almost 100 % in Italy, Romania, Croatia and Slovenia, in other Member States such as Sweden Finland UK Portugal and Estonia, their contribution is below 60 % due to the use of other feedstocks such as black liquor (Sweden Finland Portugal) other vegetal and waste (UK, Poland Spain, Denmark, Netherlands), wood pellets (Estonia Portugal). The feedstock used in different Member States is related to the availability of residues from the pulp and paper industry as black liquor or the use of other vegetal & residues for biogas (UK) or straw for combustion (Denmark) etc. An important contribution also comes from the use of wood pellets in Germany, Estonia, Latvia, France or Portugal.

Biogas production has seen an impressive growth in the European Union, from only 92 PJ in 2000 to 695 PJ in 2016. The share of biogas into bioenergy supply in the European Union increased steadily from less than 4 % in 2000 to almost 12% in 2016. The most impressive increase, from 8.5 PJ in 2000 to 515 PJ in 2016, comes from biogas from anaerobic fermentation of waste and residues from agriculture, livestock manure, organic waste, food waste or other industry residues. Biogas production from landfill gas recovery or biogas from sewage gas has increased moderately. Biogas production from thermal processes has started only recently (2011-2013) in few Member States (Finland, Spain and Italy) with a marginal contribution to biogas supply (3.3 PJ in 2016).

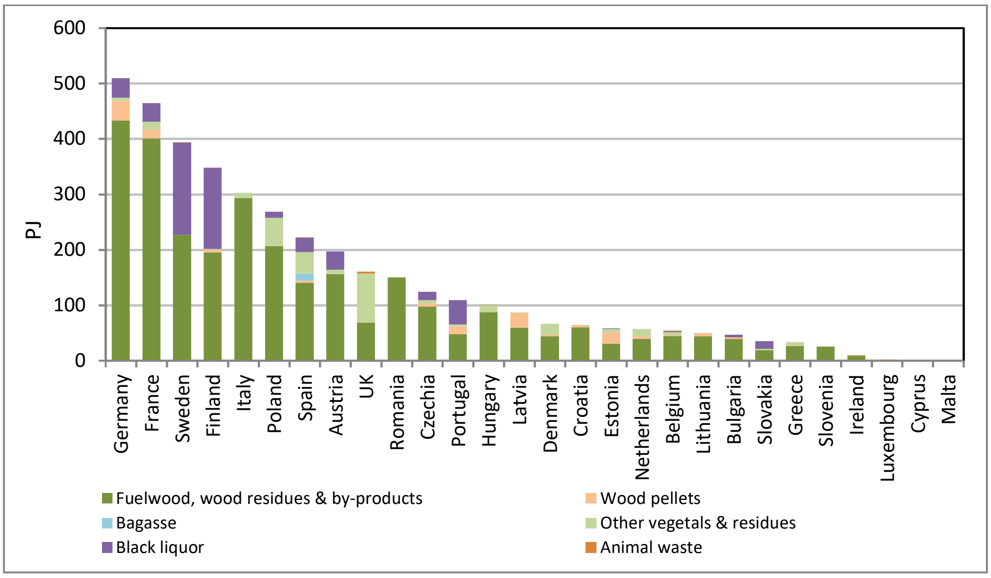

Figure 20. Primary energy production from solid biomass in the EU Member States in 2016
Source: IRENA 2018

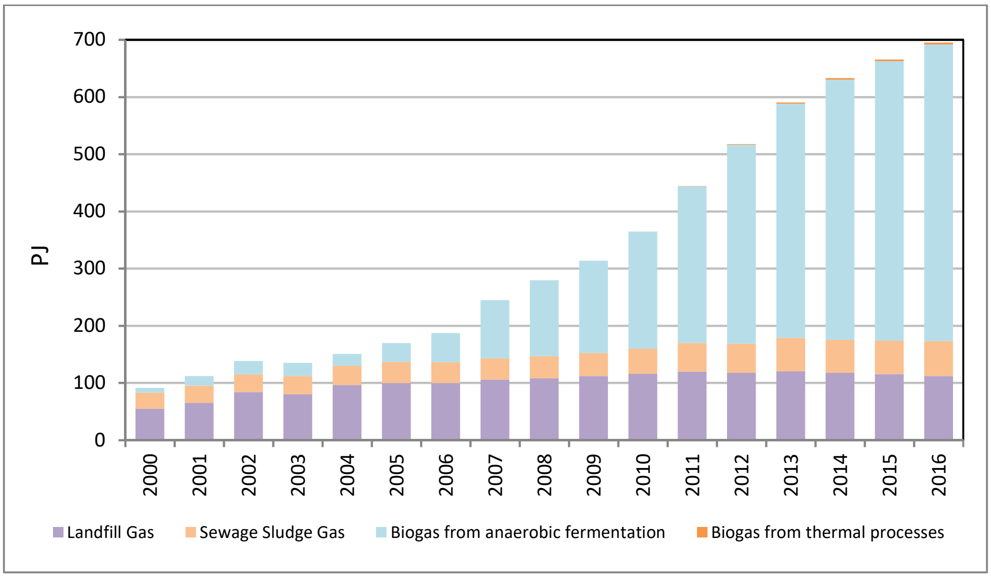

Figure 21. Evolution of primary energy supply from biogas in the EU
Source: Eurostat 2019

Looking at the deployment of biogas supply into different Member States (Figure 22), the leading country in 2016 was Germany that has a contribution of almost 50 % into the biogas production at the European Union level with 339 PJ. Significant development has been also noticed in other Member States in the last years, in particular in the United Kingdom (109 PJ), Italy (79 PJ), France (32 PJ) and Czech Republic (25 PJ). Biogas production from anaerobic digestion plants dominates in most countries in particular in Germany Italy, France and Czech Republic, etc. Biogas from landfill gas recovery, however, dominates in other Member States, including United Kingdom, Spain, Greece, Portugal and Ireland. In other Member States, landfill gas recovery is relevant without being the main source for biogas (Italy, France and Poland). Biogas production from anaerobic digestion of sewage sludge from waste water treatment plants has also an important contribution in Germany, UK followed by Poland, Sweden and France.

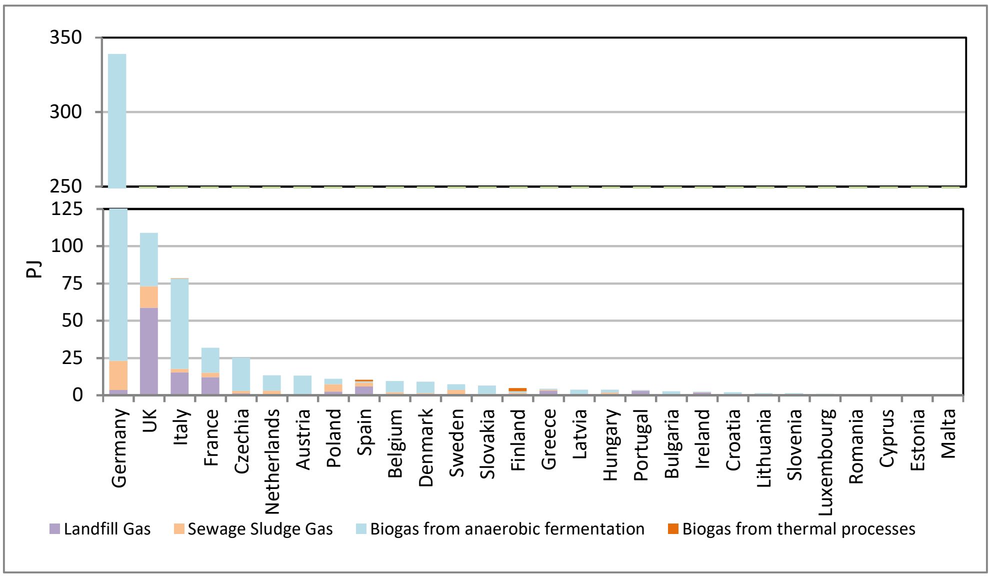

Figure 22. Primary energy production from biogas in the EU Member States in 2016

Source: Eurostat 2019a

2.2.2.2 Biomass electricity production in the EU

Electricity generation from biomass has increased significantly in the European Union, from 34 TWh in 2000 to 181 TWh in 2016 (Figure 23).

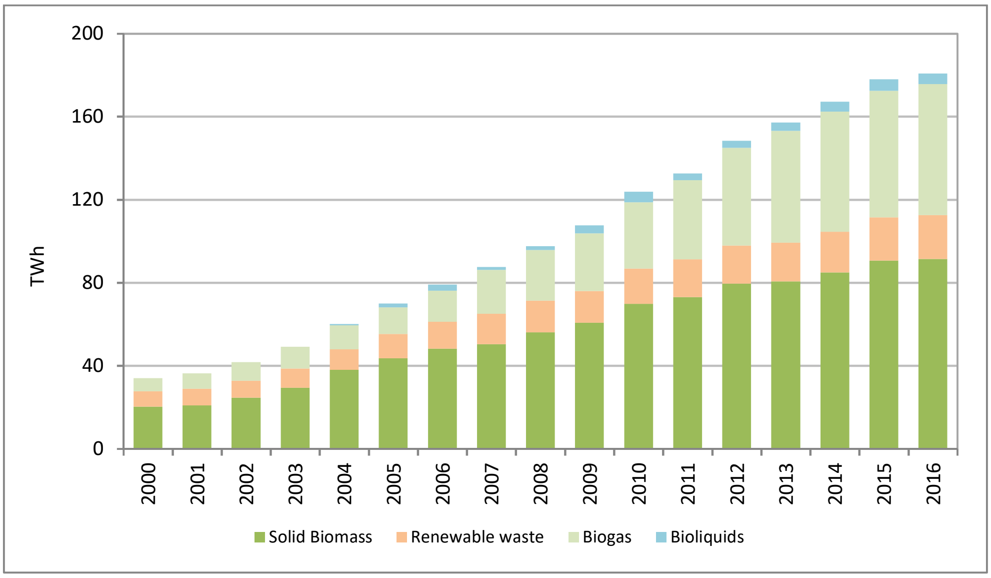

Figure 23. Evolution of biomass electricity production in the EU

Source: Eurostat 2019a

The annual increasing rate of electricity generation seems to be decreasing in the last years. Solid biomass, with an increase from 20 TWh in 2000 to 91 TWh in 2016, is the main contributor to biomass electricity generation, with a share decreasing from almost 60% in 2000 to just above 50 % in 2016. Significant progress has been achieved in biogas electricity from 6TWh in 2000 to 63 TWh in 2016. The share of biogas electricity increased significantly from 19 % in 2000 to 35 % of total biomass electricity generation in 2016. Electricity generation from municipal renewable waste has also increased from 7 TWh in 2000 to 21 TWh in 2016, with a share decreasing from almost 22 % to 12 % in 2016 due to higher growth from solid biomass and biogas electricity generation.

The production of bioelectricity looks very diverse among different Member States, as well as the contribution of solid biomass, biogas or bioliquids (Figure 24). The leading countries in biomass electricity generation in 2016 were Germany, UK, Italy, Finland and Sweden. Solid biomass was the main feedstock for bioelectricity production in 2016 in several Member States (such as United Kingdom, Finland Sweden Poland and Austria, while in other Member States, such as Italy, France, Spain, Belgium and Netherlands, different feedstocks contribute to various extent to biomass electricity production. Important aspect to notice is the high contribution of biogas to electricity production in Germany with a share of 66 % of biomass electricity and the biogas contribution to electricity production of more than 50 % in Bulgaria, Croatia and Slovenia and about 43 % in Italy.

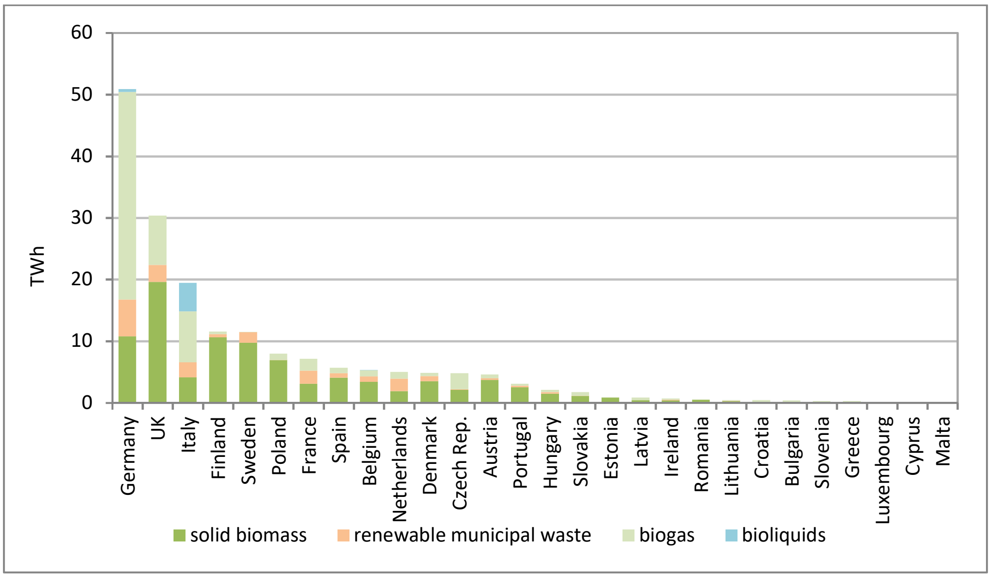

Figure 24. Biomass electricity production in the EU Member States in 2016
Source: Eurostat 2019a

The installed biomass electricity capacity in the European Union has increased significantly from 6.6 GW in 2000 to 30.6 GW in 2016 (Figure 25). The installed capacity of plants using solid biofuels increased from 2.8 GW in 2000 to 9 GW in 2016, showing very limited growth in the last years. In contrast, an important increase has been noticed in the installed capacity of biogas plants, with a growth from 1.3 GW to 11.4 GW. The installed capacity of plants using municipal renewable waste has seen also a continuous increase from 2.5 GW to 8.3 GW. Thus, this figure shows that the total biogas electricity plants dominated the European Union market in 2016, with 11.4 GW installed (37 % of total biomass capacity), followed by solid biofuels plants with 9 GW installed capacity (30 % of biomass capacity) and plants for energy recovery from waste with 8.3 GW installed capacity (27 %). The capacity of biomass plants based on the use of liquid biofuels is limited (6 GW), showing no increase in the last years due to the sustainability debate on the use of liquid biofuels.

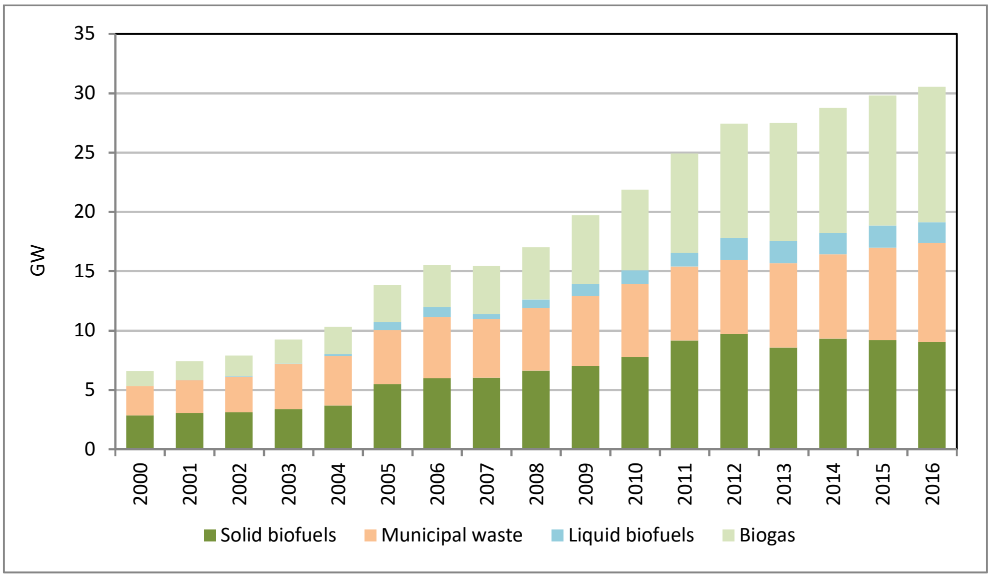

Figure 25. Evolution of bioenergy installed capacity in the European Union

Source: Eurostat 2019a

Germany was the European Union leader in terms of biomass electricity installed capacity in 2016, followed by UK, Sweden and Italy. The solid biomass plants have the main contribution to the total installed capacity in most Member States, in particular in UK, Sweden, Finland Austria, Denmark etc. In contract the highest installed capacity comes from biogas in Germany and Italy.

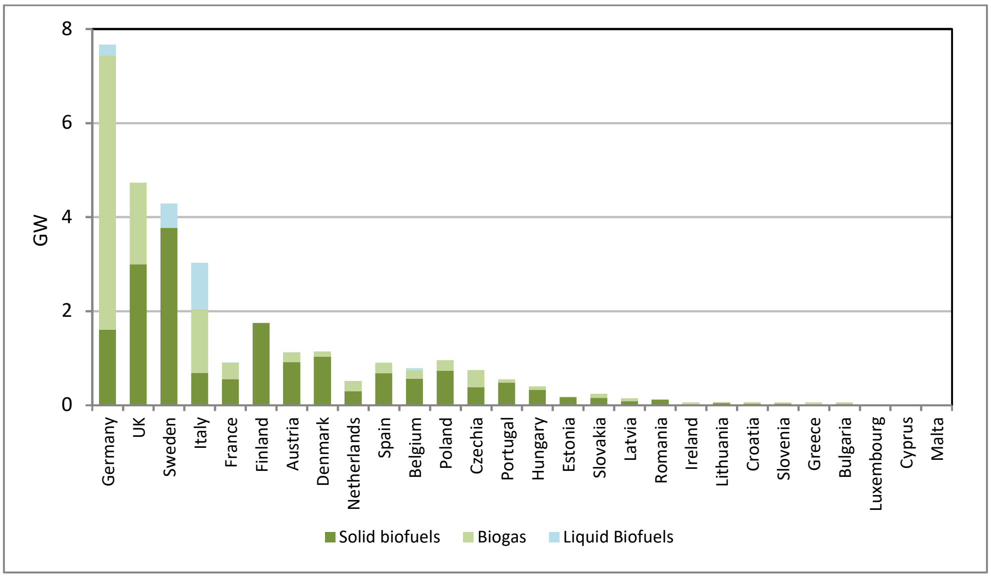

Figure 26. Bioenergy installed capacity in the EU Member States in 2016

Source: Eurostat 2019a

2.2.3 Bioenergy development and 2020 targets in the EU

The Renewable Energy Directive (RED) 2009/28/EC on the promotion of renewable energy sources, established the renewable energy target of 20 % into the gross final energy consumption in the European Union and 10% renewable energy in transport by 2020. This 20 % renewable energy objective complements the 20 % GHG emissions reduction target in the EU by compared to 1990 emission levels. The RED specifies national objectives, legally binding rather than indicative targets for the share of renewable energy. Each MS has its own target for the share of energy from renewable sources and a share of 10% renewable energy in transport. Later on, considering the potential negative impacts of the use of food based crops on land use changes a limit of 7% has been set for the use of biofuels in transport using such crops. The RED also includes a set of provisions to facilitate the development of renewable energy, such as a legal requirement for the MS to prepare National Renewable Energy Action Plans (NREAPs) with detailed roadmaps and measures taken to reach the RES targets and develop the energy infrastructure.

The EU Member States have prepared their NREAPs setting out their national targets for the share of renewable energy consumed in electricity, heating and cooling and in transport, and measures for achieving the national overall renewable energy targets (2009/548/EC). In the NREAPs, each MS proposed two scenarios for energy consumption until 2020: the Reference Scenario, only taking into account the energy efficiency and saving measures adopted before 2009; the Additional Energy Efficiency Scenario, including all energy efficiency and saving measures adopted and expected to be adopted after 2009. Member States have to prepare progress reports, every two years, on the developments in the RES against the levels set in their NREAPs, describing the overall policy developments and the progress made in the use of renewable energy and their shares.

2.2.3.1 EU bioenergy production and targets

The use of renewable energy, according to the aggregated values of the NREAPs, is projected to increase from 4.2 EJ in 2005 to about 10.3 EJ in 2020. The highest growth was expected to be achieved by solar, wind and heat pumps, with comparatively less increase from biomass and geothermal. Significant progress has been achieved far, with an increase of more than 90% of total renewable energy deployment between 2005 and 2016, from 4.4 EJ to 8.5 EJ, with a contribution of renewable energy to the gross final energy production of 17 % in 2016 and 17.5 % in 2017.

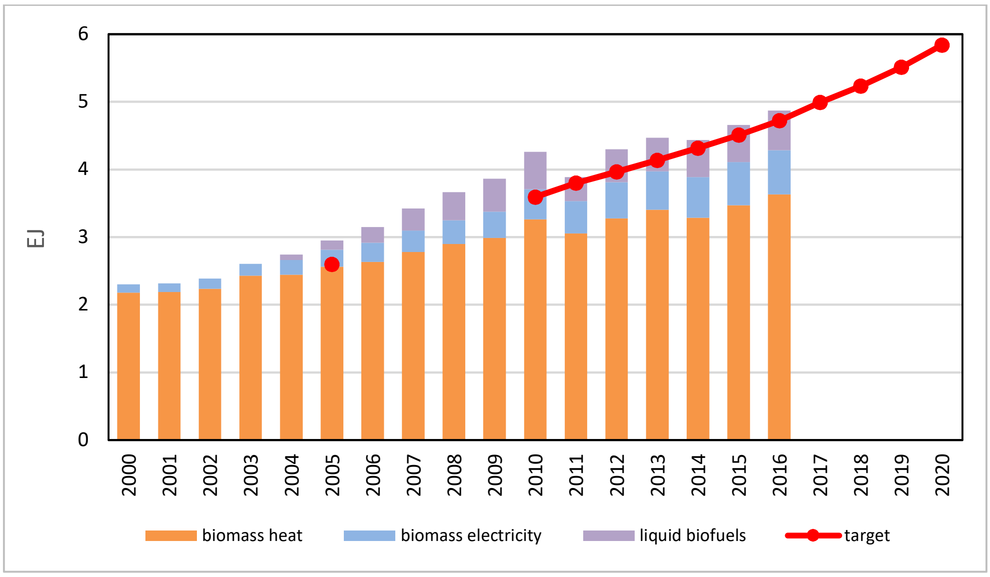

Figure 27. Progress made and targets for 2020 for bioenergy production in the European Union
Source: Eurostat 2019b

Bioenergy is the main renewable energy source used in the EU, and the Member States projections showing that bioenergy would have a contribution of about 57 % in 2020 in total renewable energy. The total use of bioenergy (electricity, heating and cooling and biofuels in transport) is estimated to double between, and to increase from 2.6 EJ in 2005 to 5.8 EJ in 2020. The bioenergy development is in general according to the NREAPs predictions (with the exception of biofuels), reaching about 4.9 EJ gross final bioenergy, in comparison to the expected level of 4.7 EJ for 2016 (Figure 27).

Despite significant growth from all renewable energy sources especially in wind and solar, bioenergy accounted 65% of renewable energy consumption in the European Union in 2016, increasing from 62 % in 2005. This shows that the progress made in bioenergy is in line with the expected trajectory and the target for 2020 for bioenergy is expected to be reached. Figure 27 shows that biomass heat has the largest contribution to bioenergy use at the European Union level since 2005 with a contribution of about 75 % to bioenergy use most of this coming from biomass consumption in households. Significant increase has been registered in biomass electricity, that contributed in 2016 with more than 15 % to bioenergy use in the European Union.

Figure 28 shows the progress made since 2005 and targets for 2020 in bioenergy supply in the Member States of the European Union in 2016. Significant variation in the contribution of bioenergy to energy supply is obvious and the leading MS supply include Germany, France, Sweden, Italy and Finland. Large differences appear also in terms in the development made since 2005 especially in Italy, UK and Poland that become leaders in bioenergy although the level of bioenergy production was quite low in 2005. Important progress has been also noticed in several other Member States, such as Germany, France, Sweden, Finland and Spain. Large gaps are still to cover in order to reach the 2020 projected levels for bioenergy in France, UK, Spain Portugal, Netherlands and Belgium.

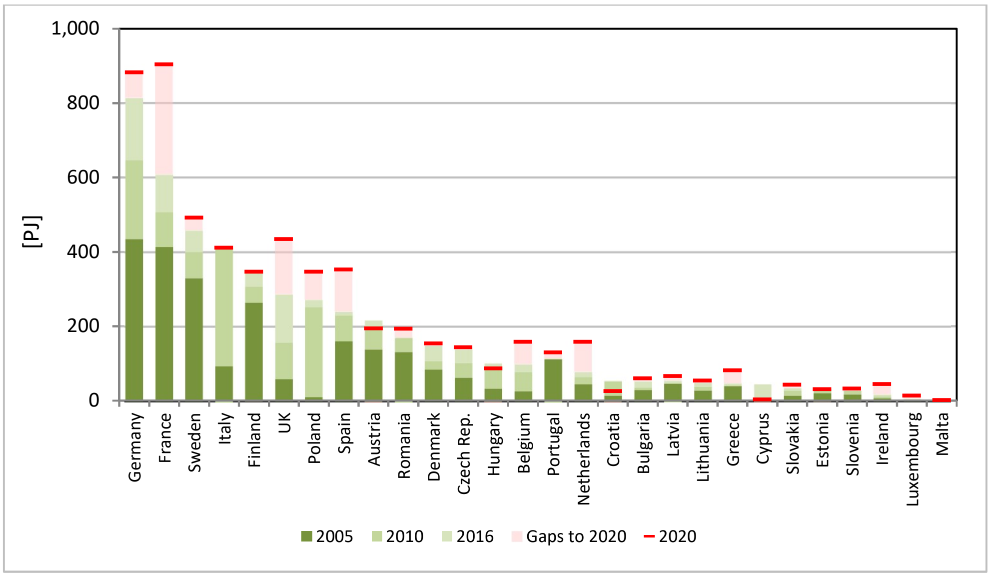

Figure 28. Progress made by 2016 and targets for 2020 for bioenergy production in different MS
Source: Eurostat 2019b

The development in biogas production in the European Union is remarkable. Biogas contribution to gross final energy supply increased from 77 PJ in 2005 to 376 PJ in 2016 being about 25 % above the projected level in the NREAPS (Figure 29). The use of biogas has still a small contribution to bioenergy production, but increasing in share from 2.6 % in 2005 to 7.7 % in 2016, having the highest growth of all bioenergy in the last decade. Significant progress has been made both in the electricity generation from biogas as well as in the heat production. Biogas also started to be used also in the transport sector with a low contribution. The past progress might give good indications that the expected level of biogas contribution to final energy supply in 2020 will be exceeded.

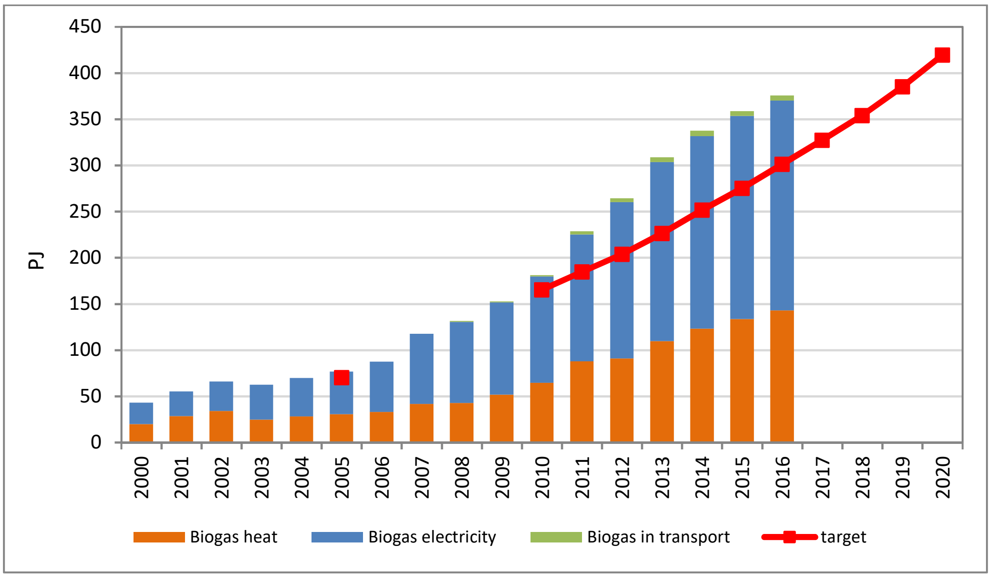

Figure 29. Evolution of final energy supply from biogas in the EU and 2020 targets

Source: Eurostat 2019b

In terms of final energy supply from biogas Germany is by far the leading Member State with a share above 50% in final energy supply from biogas in the EU (Figure 30). Other leaders in energy supply from biogas include UK Italy and France. Several MS, including Germany, United Kingdom and Italy, already exceeded the expected level for 2020. Significant progress is still expected and large gap are still to fill by several MS, such as Poland, France, Netherlands and Czech Republic. Thus, while the progress in energy supply from biogas the above the expected trajectory, biogas production is concentrated mostly in Germany and further development is expected from other Member States.

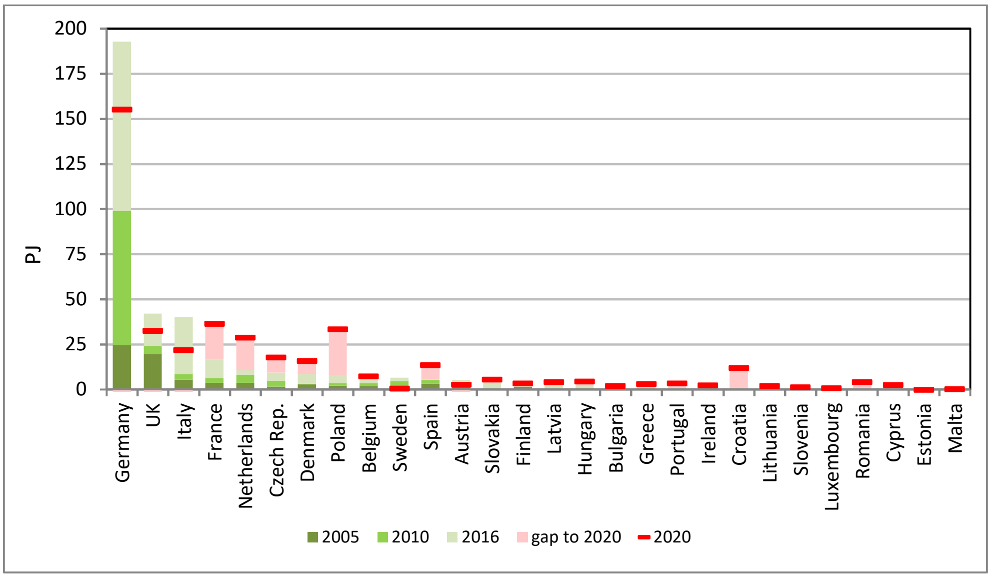

Figure 30. Progress made and targets for 2020 for the energy supply from biogas in EU Member States

Source: Eurostat 2019b

2.2.3.2 EU biomass heating and cooling and targets

Biomass is the largest contributor to renewable heating and cooling. Despite the fact that biomass heating is expected to grow from 2.5 EJ to 3.8 EJ between 2005 and 2020, its share in renewable heating will decrease from 97% in 2005 to 80% in 2020, due to higher growth of other renewables. Biomass heating has increased at a higher rate compared to the expected trajectory in the NREAPs reaching in 2016 about 96 % of the 2020 target (Figure 31). The main contributor of biomass in renewable heating is solid biomass (forest and agricultural residues, wood pellets and various waste, including municipal solid waste). Although the use of solid biomass in heating will increase, its share is projected to remain at about the same level by 2020. The most important increase, in relative terms, is expected to come from the use of biogas following the progress made so far. The biogas share in biomass heating should increase from only 1% in 2005 to 5% in 2020.

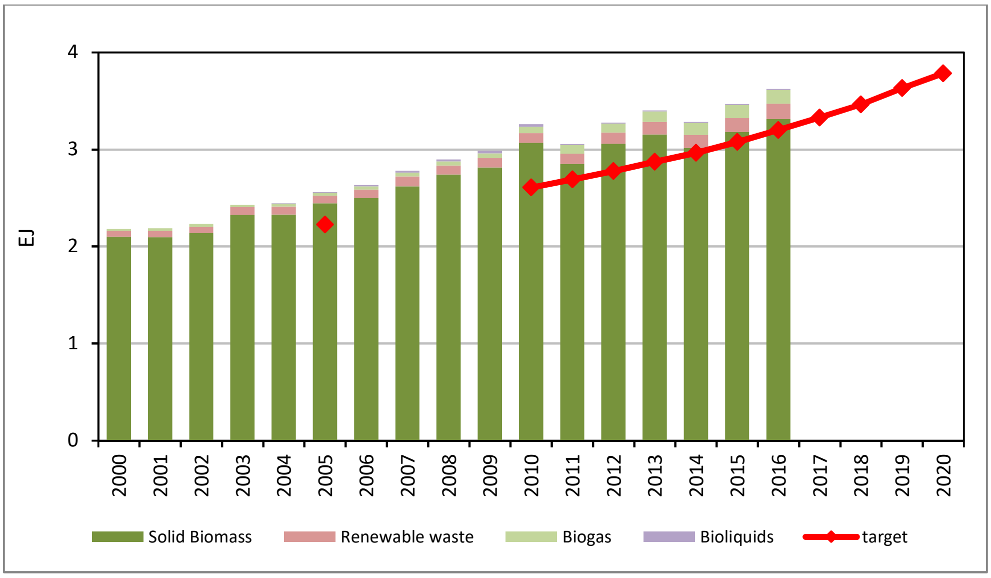

Figure 31. Evolution of biomass heat production by feedstock in the EU and targets
Source: Eurostat 2019b

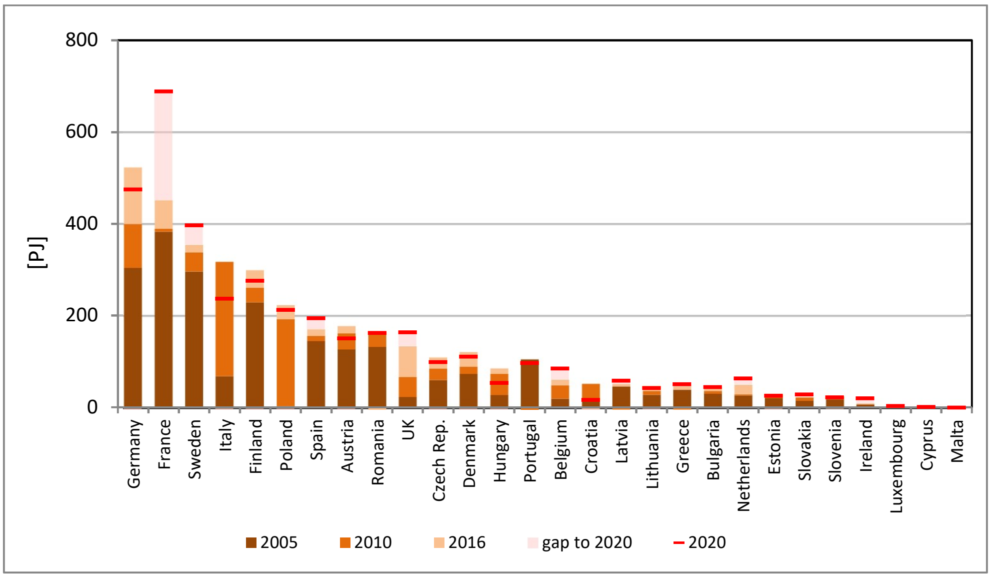

Figure 32. Progress made and targets for 2020 for the use of biomass heat in EU Member States
Source: Eurostat 2019b

Figure 32 shows the progress made since 2005 and targets for 2020 in the use of biomass heat in the Member States in 2016. Most of the MS showed a large increase in biomass heating, reaching already the level projected for 2020, such as Italy, Germany, Denmark, Finland, Austria, Croatia, etc. More developments are expected in few other Member States to reach the 2020 projected levels for biomass heating in particular in France, but also Sweden, Spain, UK or Belgium, etc. The use of heat from biogas has 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 in the European Union. With a slower progress in biogas heat use than in the electricity generation, the use of heat from biogas increased from 20 PJ in 2000 and 30 PJ in 2005 to 143 PJ in 2016 (Figure 33). The use of biogas heat in the EU still has to make progress to reach the expected levels for 2020, due to the significant growth since 2005. The current levels for heat generation from biogas, which is about 11 % above the level forecasted for 2016, offer good prospects for reaching the expected level of 189 EJ heat from biogas for 2020.

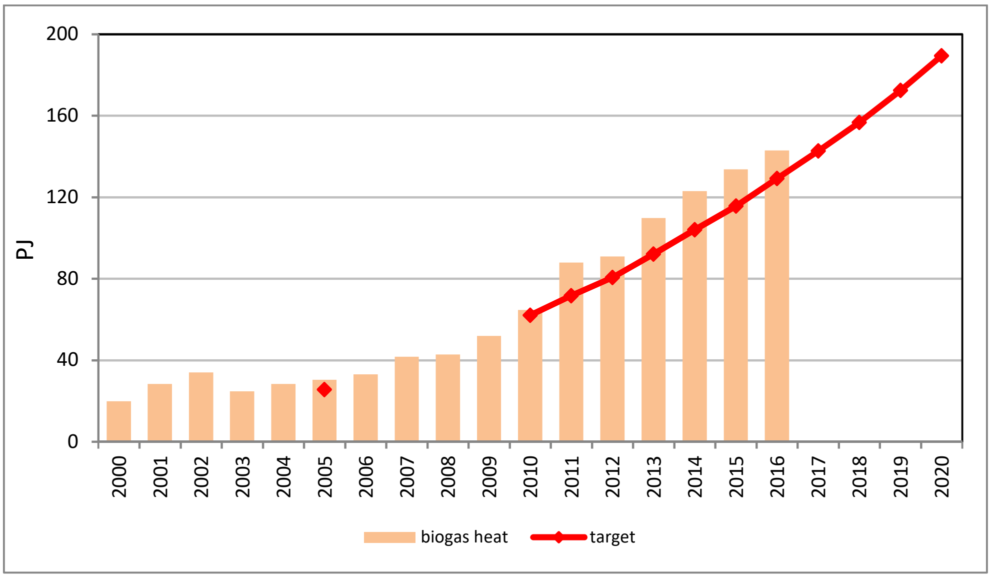

Figure 33. Evolution of biogas heat generation and targets in the EU
Source: Eurostat 2019b

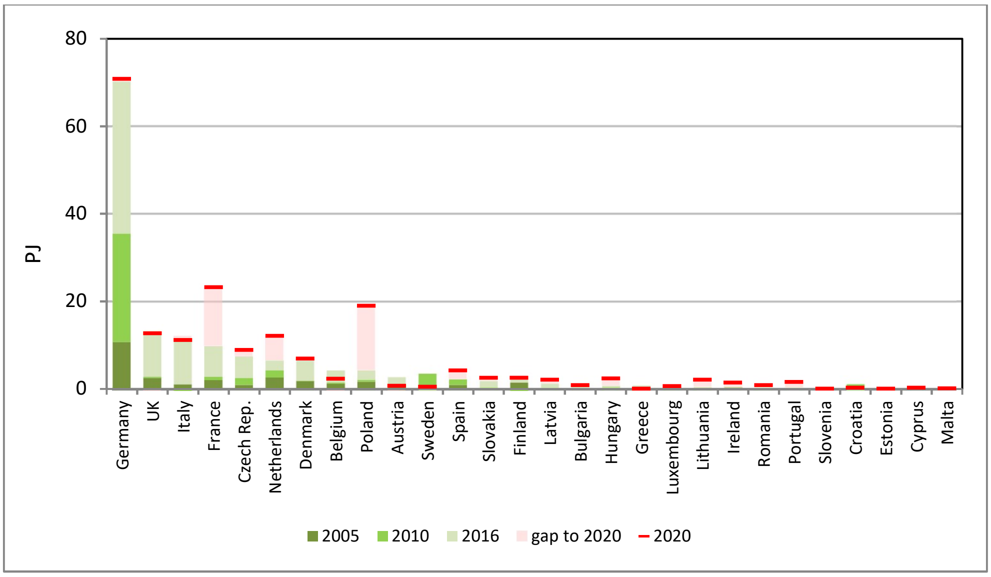

Figure 34. Progress made and targets for 2020 for the use of biogas heat in different MS
Source: Eurostat 2019b

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 (Figure 34). The leader in biogas heat generation is Germany followed by far by United Kingdom, Italy, France and Czech Republic. Austria Sweden and the United Kingdom have already surpassed in 2016 their 2020 target while Germany, Italy were very close in 2016 to reach this target. Important growth is still expected in Poland, France and the Netherlands, that had large gaps to fill in order to reach their projected target. Germany also dominated the biogas heat market in the EU with a share of about 47% in the heat generated from biogas in the European Union.

2.2.3.3 EU biomass electricity production and targets

The installed bioenergy power capacity in the EU almost doubled from 2005 to 2016, from 6.6 GW in 2000 and 18.8 GW in 2005 to 30.6 GW in 2016 (Figure 35). Despite this growth, it seems that the total installed electricity capacity is well below (88 %) the planned capacity for 2020. Thus, after some progress made until 2012, the annual addition rate of biomass power capacity started to decrease. Nowadays the share of biomass power capacity into the total renewable power capacity represents almost 7 %, increasing from only 4 % in 2000, due to the developments in wind power and solar photovoltaic capacity. The share of bioelectricity into renewable electricity represented almost 19 % in 2016, up from 14 % in 2005.

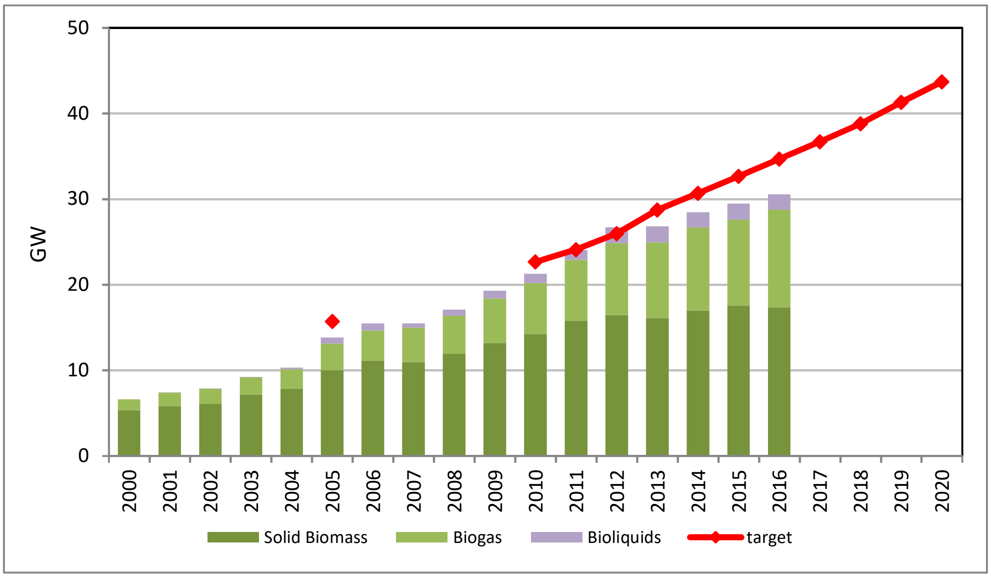

Figure 35. Evolution of biomass electricity capacity in the EU

Source: Eurostat 2019b

The capacity of solid biomass plants has the highest share of the total biomass power capacity, increasing from 5.3 GW in 2000 and 10 GW in 2005 to 17.4 GW in 2016. However, Figure 35 shows clearly a trend of decreasing the growth in the solid biomass plant capacity that led to a decrease of the share of solid biomass plant capacity into the biomass electricity capacity from 81 % in 2000 to 57 % in 2016. In contrast, the installed electricity capacity of biogas plants increased with a higher rate annually, increasing the share of the biomass plant capacity into the biomass electricity capacity from 19 % in 2000 to 37 % in 2016. These developments led to a significant gap between the actual situation and the planned capacity for 2016 that raise serious doubts about the possibility to reach the 2020 targets for biomass electricity production.

Figure 36 shows the progress made since 2005 and targets for 2020 in bioenergy installed capacity in the Member States of the European Union in 2016. Significant variation in the contribution of bioenergy to energy supply is obvious, and the leading MS in bioenergy supply include Germany, United Kingdom, Sweden, Italy and Finland. Important progress has been noticed with significant capacity additions in several other MS, such as Germany, United Kingdom and Italy. The installed capacity in 2016 was already above the 2020 projected targets in United Kingdom and in Sweden. Lower progress has been made and large gaps are still to cover in order to reach the 2020 projected levels for bioenergy in France, Netherlands, Denmark and Belgium and in several other MS.

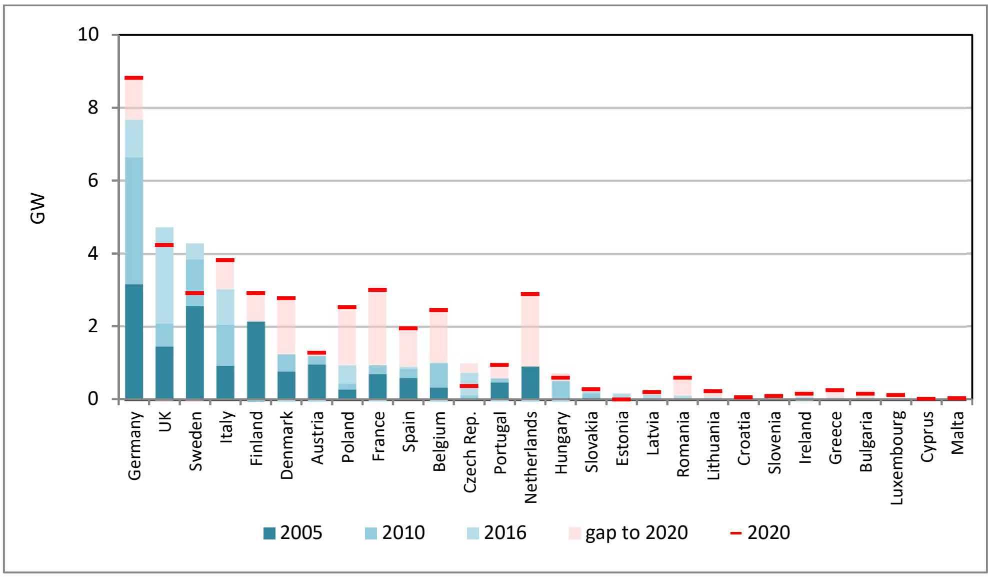

Figure 36. Evolution of biomass capacity in EU Member States and gaps to 2020

Source: Eurostat 2019b

Electricity generation from biomass is expected increase significantly, from 69 TWh in 2005 to 233 TWh in 2020. The data from progress reports shows that biomass electricity generation is on track to reach the 2020 target. The additional bioelectricity generation until 2020 is significant compared to the progress made since 2005, but less if comparing the annual progress in percentages achieved so far, and thus it could be achieved. The share of bioelectricity in renewable electricity generation increased from 2005 to 2016, despite of the progress made by other renewables.

Solid biomass continues to be the main contributor to biomass electricity since 2000, with a share expected to decrease from almost 80% to 67% in 2020. High progress is still expected, in absolute values, from solid biomass. However due to the higher progress in electricity from other biomass feedstocks (in particular biogas), the share of solid biomass in bioelectricity decreased to just above 50 % in 2016. In relative terms, biogas is expected to increase the most. The share of biogas electricity was expected to increase significantly from 18% in 2005 to 27% of total biomass electricity generation in 2020. However, the recent developments on biogas electricity production between 2010 and 2016 lead to an increase in the share of biogas to 35% of biomass electricity, above the expected 2020 levels. Despite of earlier increase of electricity generation from bioliquids until 2010, the latest developments show that their contribution shrank to half of the level reached in 2010, due to the sustainability concerns related to their use.

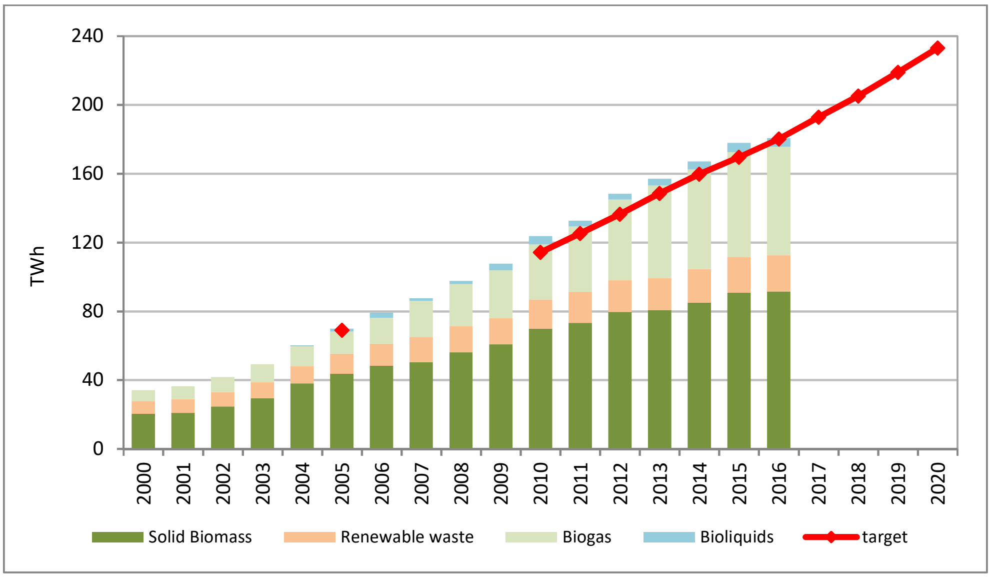

Figure 37. Evolution of biomass electricity production by feedstock in the EU
Source: Eurostat 2019b

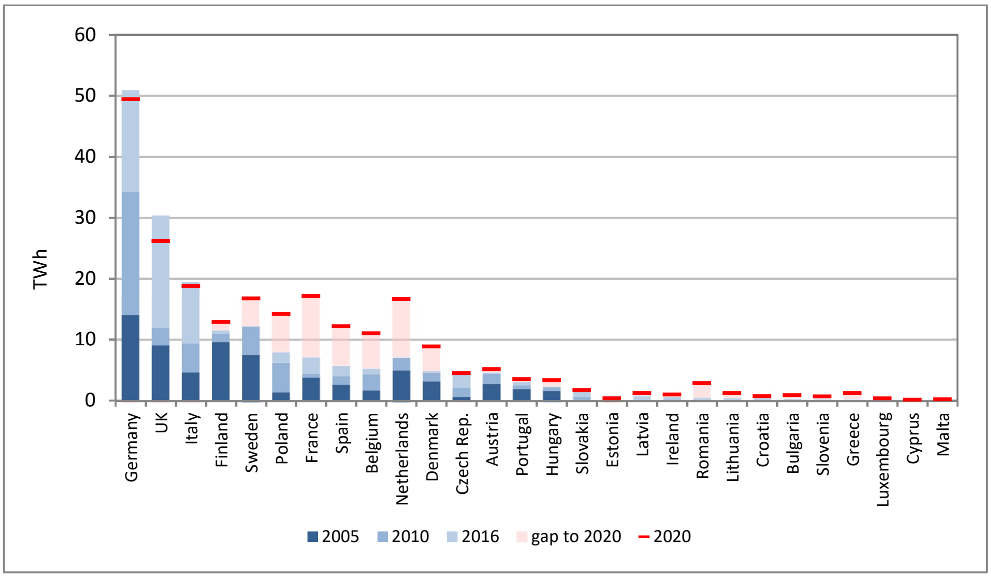

Figure 38. Progress made and targets for 2020 for biomass electricity production in different MS
Source: Eurostat 2019b

The production of biomass electricity in 2016 looks very different among Member States (Figure 38), in terms of the progress made since 2005, as well as the contribution of solid biomass, biogas or bioliquids. The leaders in biomass electricity generation in 2016 were Germany, UK, Italy, Finland and Sweden. Several Member States have already achieved the level of electricity from biomass in Germany United Kingdom and Italy, while large progress is still expected from a number of MS to fill the gap to the expected level for 2020 including Netherlands, France Spain, Belgium and Denmark.

The recent developments on biogas brought the electricity production at 63.0 TWh, 32% above the expected level for 2016 (Figure 39) and just under the expected level of 63.9 TWh biogas electricity in 2020. These developments, in comparison to bioenergy, have brought the share of biogas in the biomass electricity to 35% in 2016, in comparison to 19% in 2000. In particular, the most significant growth has been achieved from the electricity generation in Combined Heat and Power (CHP), due to the need to have higher efficiency in the conversion of biogas into energy due to the more favourable economics. Therefore the 2020 targets appear easy to reach, but the progress seems to be decreasing in the last years that raised doubts about the future developments.

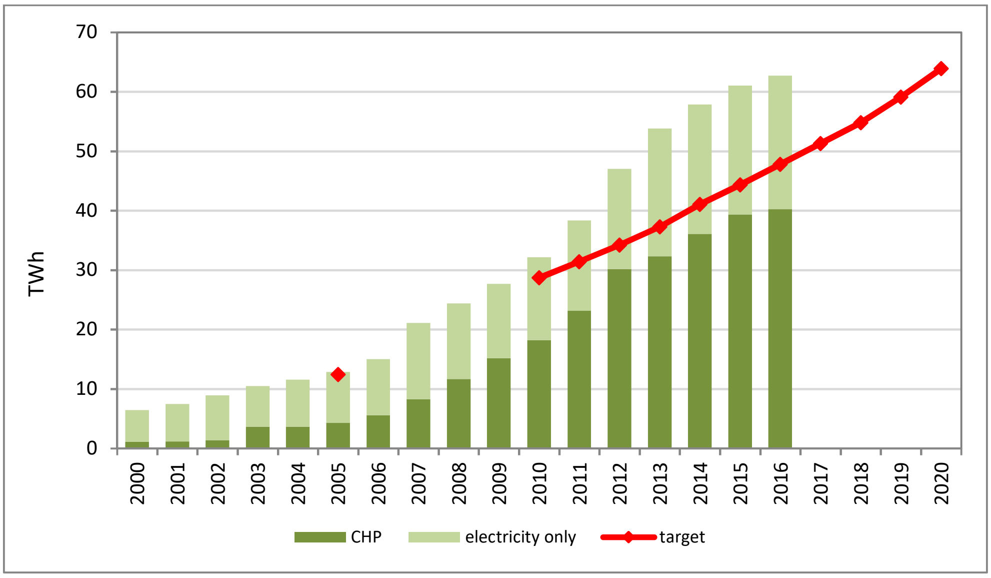

Figure 39. Evolution of biogas electricity production in the EU and 2020 targets
Source: Eurostat 2019b

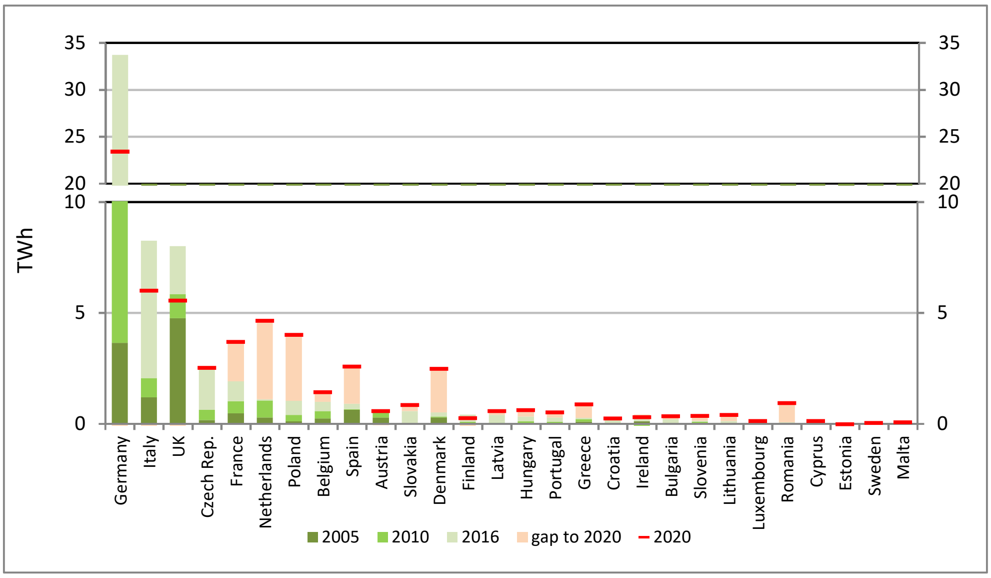

Figure 40. Progress made and targets for 2020 for biogas electricity production in different MS
Source: Eurostat 2019b

The progress made in electricity production from biogas looks very different among different Member States, as well as the progress made in comparison to the targets set (Figure 40). The progress in few leading Member States biogas electricity generation, in particular in Germany, but also in Italy and in United Kingdom, was significant and exceeded the projected level for 2020. Higher progress is needed in all other Member States toward their 2020 targets, where the progress was much smaller. More progress is needed mainly in the Netherlands, Poland, Denmark and France, where the gap to the 2020 targets is the highest, but also in most other Member States.

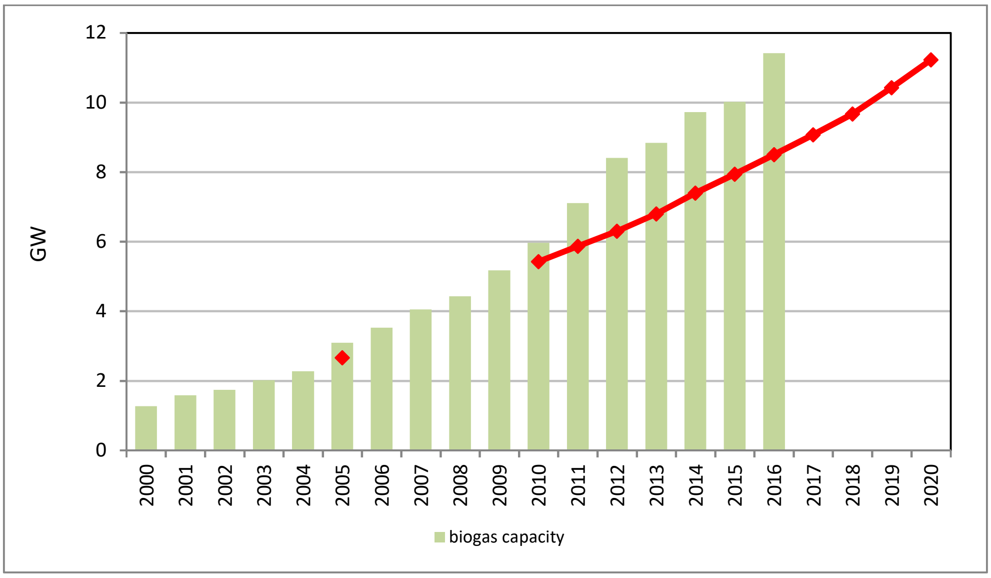

Figure 41. Evolution of biogas electricity capacity in the EU and 2020 targets
Source: Eurostat 2019b

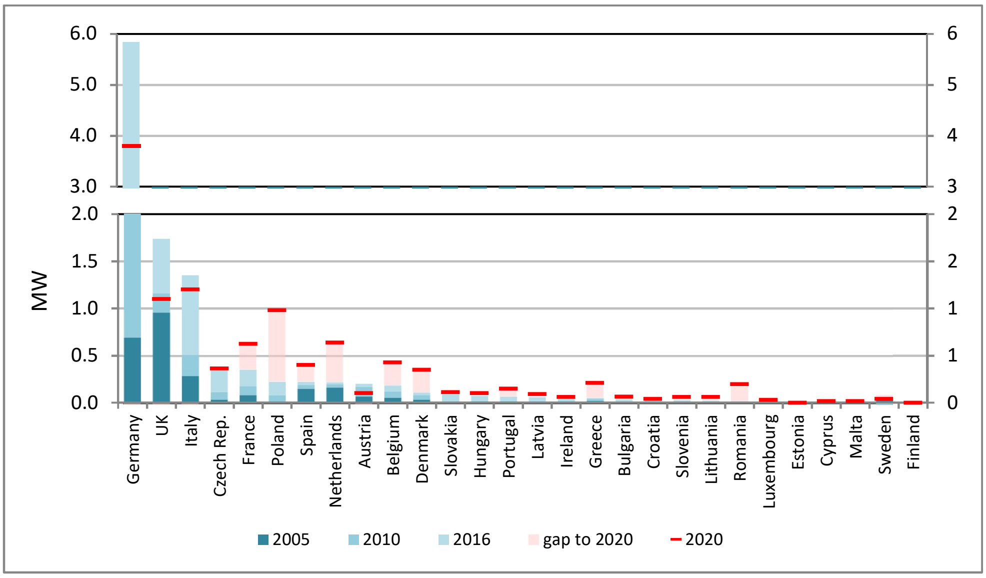

Figure 42. Evolution of biogas capacity in EU Member States and gaps to 2020
Source: Eurostat 2019b

The investments in biogas sector have brought the biogas installed electricity capacity in the European Union at 11.4 GW in 2016, increasing from 3.1 GW in 2005 (Figure 41). The biogas electricity capacity is thus already above the expected biogas capacity of 11.2 GW for 2020. In contrast to other biomass plants the capacity in biogas increased every year following an accelerated growth trend. Thus, the share of biomass plant capacity reached 37 % of biomass power capacity in comparison to only 19 % in 2000 and 22 % in 2005. The data on the biogas developments at European Union level should be complemented by an analysis of the situation of the biogas capacity in each Member State.

The analysis of the biogas plant capacity shows that the market is dominated by Germany that had in 2016 about 51 % of the total biogas capacity in the European Union. Thus most of the developments in biogas sector appeared in Germany which has an installed biogas capacity 54 % above the 2020 target. Other Member states have seen also an impressive growth in biogas capacity such as in Italy and the United Kingdom. Several Member States are lagging behind, with some important capacities that need to be added in order to reach the proposed targets for biogas capacity mainly Poland, Netherlands and Denmark.

2.3 Support policies and impact

2.3.1 Policy context

The European Union has established the ambitious goal of building a competitive low carbon economy in 2050 and set the objective of reducing Greenhouse Gas (GHG) emissions by 80% by 2050, compared to 1990 levels, in order to keep climate change below 2°C (COM(2011) 112 final). The European Commission has proposed an integrated *Energy and Climate Change package* in 2007 that includes both the energy and climate goals: *Energy policy for Europe* (COM(2007) 1 final) and *Limiting Global Climate Change to 2 degrees Celsius-The way ahead for 2020 and beyond* (COM(2007) 2 final).

Later on, the EU has adopted *A policy framework for climate and energy in the period from 2020 to 2030* (COM (2014) 15 final) building up on the 2020 climate and energy package, in line with the long-term perspective set out in the Roadmap for moving to a competitive low carbon economy in 2050 and the Energy Roadmap 2050. The *Clean Energy for All Europeans* package (COM(2016) 860 final) aims to facilitate the clean energy transition and the creation of the EU to help the energy sector become more stable, more competitive and more sustainable. At global level, the Paris Agreement, concluded at the 21st Conference of the Parties (COP21) of the United Nations Framework Convention on Climate Change (UNFCCC), established in 2015 a long-term goal and set out a plan for limiting the increase of global average temperature to well below 2°C above pre-industrial levels and to pursue efforts to keep it to 1.5°C above pre-industrial levels.

The Bioeconomy Strategy *Innovating for Sustainable Growth: A Bioeconomy for Europe* (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”. The strategy addresses five societal challenges through the introduction of a bioeconomy: 1) ensuring food security; 2) managing natural resources sustainably; 3) reducing dependence on non-renewable resources; 4) mitigating and adapting to climate change; 5) creating jobs and maintaining European competitiveness. 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, but also for chemicals and materials applications.

The Renewable Energy Directive 2009/29/EC aimed to promote renewable energy deployment and to deliver GHG emission reductions and translated energy targets for 2020 into legally-binding requirements: a 20 % share of renewable energy in gross final energy consumption at EU level; and a 10 % share of renewable energy in the transport sector. The new renewable Directive (EU) 2018/2001 includes a binding renewable energy target of 32% in the European Union for 2030. It creates the framework to accelerate the investments in innovation and modernisation and provides guiding principles on financial support schemes for RES. The Directive includes reinforced EU sustainability criteria for bioenergy to cover biofuels, biomass and biogas for heat and power to deliver high GHG savings compared to fossil fuels, to ensure that bioenergy does not cause deforestation, degradation of habitats or loss of biodiversity, and to ensure high energy conversion efficiency, promoting efficient use of limited resources and avoid unintended impacts on other uses.

A core element of the EU climate and energy policy has been putting a price on CO_2 emissions. The EU *Emissions Trading System (ETS)* covering half of the EU's CO_2 emissions, mainly from the power sector and energy intensive industry, creates such a price through a so-called cap-and-trade system, to ensure the emission reduction target is met. The Commission proposal of 2015 on the revision of the EU *Emission Trading System* (ETS) for 2021-2030, as part of its contribution to the Paris Agreement, aims to reduce EU ETS emissions by 43% compared to 2005 and accelerate the low-carbon transition. The EU ETS creates incentives to invest in technologies that cut emissions by capping overall GHG emissions. Sectors of the economy not covered by the EU ETS (transport, buildings, agriculture and waste management) must reduce emissions by 30% by 2030 compared to 2005. The European Commission proposal of 2016, the *Effort Sharing Regulation* (COM(2016) 482 final), set out binding annual greenhouse gas emission targets in the non-ETS sectors for Member States for the period 2021–2030. The Regulation on the inclusion of GHG emissions and removals from land use, land use change and forestry (LULUCF) into the 2030 climate and energy framework was adopted I 2018. This regulation introduces a binding commitment for all MS to ensure that accounted emissions from land use are entirely compensated by an equivalent removal of CO_2 through action in the sector in the period 2021 to 2030.

NER 300 is a funding programme for supporting innovative low-carbon energy demonstration projects for carbon capture and storage (CCS) and innovative renewable energy technologies on a commercial scale. Under the new EU ETS for the period after 2020, several support mechanisms will be established to help the industry and the power sectors toward the transition to a low-carbon economy. For this goal, two new funds will be set: Innovation Fund, extending existing support for the demonstration of innovative technologies and a Modernisation Fund, facilitating investments in modernising the power sector and boosting energy efficiency in lower income Member States.

The EC has proposed in November 2018 a strategic long-term vision for a prosperous, modern, competitive and climate-neutral economy by 2050 (COM (2018) 773), in line with the Paris Agreement objective to keep the global temperature increase to well below 2°C and pursue efforts to keep it to 1.5°C. The strategic building blocks include improving energy efficiency, the clean energy transition and large-scale deployment of renewables and the transformation towards a more circular bioeconomy. Net negative emissions from bioenergy, combined with CCS should play a key role to achieve zero greenhouse gas emissions by 2050, together with increasing carbon sinks capacity through afforestation and restoration of degraded land and other ecosystems.

2.3.2 Support Measures

The latest developments in renewables and technology improvements led to a major decrease in the investment costs, in particular for wind and solar photovoltaic systems and thus to significant cost reduction of energy produced. Bioenergy can be competitive in some cases, especially when cheap or even negative cost of biomass feedstock is available (such as waste and residues, landfill gas, livestock manure, etc.). Energy markets alone, however, cannot deliver the desired level of renewables in the EU since renewables are not competitive with fossil fuels, requiring high investments and high operation costs, mostly in relation to feedstock. Thus, policy support is needed in order to achieve the energy and climate targets. Support schemes for renewable energy technologies remain however a key mechanism to facilitate increased investment in renewable energy. Support schemes are necessary to encourage large scale take-up and deployment of renewable energy and to reach the renewable energy targets. However, if these public interventions are not adequately designed, they can distort the functioning of the energy market and lead to higher energy costs. Therefore, support needs to be carefully designed to provide tailored support to the technology, feedstock and plant size to avoid distortion of the energy market.

Policy instruments used include regulatory policies, public financing and fiscal incentives. The measures to support the development and deployment of renewables include schemes supporting investments, such as investment grants, investment aids, loans, tax exemptions or reductions, tax refunds and subsidies. Other direct price support schemes focus on supporting energy production and include feed-in tariffs, feed-in premium, renewable energy obligations and green certificates. Some schemes are also applied such as net metering allowing small-scale energy producers to consume electricity at a different time from generation, receiving a payment for the excess electricity, which is not consumed onsite. The focus of the majority of policy instruments is on the power sector with some specific targets addressing the use of renewable energy for heating and cooling (AEBIOM 2015, CEER 2017, RES LEGAL 2018).

Table 1 . Types of support schemes for bioenergy in Europe

		AT	BE	BG	CY	CZ	DE	DK	EE	EL	ES	FI	FR	HR	HU	IE	IT	LT	LU	LV	MT	NL	PL	PT	RO	SE	SI	SK	UK
Electricity	FiT	*		*	*	*	*			*					*	*			*					*				*	
	FiP					*	*	*	*	*		*	*		*		*	*				*							
	GC		*											*									*		*	*			
	Subsidy		*							*		*			*		*	*	*						*		*		*
	Investment grants		*									*													*				
	Loans						*							*				*					*				*		
	Net metering		*		*			*		*					*		*			*		*							
	Tax regulation									*			*				*	*				*	*			*		*	*
	Quota		*																				*		*	*			*
Heat	Subsidy	*	*			*	*		*	*	*	*	*					*	*			*	*		*		*	*	
	Investment grants	*	*										*												*				
	Loans		*	*			*			*	*		*				*	*					*				*		*
	Tax exemptions		*			*		*		*			*					*		*		*				*			
	Heat bonus/Price based											*					*	*											*
	FiP																					*							
	FiT																												*
	Other																*												
Transport	Mandatory Quota	*	*			*	*	*		*	*	*	*	*	*	*	*		*		*		*	*	*			*	*
	Tax exemptions	*	*	*		*		*		*		*	*		*			*		*		*		*		*	*	*	
	Subsidy	*							*	*								*									*		
	GHG reduction quota						*																						

Source: AEBIOM, 2015, RES LEGAL 2018

Each Member State implements a mix of different policies and multiple support measures as a common approach**.** Support schemes in the form of Feed-in Tariffs (FiT) are still the most widespread support used for various technologies. Green certificates schemes coupled with quota obligation are implemented in fewer countries. Investment grants are provided especially for solar PV, although they are applied to all RES in some cases, and especially for small scale households (solar, heat pumps or biomass) (Table 1).

The FiT system proved to be highly efficient in promoting high levels of renewables, such as in Germany and Italy, for example in PV, but incurring high costs for energy consumers if not set to reflect the actual production costs. FiT may be the better choice for less mature and small-scale technologies. Feed-in Premium (FiP) system (including a fixed premium, a floating premium and a premium with cap and floor) offer the advantage that is more market orientated than the feed-in tariff adapted to changing market prices and the price risks for renewable energy suppliers.

The quota obligation with Green Certificates system is compatible with market principles and can contribute to the deployment of the most competitive technologies. However, if quota obligations are designed in a technology-neutral way, only the most cost-effective technologies are supported, which would result in unbalanced energy systems. Tendering or auction schemes, being based on a competitive bidding procedure, can increase the cost-effectiveness of support. However, the outcome of auctions depends on the specific design and the framework conditions: the energy market, available renewable resources, economic perspectives and the administrative and grid-related barriers (Held et al 2014, AEBIOM 2015, RES LEGAL 2018). Investment support are generally used in combination with other measures, such as feed-in tariffs or feed-in premiums, to stimulate the take-up of less mature technologies. Tax incentives or exemptions are often complementary to other types of support schemes and include tax incentives relating to investments and production. Low-interest loans or soft loans that help reduce investment-related costs have been used in combination with other support schemes, such as investment incentives.

Due to technology development, cost reduction for energy production and other market conditions, renewable energy supporting policies in different MS have been changed over time. New support instruments are being introduced for new RES installations while the former ones remain in place for existing operating plants. Major changes include new support instruments, such as tendering procedures for the determination of support levels in several EU Member States (Germany, Italy, Spain, etc.) and certificates schemes; other countries are likely to follow this trend. FiT schemes often remain in place for smaller installations while FIP become mandatory for new larger installations.

In order to address market distortions that may result from the support granted to renewable energy, the European Commission has issued a guidance for designing and revising support schemes for renewable energy (EC 2014). The new State Aid framework encourages a decreasing and flexible support to renewables to what is necessary to ensure the deployment of renewables and avoid excessive burden on the energy market. The new state aid rules promote the introduction of competitive bidding processes or auctioning on the basis of clear, transparent and non-discriminatory criteria for allocating public support, while offering Member States flexibility to take account of national circumstances. For the support for electricity production from RES, feed-in-premiums allocated through tenders and based on the technology neutrality principle have to replace feed-in tariffs. Given the different stages of technological development of renewable energy technologies, technology-specific tenders could to be carried out in some cases.

The aid to renewable energy can be granted as investment or operating aid as a premium in addition to the market price with the exemption of small RES installations or demonstration projects. State aid can be granted to energy from renewable sources using waste, including waste heat, as input fuel can make a positive contribution to environmental protection, provided that it is in line with the EU legislation on waste and waste hierarchy. Support cannot be given to biofuels that are subject to a supply or blending obligation, unless a Member State can demonstrate that the aid is limited to sustainable biofuels that are too expensive be commercialized with a blending obligation (EC 2014).

An appropriate policy framework and strong policy measures are needed to support the expansion of bioenergy and to move toward a low carbon energy system. Targets for emissions reduction, targets for renewable energy and policies phasing-out fossil fuels would provide a favourable investment climate in low carbon technologies (IEA 2017). To enable the adequate development of the low carbon energy system, support should be differentiated between technologies, feedstock and plant size, taking into account specific circumstances, avoiding disproportionate support, but allowing technology deployment. This enables balanced market development and adequate energy mix and ensures the deployment of technologies that are at different level of development (Held et al 2014). Support policies need to target the deployment of renewable electricity and heat and include mandatory targets and quotas for bioenergy while rewarding multiple socio-economic benefits of bioenergy, in addition to carbon emission reduction.

2.4 R&D investment

Public and private investment for R&D in bioenergy technologies can play an important role in bioenergy deployment, especially in technologies that are at the early stage of development. R&D activity can be measured directly through the capital invested in relevant activities or indirectly by assessing the technological and safety output indicated by the patent activity and scientific publications. The present subsection builds on JRC's previous work on monitoring research innovation and competitiveness in the Energy Union (JRC SETIS 2018). Figure 43 presents the trends in the public and private spending in bioenergy technology R&D in the European Union and the cumulative investments during 2003-2014 in the EU Member States.

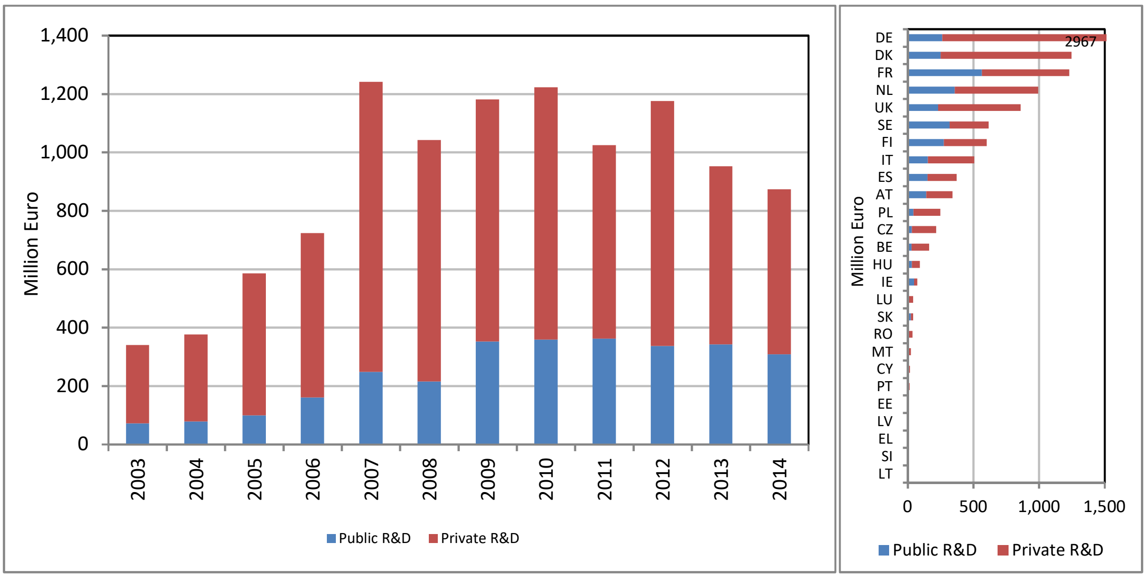

Figure 43. Public and private R&D investments in bioenergy in the European Union

Source: JRC SETIS 2018

The analysis of the R&D investment trends show an increase in total investments in the European Union between 2003 and 2010, followed by a decline that showed a decrease in the interest in technology development both from public and private sector. Leading Member States on cumulative total R&D investments in bioenergy during 2003-2014 include Germany (€ 2967 million) followed by Denmark (€ 1248 million), France (€ 1230 million), Netherlands (€ 996 million), UK (€ 860 million), Sweden (€ 616 million) and Finland (€ 602 million). The R&D investments are concentrated in few Member States. The R&D investment in top five Member States represented 68 % of the total investments in the European Union while the total R&D investment in top ten Member State represented 91 % of the total. Figure 43 also shows a large difference between the share of the private and public R&D investments in various Member States although the private R&D investments seem to be the main R&D expenditure in most Member States. The analysis of the R&D investments also shows that the EU leaders in R&D investments are also the leaders in bioenergy production and also a good correlation between the investments in R&D and bioenergy deployment.

Public R&D investments

Figure 44 shows the annual public spending in R&D on bioenergy in the European Union presents a significant increase from 2003 until 2011 followed by a decrease. This also seems to be driven by short-term national policies and specific programs. Leading Member States Moreover, on the cumulative public R&D investments in bioenergy technology during 2003-2014 include France (€ 566 million) followed by Netherlands (€ 359 million), Sweden (€ 318 million), Finland (€ 275 million), Germany (€ 264 million), Denmark (€ 250 million) and UK (€ 232 million). The public R&D investments were concentrated in few Member States. The total R&D investment in top five Member States during 2003-2014 represents 61 % of the total investments in the European Union while the total R&D investment in top ten Member State represents 92 % of the total.

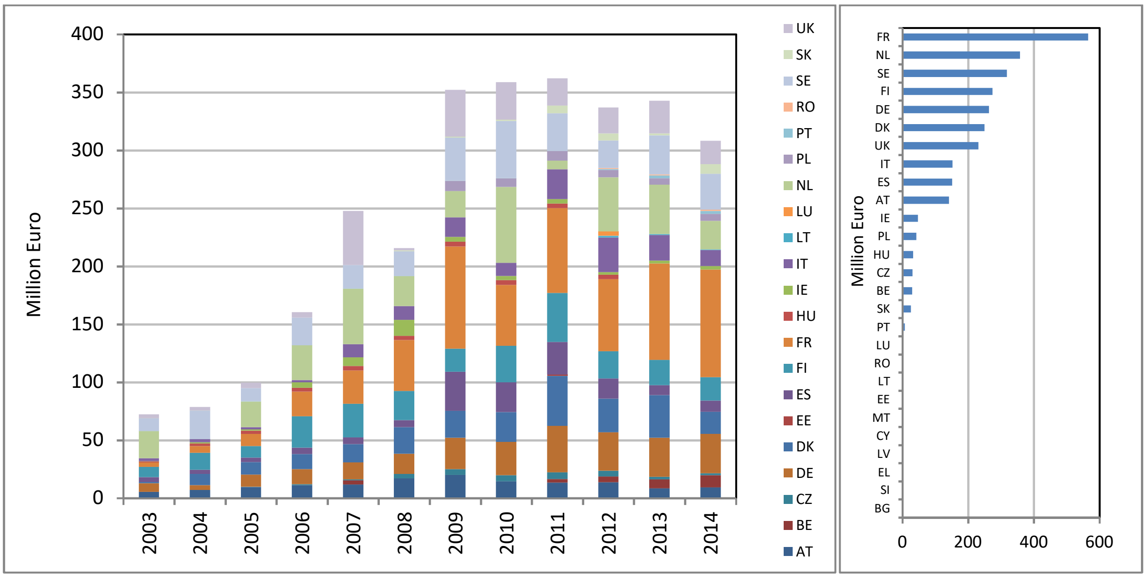

Figure 44. Public R&D investments in bioenergy in the European Union

Source: Source: JRC SETIS 2018

Private R&D investments

Figure 45 shows the developments in the private R&D spending in bioenergy in the European Union between 2003 and 2014 and the major leaders in cumulative private R&D investments. The private R&D investments show an increase in the European Union between 2003 and 2010 followed a steep reduction. The undeniable leader in this respect is Germany with total private R&D investments of €2700 million euros during the analysed period which shows a clear correlation with the leading role of Germany in the bioenergy deployment. Other leaders in private R&D investments in bioenergy during 2003-2014 include France (€ 665 million), Netherlands (€ 637 million), UK (€ 628 million), Italy (€ 355 million), Finland (€ 328 million) and Sweden (€ 297 million). The private R&D investments are again concentrated in few Member States. The total R&D investment in top five Member States during 2003-2014 represented 77 % of the total investments in the European Union while the total R&D investment in top ten Member State represented 93 % of the total.

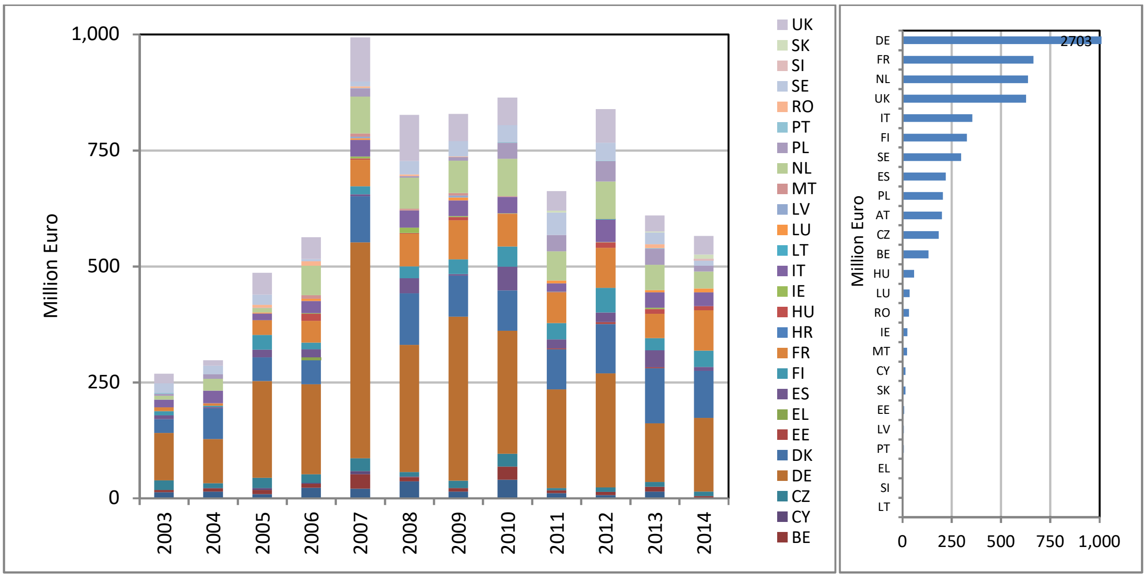

Figure 45. Private R&D investments in bioenergy in the European Union

Source: JRC SETIS 2018

Global R&D investments

Figure 46 shows the global cumulative R&D investments in bioenergy between 2003 and 2014, including major actors in bioenergy.

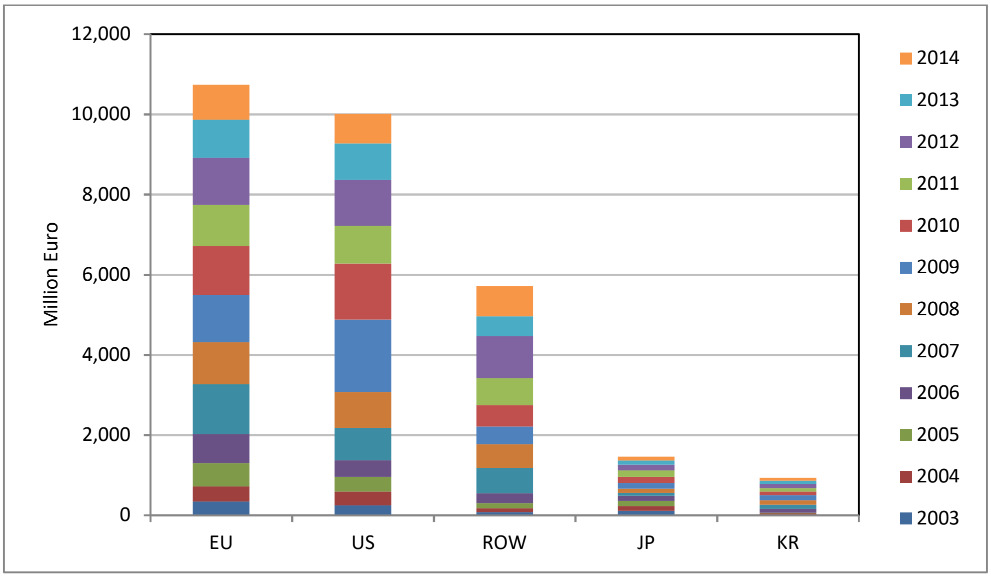

Figure 46. Total global R&D investments in bioenergy between 2003 and 2014

Source: JRC SETIS 2018

The analysis includes the areas that have traditionally been important centres for technological development and markets. The European Union is a world leader in terms of R&D investments in bioenergy with cumulative EU public spending of € 10.7 billion followed by the United States with € 10.0 billion, Japan with € 1.5 billion, Korea with € 930 million, with the Rest of the World (RoW) counting for total R&D investments of € 5.7 billion (20 % of total global R&D investments).

Figure 47 shows the evolution of the global public R&D investments in bioenergy and the world leaders between 2003 and 2014. For the whole period analysed the United States was the world leader in terms of public R&D spending with € 4.1 billion followed by the European Union with € 2.9 billion, Japan with € 556 million, Canada with € 420 million, Australia with € 190 million and Korea with € 96 million. This Figure shows a general increasing trend, with some significant variations, followed by a decrease in the last years in most countries.

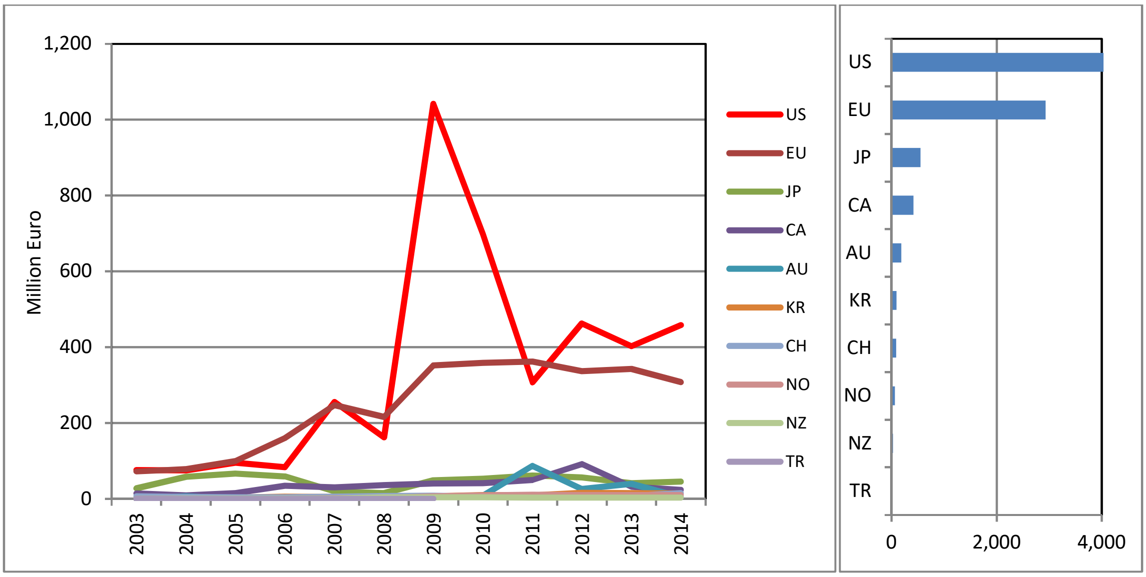

Figure 47. Global public R&D investments in bioenergy

Source: (Pasimeni et al., 2018)

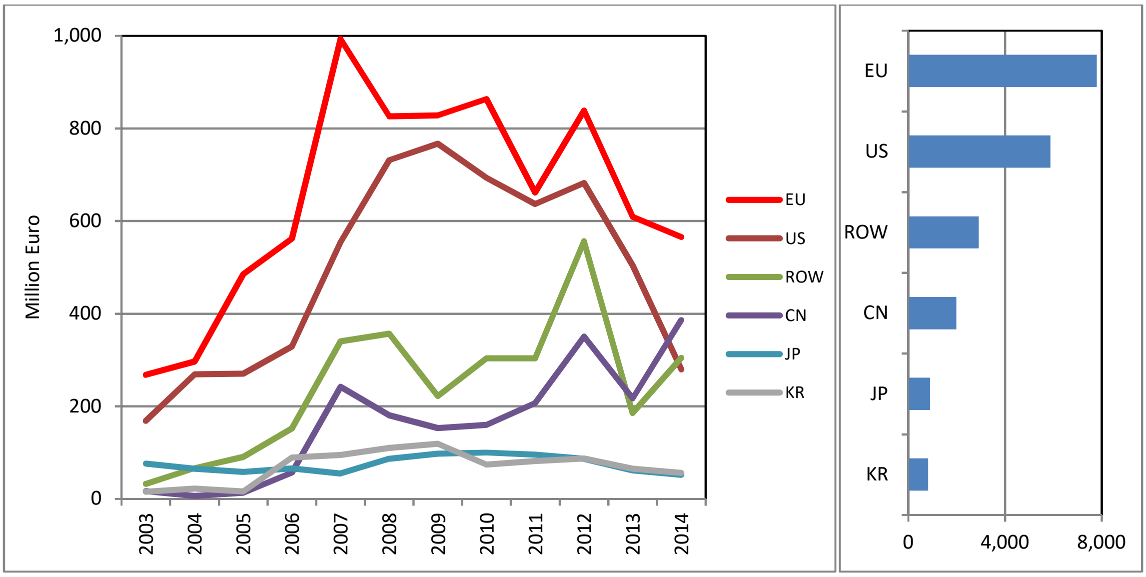

Figure 48. Global private R&D investments in bioenergy

Source: (Pasimeni et al., 2018)

Figure 48 presents the progress of private R&D expenditure during the analysed period and the major world actors. The world leaders on the cumulative spending between 2003 and 2014 include European Union with € 7.8 billion, the United States with € 5.9 billion China with € 2.0 billion, Japan with € 903 million and Korea with € 834 million while the Rest of the World had a cumulative R&D expenditure of € 2.9 billion representing just 14 % of the global private R&D. This figure also shows some decrease in the last years in terms of the investments in global corporate R&D. China shows the highest growth in the world, which is also correlated to the important increase in the bioenergy deployment during the last years.

2.5 Patenting trends

An analysis of patents trend for the biomass for heat and power sector was carried out in order to assess the progress in the technology development through the last years. Patent analysis is based on data available from the European Patent Office (Patstat).

Patents related to biomass for heat and power sector are identified by using the relevant code families of the Cooperative Patent Classification (CPC), for the technologies or applications for mitigation or adaptation against climate change, reduction of greenhouse gases emission related to energy generation, transmission or distribution.

Figure 49 shows the trends for patents for biomass for heat and power technologies at global level until 2014 due to the fact that data beween 2015 and 2017 were incomplete and could provide a distorted view on the real patents. The leading country on the number of patents filled in the last years is by far China that showed a very large increase in the numbers of patents filled every year. The European Union shows some increase in the number of patents filled with a peak in 2014. Other countries also showed a moderate increase in the number of annual patents in contrast with Japan who followed a marketed decrease since 2000. Looking at the cumulative number of patents filled between 2000 and 2014 China is the leading country followed by Japan, European Union and the United States.

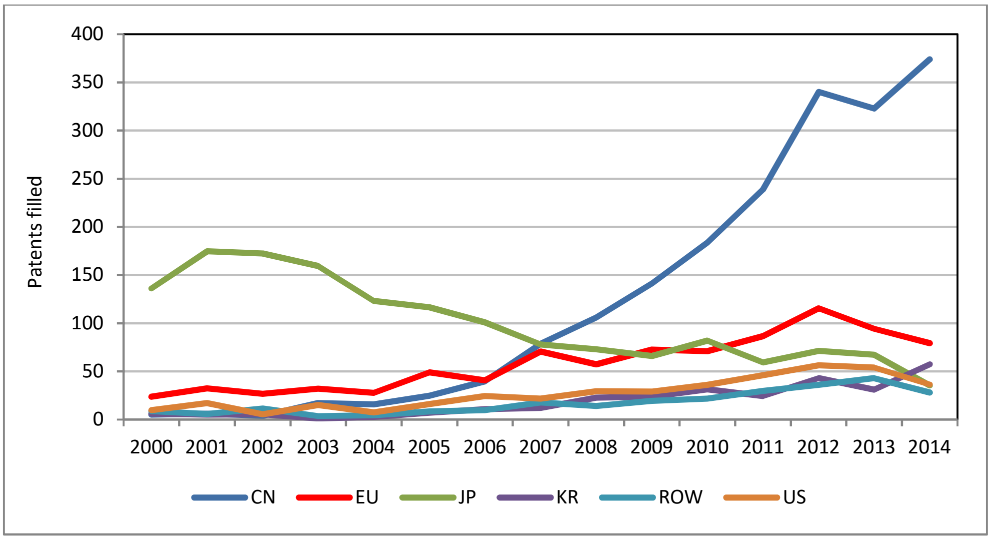

Figure 49 Patents trend in the world for biomass for heat and power technologies

Source: Fiorini et al., 2017

The relevant patents are grouped under the following classes of patents:

Y02P Biomass or waste as fuel

Y02P 20/136 - of biological origin, e.g. biomass, biofuels, biogas

Y02P 40/126 - Waste

Y02P 40/128 - Biomass

Y02P 80/21 - Biomass as fuel

Y02E Biofuels

Y02E 50/11 - CHP turbines for biofeed

Y02E 50/12 - Gas turbines for biofeed

Y02E 50/14 - Bio-pyrolysis

Y02E 50/15 - Torrefaction of biomass

Y02E 50/34 - Methane (not used, see subgroups)

Y02E 50/343 - production by fermentation of organic by-products

Y02E 50/346 - from landfill gas

Figure 50 shows the annual number of patents filled for biomass for heat and power technologies according to CPC classes for biomass for heat and power in the European Union between 2000 and 2014. A significant large number of patents and a large increase have been noticed for methane production by fermentation of organic by-products or from landfill gas which show a large interest in developing biomethane technologies. Another large share of patents concerns bio-pyrolysis that had the second largest field, followed by torrefaction and CHP and gas turbines.

The total number of patents registered directly for the biomass for heat and power sector in the European Union accounted, along the years, for more than 880 patents. The leader in the European Union is Germany with almost half of the total number of patents field, followed by France, Netherlands, UK and Finland top five Member States registering about 75 % of the total numbers filled between 2000 and 2014 in the European Union (Figure 51).

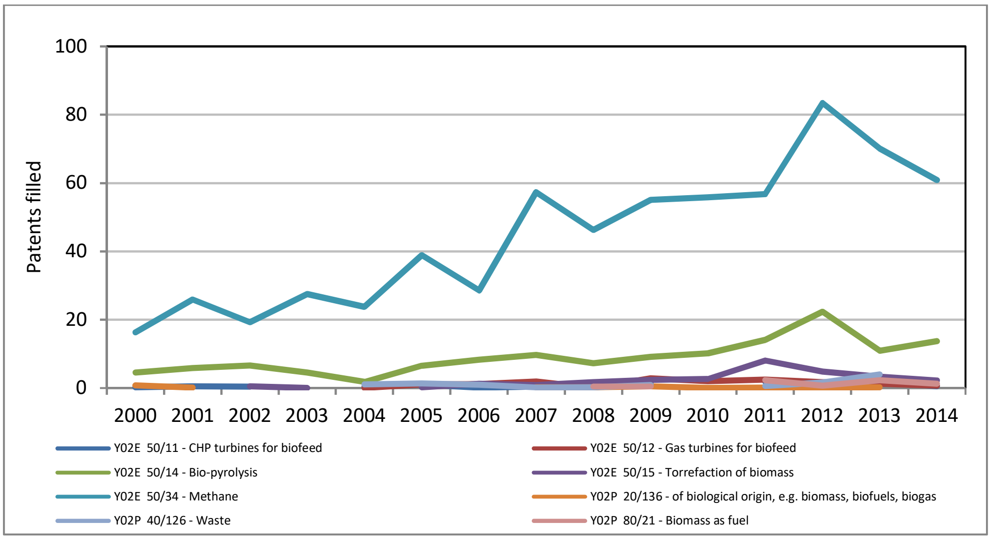

Figure 50. Patents trend in the EU according to CPC classes for biomass for heat and power

Source: Fiorini et al., 2017

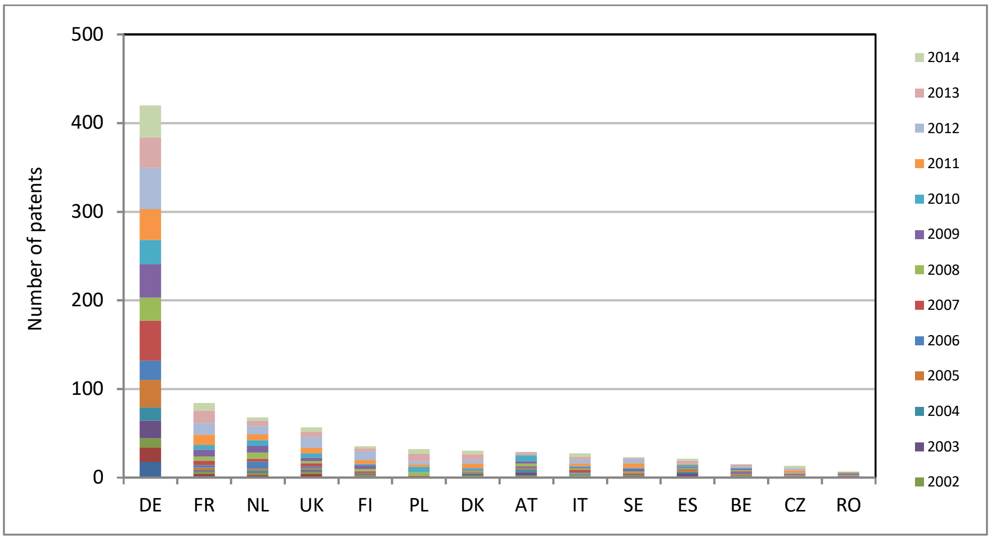

Figure 51. Patents for biomass for heat and power in leading EU Member States

Source: Fiorini et al., 2017

3. Market overview

3.1 Market applications

Biomass has long been used for cooking and heating and still has an important contribution to energy supply in many areas of the world. Bioenergy is the largest renewable contributor to energy supply worldwide. The global bioenergy market includes many applications, such as the heat and power market, off-grid electricity, household, industrial and transportation applications. Biomass can be used to produce heat for cooking and for space and water heating in the residential sector, in stoves or in boilers. Biomass can provide heat for public and commercial buildings as well as for industry, where it can provide either low-temperature heat for heating and drying applications or high-temperature process heat. Biomass can also be used to generate electricity and heat via Combined Heat and Power (CHP) systems, either for buildings or distributed from larger production facilities via district energy systems, to provide heating or cooling to residential, commercial and industrial buildings (REN21 2018).

Bioenergy is a suitable alternative for off-grid electricity generation using biodiesel. Diesel generators are the key sources of power in rural areas where connection to a power grid is not easily available. Internal ignition engines and gas turbines are used for the conversion of biogas into electricity and heat. Biogas can be used in the off-grid electricity systems in remote areas and where electricity grid id not available.

Solid biomass is used widely in households for heating and cooking, in particular in low-income countries in Africa and Asia. Biomass can also be used in improved cooking stoves with improved efficiency and reduced emissions, reducing deforestation, air pollutant emissions and greenhouse gas emissions. Biogas can be produced on a small scale in households for heating and cooking or in large quantities for use in industries. Bioenergy is widely used in industrial in-house processing such as firing, heating, and drying in industrial applications, in food and beverages, ceramic, pharmaceutical, chemical, cement, and other industries.

A number of conversion technologies are available for bioenergy production, based on thermo-chemical (combustion, torrefaction, pyrolysis, gasification, hydrothermal processing) and biochemical/biological (digestion and fermentation) processes. Bioenergy technologies are a cluster of many individual technologies at different levels of development, from lab-scale, pilot scale, demonstration to commercial operation, as shown in Annexes I - VI. There are a wide range of commercially accepted biomass power conversion technologies that use biomass as a fuel for power generation. The market for biomass power generation, based on technology, includes combustion, co-firing, gasification, anaerobic digestion, and landfill gas recovery.

Nowadays, commercial bioenergy production is based on a large extent on biomass combustion, including biomass combustion, biomass co-firing, waste incineration in waste to energy plants and biogas production in anaerobic digestion plants and from landfill gas recovery. In terms of both installed capacity and power generation, the direct combustion segment has the major share and is expected to dominate the market during the next period. Biomass combustion, based on steam turbine cycle, produce heat, electricity or CHP using a large range of biomass feedstock from wood chips, wood pellets, agricultural and forestry waste, etc. Commercially available direct combustion technologies can be scaled up from 1 MW to a level of few 100 MW or more. Biomass combustion and biogas production for electricity generation can be economically viable in some cases, where low-cost or no-cost biomass feedstock is available (such as waste and residues from agriculture forestry, households or industry). The production of heat by direct combustion of biomass is often cost-competitive with fossil fuel alternatives residential and industrial applications. In most cases, bioenergy production, due to high investment costs and operation costs, requires support to compete with cheap fossil energy (feed in tariffs, premiums, investment grants, etc.).

Anaerobic digestion is a commercially proven technology for biogas production, having the second-largest market in the overall biomass power installed capacity and electricity generation. Small-scale household anaerobic digestion systems produce biogas for heating, cooking and lighting. Anaerobic digestion projects reduce pollution through integrated waste management, reduce pollution of water courses by reducing run-offs from livestock farms. Most anaerobic digestion plants are based on co-digestion of several types of feedstock (livestock manure, energy crops, food and organic waste, etc.) to achieve the best balance between the yields and process stability. Anaerobic digestion plants are limited in scale by local feedstock availability. Biogas production from LandFill Gas (LFG) recovery is a commercial technology for collecting, processing, and treating the methane gas emitted from decomposing waste to produce heat, electricity, fuels, and various other chemical compounds. LandFill Gas from waste landfill sites can migrate to the atmosphere and can contribute to health and safety impacts, odours, and greenhouse gas emissions.

Biomass gasification is relatively a new technology and it occupies a small market share of the overall biomass capacity installations. Biomass gasification technology offers significant advantages over combustion, as it can use low-value feedstock to produce a synthesis gas that could be used to produce heat and power, but also building blocks for chemicals and transportation fuels. Producer gas can be used in a variety of applications such as in boilers, internal combustion engines, gas turbines as a substitute for fossil oil in heat and power applications and chemical industries.

New biomass conversion technologies, such as torrefaction, gasification, pyrolysis and hydrothermal processing, have good prospects for entering soon on the market. These technologies, in different stages of development, are still at pilot or demonstration stage. Although these technologies have experienced significant improvements and technical advances in the last years, they require further technological improvements and demonstration of technical and economic performances at large, commercial scale. Most of them face technical and non-technical challenges and barriers that impede on their large scale commercial application.

Some technologies still require further research to improve their technical, economic and environmental performances to achieve commercial operation. They need to scale up and demonstrate their technical and economic data and achieve cost effectiveness in stand-alone systems or in combination and integrated into more complex facilities. Several demonstration plants have been built and the technologies are being tested at pilot, or semi-commercial scale based on pyrolysis, gasification, torrefaction or hydrothermal processing (liquefaction) and considerable experience been gained. Novel promising feedstocks such as aquatic biomass (algae), offers great perspectives for future bioenergy development from the point of view of large potentially available resources, versatility of production options and technologies that could be used: anaerobic digestion, hydrothermal liquefaction, etc.

3.2 Market structure

Bioenergy supplied almost 500 TWh of electricity in 2016, accounting for 2% of global electricity production. In the same year cumulative bioenergy electricity capacity reached almost 110 GW. In terms of bioenergy capacity Asia has a leading place, with an installed capacity of 32 GW (30 % of global capacity), followed by the European Union with an installed capacity of 30.2 GW in 2017 or 32 % of total global installed capacity, 17 GW (15.6 %) in South America and 14.4 GW (15.1 %) in North America. Africa, despite a leading global position in the use of biomass for energy, had only 1.2 GW installed capacity in 2017, clearly proving the prominent role of the traditional role of traditional use of biomass. Worldwide, the installed electricity capacity using solid biomass reached almost 90 GW (82 % of total biomass electricity installed capacity), of which 60 GW capacity plants used other solid biofuels (55 % of biomass installed capacity), followed by 18 GW bagasse plants (16 %) and 11 GW plants used renewable municipal waste (11 %). About 17 GW capacity is made out of plants using biogas (16 %) and 2.3 GW plants used liquid biofuels (Figure 52).

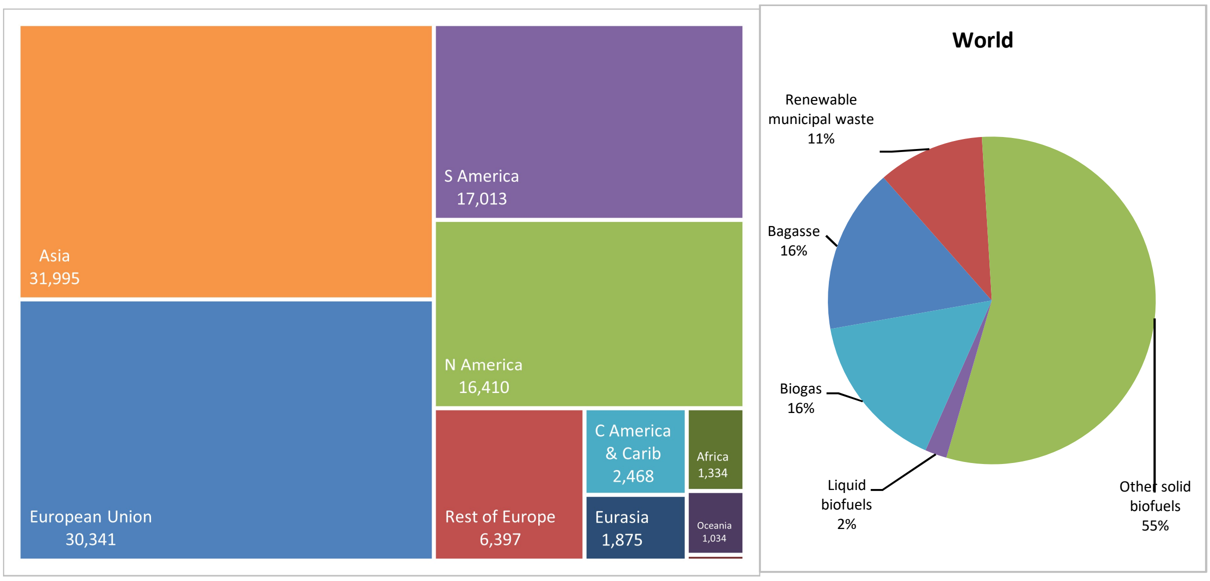

Figure 52. Bioenergy electricity capacity in different world regions in 2017

Source: IRENA 2018

World leading countries on bioenergy installed capacity in 2017 (Figure 52) include Brazil (14.6 GW), United States (13.1 GW), China (11.2 GW), India (9.5 GW), Germany (9.0 GW), United Kingdom (5.5 GW), Sweden (4.9 GW), Thailand (3.8 GW), Italy (3.4 GW) and Canada (2.5 GW). There are clear differences between different countries on the capacities of bioenergy plants using different feedstocks. Brazil was the world leader in terms of capacity of bagasse-based biomass power plants (11.2 GW). Regarding the use of municipal renewable waste, China was the world leader (3.6 GW), followed by United States (1.1 GW), Germany (1.0 GW) and Sweden (0.6 GW). Germany is the world leader on biogas electricity capacity (6.2 GW) followed by United States (2.4 GW), and other European Union Member States such as the United Kingdom (1.8 GW) and Italy (1.4 GW). The use of other solid biofuels (including wood residues, wood waste, crop residues, etc.) dominates the biomass power capacity, with the global leaders including United States (9.4 GW), India (9.4 GW), China (7.1 GW) and Sweden (3.8 GW).

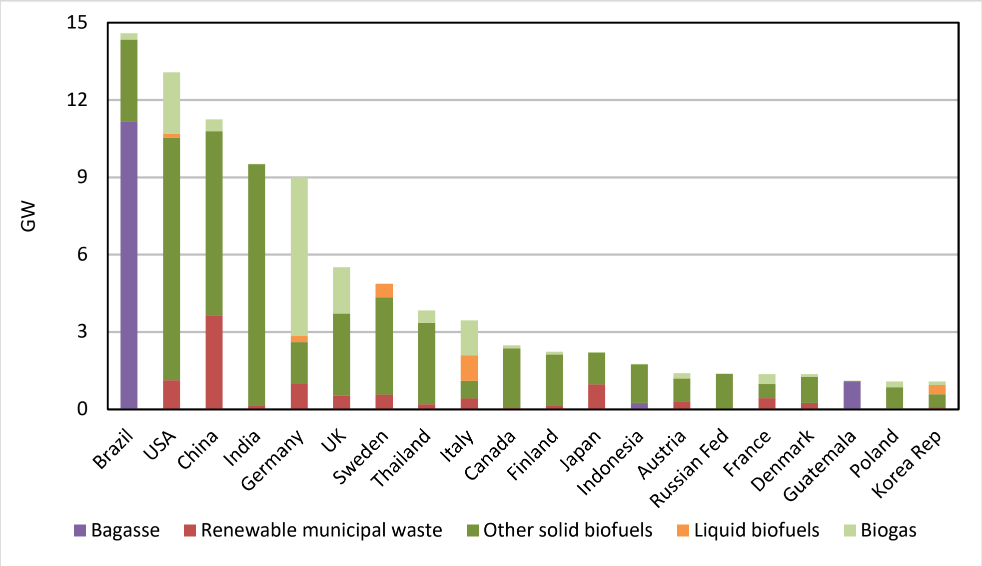

Figure 53. World leading countries on bioenergy installed capacity in 2017

Source: IRENA 2018

Looking at the most relevant feedstock types used worldwide, Asia has the highest installed capacity using solid biomass (Figure 54) with 30 GW (33.9 %) followed by the European Union with 22.6 GW (25.2 %), South America with 16.7 GW (18.6 %) and North America 13. 7 GW (15.2 %). The European Union is by far the world leader in biogas electricity installed capacity in 2017 (Figure 54), with 12.0 GW (70.4 %), followed by North America with 2.6 GW (15.3%) and Asia with 1.2 GW (7.1 %). Asia has the highest installed electricity capacity in renewable municipal waste with 5.5 GW (48.1 %), followed by the European Union with 4.4 GW (38.9 %) and North America with 1.2 GW (10.1 %).

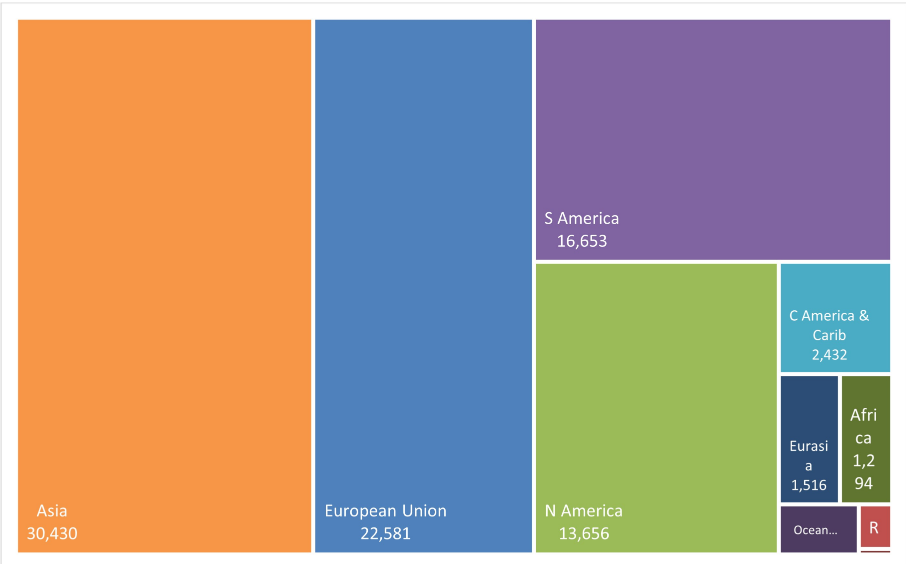

Figure 54. Share of different world regions in solid biofuels electricity capacity in 2017

Source: IRENA 2018

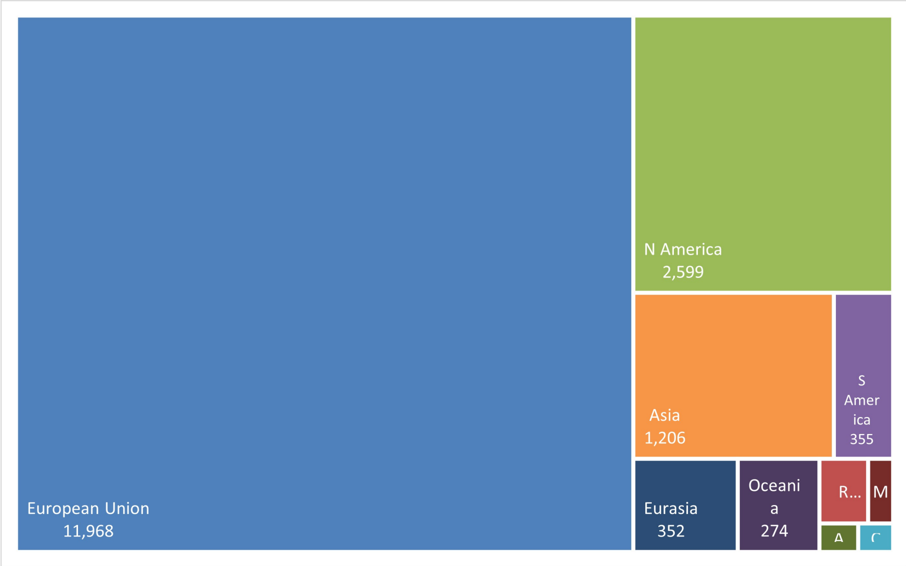

Figure 55. Share of different world regions in biogas electricity capacity in 2017

Source: IRENA 2018

3.3 Market shares

In terms of biomass electricity production (Figure 56) the European Union has a leading place, with a bioelectricity production of 180 TWh in 2016 or 38.6 % of total global installed capacity, followed by Asia, with a biomass electricity production of 123 TWh (26.4 % of global biomass electricity production), 83 TWh (17.8 %) in North America and 64 TWh (13.6 %) in South America. Africa, despite a leading global position in biomass use for energy, had only 3.1 TWh electricity produced from biomass in 2016, proving the prominent role of traditional use of biomass. The major source of biomass worldwide came from the use of other solid biofuels (including wood residues, wood waste, crop residues, etc.) with 58 % followed by biogas with 19 %, bagasse with 11 % and renewable municipal waste with 11 % (Figure 56).

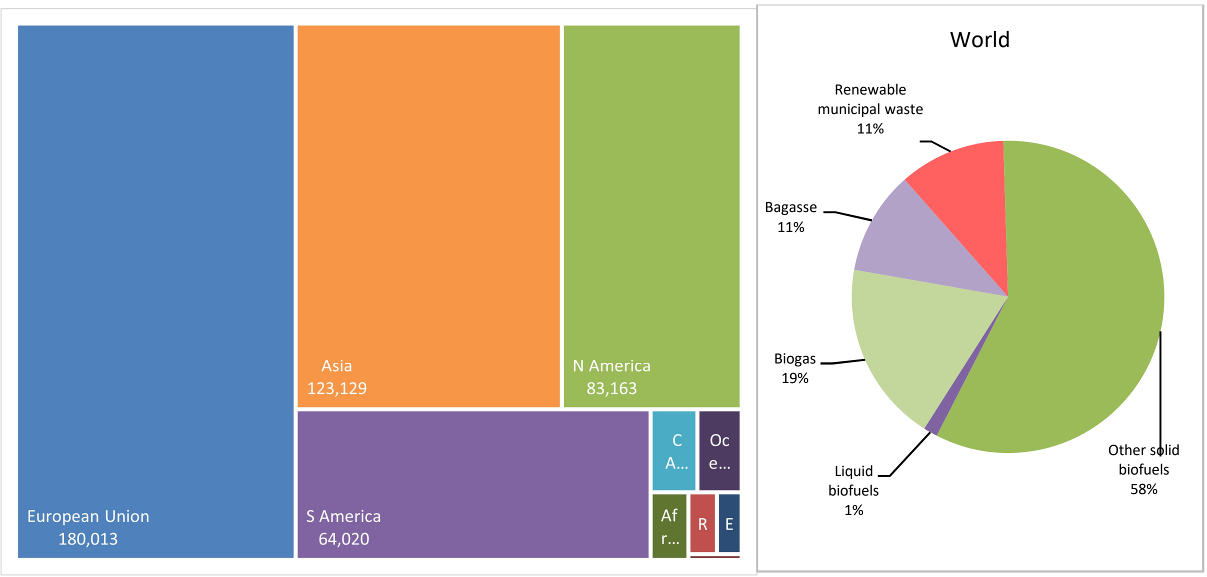

Figure 56. Biomass electricity production in different world regions in in 2016

Source: IRENA 2018

Solid biomass (renewable municipal waste, bagasse and other solid biofuels) has a major role in bioelectricity production at global level, with a contribution of 372 TWh (almost 80 % of total bioelectricity production), of which 271 TWh from other solid biofuels (58 %), 51 TWh (11 %) from renewable municipal waste and 50 TWh from bagasse (11 %). Biogas also contributes with 88 TWh to electricity generation, followed by liquid biofuels with 7 TWh (1 %).

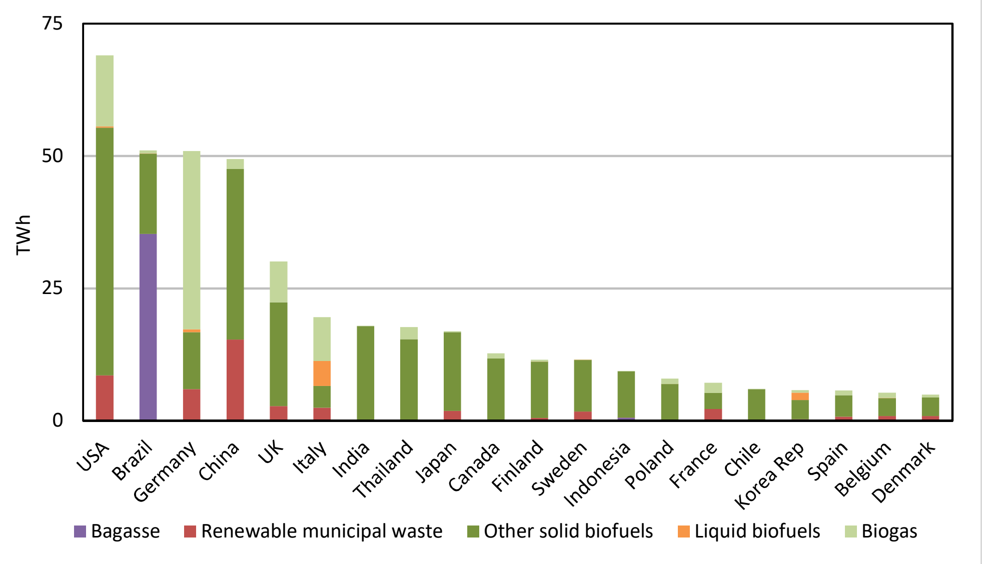

Figure 57. World leading countries on bioenergy electricity production in 2016

Source: IRENA 2018

World leading countries on electricity generation from biomass in 2016 (Figure 57) include United States (69 TWh), Brazil (51 TWh), Germany (51 TWh), China (49 TWh), United Kingdom (30 TWh), Italy (20 TWh), India (18 TWh), Thailand (17 TWh), Japan (17 TWh) and Canada (13 TWh). A mix of feedstock is used for electricity generation in most countries, with significant differences between countries. In general, the use of other solid biofuels (including wood residues, wood waste, crop residues, etc.) dominates in most countries with few exemptions: Brazil, Germany or Italy.

The higher share of electricity comes from the use of other solid biofuels (including wood residues, wood waste, crop residues, etc.) in particular in the United States (47 TWh), China (32 TWh), UK (20 TWh), India (18 TWh), Thailand (15 TWh), Brazil (15 TWh), Japan (15 TWh), Canada (12 TWh), Germany (11 TWh) and Finland (11 TWh). Unites Stater were the world leader in 2016 in electricity generation from other solid biofuels (wood and wood residues, etc.), with a significant share being also provided from biogas and municipal renewable waste. Brazil was the world leader in terms of electricity production from bagasse and the rest coming from other solid biofuels (wood and wood residues, etc.). China was the world leader for electricity production from municipal renewable waste (15 TWh) followed by United States (9 TWh), Germany (6 TWh), UK (2.7 TWh), Italy (2.4 TWh), France (2.2 TWh), Netherlands (2.0 TWh), Japan (1.8 TWh) and Sweden (1.7 TWh). Germany is the world leader on biogas electricity (34 TWh), followed by United States (13 TWh), Italy (8 TWh), UK (8 TWh), Czech Republic (2.6 TWh), Thailand (2.3 TWh) France (1.9 TWh), China (1.9 TWh) Turkey (1.6 TWh) and Australia (1.3 TWh) (Figure 57).

Asia has a leading position in terms of electricity production from solid biomass (Figure 58), with a production of 117 TWh (31.3 % of global biomass electricity production), followed by the EU with 112 TWh (30.1 %), North America and 68 TWh (18.4 %) and South America with 63 TWh (17.0 %).

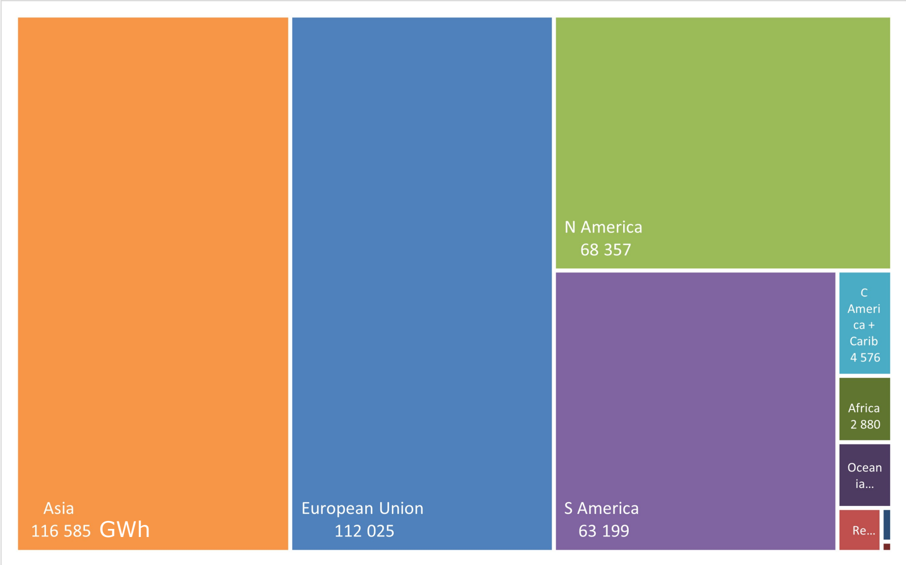

Figure 58. Share of different world regions in solid biofuels electricity production in 2016

Source: IRENA 2018

European Union has the leading role in electricity generation from renewable municipal waste, with 21 TWh (41.0 % of global electricity generation from waste), followed by Asia with 20 TWh (38.9 %) and North America with 8.7 TWh (16.9 %) with the rest of the world playing a minor role (Figure 59). European Union has also the leading role in electricity generation from biogas, with 63 TWh (71.6 % of global electricity generation from biogas), followed by far by North America with 14.6 TWh (16.7 %) and Asia with 5.2 TWh (5.9 %) (Figure 60).

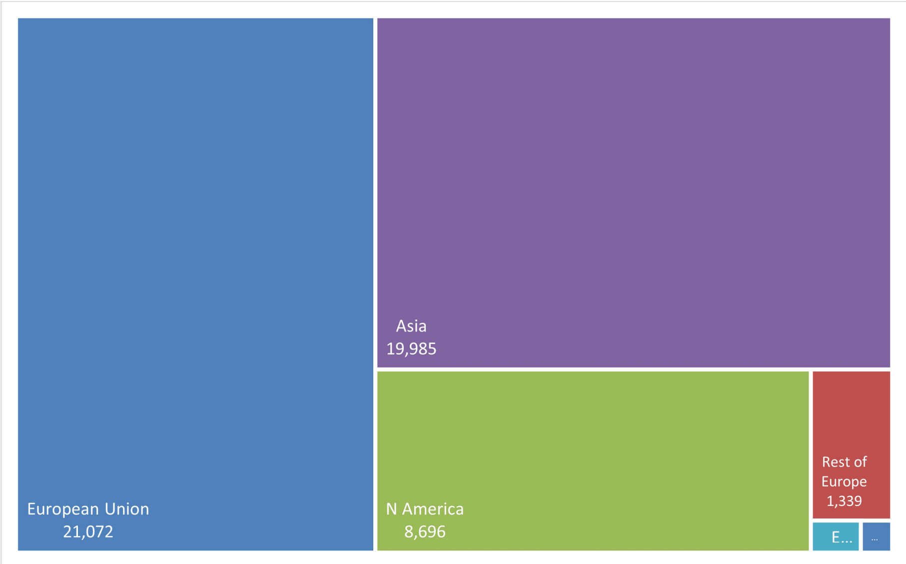

Figure 59. Share of different world regions in renewable waste electricity production in 2016

Source: IRENA 2018

Electricity generation from biogas has seen a significant increase at global scale in particular in developed countries and regions. Thus, world leading regions on electricity generation from biogas include the European Union (62 TWh), followed by far by North America (15 TWh) and Asia (5 TWh). Figure 60. Share of different world regions in biogas electricity production in 2016 with more than 74 % biogas electricity being produced in the European Union almost 17 % in North America and almost 6 % in Asia.

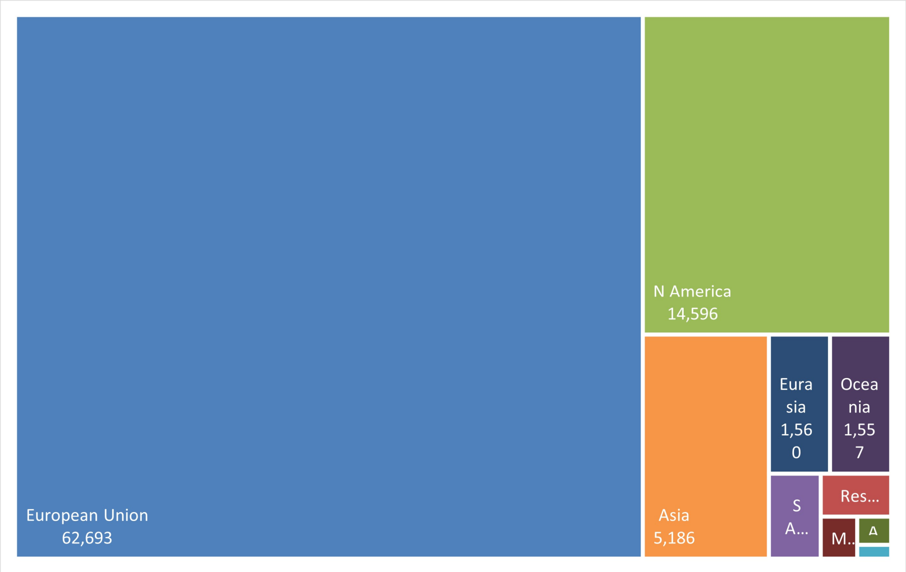

Figure 60. Share of different world regions in biogas electricity production in 2016

Source: IRENA 2018

3.3 Major players

The European biomass industry is leader in the field of biomass power, in particular in solid biomass and biogas. European biomass heat industry deals with small scale (domestic scale stoves boilers using solid biomass such as wood pellets, fuelwood woodchips, etc.) to medium and large scale for heat generation. Even though subsidies are declining in the European Union, it remains the world's most important market for biomass power plants.

This section provides an overview of major players in the field of bioenergy, showing a non-exhaustive list of actors in the field. This shows few leading companies in manufacturing equipment and developing bioenergy technologies having a significant contribution to the deployment of bioenergy in the world, not considering however a ranking in terms of their market shares, capitalisation or R&D investments.

Alstom

Alstom (headquarters in Levallois-Perret, France) company designs, manufactures, installs and services transmission and distribution systems, and products for the power generation and electrical grid markets. Alstom power activities (Alstom Power Systems) included the design, manufacturing, services and supply of products and systems (gas, coal, nuclear, hydro, wind and biomass) for power generation and industrial markets. Alstom Power Systems provided components including: boilers and emissions control equipment, steam turbines and gas turbines, wind turbines, generators, air quality control systems and monitoring and control systems for power plants and related products. Alstom's product and services portfolio includes software solutions and power equipment for the efficient transmission of electricity across the energy chain. Alstom Power Systems also provided services, such as product retrofitting for nuclear and fossil steam turbines and refurbishment of existing power plants. Following the sale of the company's power and transmission business to GE, they were integrated into GE Power & Water. The remainder of the business was entirely focused on rail transport.

Ameresco

Ameresco Inc. (headquarters in Framingham, the U.S) is a supplier of renewable energy and energy efficiency solutions. Ameresco is involved in the development, construction and operation of biomass power plants and provides financial solutions to bioenergy vendors. Ameresco's service activities include the design, development, engineering and installation of projects that reduce the energy and operations and maintenance (O&M) costs of power plants. Ameresco provides solutions ranging from the upgrades of energy infrastructure such as distributed generation plants and onsite cogeneration to the development, construction and operation of renewable energy plants combined with tailored financial solutions that helps customers reduce CO2 emissions and energy consumption. Ameresco builds power and cogeneration facilities for renewable waste to generate power and heat from large, utility-scale biomass-to-energy plants, as well as smaller on-site biomass cogeneration and distributed generation plants as well as methane digester facilities and pipelines. Ameresco provides financing assistance through power purchase agreements (PPA), own and operate solutions or an energy savings performance contract (ESPC).

Babcock & Wilcox

The Babcock & Wilcox Enterprises Inc. (headquarters in Barberton, Ohio the U.S) is a global leader in advanced energy and environmental technologies and services for the power, renewable and industrial markets. The company is a supplier of energy services and products such as biomass-fired boilers, biomass gasification, boiler pressure parts and field engineering services. Babcock & Wilcox is been the supplier of biomass combustion and gasification technologies for many years that include pre-treatment technologies, vibrating grate, burners, stokers, bubbling, circulating fluidized-bed and stoker boilers, gasifiers, black liquor recovery boilers. Historically, the company is best known for steam boilers, biomass to energy, emissions control equipment, waste-to-energy facilities, boiler cleaning equipment, ash handling and conveying, and aftermarket parts and services. The company designs, manufactures and constructs energy solutions for industrial utilities. The Babcock & Wilcox Company provides a wide range of services for the management of biomass power operations and laboratory facilities.

Drax

Drax Group plc is an electrical power generation company (headquarters North Yorkshire, UK). The company operates three core business activities: wood pellet production processing biomass for electricity production; flexible, low carbon and renewable energy generation; and energy sales and services to business customers. The company also focusses on power generation, producing flexible, low carbon and renewable electricity as well as providing system support services to the grid from a portfolio of biomass, hydro, gas and coal technologies. Drax Power Limited runs Europe's biggest biomass-fuelled power station, Drax power station in UK (2.6 GW capacity for biomass and 1.29 GW capacity for coal). The company is planning investments for improving the performance of its biomass business unit. Drax Group plc plans to conduct R&D activities for developing new types of biomass that can be burned efficiently.

ENGIE

Engie SA (headquartered in Courbevoie, France) was formerly known as GDF SUEZ S.A.. ENGIE operates in the fields of electricity generation and distribution, natural gas, nuclear, renewable energy and energy services. It engages in the generation and sale of power through nuclear, thermal, and biomass resources; and seawater desalination activities, as well as offers engineering services in the areas of energy, hydraulics, and infrastructure. ENGIE decided to stop new investments in coal plants and invest into projects that promote low-carbon, renewable energies (solar, wind, geothermal, biomass, hydroelectric), nuclear, energy services such as heating and cooling networks and decentralized energy technology. ENGIE has conducted a number of pioneering R&D projects to improve biomass combustion process and make it possible to use resources other than wood, including olive stones and pulp, vegetable oils, coffee grounds, crop residues and wastewater treatment plant sludge as well as for developing gasification for converting biomass into fuel, which can then be used in many different ways.

Fortum

Fortum is a leading energy company developing and offering services for the power generation industry and solutions in electricity, heating, cooling, as well as resource efficiency. Fortum's business activities cover the production and sales of electricity and heat, waste-to-energy and circular economy solutions. The City Solutions division includes heating, cooling, waste-to-energy, biomass, and other circular economy solutions, as well as solar power production. Fortum has grown its waste-to-energy and biomass-fired heat and power capacity, and recycling and waste solutions. Fortum Otso bio-oil is produced from wood-based raw materials (forest residues, wood chips or sawdust) by fast pyrolysis, can replace heavy or light fuel oil e.g. at heat plants and industrial steam production. Fortum Bio-oil production, integrated with a CHP plant started in Joensuu, Finland in the first of its kind in the world on an industrial scale in 2013. Fortum, UPM and Valmet have started in 2014 the LignoCat project to develop a new technology to produce advanced high value lignocellulosic fuels, such as transportation fuels or higher value bioliquids through catalytic pyrolysis technology for upgrading bio-oil. Fortum has launched a project that aims to manufacture high-value products from agro residues and woody biomass replacing fossil fuels.

Nature Energy

Nature Energy (headquartered in Funen, Denmark), the largest producer of biogas in Denmark, and the leading producer of green gas to grid in Europe from farm and food waste Nature Energy (former Naturgas Fyn), Europe's largest producer of green biogas for the gas grid from farm and food waste, owns and operates seven large-scale biogas biogas plants and currently has a production capacity of more than 100 million m3 (approx. 5 % of the green gas in the European gas grid). Nature Energy has acquired in 2018 Xergi from Schouw & Co. and Hedeselskabet, one of Europe's leading suppliers of turnkey biogas plants. Xergi has more than 30 years of experience in designing and constructing biogas plants around the world. Nature Energy is plans to grow from 5 operational plants up to 17 plants within the next 5-10 years and to leverage Denmark's pioneering position in green gas to grid production by expanding internationally.

Ørsted A/S

Ørsted A/S (formerly DONG Energy) is a power company based in Fredericia, Denmark that develops, constructs and operates offshore and onshore wind farms, bioenergy plants and innovative waste-to-energy solutions. DONG Energy used to produce and supply heat and electricity from thermal and biomass power stations to business and residential customers. The Ørsted bioenergy business includes converting from coal and gas to multifuel biomass plants, for combined heat and power (production. The bioenergy plants from Ørsted use residues from forestry and agriculture such as straw, wood pellets and wood chips from wood residues and waste, mainly tree tops, branches and sawdust from sawmills as well as low quality roundwood to produce electricity & district heating. Latest focus includes industrial biogas production from industrial waste streams (insulin and enzyme production at Novo Nordisk and Novozymes).

UPM

UPM (headquarters in Helsinki Finland) is a world leader in biomass use for pulp and paper, biochemical, biomaterials, biofuels and bioenergy and the second largest electricity producer in Finland. CHP plants are located and primarily serving in paper, pulp, timber and plywood mill sites. UPM invested in replacing a number of old fossil fuel-fired power plants with biomass power plants. The CHP plants use renewable fuels such as bark, forest residues, fibre residues and solid residues from deinking and effluent treatment plants, bark and black liquor from the pulping process. UPM Biofuels produces innovative, advanced biofuels for transport and for petrochemicals use. UPM has invested EUR 179 million in the UPM Lappeenranta Biorefinery, the world's first biorefinery that started commercial production in 2015 of 120 million litres wood-based renewable diesel from crude tall oil (UPM BioVerno). UPM plans to produce wood-based chemicals for a variety of uses for replacing fossil based-ingredients in various industries and applications. This includes the development of an industrial scale biorefinery in the Chemical Park Frankfurt-Höchst in Germany to convert wood into 150,000 tonnes per year bio-monoethylene glycol (bMEG), bio-monopropylene glycol (bMPG) and lignin. Bio-monopropylene glycol is used in composites, pharma and cosmetics or detergents. Lignin can be used in wood resins, plastics, foams and coatings.

Vattenfall

Vattenfall AB (headquartered in Solna, Sweden) is a state owned company for the production and distribution of electricity and heat from coal, natural gas, nuclear, wind, hydropower, solar power, biomass and waste. The company is also involved in the provision of energy services, such as battery storage, network services, charging solutions for electric vehicles and smart meters. Vattenfall AB invests in renewable resources and develops modern energy systems to reduce carbon emissions from its operations. Vattenfall operates over 15 biomass plants using wood chips, forest residues and sawmill by-products, landscape conservation material and compost residues. The Vattenfall subsidiary Energy Crops GmbH operates over 2,000 hectares of energy wood plantations providing fuel supply of the heating installations in Berlin. Vattenfall is a founding member of the industry-led initiative Sustainable Biomass Program (SBP), a certification system aiming to develop an industry standard to comply with the EU sustainability requirements for woody biomass, mostly in form of wood pellets and wood chips, used in large thermal power plants.

3.4 Emerging markets

The use of biomass, such as crop residues from agriculture, wood residues, fuelwood and charcoal played a key role for heating for long time. Modern bioenergy production of electricity, heating or biofuels for transport through a range of technologies emerged lately as an option to address a number of energy and climate challenges. The large local available biomass resources (from forestry, agriculture or waste), together with favourable energy policies and support schemes promoting renewable energy development have been the key drivers for technology advancements and the development of modern bioenergy markets. In particular the availability of forest residues from a large forestry sector, wood processing and pulp and paper industry, with well-developed infrastructure, played a key role to bioenergy deployment.

Despite significant development over the last decade, bioenergy markets are still immature and face complex interactions between agriculture, forestry and energy sectors. Coupled with high investment costs, the economic viability of bioenergy production depends on the existence of cheap feedstock. Critical issues for further market development are the policy framework conditions. The latest developments in biofuels markets showed clearly that the uncertainties and the debates on sustainability requirements and risks for biofuels cause markets to stagnate.

In most markets, solid biomass and wastes are the main contributors, accounting for over 70% of bioenergy electricity capacity. In the United States bioenergy generation consists mainly in heat and power plants using wood and agricultural residues, mainly in industrial facilities such as pulp and paper mills. In China, bioenergy capacity is based on the use of municipal solid waste and agricultural residues (straw) fuels. In Brazil, electricity production from biomass coming primarily from sugarcane bagasse and black liquor, while India biomass power is produced mainly from sugarcane bagasse and other agricultural waste (Scarlat et al 2018).

Biogas market development has been favoured 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 is also increasing in particular as an option to improve the economics of biogas plants, own purposes and internal processes as industrial heat and for small district heating systems. Biogas upgrading and biomethane production has started in some European Union countries for the use for transport and for the substitution of natural gas, overcoming the limitations for the use of electricity and heat and for improving the economics of biogas plants.

Biogas production from wet-waste biomass, wastewater treatment plants and landfill gas recovery is expanding in a number of low-income countries as result of different support programmes. These programmes aimed to develop household systems to provide biogas to substitute traditional cooking fuels and provide clean energy for cooking. They were applied in countries in Asia (China, Thailand, India, Nepal, Vietnam, Bangladesh, Sri Lanka and Pakistan) and several countries in Africa (Burundi, Botswana, Burkina Faso, Cote d'Ivoire, Ethiopia, Ghana, Guinea, Lesotho, Kenya, Namibia, Nigeria, Rwanda, Senegal, South Africa, Uganda and Zimbabwe) (Scarlat et al 2018). Biogas production in these areas can help develop community micro-grids and provide electricity in disconnected communities.

The international bioenergy market is expected to further increase driven by the global agreement to limit climate change. Bioenergy production is expected to increase for small-scale applications in residential heating systems and large-scale power plants as well. The traditional use of biomass is expected to decrease in Africa and Asia, replaced by modern bioenergy, with higher conversion efficiency and lower environmental impacts. Bioenergy market developments in various regions of the world will depend on the future policies supporting bioenergy. Bioenergy market is expected to include a large number of suppliers and biomass users from different world regions. The world bioenergy markets are rapidly growing in particular in Asia (China, Korea, Japan, India, etc.), Latin America, North America and the European Union. In the emerging economies of Africa, Asia, and Latin America, the wide availability of biomass, combined with limited access to other sources of energy, provides promising opportunities to expand bioenergy production. Asia is expected to replace the European Union as the largest bioenergy market due to increasing energy demand, low-cost biomass waste and residue resources, and long-term targets in emerging economies (IEA 2017).

In the context of the expected increase of bioenergy deployment, the global biomass demand is expected to increase. The current market trends indicate that bioenergy is growing in some markets but not expanding strongly into a number of countries, despite biomass resource availability. The global trade of biomass, given the global distribution of biomass resources and expansion of bioenergy in key global markets is thus expected to increase. So far, some biomass feedstocks low-value, high-bulk volume feedstock (e.g. fuelwood, charcoal and wood residues) have been largely sourced locally and this is expected to continue. Liquid biofuels and biomass with high energy density (such as wood pellets, wood chips), are now transported over long distances. The use of wood pellets derived from forestry or processing residues, is expected to increase, although limited by the sustainability constraints.

The biomass pre-treatment technologies to increase bulk density and energy density (e.g. drying, pelletizing, torrefaction, etc.) facilitate long-range transport to areas with low resources available. New trade streams of biomass for energy can emerge driven by biomass demand, such as torrefied biomass, pyrolysis oil or bio-crude from hydrothermal liquefaction, with improved characteristics and enhanced energy density. In the future, biomass feedstock is likely to originate from Russia, Canada, South America, Africa and Russia toward new emerging markets and to EU, India, and China (Matzenberger et al 2015). Trade flows of biofuels and of biofuel feedstocks toward the EU are likely to decrease in the future, due to the cap set on the use of first-generation biofuels in transport. Biomass trade is likely to grow for advanced biofuel production in the longer term, while advanced biofuels are likely to be used locally, driven by the mandates set in the EU and US. Wood pellet market and trade could continue to increase using the existing infrastructure, such as storage, loading and handling capacities in production areas and harbours. However, future developments in the wood pellet trade are uncertain, as depending on additional sustainability requirements for solid biomass that might hinder future bioenergy development (Scarlat and Dallemand 2019).

4. Market outlook

4.1 Outlook for future bioenergy developments

The IEA prepared a Bioenergy Roadmap to reveal the future configuration of global energy system that would be able to deliver the carbon emission reductions necessary to achieve the long-time goal of limiting climate change (IEA 2017). The Roadmap, based on the Energy Technology Perspectives (ETP) modelling framework has proposed three scenarios for the development of the future low-carbon energy system until 2060, identifying the role of a portfolio of technologies in a future sustainable global energy system in each scenario.

The **Reference Technology Scenario (RTS)** is the baseline scenario that takes into account existing and planned energy and climate-related commitments, following the global climate agreement reached during the 21st Conference of the Parties (COP21) of the United Nations Framework Convention on Climate Change (UNFCCC). This reference scenario would result in an average temperature increase of 2.7°C by 2100 that would continue to rise.

The **2°C Scenario (2DS)** considers the energy technology deployment in a future energy system that allows limiting the global average temperature increase to 2°C by 2100. In the 2DS scenario, carbon neutrality is reached in the energy system by 2100. The 2DS scenario requires major improvements in energy efficiency across all sectors, the widespread deployment of renewable energies, fuel switching and the use of Carbon Capture and Storage (CCS) technologies. In the 2DS scenario, annual energy sector CO_2 emissions are reduced by 70% from current levels by 2060, with cumulative emissions from the energy sector of around 1100 $GtCO_2$ between 2015 and 2100.

The **Beyond 2°C Scenario (B2DS)** involves accelerated clean energy technology deployment that allows reaching the more ambitious climate goal of limiting the global average temperature increase to 1.75°C by 2100. In the B2DS, CO_2 emissions rapidly decline to reach net-zero emissions in 2060 following a with a much faster decarbonisation pathway compared to the 2DS, with cumulative emissions from the energy sector of around 750 $GtCO_2$ between 2015 and 2100. The more ambitious decarbonisation pathway relies on essential role of Bioenergy with Carbon Capture and Storage (BECCS) in the B2DS to reach net-zero emissions in 2060 (IEA 2017).

The global primary energy demand is expected to increase, in the RTS scenario, from 576 EJ in 2016 to 843 EJ in 2060. Fossil fuels continue to dominate primary energy supply, their share decreasing from 82 % in 2014 to 67 % in 2060, with the rest coming from biomass (12 %), other renewables (14 %), and nuclear energy (7 %). The growth in primary energy supply is about 20% (180 EJ) lower in the 2DS scenario, than in the RTS scenario. The role of fossil fuels decreases from 82 % in 2014 to 35 % of the energy mix in 2060, while renewables having 52 % (348 EJ). In the B2DS scenario, the growth in primary energy demand is limited to 841 EJ (or 10 % growth) until 2060, due to the application of energy savings measures. The share of fossil fuels decreases from 82 % in 2014 to 26 % in 2060 while the share of renewables increases from 13 % to 60 %.

Nowadays, bioenergy is the main source of renewable energy supply worldwide with about 56 EJ and plays an important role as a modern and efficient source of energy to generate electricity, heat for heating in buildings or for industrial processes and biofuels for transport (IEA 2017). Modern bioenergy will remain an essential component of the future low carbon global energy system in both the 2DS and the B2DS (IEA 2016c). Compared to the current level of deployment, the contribution of bioenergy should increase significantly if global climate change goals are to be met. According to the projections, biomass use is expected to grow from 56 EJ in 2015 (IEA 2017) to almost 100 EJ in 2060 in the RTS and to around 145 EJ in both 2DS and B2DS in 2060 (Figure 61). In the 2DS scenario, the contribution of bioenergy to electricity production is higher than in the RTS scenario. The contribution of bioenergy was limited however at around 145 EJ, due to the constraints on biomass availability, although different studies provide a range of estimates for the sustainable biomass potentials, most of them between 150 – 300 EJ (Scarlat and Dallemand 2019).

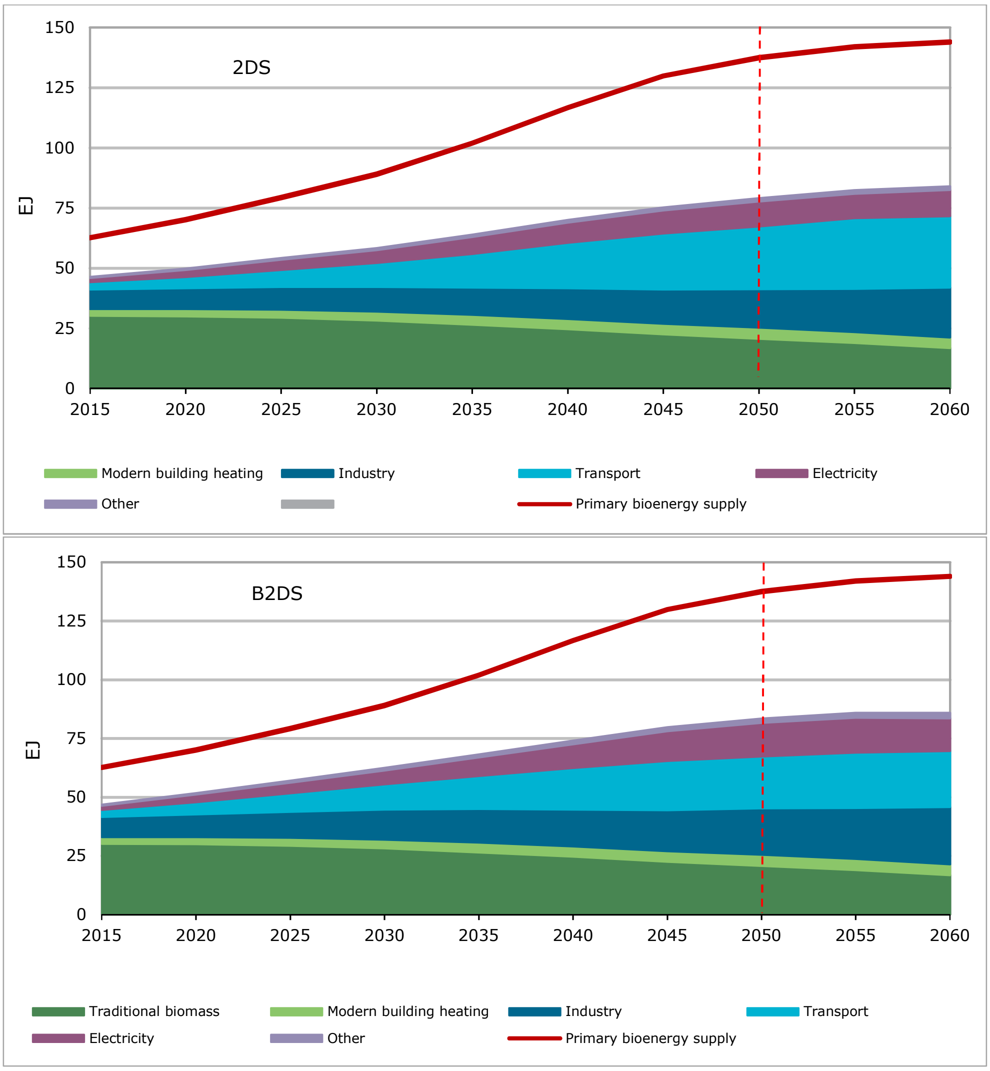

Figure 61. The global contribution of bioenergy to energy supply in 2DS and B2DS

Source: IEA 2017

Traditional use of biomass plays nowadays an important role for energy supply for 2.7 billion people in developing countries, being used for cooking and heating. A decline in traditional use of biomass from the current level of 28 EJ to 17 EJ is expected by 2060 in the RTS compensated by an increase in the modern bioenergy production, driven by the progress on improved access to clean energy and better economic circumstances in a number of developing countries (IEA 2017). Traditional biomass use follows the same pattern in the 2DS and B2DS as in the RTS, following a decreasing trend of around 40% between 2015 and 2060, still playing a major role in supplying energy in residential sector in low income countries.

Biomass use for electricity generation can play a key role in the electricity grid by providing flexible, dispatchable power and thus allowing high levels of variable electricity from wind and solar into the power grid. Thus the biomass use for electricity generation is much higher in the B2DS in comparison to 2DS, due to a strong shift to increased use of electricity, coupled to BECCS in order to generate negative emissions. Major expansion is expected for the use of biomass in the transport sector under the 2DS, reaching nearly 30 EJ in 2060. In the B2DS, the contribution of biofuels to transport is lower in the than in the 2DS (24 EJ), due to the reduction of energy demand in transport and a higher role of biomass and BECCS to generate negative emissions.

4.2 Projections of the EC 2050 long-term strategy

In the European Union, the *Energy Roadmap 2050* investigated possible pathways for a transition towards a low-carbon energy system until 2050 and the associated impacts, challenges and opportunities. A number of scenarios have been examined to achieve 80% reduction in GHG and about 85% reduction of energy-related CO_2 emissions. Different energy options can contribute to the achievement of the 2050 decarbonisation goals, in particular energy efficiency and renewable energy. The highest share of energy supply in 2050 is expected to come from renewables. Several scenarios have been analysed and include the following:

Current trend scenarios

- **Reference scenario** includes current trends and long-term projections on population growth, economic development, fossil fuel prices, and technological developments in the framework of the EU policies and measures adopted by March 2010, including the 2020 targets for RES and GHG reductions as well as the Emissions Trading Scheme (ETS) Directive.
- **Current Policy Initiatives (CPI):** considers updated measures adopted and proposed in the Energy 2020 strategy or actions relating the Energy Efficiency Plan and Energy Taxation Directive.

A number of decarbonisation scenarios have been investigated:

- **High Energy Efficiency:** considers very high energy savings and stringent requirements for appliances, new buildings and energy utilities.
- **Diversified supply technologies:** includes all energy sources, comprising nuclear and Carbon Capture and Storage (CCS), on the market with no specific support measures for different technologies, while decarbonisation is driven by carbon pricing.
- **High Renewable energy sources (RES):** is based on strong support measures for RES, leading to a very high share of renewable energy in gross final energy consumption (75% in 2050) and a share of renewable energy in electricity generation reaching 86%.
- **Delayed CCS:** considers all energy sources, but CCS is delayed, leading to higher shares for nuclear energy, with decarbonisation driven by carbon prices rather than technology push.
- **Low nuclear:** consider all energy sources, but no new nuclear plants in addition to those currently under construction are being built, resulting in a higher penetration of CCS (around 32% in power generation).

The Roadmap projects a decrease of primary energy consumption in all decarbonisation scenarios, between 11 % and 20 % by 2030 and between 30 % and 41 % by 2050, compared to the Reference scenario. Driven by strong support, renewable energy sources were expected to increase their share in primary energy supply in all decarbonisation scenarios to reach between 22 % and 26 % by 2030 and between 41 % and 60 % by 2050, with the maximum values reached in the High RES scenario. The Reference scenario assumes that the 2020 RES target is reached and the RES share in gross final energy consumption increases to at least 24% in 2030 and 26% in 2050. In the decarbonisation scenarios, the RES share is projected to rise substantially, reaching between 28% and 31% in 2030 and between 55% and 75% in 2050 (SEC(2011) 1565).

The EU Reference Scenario (REF2016) has been updated based on the last assumptions on population growth, economic development, fossil fuel price, technology improvements, and policies. The updated scenario shows that current policies and market conditions will not allow reaching the 2030 targets and the 2050 objective of 80 - 95 % GHG emission reductions. In this scenario, the RES share in gross final energy consumption reaches 21 % in 2020, 24 % in 2030 and 31 % in 2050. Energy savings relative to the baseline will reach 18% in 2020, and 24 % in 2030. The GHG emissions are expected to decrease by 26 % in 2020, 35 % in 2030 and 48 % in 2050 (EC 2016).

Biomass is expected to play a significant role in the in future European Union low-carbon energy system in all decarbonisation scenarios. From the 5.8 EJ biomass use for energy in 2016, it was projected to reach about 7.5 EJ in 2030 and 7.8 EJ in 2050 in the reference scenario. In the decarbonisation scenarios, biomass consumption could grow more, to reach between 6.8 EJ and 8.0 EJ in 2030 and between 10.1 EJ and 12.6 EJ in 2050 (Figure 62). This trend at the European Union level is similar to the projections made by the IEA for the global bioenergy use that predicts doubling the biomass use for bioenergy. The key issue for bioenergy development is related to the availability of reliable and affordable sustainable biomass supply (SEC(2011) 1565).

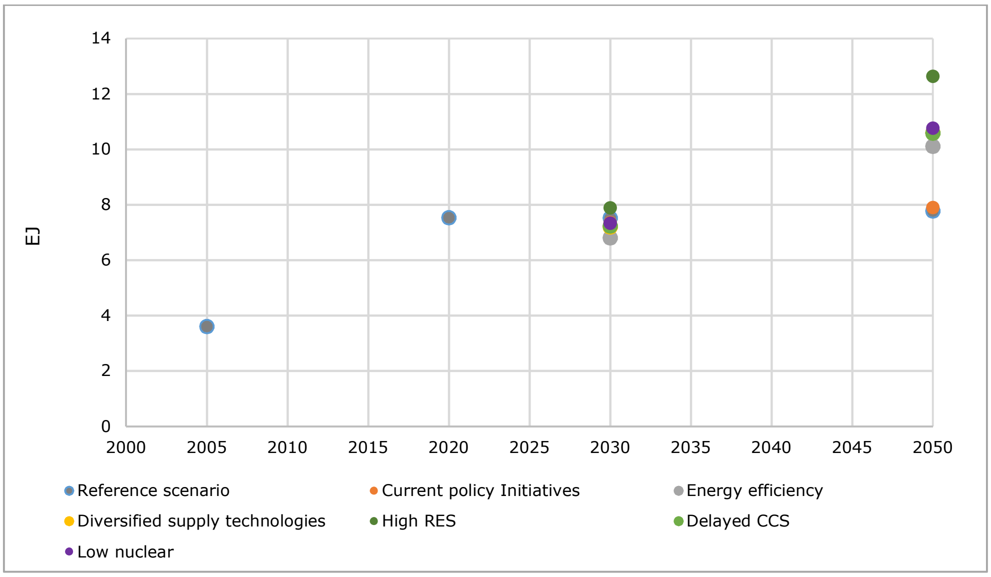

Figure 62. Expected biomass use in the European Union until 2050

Source: Energy Roadmap 2050 (COM(2011) 885 final)

There is a strong increase of power generation from RES in all scenarios with their share of electricity expected to reach between 51 % and 60 % in 2030 and between 60 % and 86 % in 2050 in the High RES scenario. The High RES scenario would require major investments with RES capacity in 2050 reaching 1740 GW, from about 423 GW in 2016. The installed bioenergy power capacity is expected to reach 43 GW in 2020 and 87 GW in 2050 in the reference scenario. The growth in biomass capacity is higher in different decarbonisation scenarios, ranging between 106 and 163 GW in 2050 (Figure 63). Biomass electricity generation in the EU increased from 69 TWh in

2005 to 180 TWh in 2016 and is expected to reach 232 TWh in 2020. Later on the biomass electricity production is projected to further grow to 360 TWh in 2050 in the reference scenario and to 460 – 494 TWh in 2050 in the decarbonisation scenarios. Bioelectricity contribution could rise from 2.6 % share in power generation in 2005 and 5.6 % in 2016 to 7.3 % in 2050 in the reference scenario and between 9.3 - 10.9 % in the decarbonisation scenarios SEC(2011) 1565).

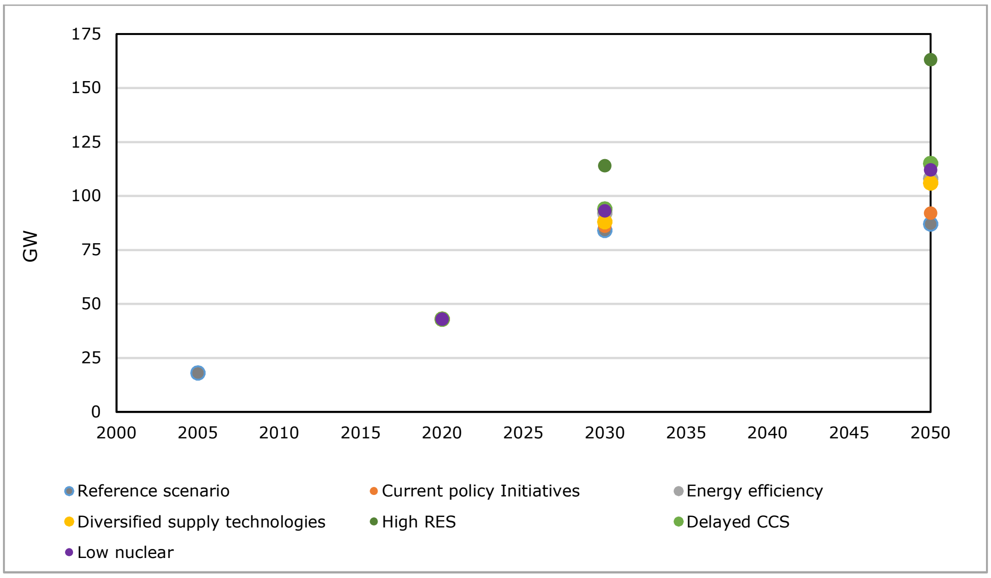

Figure 63. Expected bioenergy installed plant capacity biomass use in the European Union until 2050

Source: Energy Roadmap 2050 (COM(2011) 885 final)

The RES share in gross final consumption of heating and cooling is expected to increase from around 10 % in 2005 and 19 % in 2016 to 21 % in 2020. Under different scenarios until 2020, RES share in heating and cooling would double, to reach at least 44 % by 2050 under various decarbonisation scenarios and up to 54 % in the High RES scenario. Currently, heating is the main bioenergy market, accounting for 3.3 EJ in the European Union, and almost 90 % of renewable heat and 15 % of total heat generation in the EU in 2016. (SEC(2011) 1565). In order to contribute to the decarbonisation efforts in the transport sector, the share of renewables in transport is expected to reach 19-20% in 2030 and up to 62-73% in 2050 in different decarbonisation scenarios. The use of biofuels in transport sector in decarbonisation scenarios was projected to increase to 1.0 - 1.5 EJ in 2030 and 2.8 - 3.0 EJ in 2050, in different scenarios. In the light of the last changes related to the first generation biofuels and the developments on advanced biofuels, future contribution of biofuels to transport could be different.

The EU long-term strategy for a climate-neutral economy by 2050 (COM (2018) 773) considers the possible contribution of the EU to the global pathways that enable limiting global warming to 1.5°C in accordance with the Paris Agreement. The assessment in support of the development of the strategy for long-term EU greenhouse gas emissions reduction was looking at a range of GHG reduction scenarios, considering -80% to -100% GHG emission reductions by 2050 compared to 1990. Different scenarios project a significant, change from current situation that incorporate a wide portfolio of mitigation options. Three categories of scenarios are analysed (Table 2): Table 2

- well below 2°C scenarios, GHG emissions reduction levels in 2050 of around 80% compared to 1990, switching from the direct use of fossil fuels to zero/carbon-neutral energy carriers that include Electricity (ELEC), Hydrogen (H2) and E-fuels (P2X), stronger Energy Efficiency measures (EE) or the transition to a more Circular Economy (CIRC);

- net GHG emissions reduction in 2050 close to 90% compared to 1990 representing a bridge between the other two main scenario categories explored, combining the actions and technologies of the five scenarios (COMBO)
- reaching net zero GHG emissions by 2050 scenarios, pursuing efforts to achieve a 1.5°C temperature change. The remaining emissions that cannot be abated need to be balanced out with negative emissions, including from the LULUCF sink. One scenario (1.5TECH) assumes increased contribution of all technology options, and relies more on the deployment of biomass with carbon capture and storage (BECCS) to reach net zero emissions in 2050. The second scenario (1.5LIFE) relies less on the technology options of 1.5TECH, but assumes a drive by EU business and consumption patterns towards a more circular economy, lifestyle changes, less carbon intensive diets, and more rational use of energy.

Table 2 Long-term strategy options.

	Electrification (ELEC)	Hydrogen (H2)	Power-to-X (P2X)	Energy Efficiency (EE)	Circular Economy (CIRC)	Combination (COMB)	1.5°C Technical (1.5Tech)	1.5 Sustainable Lyfestiles (1.5LIFE)
Main drivers	Electrification in all sectors	Hydrogen in industry, transport and buildings	E-fuels in industry, transport and buildings	Deep energy efficiency in all sectors	Increased resource and material efficiency	Cost-efficient combination of options from 2°C scenarios	Based on COMBO with more BECCS, CCS	Based on COMBO and CIRC with lifestyle changes
GHG target for 2050	-80% GHG (excl. sinks) (well below 2°C ambition)					-90% GHG (incl. sinks)	-90% GHG (including sinks)	-100% GHG (incl. sinks) (1.5°C ambition)
Major common assump-tions	•Higher energy efficiency post 2030 •Deployment of sustainable, advanced biofuels •Moderate circular economy measures •Digitilisation				•Market coordination for infrastructure deployment •BECCS present only post-2050 in 2°C scenarios •Significant learning by doing for low carbon technologies •Significant improvements in the efficiency of the transport system.			

The use of biomass in the energy sector is expected to increase significantly in decarbonisation scenarios at global level (Figure 64). All the scenarios analysed rely on a substantial use of biomass for energy in the EU. The 2050 gross inland consumption of biomass ranges from 190 Mtoe (8.0 EJ) in the EE scenario to just over 250 Mtoe (10.5 EJ) in 1.5TECH scenario increasing from 140 Mtoe (5.9 EJ) of biomass used in 2016 for energy. In addition to the standard scenarios, a low biomass variant of the 1.5LIFE scenario has been introduced (1.5LIFE-LB) to better analyse the implications of achieving net zero GHG emissions with reduced biomass use that consider circular economy, changing consumer preferences and enhanced natural land sink. The 1.5LIFE-LB scenario assumes increased use of technology options available in 1.5TECH scenario that require less biomass (about 170 Mtoe in 2050). The decarbonisation of transport requires advanced biofuels that could be produced at scale after 2030, to represent up to 20% of the total use of biomass in all scenarios.

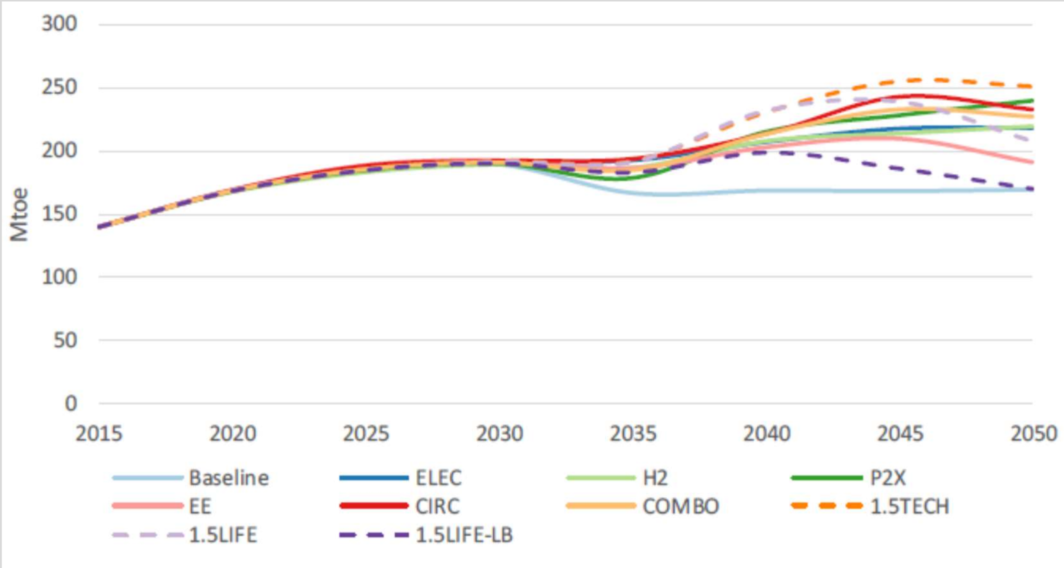

Figure 64. Gross inland consumption of biomass until 2050 under different scenarios

Source: COM (2018) 773

The analysis of the IEA Bioenergy Roadmap and the EU Roadmap for 2050 show similar results in terms of the expected contribution of biomass to energy supply in the EU at the 2050 time horizon in comparable scenarios. Thus the IEA Bioenergy Roadmap data for the European Union shows that the primary energy supply is expected to grow in the European Union from 5.0 EJ in 2014, the reference year, to 9.1 EJ in the RTS, with a higher growth in the D2S and B2DS, with 11.5 EJ and 11.8 EJ in 2050, respectively (IEA 2017). This is well in accordance with the results of the High Renewable Energy Sources scenario of the EU Renewable Energy Roadmap for 2050. The IEA Roadmap shows that the bioenergy capacity will increase in the European Union in the RTS to 81 GW in 2050, while the expected installed capacity would range between 103 GW and 137 GW in 2050, which are also within the ranges of the EU Renewable Energy Roadmap. The results confirm that the High Renewable Energy Sources scenario in the European Union is in line with the global effort aiming at the achievement of the global long-term goal to limit the temperature increase to maximum 2 °C.

4.3 Outlook for future developments JRC-EU-TIMES model

4.3.1 Outlook for the market

The JRC-EU-TIMES model has been used for analysing the role of the biomass up to 2050 in the energy system for meeting the EU's energy and climate change policy objectives (Simoes et al., 2013). This is a partial equilibrium energy system model aiming to analyse the role of energy technologies development and their potential contribution to decarbonisation pathways. The model is a linear optimisation, bottom-up model that provides the optimum cost investment portfolio of technologies while fulfilling the energy demand of the EU at EU and Member States level in different scenarios (Figure 65). It models technologies uptake and deployment and produces projections of the EU energy system under different sets of specific assumptions and constraints.

The main pathways investigated by the JRC-EU-TIMES model are following a scenario setting the reference (Baseline) and two decarbonisation scenarios (Diversified and ProRES) striving for fulfilling the 80 % CO_2 emission reduction target for 2050, as compared to 1990 levels. The Diversified and the ProRES decarbonisation scenarios achieve similar emission reduction globally (80 % by 2050 compared to 1990) with different technology portfolio with respect to fossil fuels, nuclear energy and CCS. The three scenarios cover a plausible range of global development of low carbon energy technologies to 2050. In addition the more ambitious 'NearZero'-scenario aims for 95 % CO_2 reduction by 2050. Table 3 describes the main assumptions of the four main scenarios.

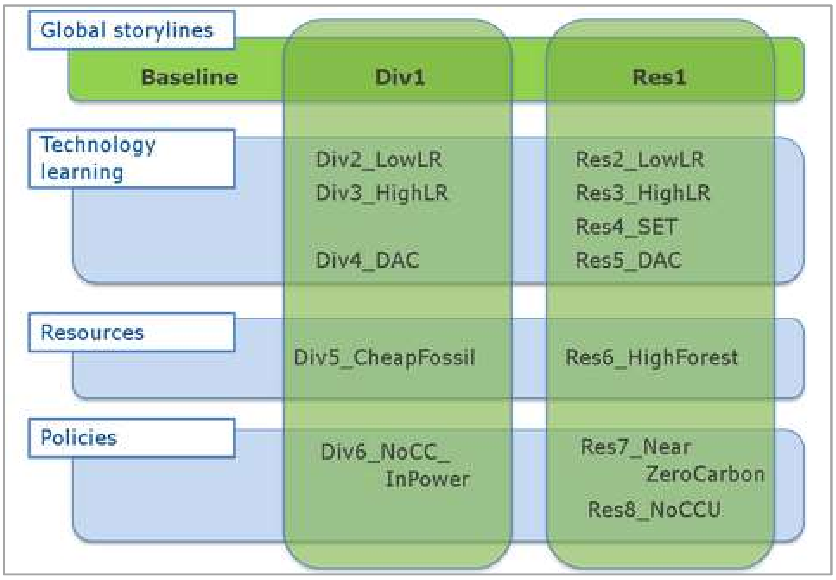

Figure 65 Global Storylines that covers worldwide development of low carbon energy technologies.

Source: JRC-EU-TIMES model

The **Baseline** scenario represents a "business as usual" world in which no additional efforts are taken on stabilising the atmospheric concentration of GHGs. The global deployment of RES is based on the "6DS" scenario of the Energy Technology Perspectives of the IEA (2016). It represents a world in which no additional efforts are taken on stabilising the atmospheric concentration of GHGs. In the EU, it is assumed that there is a 46% CO_2 reduction by 2050.

Table 3. LCEO main scenario assumptions

Scenario	Description
Baseline	Continuation of current trends; primary energy consumption reaches about 940 EJ, renewable energy supplies about 30 % of global electricity demand and emissions climb to 55 $GtCO_2$.
Diversified	Usage of all known supply, efficiency and mitigation options (including CCUS and new nuclear plants); primary energy consumption remains at about 580 EJ, the share of renewable electricity in the mix is 74 % while emissions decline to 4.7 $GtCO_2$ by 2050.
ProRES	Advancement towards decarbonisation by high development RES technologies, significantly reducing fossil fuel use, rapid phase out of nuclear power and no CCS. Primary energy consumption is about 430 EJ, renewables supply 93 % of electricity, global CO_2 emissions are 4.5 $GtCO_2$ and the CO_2 reduction reaches 80 % CO_2 by 2050.
NearZero	Same as for the ProRES scenario with 95 % CO_2 reduction by 2050.

The **Diversified** portfolio scenario follows the B2DS scenario of the IEA's 2017 Energy Technology Perspectives. To achieve rapid decarbonisation in line with the global policy goals, all known supply, efficiency and mitigation options are available, including CCS, fossil fuels and new nuclear plants. At a global level, the main difference between the Diversified and ProRES scenarios is that by 2050 electricity in ProRES is almost exclusively produced by renewables

Table 4. Parameters considered in the JRC-EU-TIMES modelling scenarios.

Name	CO_2 2050	NUC +20yr	New NUC	CO_2 STOR	CO_2 Reuse
Baseline	-46%	YES	YES	YES	YES
Diversified	-80%	YES	YES	YES	YES
Diversified: NoCC InPower	-80%	YES	YES	YES	YES
Pro-RES	-80%	YES	NO	NO	YES
Pro-RES: High Forest	-80%	YES	NO	NO	YES
Pro-RES: Near Zero CO_2	-95%	YES	NO	NO	YES
Pro-RES: No CCU	-80%	YES	NO	NO	NO

The **ProRES** scenario is the most ambitious in terms of capacity additions of RES technologies. This scenario assumes a global decarbonisation of the energy system by significantly reducing fossil fuel use, however, in parallel with a strong decrease of nuclear power. In the ProRes scenario, there are no new nuclear plants, no CCS and no underground storage of CO_2. High emission reduction is achieved with high RES deployment, electrification of transport and heat, and high efficiency gains. The deployment of RES is based on the 2015 Energy Revolution scenario of Greenpeace.

The **Pro Res Near Zero** scenario follows the ProRES assumptions with a long-term decarbonisation target of 95% below 1990 levels in 2050.

The Diversified and the ProRES scenarios achieve similar emission reduction globally (about 80 % by 2050 compared to 1990), but with different technology portfolio with respect to fossil fuels, nuclear energy and CCS. The main difference between the Diversified and the ProRES scenarios is that by 2050 electricity in ProRES is almost exclusively produced by renewables. The scenarios were further investigated in sensitivity cases by considering different technologies, resources and policy strategies (Table 4), together with the main parameters considered in the JRC-EU-TIMES scenarios.

4.3.2 Deployment trends

The overall renewable energy share is very dependent on the scenario considered in the JRC EU Times model. The RES share in 2030 is 28 % - 30 %, close enough to the new 2030 target of 32 %. After 2030, there is a slow increase in the baseline reaching 34 % and a significant increase in the decarbonised scenarios reaching 56 % and 84 % in the Diversified and ProRES scenario respectively. Biomass conversion technologies are modelled explicitly in the JRC-EU-TIMES model including current technologies, including biomass combustion (heating, electricity and CHP), anaerobic digestion and gasification (JRC EU TIMES).

For the JRC-EU-TIMES model, the biomass production sectors are agriculture, waste, and forestry. The main quantitative model used to derive biomass potentials for agriculture is CAPRI, an agricultural partial equilibrium model that covers from global to regional and farm type scale (Britz W. and Witzke PP. 2014). Agriculture biomass resources are distributed between energy crops (sugar, starch and oily crops, maize silage, and lignocellulosic biomass), and primary (manure from livestock), and secondary agricultural residues (pruning residues, straw and stubble, olive pits). The waste sector produces primary residues (landscape care management, roadside verges and abandoned lands) and tertiary residues (residues from industries and municipal solid waste). Biomass from the forestry sector is classified into roundwood production, other wood from harvesting (logging residues and other pre-commercial thinnings) and secondary residues (woodchips and pellets, sawdust and black liquor coming mainly from the paper industry). The biomass availability for energy use is constrained on the basis of the reference potentials derived in the JRC Biomass project (Camia et al., 2016). Regarding agriculture-related feedstock availability, the JRC-EU-TIMES potential follows the CAPRI model outputs as described in P. Ruiz et al. 2019.

The JRC-EU-Times model projections show that the use of biomass for heat and power production will increase until 2050 (Figure 66) to small extent. The ProRes and the ProRes NearZero scenarios estimate a biomass supply of 7.0 EJ and 7.2 EJ respectively in 2050, while the Baseline and Diversified scenarios suggests a supply of 6.1 EJ and 6.2 EJ, respectively, in comparison to the biomass supply for energy production of 5.9 EJ in 2016. As the bioenergy deployment is constrained by the biomass availability, an additional analysis included a high mobilization scenario for forestry biomass that assumed that the full forest harvest potential is exploited for material and/or energy purposes. This ProRes HighForest scenario showed that the bioenergy supply could reach higher levels reaching up to 8.5 EJ in 2050 in the European Union. Overall, the projections shows a very limited growth in the use of biomass for energy, flattening out after 2020 in the Baseline and Diversified scenarios and a growth of only about 20% between 2016 and 2050. In these scenarios, most of the biomass resources will come from forest and agro systems, in particular from the forest residues and agricultural crops, followed by forest biomass, agricultural crops and various wastes.

Figure 66. Evolution of primary energy supply from biomass in the EU in the main LCEO scenarios [PJ].
Source: JRC-EU-TIMES model

In the ProRES scenario, electricity generation is the main sector for the use of renewable energy. Electricity is largely produced by solar and wind plays a key role and is well inside the range of their potential in the EU. These technologies take the major share of investments but all forms of renewables are deployed. The simulations show that the installed capacity of biomass power have an upward trend in all considered scenarios for 2050 (Figure 67).

The modelling results indicate that the biomass electricity installed capacity will increase steadily until 2030, when it reaches 74 GW in the Baseline scenario, 72 GW in the Diversified scenario, 69 GW in the Pro Res scenario and 68 GW in the Pro-RES Near Zero carbon scenarios. In both the Baseline and the ProRes scenarios there is a decrease in the biomass electricity installed capacity down to 67 GW and 57 GW, respectively, in 2050. The ProRES scenario, in spite of being favourable to RES, foresees a lower biomass power capacity. The Pro-RES scenario has a higher decrease of biomass electricity capacity in a long term, reaching only 57 GW in 2050, in comparison to 67 GW for the Baseline scenario for the same period. The Pro-RES is the only scenario that will have inferior installed capacity of bioenergy plants compared to the Baseline scenario. In comparison, the total installed capacity of all renewables is projected to reach by 2050 in the EU 1428 GW in the Baseline scenario 1944 GW in the Diversified scenario, 4557 GW in the ProRes scenario and 6249 GW in the ProRes NearZero scenario.

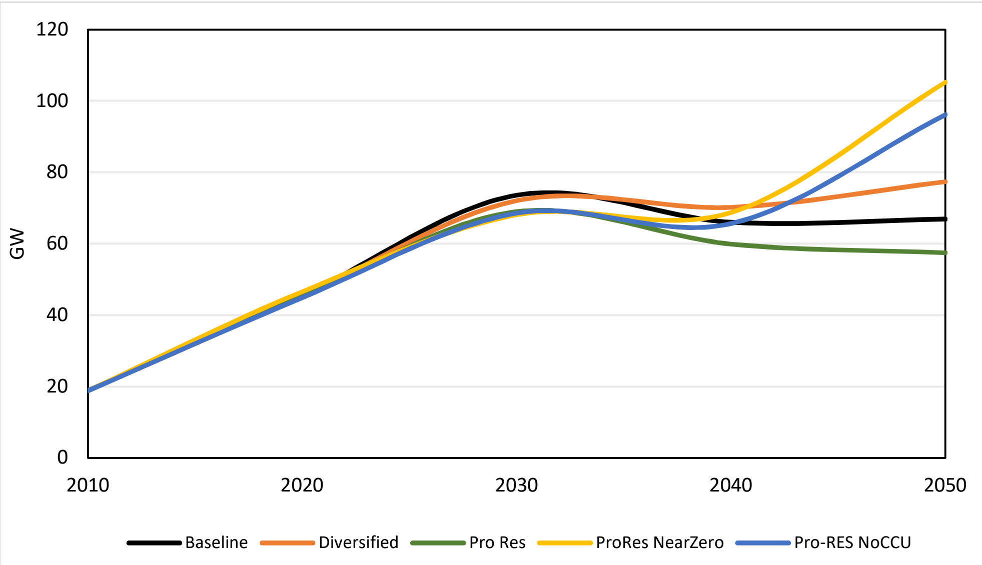

Figure 67. Evolution of the installed biomass electricity capacity in the EU in the main LCEO scenarios.

Source: JRC-EU-TIMES model

All scenarios show a lack of progress of the installed biomass capacity after 2030 until 2040 and even a decrease in the ProRes scenario, to 60 GW in 2040. In the ProRes Near Zero carbon and ProRes NoCCU scenarios, the installed capacity changes slightly in the period of 2030-2040, but increase rapidly in the last simulation period to reach 105 and 96 GW, respectively in 2050. Thus, significantly higher biomass power deployment can be witnessed for the scenario a further reducing CO_2 in the energy system aiming at the long-term decarbonisation target of 95% below 1990 levels in 2050 (NearZero scenario). This CO_2 reduction targets combined with restrictive nuclear and CCUS policies require significant additional biomass capacity in the ProRes NearZero. However, after reaching the 2050 target, the incentive to build biomass capacity disappears as there are no additional policies in place and the installed biomass electricity plant capacity decreases by 2060.

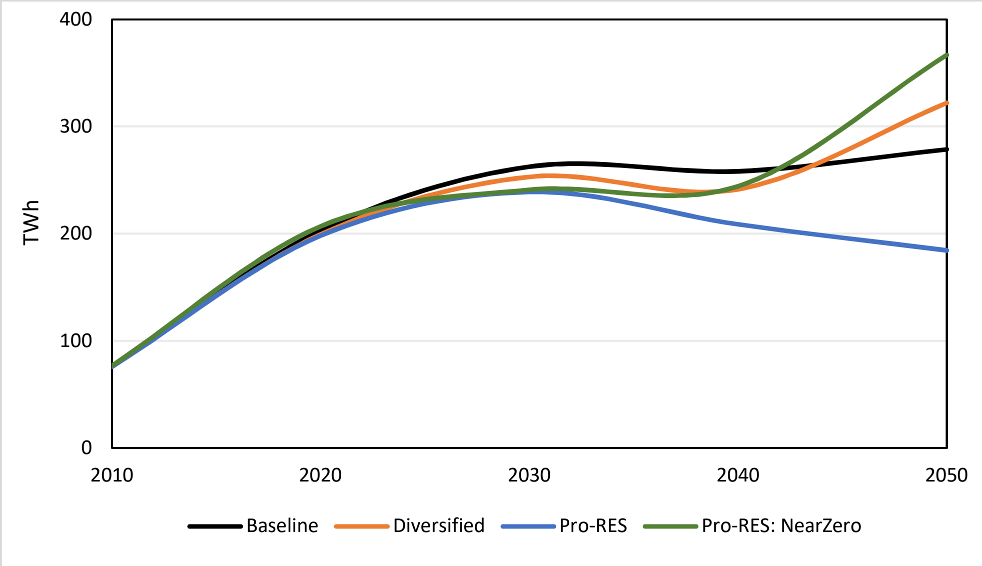

Figure 68. Evolution of the total of electricity production of bioenergy plants.

Source: JRC-EU-TIMES model

The analysis of the electricity production from bioenergy plants shows similar trends from the installed capacity simulations (Figure 68). The different scenarios will keep the growth trends until 2030, when they will reach production values between 239 and 262 TWh. Remarkably, the highest biomass electricity production occurs in the Baseline scenario and the lowest appears in the ProRes scenario. In particular, the ProRes scenario shows a decrease of electricity generation from biomass after 2030 to 184 TWh in 2050, the lowest value of all scenarios. The period of 2030-2040 shows a trend of decreasing electricity generation for all scenarios, with the exemption of the ProRes NearZero scenario, which shows a very limited growth. The other scenarios show increased trends in the last simulation period, especially for the Pro-RES Near Zero and Pro-RES No-CCU scenarios, which will reach production values of 367 TWh in 2050.

On short term, the Baseline and Diversified scenarios show an increase of the annual capacity additions of the heat and power plants in the European Union, with the maximum reached in the baseline scenario in 2030, as provided in Figure 69.

The ProRes and the ProRes NearZero scenarios show a decrease in the annual new capacity until 2030, despite of favourable renewable energy deployment policies. All scenarios show a large decrease in annual installed capacity between 2030 and 2040 due to the lack of a 2040 clear target. All scenarios show a rapid growth between 2040 and 2050 followed after 2050 by a fast decrease in the annual installed capacities, with the lowest decrease however in the ProRes NearZero scenario. The Baseline and Diversified scenarios show both higher annual additions in heat and power capacities than in in the ProRes and in the ProRes NearZero scenarios. The ageing biomass plants result in a growing market for biomass plants being replaced or repowered. By assuming an average lifetime of 25 years for solid biomass plants and 20 years for biogas plants JRC-EU-TIMES calculates the annual capacity to be replaced. Figure 69 shows in particular a large share of new sites capacity build every year until 2030 that decrease severely after that. After 2040 the major increase is due to the replacement of old plants.

In comparison to other renewables, such as wind and solar, the annual capacity additions of the biomass electricity plants is much lower (Figure 70). On short term until 2030, most scenarios show an increase of the annual capacity additions in the European Union, with the maximum reached in the baseline scenario in 2030. The Near Zero scenario shows a decrease in the annual new capacity until 2030 while the ProRes scenarios predict an almost constant level. The ProRES scenario, in spite of being favourable to high renewable energy deployment, does not foresee increased biomass power capacity additions. All scenarios show a decrease in annual installed capacity between 2030 and 2040 due to the lack of a 2040 clear target. All scenarios show a rapid growth between 2040 and 2050 driven by the 2050 target for carbon emission reduction, in particular in the ProRes NearZero carbon scenario. After 2050, the lack of post-2050 policies leads to a fast decrease in the annual installed capacities, with the lowest decrease however in the Diversified scenario. While the addition of new capacities every year increases for most scenarios until 2030 with the exemption of ProResNearZero, all scenarios show significant increase in the replacement of capacity from 2030 onwards. Given the steeper increase of new deployment in the period 2020-2050, the Baseline and ProRes scenarios show comparable replacement rates by 2050; for Baseline and ProRes scenarios, when the replacement of old capacities reaches a share of almost 100 % in 2050.

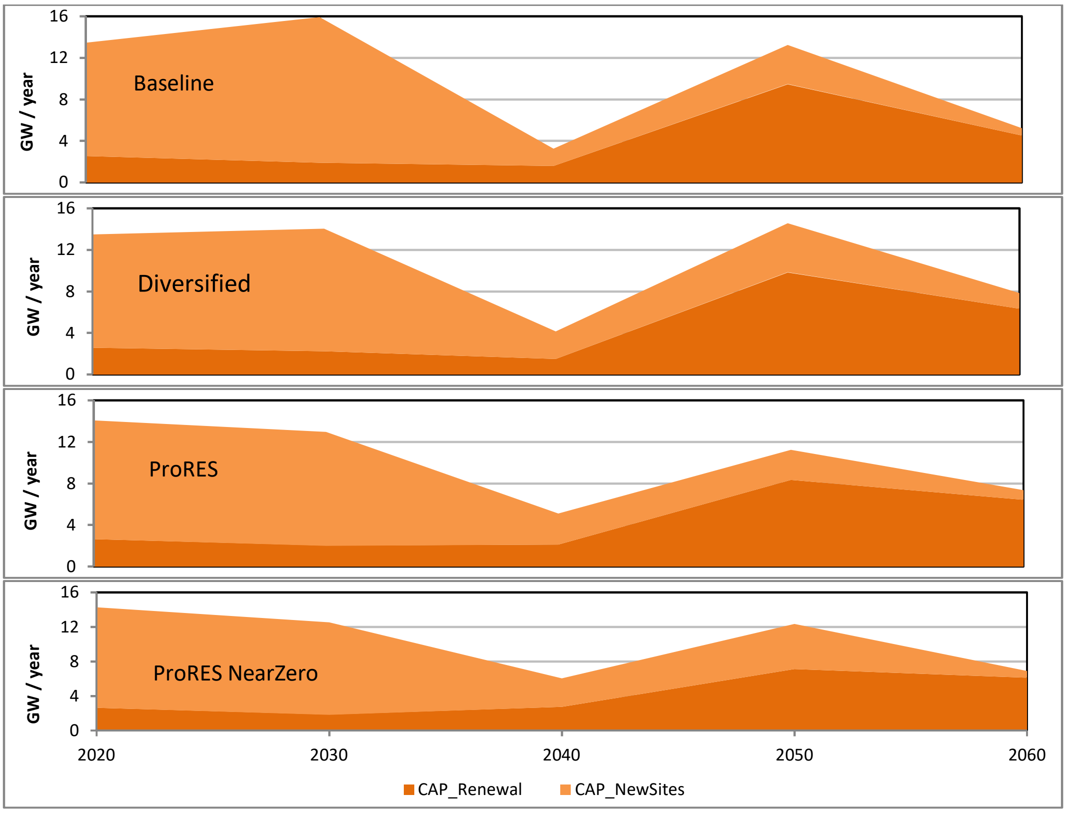

Figure 69 Annual capacity additions in biomass heat and power in the EU in the main scenarios

Source: JRC-EU-TIMES model

Capital investment cost trajectories of individual low carbon energy technologies are derived based on their projected deployed capacity in the Baseline, Diversified and ProRES scenarios, considering the assumptions made for each scenario on investment costs developments of high, reference and low technological learning, expressed by varying learning rates. The JRC-EU-TIMES model results show investments in biomass heat and power plants between EUR 394- 617 billion until 2050, with EURO 394 billion in the Baseline scenario, EURO 468 billion in the Diversified scenario, EURO 353 billion in the ProRes scenario and EURO 617 billion in the ProRes NearZero scenario. Thus, despite the policy support for renewables in the ProRes scenario, the investments made in bioenergy are expected to be the lowest among all scenarios. Figure 71 shows the annual EU investments in biomass power plants during the whole analysed period. All scenarios show a decrease in the annual investments between 2020 and 2030, despite the 2030 renewable targets and the increase in annual capacity additions; this trend continues until 2040 in the Baseline scenario.

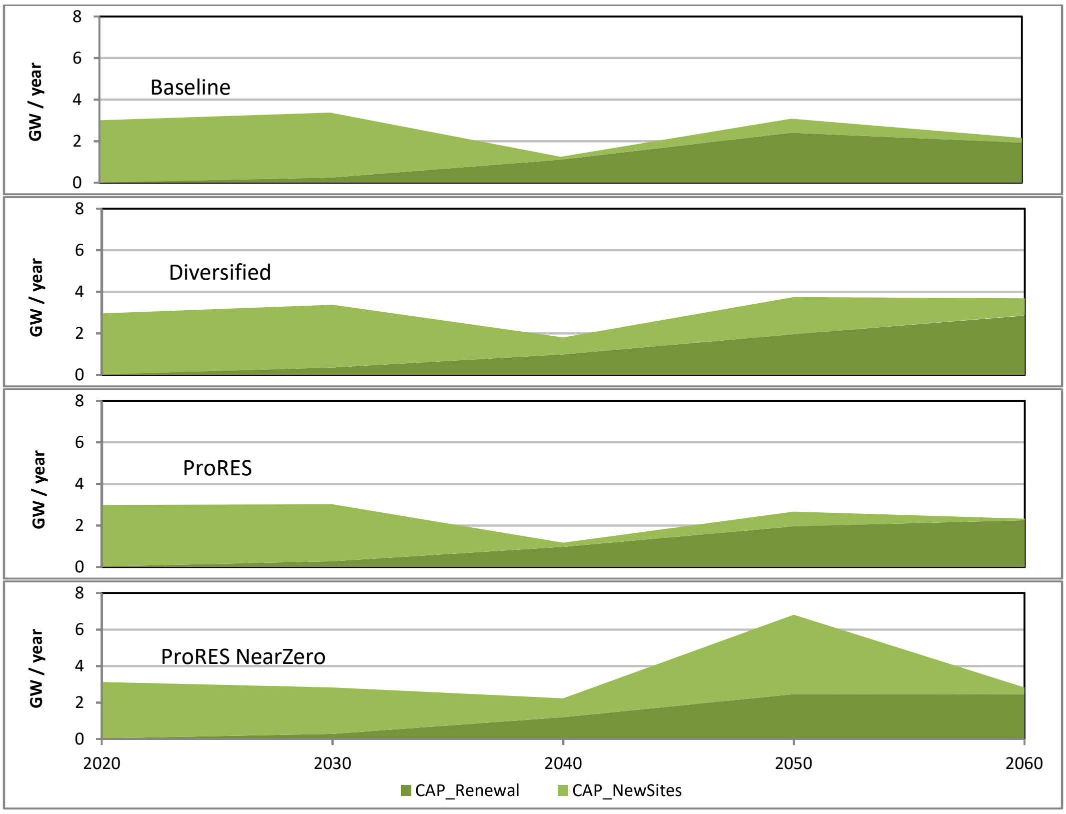

Figure 70. Annual capacity additions in biomass electricity in the EU in the main scenarios

Source: JRC-EU-TIMES model

The annual investments in the new biomass heat and power capacity also dominates the market until 2040 in most scenarios with the exemption of the Baseline scenario, where the investments in renewal of the biomass plants have the highest share in 2030 in total investments in biomass heat and power plants. The market for the new plants has the highest share in both the Diversified and the ProRes NearZero scenarios. There is a clear trend of increasing the annual investments in biomass heat and power for the renewal of biomass plants that reach the operational lifetime. All scenarios predict a strong increase in annual investments in heat and power toward 2050, followed by a step decrease between 2050-2060 due to the lack of policy drivers post-2050.

The JRC-EU-TIMES model envisages between EUR 211- 468 billion investments in biomass electricity plants until 2050. In particular, the lowest investment in biomass electricity occur in the ProRes scenario, with EURO 179 billion followed by the Baseline scenario with EURO 211 billion Diversified scenario with EURO 292 billion and EURO 468 billion in the ProRes Near Zero scenario. Thus despite the policy support for renewables in the ProRes scenario the investments made in biomass power are the lowest among all scenarios.

Figure 72 shows the annual EU investments in biomass power plants projected by JRC-EU-TIMES for the whole analysed period. All scenarios show a decrease in the annual investments in biomass power capacities between 2020 and 2040, despite the 2030 renewable targets, followed by a strong increase in annual capacity additions in the ProRes NearZero scenario between 2030 - 2040.

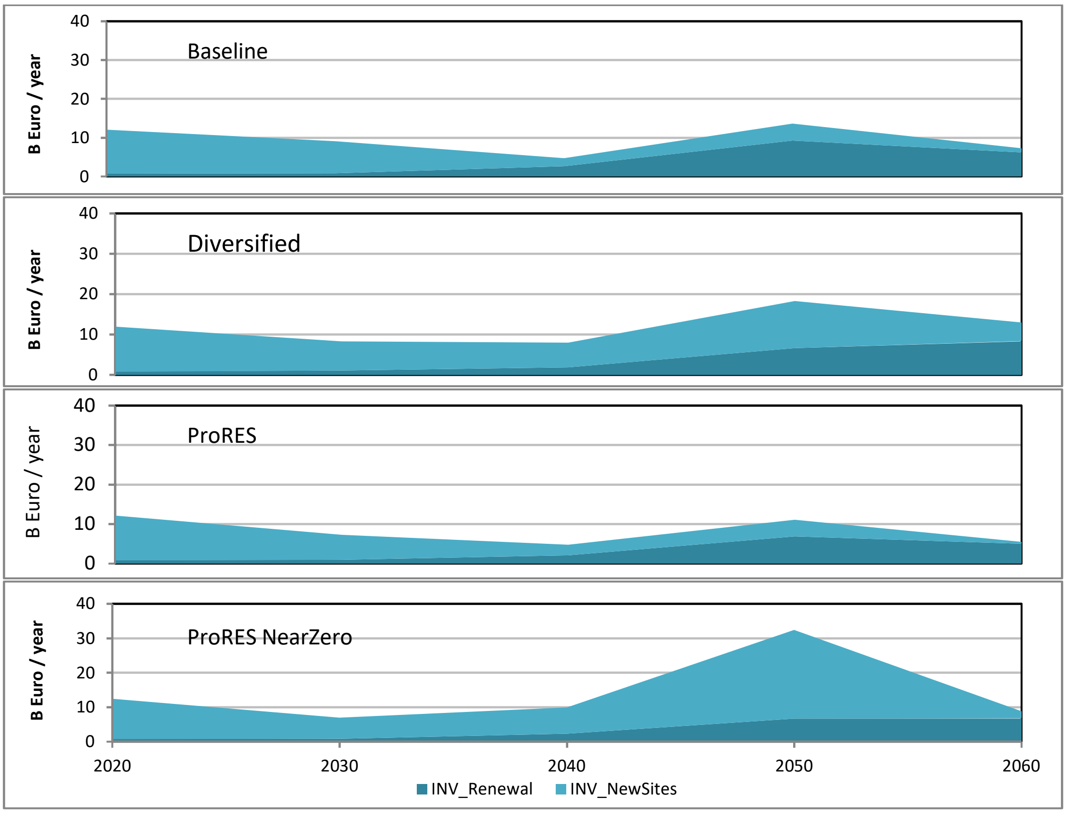

Figure 71. Annual investments in biomass heat and power in the EU in the main LCEO scenarios

Source: JRC-EU-TIMES model

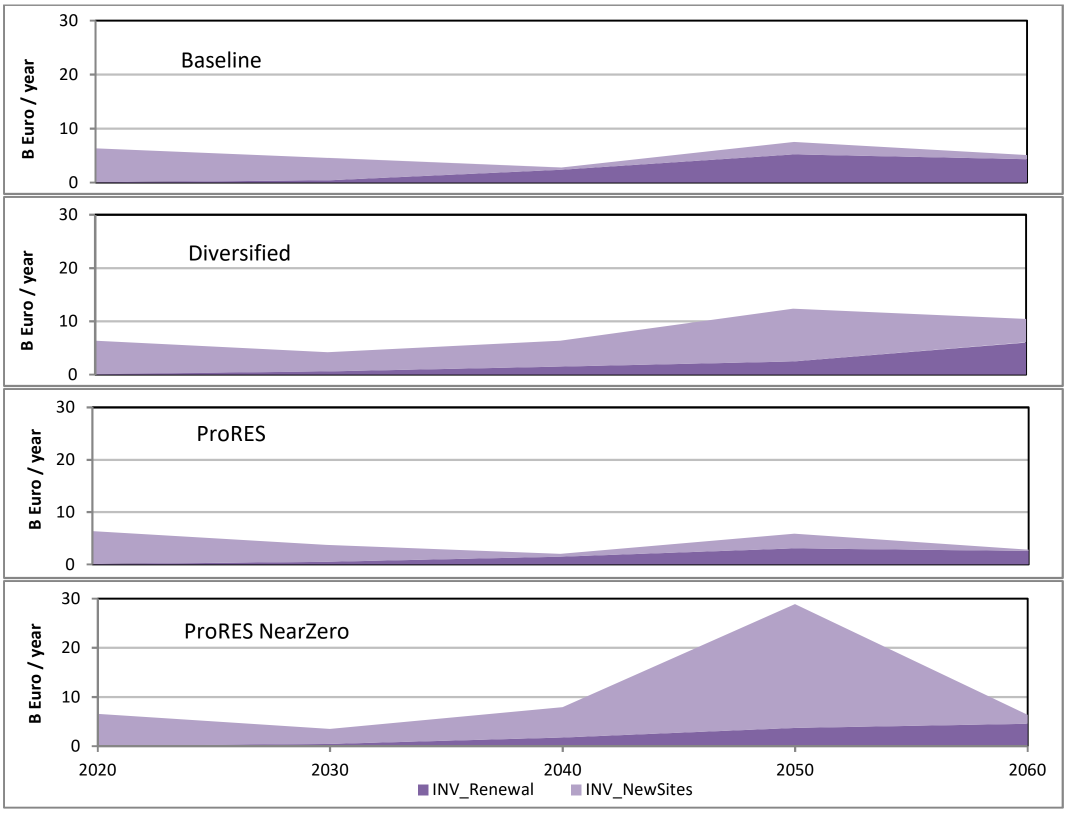

Figure 72. Annual investments in biomass electricity in the EU in the main LCEO scenarios

Source: JRC-EU-TIMES model

The annual investments in the new biomass electricity capacity dominates the market until 2040 in most scenarios with the exemption of the Baseline scenario, where the investments in renewal of the biomass plants have the highest share in 2030 in total investments in electricity plants. There is a clear trend of increasing the annual investments in biomass electricity for the renewal of plants that reach the operational lifetime. The decrease in annual investments in biomass electricity continues in the ProRes scenario continues until 2040. All scenarios anticipate a strong increase in annual investments toward 2050, followed by a step decrease between 2050-2060 due to the lack of policy drivers post-2050.

4.3.3 Capacity additions and investments per Member States

Figure 73 shows the renewable energy capacity installed in the EU Member States until 2050 as resulted from the main scenario of the JRC-EU-TIMES: Baseline, Diversified, ProRes and ProRes NearZero. The results show the distribution of the capacities added by 2050, per country and the significant differences among different countries, between different scenarios and the contribution of different types of plants. The total capacity increases where more ambitious carbon policies aiming at higher CO_2 reduction by 2050 are implemented (ProRes and Prores NearZero scenarios). Thus, achieving 95 % CO_2 reduction by 2050 without new nuclear and CCUS ("NearZero'-scenario) would lead to the highest capacity installed until 2050 in all EU Member States. While the Baseline and Diversified scenarios predict a large contribution of power plants using fossil fuels (coal and gas), the ProRes and ProRes NearZero scenarios predicts a significant large capacity of wind and solar in particular in the more ambitious scenario. Leading countries in the installed renewable electricity capacity include France Italy, Germany and UK in all scenarios, but with a slightly different order. The top five countries have in all scenarios around 65 % of the total capacity in the EU with the top three countries having between 40 % - 45 % of the total capacity in the EU.

Figure 74 shows the biomass capacity installed in the EU Member States until 2050 in the Baseline, Diversified, ProRes and ProRes NearZero scenarios respectively. Significant differences among the different countries are noticeable. The biomass electricity (electricity only and Combined Heat and Power) capacity increases for the Prores NearZero scenario aiming higher CO_2 reduction by 2050 compared to other scenarios. The Baseline and ProRes scenarios predict similarly low capacity of biomass power plants in various Member States. Leading countries in the installed renewable electricity capacity include France, Italy, Germany, UK and Poland in all scenarios, but with a slightly different order. The top five leaders have up to 60 % of the total biomass electricity capacity in all scenarios with the top three countries having about 40 % of the biomass power capacity in the EU.

Figure 74 show large differences between the biomass capacity in different Member States, between different scenarios and between the share of power plants and the heat plants capacities. The top five MS have a share of between 55 – 60 % of the overall heat and power capacity in the EU. The share of the power plant capacity in total biomass plant capacity lies at around 30 %, while for the ProRes NearZero this share increases to almost 50 %. The ProRes NearZero scenario clearly shows a larger capacity of power plants for most Member States in comparison with heat plants due to the high driver to produce electricity from biomass in this scenario. The largest plant capacity is expected however to come from the heat plants in all scenarios.

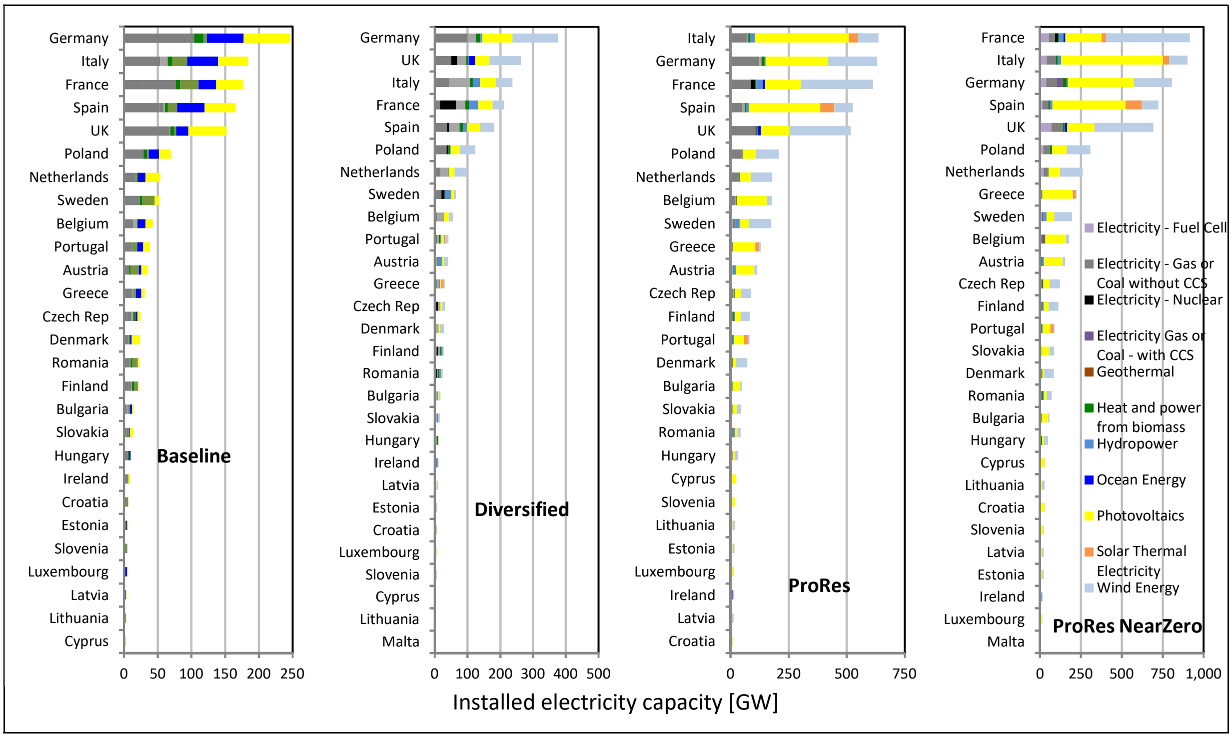

Figure 73. Installed renewable electricity capacity by 2050 in the EU Member States

Source: JRC-EU-TIMES model

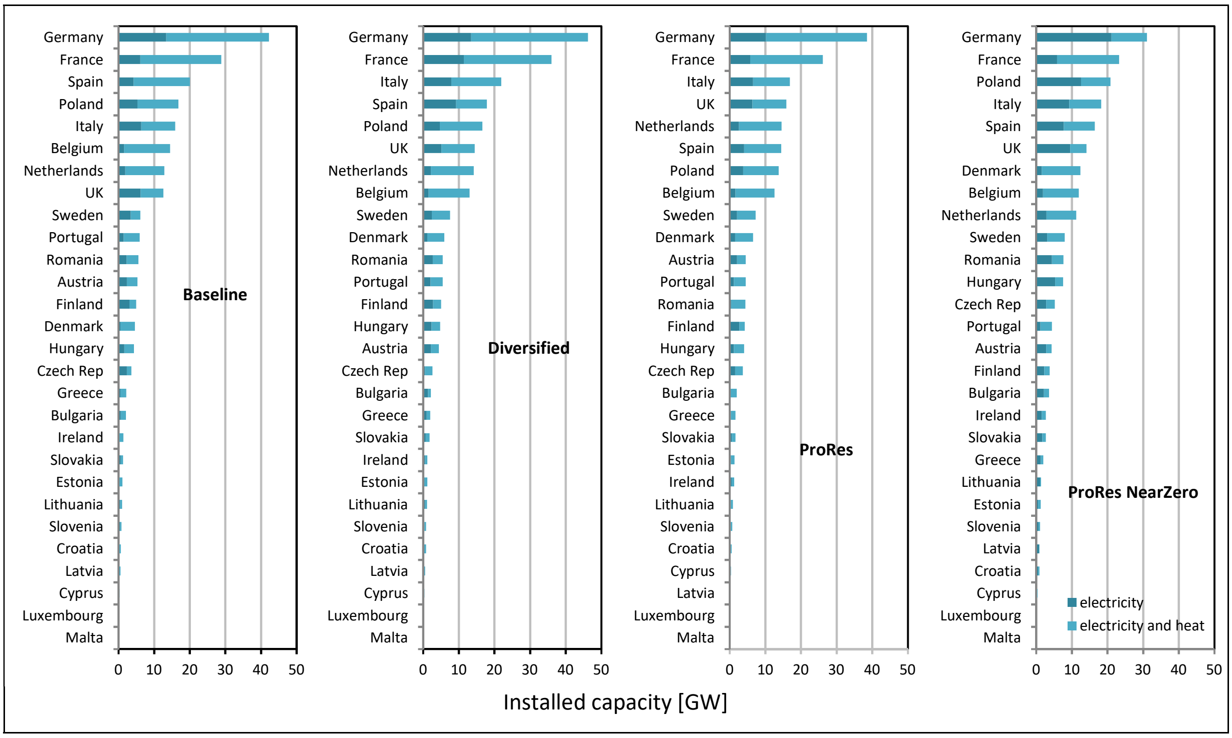

Figure 74. Installed biomass heat and power capacity by 2050 in the EU Member States

Source: JRC-EU-TIMES model

The investments in the biomass power plants have the highest share in the total investments especially in the ProRes NearZero scenario. Thus while the investments in biomass power in total biomass plants ranges between 51-54 % in the Baseline and ProRes scenarios, this share increases to 63 % in the Diversified scenario and up to 76 % in the ProRes scenarios. Figure 75 represents the investments made in the European Union Member States in biomass plants up to 2050 in different JRC-EU-TIMES scenarios. The highest investments during the analysed period are expected to be made in Germany, France, Italy, Spain, UK and Poland, with some variations in different scenarios. The investments in biomass plants the top five Member States are expected to have a share of about 60 %. The differences between different Member States in the investments in power or heat plants are also important, especially in the Baseline, Diversified and ProRes scenarios.

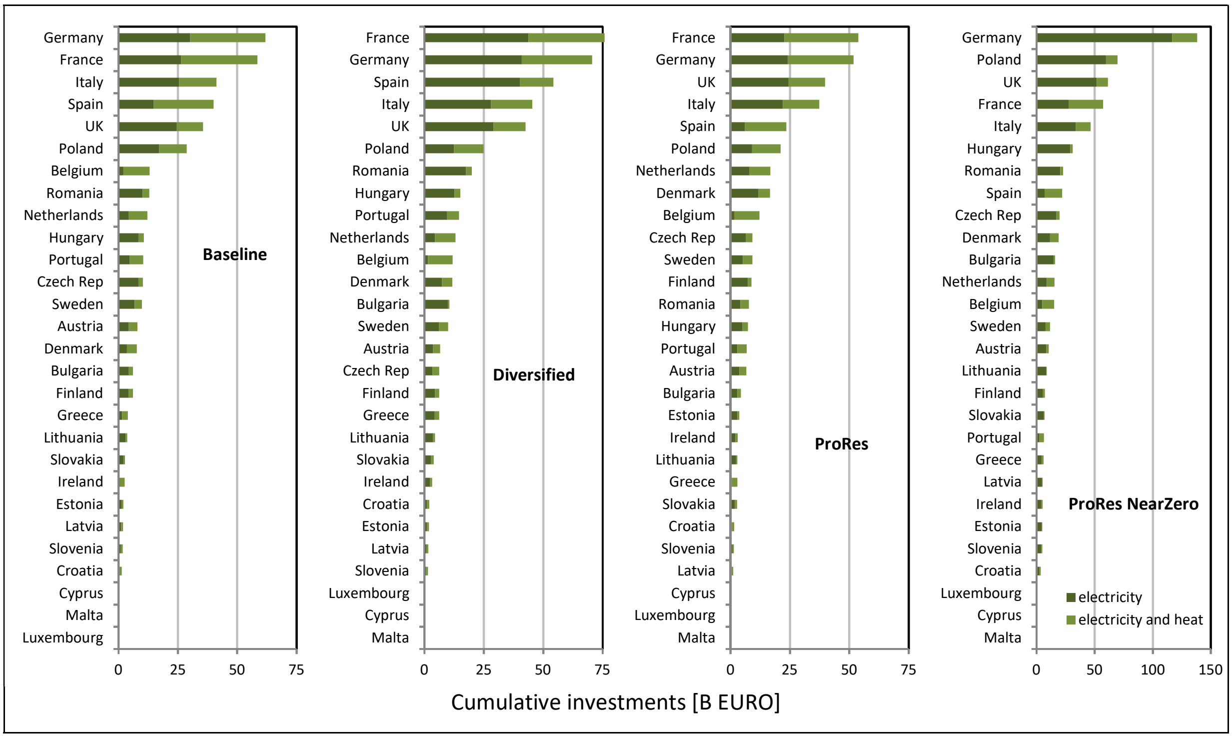

Figure 75. Cumulative investments in biomass heat and power by 2050 in the EU Member States

Source: JRC-EU-TIMES model

4.3.4 Sensitivity analysis

The biomass plants deployment and associated annual investments are not only highly dependent on the assumptions made on biomass electricity and heat costs (CAPEX and OPEX) but also on technology relative performance as compared to other technologies and policy or resource availability restrictions. Sensitivity analysis has been performed on a number of sensitivity cases that have been run to assess the impact of different economic conditions, deployment rates and Learning Rates (LR). The long term cost trajectories of all low carbon energy technologies have been estimated under all scenarios and all detailed related assumptions, derived based on their projected deployed capacity in the Baseline, Diversified, ProRES and ProRES and NearZero scenarios, under the assumptions of high, reference and low technological learning, expressed by varying learning rates. (Nijs et al 2018). Specific inputs include capital expenditure (CAPEX) and fixed operation expenses (OPEX) cost trends, together with learning rate values for solid biomass and biogas for biomass heat and power gasification, ORC and AD, having Reference Learning Rates, Low Learning Rates and High Learning Rates[1].

[1] Solid biomass: Reference LR: 5 %, Low LR 2 %, High LR: 7 %. Biogas: Reference LR: 2 %, Low LR 2 %, High LR: 7 %.

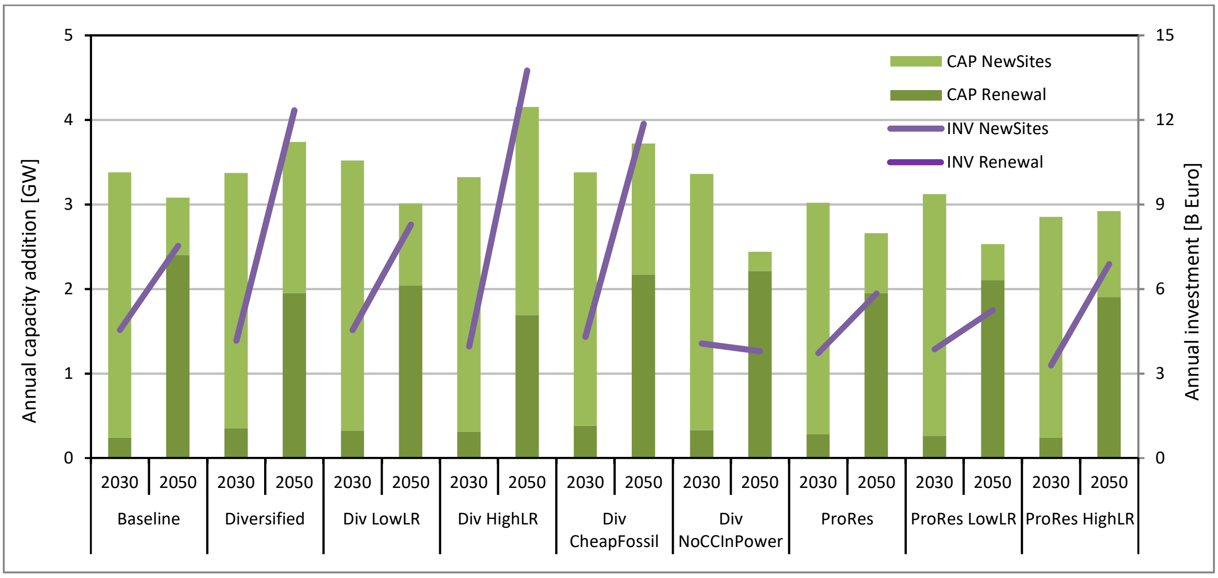

Figure 76. Outlook on the sensitivities of biomass power developments in the EU

Source: JRC-EU-TIMES model

The sensitivity analysis aimed to test the robustness of the scenario results of the main storylines using different technology learning rates (LR) on the costs of biomass heat and power (high LR, low LR), considering variations in main commodities (cheaper fossil fuels) and implementing specific policy related restrictions (no CCS in the power sector). The resulting annual additions and investments for biomass plants have been analysed in the mid- (2030) and long-term (2050) and compared against the different scenarios of the main storylines.

In biomass power in the Diversified scenario the annual capacity additions increases in case of low technology learning (low LR) as the relative beneficial difference with the other technology competitors decreases as compared to the reference case (Diversified); similarly the annual capacity additions increase in the case of high technology learning (high LR) in comparison to the reference technology learning (reference LR) even higher toward 2050 (Figure 76). Annual investments in biomass power plants increase in the high LR as well as the annual investments in biomass power. In case of ProRes scenario with low technology learning (low LR) scenario the results show a decrease in biomass power plant additions in comparison to the reference technology learning, and an increase in additional biomass power capacity in the high technology learning (low LR) scenario. The reduction in fossil fuel (oil and gas) prices by 2030 in the CheapFossil scenario are causing a drop in deployment rates and investments as conventional technologies are more competitive in this scenario as well as a severe drop in the investments in biomass heat due to competition. Conversely, the NoCC InPower-scenario excludes carbon capture from the power and thus the biomass electricity deployment in this scenario decreases and investments are mostly related to the renewal of existing capacities. The investments in biomass power are expected to see a large increase between 2030 and 2050 due to the higher role of electricity in the energy system.

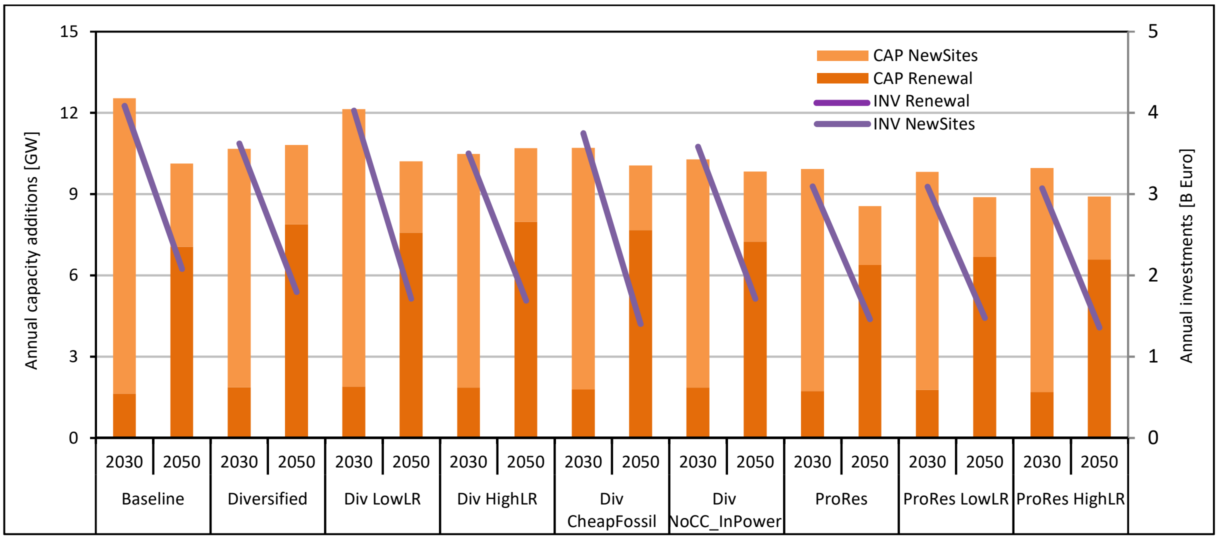

Figure 77. Outlook on the sensitivities of biomass heat developments in the EU

Source: JRC-EU-TIMES model

In biomass heat in the Baseline scenario the annual capacity additions decreases between 2030 and 2050 both for heat plants together with a large decrease in the annual investments (Figure 77). In biomass heat in the Diversified scenario the annual capacity additions increases in case of low technology learning (low LR) as the relative beneficial difference with the other technological competitors decreases as compared to the reference case (Diversified); similarly the annual capacity additions increase in the case of high technology learning (high LR) in comparison to the reference technology learning (reference LR). Annual investments in biomass heat plants also decrease much more in low LR than in the high LR due to the advantages in biomass heat compared to other low carbon technologies. In case of ProRes scenario with low technology learning (low LR) scenario the results show an increase in biomass heat plant additions in comparison to the reference technology learning, and an increase in additional biomass heat capacity in the high technology learning (low LR) scenario. The investments in biomass heat are expected to see a larger decrease between 2030 and 2050 due to technology learning compared to the trends in annual capacity additions. The reduction in fossil fuel (oil and gas) prices until 2050 in the CheapFossil scenario are causing a drop in deployment rates as conventional technologies are more competitive in this scenario as well as a severe drop in the investments in biomass heat due to competition.

The results of the JRC-EU-Times model are well in line with the EC 2050 long-term strategy, the EU long-term strategy for a climate-neutral economy by 2050 and the IEA Bioenergy Roadmap and the EU Roadmap for 2050 as well. The JRC-EU-Times model provides a more comprehensive and detailed analysis of the future energy developments until 2050 both at European Union level and the Member States level as well. In addition it provides, a more detailed technical-economic analysis for the power and heat sectors at Member States level including detailed capital expenditure (CAPEX) and fixed operation expenses (OPEX) cost trends, together with learning rate values for different biomass feedstocks and bioenergy technologies.

4.4 Key sensitivities and barriers to market expansion

4.4.1 Benefits and risks of bioenergy

Bioenergy production brings significant opportunities to deliver a number of social, environmental and economic benefits in addition to the energy and climate goals and to promote sustainable rural development (IEA 2016b). The benefits and the impacts of biofuels or bioenergy production depend however, on the specific context. Local bioenergy production reduces the need for imported fossil fuels, increases energy security and provides income-generating opportunities, thus contributing to local economies (Diaz-Chavez et al 2014, Fritsche et al 2017, IEA 2016b). Bioenergy contributes to food supply, in particular in the areas where the lack of energy creates difficulties in ensuring food supply, supporting food industry, storage and refrigeration and providing fuel for transport. There are, however, environmental, social and economic concerns about the use of biomass for bioenergy. Bioenergy can have negative impacts if not developed properly. Key concerns are the real GHG emissions from some bioenergy pathways, impact on food security, land use change and biodiversity, and increased competition for raw materials (food, feed, fibres, materials or energy).

There are both technical and non-technical barriers to large scale bioenergy market expansion. Thus, the deployment of sustainable bioenergy is affected by many factors, such as biomass characteristics and variability, availability of sustainable biomass, logistics of feedstock supply, technology development and economical and social factors. One of the most important barriers to large scale deployment of bioenergy technologies includes uncertainties about legislation and unpredictable economic conditions that affects the confidence of investors on bioenergy. Other major barriers faced by large-scale bioenergy deployment include the inadequate information on biomass availability, absence of organized formal biomass markets, logistics (collection, handling, transportation, processing and storage), problems associated with setting up large size biomass plants and lack of capability to generate bankable projects.

4.4.2 Biomass characteristics, availability and logistics

The availability of sustainable biomass is a major barrier for large scale deployment of bioenergy technologies. There are significant uncertainties with regard to real biomass potential (either technical, economic and sustainable) for energy use and a wide range of estimates due to difference in approaches, assumptions, aggregation levels. Biomass mobilisation, the cost of mobilisation and competitive uses are important factors for bioenergy deployment. The location of a biomass plant depends on the spatial distribution of biomass and on local availability of biomass and accessibility, which are determining factors for the plant capacity and cost of feedstock.

A major issue of biomass use relies on its physical properties (e.g. low density and bulky nature), chemical properties (e.g. high ash and moisture content, nitrogen, sulphur or chlorine content) and wide variability among different feedstocks and even for the same feedstock. Biomass properties make transport, handling and storage highly challenging. High moisture content can lead to quality degradation, material loss, and safety issues during storage. Biomass quality is variable and inconsistent with feedstock type, source and season, resulting in significant challenges in handling, pre-treatment and conversion systems and reducing the reliability and efficiency of the plants. Biomass densification and pre-processing could result in feedstock losses and increased cost.

A main issue regarding the viability of bioenergy lies in the development of a reliable, integrated biomass supply chains from cultivation, harvesting, transport, storage to conversion and by-product use. Secure, long-term supply of sustainable feedstock is essential to the economics of bioenergy plants. There are a number of issues that must be considered in terms of resources (amount, multi-annual variability), logistics (security of supply, harvesting period, storage, and transportation), energy (heat) demand etc. The complex logistics of supplying a plant with high amounts of bulky biomass with variable characteristics are a serious limitation for bioenergy deployment. The transport of high biomass volumes over long distances leads to high traffic and high cost of feedstock. The operation of the plant requires high number of supply contracts over long term, which might be challenging. In addition, the increased demand of biomass in the area drives up local feedstock costs, which affects the cost-effective plant operation.

Planning a bioenergy plant is a challenge, requiring a careful evaluation of the resources available, but also other competitive uses of biomass and local heat demand, and requires a detailed local analysis. The competition for biomass resources can be important, involving traditional small-scale energy use but also large-scale applications, for pulp and paper, wood processing, biobased industry, etc. Water availability is also an important issue to consider and might have a large impact on future biomass availability.

There is a lack of a commodity market for biomass as feedstock (wood chips, crop residue etc.), with clear technical specifications in a product standard (e.g. size, chemical and physical properties, density, energy content, etc.). This would enable market transactions and trade in biomass feedstocks. In contrast, wood pellet standardisation of a feedstock with certain specifications has created a global market where pellets are traded on a large scale.

4.4.3 Economics

The economics of bioenergy production are one of the major challenges for the large-scale deployment. In most cases, bioenergy cannot compete on cost and reliability with conventional fossil fuel options. The economics of bioenergy production depend on many factors, such as the general economy conditions (energy price, support policies and regulations, carbon pricing, etc.), the technology and process configuration (capital and operating costs, conversion efficiency, process reliability), plant capacity, feedstock used (type, quality, and cost), etc. (IEA 2009). Since bioenergy technologies require significant investments, the financial support has so far been a significant factor for large scale bioenergy deployment.

The main barriers for bioenergy deployment are the high up-front costs for bioenergy projects. Capital costs show a large range, depending on various factors: process configuration, plant capacity and feedstock type. Biomass plants, using complex handling and feeding systems or pre-treatment (steam explosion, hydrolysis, torrefaction, etc.) for difficult feedstocks require higher capital and operating costs. Thermal processes are especially expensive due to the large effort needed for gas cleaning to comply with stringent air emission limits and the requirements of subsequent process steps (poisoning catalysts or affecting biological processes, etc.).

Various bioenergy routes vary in terms of commercial maturity and their cost reduction depend on the technology improvements. The process reliability is a significant factor driving up the operation cost and thus the overall economics of the plant. New technologies also have high investment risks, as the technology or costs are still to be proved and this might impair on the technology deployment. Technology advancement could lead to cost improvement over time through learning and improvement in competitiveness. This could also impact on lowering the investment risk and contribute to higher deployment rates over time.

There are significant economies of scale of bioenergy. While higher capacity plants require lower specific investment costs, their capacity is generally limited by the feedstock availability and increasing transportation cost for large amounts of biomass (Mott MacDonald 2011). In many cases, a bioenergy plant is economically viable if biomass feedstock is available at low cost, especially due to the fact that feedstock cost has a significant share in the overall cost of energy production. Biomass feedstock costs can be zero for some by-products (e.g. black liquor, bagasse etc.) or wastes which would otherwise have disposal costs (e.g. municipal solid waste). On the other hand, increased demand for feedstock might lead to increased feedstock prices locally (JRC 2013).

The economic competitiveness of bioenergy could be improved in biorefineries with the production of high-value products in addition to bioenergy. Combined Heat and Power (CHP) could improve the economic performances of bioenergy plants, providing additional income from the selling of heat. However, the use of heat is limited by the local heat demand for buildings or industry, by its seasonal variation, and by capital costs of the heating/cooling network (LCICG 2012, JRC 2013).

4.4.4 Technological development

The bioenergy conversion technologies undergo significant advances. However, technological development still remains a key issue to improving the economics of bioenergy through the improvement of the performances, reliability and conversion efficiency. Biomass characteristics pose technical challenges for handling, pre-treatment, plant reliability and plant performances. The raw material flexibility of processes is also a challenge, and still needs to be improved.

A major issue of thermochemical conversion processes is the high complexity of processes, leading to a high number of co-products that require advanced process control, cleaning and purification. Flue gas and syngas contain a range of contaminants, depending on the feedstock, design and the process parameters, requiring extensive gas clean-up to reduce contaminant concentrations to very low levels, depending on subsequent steps. A key challenge is further improvement of cleaning, separation and purification technologies, requiring new materials and processes. A key challenge remains ensuring consistent and controlled quality of the end-product through better controlled processes, which is a prerequisite for market penetration and reliable use in various applications.

Improving energy conversion efficiencies (combustion, liquefaction, pyrolysis etc.) requires optimisation, improving of operating parameters, which entails new materials, improved design and process control systems. Air emissions from combustion could affect air quality and pose health risks. Numerous technologies are available for flue gas cleaning from large-scale combustion to reduce emissions to acceptable levels. Advanced process control systems and cleaning technologies are also available for small-scale heating applications that would produce low level of pollutants, although requiring higher costs. Replacing the traditional use of biomass by modern bioenergy contributes to the improvement of air quality by reducing indoor and outdoor air pollution.

Various biological technologies are at early stages of development, with only low conversion efficiencies achieved so far, requiring long-term basic and applied research. Key technical challenges include improving biodegradability, optimising conversion, engineering design and process integration. Poor performance of conversion technologies requires to improve cultivation techniques, to identify/engineer new strains that are robust to a variety of conditions and less susceptible to contaminants/pathogens to increase conversion efficiencies to achieve optimal process operation. There is a need to integrate biological and thermochemical processes. A key point for the integration of biochemical processes is their adaptation to the processes that can result in by-products that inhibit down-stream processes.

A major issue for deployment is the lack of the demonstration the technical and economic performances. This impairs the scale-up of and large-scale deployment of bioenergy technologies. Deployment of bioenergy requires demonstration projects at a relevant scale, which will be costly but crucial for improving and verifying technical performance and to achieve cost reduction. As biomass-based processes are often resource constrained, another general challenge is downscaling of the processes, in order to enable smaller units to be developed and operated profitably.

4.4.5 Rural sustainable development

The debate on the sustainability of biofuels, food versus fuel, and land use change often overlooked potential positive effects, such as sustainable rural development. Improved access to reliable and affordable energy, through the use of modern bioenergy, offers opportunities for poverty reduction and rural development, by supporting economic activities and economic growth. Higher income from various economic activities improves access to energy. Biomass can be used for distributed generation of power at small-scale, against the centralized power production and thus local modern bioenergy enhances energy access for energy-deprived and remote and off-grid communities.

Bioenergy provides opportunities to promote sustainable agriculture, to improve agricultural practices and drive sustainable rural development. Countries that lack energy access are very often dominated by subsistence agriculture, with poor people living in rural areas lacking adequate access to basic infrastructure, clean water, sanitation and electricity. The production of biomass for energy leads to enhancing agricultural or forest production systems while mitigating negative impacts on the landscape and local communities, and avoiding unsustainable land use through adequate land use planning (IEA 2016b). Integrating novel biomass production into agriculture and forestry in multi-functional land uses, through crop rotations, multi-cropping, multi-purpose crops, intercropping, and agroforestry can meet the increased demand for multiple uses.

The use of biomass for energy raised concerns that include the risks of increased competition between food and non-food uses of biomass that might put at risk local food supplies, food security and access to land and water resources, while bringing little benefits for local population other than additional income. Positive effects of bioenergy production include enhanced economic conditions of rural communities, leading to increased energy and food security, food accessibility and affordability (IEA 2016b). Bioenergy pathways, from biomass production to end use, provide job opportunities, including skilled labour that can be a driver of industrial development (including food industry) in rural areas (Nogueira et al 2015, Osseweijer et al 2015, FAO 2017).

Biomass production for energy stimulates rural development and leads to improvement of supply chain logistics and local infrastructure that are beneficial for food production as well. New infrastructure for bioenergy could offer new job opportunities and thus income generation, thereby increasing overall food availability and accessibility. Bioenergy can increase food security by improving farming practices and investments leading to increased crop productivity. The use of agri and forestry residues for bioenergy, and the use of marginal, abandoned or degraded land for feedstock production can minimize food-bioenergy competition (Fritsche et al 2017).

4.4.6 Integration into energy systems

A number of bioenergy solutions are available and they are applied at various size ranges. Sustainable and modern bioenergy is not only relevant for residential uses, small-scale in stand-alone applications or mini-grids, providing solutions for rural electrification. Bioenergy provides solutions for large-scale power production, high-temperature process heat for industry and biofuels for agriculture and transport. Biomass use for heat and power production can be used as a base-load to provide continuous electricity, as well for load-balancing. Biomass power production offers certain flexibility capability in operation, allowing generating electricity at the moment it is needed.

Increasing shares of variable renewable in energy grids requires changes in infrastructure including energy storage, transmission capacity, and frequency and power flow control systems. Bioenergy can provide flexibility of generation patterns to balance the expansion of intermittent and seasonal wind and solar and thus allowing the integration of higher shares of renewables into the electricity grid. Biogas can be used in connection with gas storage to compensate for the variable renewable energy production and energy demand. Biogas can be also upgraded at natural gas quality and injected into the gas network to be used where energy is needed and at the moment where it is needed. Biogas can be upgraded and be used as sustainable transport fuel.

Bioenergy can have a significant role as a flexible component for heat production. Biomass CHP plants could offset heat shortfalls through heat storage and vary their electricity output in response to grid conditions and provide grid flexibility. However, the flexibility is limited and also depends on the heat demand which has to be satisfied through the steam extraction. Bioenergy hybrid systems are available in the heating sector, particularly for small scale in residential sector and in the district heating network at larger scale. Integrated bioenergy hybrids for energy conversion can ensure flexible operation for both energy supply and energy storage in combinations that include solar thermal systems, concentrated solar power, heat pumps, geothermal and waste heat recovery.

Biomass is a key option for a fast and significant decrease of carbon emissions into the atmosphere on short term. Biomass combustion coupled with Carbon Capture and Storage (CCS) is a unique option for providing negative emissions from power production. This is a key solution for the various scenarios where a much faster decarbonisation pathway is pursued and carbon emissions rapidly decline in order to reach net-zero emissions sooner. Carbon captured from anaerobic digestion and from power production can be used as a feedstock for biomethanation and for algae production.

4.4.7 Sustainability

Various concerns have been expressed on several aspects related to the sustainability of biomass use for biofuel production. The sustainability of biofuels has been mostly questioned based on the concerns over the real GHG emission reduction of biofuels, as well as the impact on food security or indirect land use changes. Although sustainability encompasses three dimensions (economic, social and environmental) most interest focussed on the environmental aspects.

As result of these concerns on biofuels, sustainability certification has emerged to make sure that biofuels are produced in a sustainable way, while negative effects are reduced or eliminated. Certification schemes have been developed long time ago, addressing agriculture or forestry, as result of various concerns or specific purposes (fair-trade, environmentally sound cultivation, organic agriculture, etc.) to gain market access, or to develop a green business profile. Due to the fact that these systems have been developed with different interests and priorities, their scope and requirements vary. No forest certification systems have yet included carbon accounting, due to the different scope of certification or disagreement about methodologies. Agricultural certification schemes include environmental, economic and social aspects and cover to some extent soil conservation and air quality issues (Scarlat and Dallemand 2011, Pelkmans et al 2014).

Along with the proposed targets for renewable energy, the Renewable Energy Directive 2009/28/EC proposed a set of mandatory sustainability criteria as part of an EU sustainability scheme. A large number of national and international initiatives, regulations and voluntary sustainability standards have been developed, driven by the legal sustainability requirements set in the United States and in the European Union. Sustainability certification systems for biofuels in the European Union, such as International Sustainability & Carbon Certification (ISCC), RSB, REDCert, NTA 8080, 2BSvs, etc., have been developed to show compliance with the European RED requirements. The sustainability criteria for liquid biofuels for transport, did not apply for solid and gaseous biomass on EU level.

The new Directive 2018/2001 includes new, reinforced EU sustainability criteria for bioenergy and extended their scope to cover biomass and biogas for heating and cooling and electricity generation in addition to biofuels. A new requirement is being introduced for ensuring proper carbon accounting of forest biomass used in energy generation, in line with the Land Use, Land Use Change and Forestry (LULUCF) sector rules. Sustainability and GHG criteria apply to all biofuel/bioliquid and biogas plants with a capacity above 0.5 MW and to solid biomass plants with a capacity above 20 MW. Bioenergy from waste and residues needs to meet only the GHG saving criteria. The GHG saving requirement applying to biofuels is increased to 60% for plants in operation after October 2015 and to 70% for new plants (plants in operation after January 2021). A 80% GHG saving requirement is applied to biomass heat and power (after 1 January 2021) and 85% for plants starting operation after 1 January 2026. Electricity in large scale plants (above 20 MW) must be produced through high-efficient cogeneration and meet the sustainability and GHG criteria.

The new sustainability requirements covering all bioenergy pathways are a major step forward, being expected to provide more transparency and play a positive role in addressing sustainability concerns. Although strict sustainability requirements could limit biomass availability, adequate requirements are critical to ensure the long-term availability of biomass and to increase public acceptance of bioenergy. Currently sustainability requirements have been established only for the biomass use for biofuels and bioenergy. The same feedstock, even having similar environmental, social and GHG impacts, do not need to fulfil such requirements when used for other purposes. Applying a double-standard policy between biomass production for bioenergy and food, feed, fibre or biomaterials is very likely to lead to indirect displacement effects (Scarlat and Dallemand 2011).

4.4.8 Public perception and public acceptance

Although the European public is generally aware of climate change and supportive of renewables, public acceptance has been a major barrier to all renewable energy projects, due to a generally limited knowledge and understanding among the general public. The public perception is a determining factor for their acceptance or resistance toward bioenergy. In general, public perception on bioenergy has been shaped by the long debates on the sustainability of biofuels and alleged negative impacts on food security and impacts on (indirect) land use. Perception of bioenergy differs from country to country, directly linked to local economies and traditions. In the case of bioenergy, many people might be aware about the bioenergy benefits and the environmental, social and economic advantages for a society, but also about the risks and negative aspects of unsustainable large-scale cultivation of energy crops on agricultural land. Public acceptance is often better for small scale systems than for large scale applications, irrespective of emissions or compliance with sustainability criteria.

Public acceptance is a vital for any project and a key factor influencing the large-scale implementation of renewable energy technologies and the achievement of energy policy objectives. Public acceptance affects the support for a new technology among policy makers. The public acceptance of bioenergy can be, in some cases, lower than other renewables like wind or solar energy, especially in the areas where there is a lower level of awareness about bioenergy. This is based on negative perceptions of the impact of bioenergy on GHG emissions, land use changes or food security. There is also a negative perception about the economic impact of various support schemes, which are perceived as providing overpayment to renewable energy projects. Local people accept the need for renewables in addressing the energy and climate challenges, but do not necessarily accept the need to build plants locally due to the potential negative impacts on the local environment, biodiversity, air emissions, competitive uses of biomass, etc. This results in low public support to bioenergy and even opposition to some projects.

Public opposition might come from local residents that would be affected by bioenergy projects (traffic congestion, odour, noise, emissions, biodiversity, local economy, but also from NGOs and environmental protection organisations that are concerns about the global impacts (biodiversity, GHG emissions, food security etc.). A relatively high level of support for renewable energy and bioenergy can be expected from the people who are more concerned about the environmental and climate change issues. The level of knowledge and awareness about the real impacts and benefits of bioenergy are determining for the support for bioenergy development.

One of the most important ways to improve the understanding and acceptance of bioenergy is to develop efficient and transparent communication. Providing complete and adequate information on the various aspects would aid decision makers and facilitate investments. More information is needed on the real environmental and sustainability impacts of bioenergy projects and their net benefits through improved communication of success stories for bioenergy production and how different potential negative impacts have been avoided or reduced. Additional bioenergy benefits need to be publicised, such as social aspects (employment, income and wealth creation) and contribution to regional development (increased productivity, improved infrastructure, induced investment, support for related industries). Integrating local stakeholders in the bioenergy pathways can improve the acceptance of bioenergy projects. Bioenergy sustainability certification is a good approach to address the concerns about sustainability of bioenergy as a way to improve the acceptability of bioenergy systems among people, environmental organizations, and policy makers.

5. Conclusions

Global developments

The global use of biomass for energy production has increased to about 56 EJ in 2016, a 30 % increase between 2000 and 2016. The major feedstock used for bioenergy production are been solid fuels (fuelwood, charcoal, wood chips, wood and forestry residues, etc.) with a marginal contribution from the use of municipal waste, biogas, bioethanol, biodiesel or other liquid biofuels.

The share of biomass of the total global primary energy consumption is around 10% while the biomass share in the final energy consumption is about 12%. Bioenergy represents the major component of the renewable energy portfolio, although its share decreased to about 72 % in 2016, together with a large growth in other renewables, in particular in the solar and wind sectors. Even in the European Union, bioenergy has a major role as renewable energy source in the energy of mix about 60 % of renewable energy. The share of bioenergy in primary energy supply is particularly high in Africa (above 50 %), Central and South America with a contribution of 21 % and 24 % respectively, mostly due to the traditional use of biomass (for cooking, lightning).

Biogas production from the treatment of wet-waste biomass, wastewater treatment plants and landfill gas recovery is expanding worldwide. Biogas is produced primarily by landfill gas recovery plants or small-scale family digesters, mainly in small, domestic-scale digesters to provide a fuel for cooking or even lighting in developing countries.

The use of biomass for heat production plays a key role to renewable heat supply worldwide, with 45 EJ in 2014, a share of 80 % of total global biomass demand. Almost two third of biomass use for heat production was traditional biomass use, mainly in rural areas in low-income areas in Asia and Africa. Biomass also accounted for over 90% of modern renewable heat generation in 2016 at large scale in households in stoves or small boilers and in large-scale boilers or in district heating.

The analysis of the sources of biomass into the final energy supply shows significant differences between different world regions). While the major sources of biomass come from the use of solid biofuels in Africa and Asia with a share above 90 %, other regions of the world show a more balanced distribution of biomass feedstock that include solid biofuels, bioethanol biodiesels, biogas and other liquid biofuels.

Biomass power generation has a major role in the renewable electricity generation worldwide, reaching almost 500 TWh in 2016, from 131 TWh in 2000. Bioelectricity production increased significantly worldwide, in particular in the European Union and Asia, followed by South America, but the growth rate decreased in the last years due to policy uncertainties about debates about biomass sustainability. Electricity production from biomass represented globally 8% of total renewable electricity production in 2016, while this share was about 19 % in the European Union.

Global bioelectricity capacity increased from 29 GW in 2000 to 109 GW in 2016. Significant increase in the biomass installed power capacity has been noticed in all world regions. In terms of bioenergy capacity, Asia has a leading place (32 GW), followed by the European Union (30 GW) South America (17 GW) and North America (14 GW). Africa, despite a leading global position in the use of biomass for energy, had only 1.2 GW installed capacity, clearly proving the prominent role of the traditional use of biomass. The market in Asia seems to be more dynamic compared to all world regions, while the increase of power capacity seems to be levelled up lately in the EU.

The global installed biogas capacity reached in 17 GW in 2016, from only 2.4 GW in 2000. The European Union is by far the leading region in terms of biogas installed electricity capacity with 12 GW. While the annual growth rate in the biogas installed capacity decreased in the European Union, the annual increase in installed capacity is significantly higher in Asia. Electricity production from biogas has increased significantly worldwide from 13 TWh in 2000 to 85 TWh in 2016 (17% in total biomass power production), favoured by the possibility of using various wet biomass feedstocks.

Heat and Power from Biomass in the European Union

The European Union is a world leader in bioenergy production. In the European Union, significant progress has been registered in biomass supply for bioenergy production, which increased from 2.5 EJ in 2000 to 5.8 EJ in 2016. Despite important developments in all renewables, the share of bioenergy in renewable energy in the European Union still represents about 60 %. The growth trend seems to be levelling out in the last years both in bioenergy and in other renewables due to the uncertainties in supporting policies and decrease in oil prices.

The bioenergy development in the European Union is in general according to the projections made in the National Renewable Energy Action Plans (NREAPs) (with the exception of biofuels), reaching about 4.9 EJ gross final bioenergy in 2016, in comparison to the expected level of 5.8 EJ for 2020. This shows that the progress made in bioenergy is in line with the expected trajectory and the target for 2020 for bioenergy is expected to be reached.

The development in biogas production in the European Union is remarkable. Biogas production has seen an impressive growth in the European Union, from only 92 PJ in 2000 to 695 PJ in 2016. The share of biogas into bioenergy supply in the European Union increased steadily from less than 4 % in 2000 to almost 12% in 2016. Biogas contribution to gross final energy supply increased from 77 PJ in 2005 to 376 PJ in 2016 being about 25 % above the projected level in the NREAPS.

Biomass is the largest contributor to renewable heating and cooling. Despite the fact that biomass heating is expected to grow from 2.5 EJ to 3.8 EJ between 2005 and 2020, its share in renewable heating will decrease from 97% in 2005 to 80% in 2020, due to higher growth of other renewables. Biomass heating has increased at a higher rate compared to the expected trajectory in the NREAPs reaching in 2016 about 96 % of the 2020 target.

Electricity generation from biomass has increased significantly in the European Union, from 34 TWh in 2000 to 181 TWh in 2016 and is expected to increase to 233 TWh in 2020. Although the annual growth rate of electricity generation seems to be decreasing in the last years, the data from progress reports shows that biomass electricity generation is on track to reach the 2020 target, despite the additional capacity needed until 2020. The installed bioenergy power capacity in the EU increased from 19 GW in 2005 to 30 GW in 2016. Despite this growth, it seems that the total installed electricity capacity is well below the planned capacity for 2020. Thus, after some progress made until 2012, the annual addition rate of biomass power capacity started to decrease.

The investments in biogas sector have brought the biogas electricity capacity in the European Union at 11.4 GW in 2016, increasing from 3.1 GW in 2005. The biogas electricity capacity is thus already above the expected biogas capacity for 2020. The recent developments on biogas brought the electricity production at 63.0 TWh, 32% above the expected level for 2016 and just under the expected level of 63.9 TWh biogas electricity in 2020. These developments, in comparison to bioenergy, have brought the share of biogas in the biomass electricity to 35% in 2016.

Outlook

Compared to the current level of deployment, the contribution of bioenergy should increase significantly if global climate change goals are to be met according to the IEA Bioenergy Roadmap. Biomass use is expected to grow from 56 EJ in 2015 to almost 100 EJ in 2060 in the RTS scenario and to around 145 EJ in both 2DS and B2DS scenarios. The contribution of bioenergy was limited at around 145 EJ, due to the constraints on biomass availability, although different studies provide a range of estimates for the sustainable biomass potentials, most of them between 150 – 300 EJ.

Biomass use for electricity generation can play a key role in the electricity grid by providing flexible, dispatchable power and thus allowing high levels of variable electricity from wind and solar into the power grid. A decline in traditional use of biomass from the current level of 28 EJ to 17 EJ is expected by 2060 in the RTS compensated by an increase in the modern bioenergy production, driven by the progress on improved access to clean energy.

Biomass is expected to play a significant role in the future European Union low-carbon energy system in all decarbonisation scenarios of the Energy Roadmap 2050. The biomass use for energy was projected to grow from 5.8 EJ in 2016 to about 7.8 EJ in 2050 in the reference scenario and between 10.1 EJ and 12.6 EJ in the decarbonisation scenarios. This trend at the European Union level is similar to the projections made by the IEA for the global bioenergy use. Biomass electricity generation is expected to reach 360 TWh in 2050 in the reference scenario and to 460 – 494 TWh in the decarbonisation scenarios. Bioelectricity could rise from a share of 5.6 % in power generation in 2016 to 7.3 % in 2050 in the reference scenario and between 9.3 - 10.9 % in other scenarios.

The JRC EU Times model provides estimates for the developments in the energy sector in various scenarios including the Baseline, Diversified and ProRes main scenarios. The model projections show that the use of biomass for heat and power production will increase to small extent in the EU. The Baseline and Diversified scenarios suggest a biomass supply of 6.1 EJ and 6.2 EJ respectively, while the ProRes and the ProRes NearZero scenarios estimate 7.0 EJ and 7.2 EJ respectively in 2050.

The modelling results indicate that the biomass electricity installed capacity will increase steadily until 2030, when it reaches 74 GW in the Baseline scenario, 72 GW in the Diversified scenario, 69 GW in the Pro Res scenario and 68 GW in the Pro-RES Near Zero carbon scenarios. In comparison, the total installed capacity of all renewables is projected to reach by 2050 in the EU 1428 GW in the Baseline scenario 1944 GW in the Diversified scenario, 4557 GW in the ProRes scenario and 6249 GW in the ProRes NearZero scenario.

The various scenarios show a limited increase in electricity production from biomass, with the exemption of the ProRes scenario that shows a decrease of electricity generation from biomass after 2030 to 184 TWh in 2050, the lowest value of all scenarios. The other scenarios show increased trends in the last simulation period, especially for the Pro-RES Near Zero and Pro-RES No-CCU scenarios, which will reach production values of 367 TWh in 2050.

The new Renewable Energy Directive 2018/2001 as well as the recent EU long-term strategy for a climate-neutral economy by 2050 (COM (2018) 773) provides better, long-term perspectives for the decarbonisation of the energy system. Bioenergy should play a key role in achieving net zero GHG emissions goal, toward the long-term goal of limiting global warming to 1.5°C. Several technologies are available (including biomass combustion and anaerobic digestion for biogas production), while others are developing fast (biomass gasification, pyrolysis, hydrothermal liquefaction, etc.). The Strategic Energy Technology Plan is expected to play a key role in the advancement of key bioenergy technologies through performance and GHG emission savings improvements and cost reduction toward commercial operation and large scale deployment in the European Union.

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Annexes

Annex I. Selection of co-firing plants worldwide (TRL 9 Commercial)

Country	Project Owner	Project name	Technology	Power	Heat
Austria	Mondi Papier & Zellstoff	Mondi Papier&Zellstof	CFB	29 MWel	61 MWth
Belgium	Electrabel	Les Awirs	PF	80 MWel	
Belgium	Electrabel	Rodenhuize	PF	180 MWel	
Belgium	Electrabel	Ruien	PF	540 MWel	
Canada	OPG	Atikokan	PF	227 MWel	100 MWth
Canada	OPG	Lambton 1	PF	500 MWel	20 MWth
Canada	OPG	Nanticoke 4	PF	500 MWel	20 MWth
Canada	OPG	Thunder Bay 2	PF	155 MWel	20 MWth
Denmark	Vattenfall	Amager #1	PF	80 MWel	250 MWth
Denmark	DONG Energy	Avedore #2	Grate	365 MWel	480 MWth
Denmark	DONG Energy	Esbjerg Po Station	PF	150 MWel	
Denmark	Vattenfall	Fynsvaerket #8	Grate	31 MWel	88 MWth
Denmark	DONG Energy	Herningvaerket	Grate	88 MWel	171 MWth
Denmark	Energi Randers	Randers Cogen PP	Grate	52 MWel	112 MWth
Finland	Aanevoima Oy	Aanekoski PP	BFB	38 MWel	230 MWth
Finland	Pori Energia Oy	Aittaluoto PP	BFB	64 MWel	216 MWth
Finland	Stora Enso Publ Papers	Anjalankoski mill	BFB	160 MWel	328 MWth
Finland	Kainuun Voima Oy	CHP plant	CFB	105 MWel	206 MWth
Finland	Kuopion Energia	Haapaniemi PP	PF	89 MWel	180 MWth
Finland	Kanteleen Voima Oy	Haapavesi PP	PF	154 MWel	
Finland	Vattenfall Kaukolämpö	Hameenlinna PP	BFB	60 MWel	175 MWth
Finland	Kotkan Energia Oy	Hovinsaari PP	BFB	50 MWel	85 MWth
Finland	Stora Enso Oyj	Imatra mill	BFB	154 MWel	859 MWth
Finland	UPM-Kymmene Oyj	Jamsankoski PP	BFB	46 MWel	324 MWth
Finland	UPM-Kymmene Oyj	Kaipola mill	BFB	26 MWel	191 MWth
Finland	UPM-Kymmene Oyj	Kaukaa mill	BFB	90 MWel	559 MWth
Finland	Oy Metsä-Botnia Ab	Kemi mill	BFB	83 MWel	466 MWth
Finland	Fortum Power & Heat	Kokkola CHP plant	CFB	188 MWel	287 MWth
Finland	Fortum Power & Heat	Kontiosuo CHP plant	BFB	50 MWel	120 MWth
Finland	Kymin Voima	Kuusankoski PP	BFB	80 MWel	185 MWth
Finland	Lahti Energia	Kymijarvi PP	PF	175 MWel	263 MWth
Finland	Kaukaan Voima	Lappeenranta PP	BFB	117 MWel	252 MWth
Finland	Oy Turku Energia Ab	Linnankatu PP	PF	35 MWel	269 MWth
Finland	Fortum Power & Heat	Naantali CHP plant	PF	260 MWel	440 MWth
Finland	Tampereen Sähkölaitos	Naistenlahti PP	BFB	190 MWel	260 MWth
Finland	Stora Enso	Oulu mill	BFB	95 MWel	569 MWth
Finland	Oy Alholmens Kraft Ab	Pietarsaari PP	CFB	265 MWel	310 MWth
Finland	UPM-Kymmene	Rauma mill	CFB	76 MWel	350 MWth
Finland	Vaskiluodon Voima	Seinajoki PP	CFB	125 MWel	111 MWth
Finland	Stora Enso Publ.Papers	Summa mill	BFB	45 MWel	193 MWth
Finland	Rovaniemen Energia	Suosiola PP	CFB	32 MWel	89 MWth
Finland	UPM-Kymmene	Tervasaari mill	BFB	46 MWel	270 MWth

Country	Project Owner	Project name	Technology	Power	Heat
Finland	Oulun Energia	Toppila PPs	CFB	188 MWel	401 MWth
Finland	Tornion Voima	Tornio PP	CFB	40 MWel	90 MWth
Finland	Vaskiluodon Voima	Vaskiluoto 2 -PP	PF	258 MWel	182 MWth
Finland	Stora Enso	Veitsiluoto mill	BFB	64 MWel	545 MWth
Italy	ENEL	Genova	PF	245 MWel	
Italy	Endesa Italia	Monfalcone	PF	165 MWel	
Italy	ENEL	Sulcis 2	PF	340 MWel	
Netherlands	Essent	Amercentrale 9	PF	600 MWel	350 MWth
Netherlands	EPZ	Borssele 12	PF	403 MWel	
Netherlands	Nuon	Hemweg Centrale	PF	670 MWel	
Netherlands	E-ON Benelux	Maasvlakte 1+2	PF	1,062 MWel	
Poland	EC Webrzeze	Gdansk 2,3,4,5	PF	55 MWel	179 MWth
Poland	ECK	Krakow 1	PF	120 MWel	306 MWth
Poland	ERSA	Rybnik 1,2,3,4	PF	215 MWel	
Poland	Kogeneracja	Wroclaw 1,2,3	PF	3x55 MWel	3x150 MWth
Sweden	Fortum Power&Heat AB	Hasselbyvaerket	PF	279 MWel	
Sweden	Uppsala Energi AB	Uppsula Energi	PF	320 MWel	
UK	RWEnpower	Aberthaw	PF	1,599 MWel	
UK	EDF Energy	Cottam 1,3,4	PF	500 MWel	
UK	RWEnpower	Didcot	PF	2,100 MWel	
UK	British Energy	Eggborough	PF	1,960 MWel	5,200 MWth
UK	Scottish&Southern En.	Ferrybridge	PF	2,035 MWel	
UK	Scottish Power	Longannet	PF	2,400 MWel	
UK	Eon	Ratcliffe	PF	2,010 MWel	
UK	RWEnpower	Tilbury	PF	1,085 MWel	
UK	Drax Power	UK	PF	4,000 MWel	
UK	Welsh Power Group Ltd	Uskmouth	PF	363 MWel	
UK	EDF Energy	West Burton	PF	1,980 MWel	
US	TVA	Allen Fossil Plant	PF	272 MWel	
US	Northern States Power	BL Station 1	PF	120 MWel	
US	NIPSCO	Bailey Gen. Stat. 7	PF	160 MWel	
US	Otter Tail Power.	Big Stone Plant #1	PF	450 MWel	
US	Madison Gas&Electric	Blount Street	PF	100 MWel	
US	TVA	Colbert Plant 1	PF	182 MWel	
US	Niagara Mohawk Po.	Dunkirk Steam 1	PF	90 MWel	
US	Tri-State Gen&Transm	Escalante Gen. 1	PF	250 MWel	
US	Southern/Alabama Po.	Gadsden Steam 2	PF	60 MWel	
US	Tampa Electric Co	Gannon Gen. 3	PF	165 MWel	

Country	Project Owner	Project name	Technology	Power	Heat
US	New York State Elc&Gas	Greenidge Station 6	PF	108 MWel	
US	Southern/Georgia Po.	Hammond Gen. 1	PF	100 MWel	
US	Southern/Georgia Po.	Harlee Branch Gen.	PF	1,539 MWel	
US	Santee Cooper	Jefferies Station 3, 4	PF	165 MWel	
US	Northern States Power	King Gen. Station 1	PF	560 MWel	
US	TVA	Kingston Plant 5	PF	180 MWel	
US	Kansas City Po&Light	La Cygne Gen. 1	PF	840 MWel	
US	Lakeland Electric	Lakeland Electric 3	PF	350 MWel	
US	Duke Power Co	Lee (W.S) Station 3	PF	170 MWel	
US	Future Energy Res.	McNeil Gen. Station	Grate	50 MWel	
US	Northern Indiana Publ	Michigan City 12	PF	469 MWel	
US	IES Utilities Inc	Ottumwa Gen. 1	PF	650 MWel	
US	Rumford Cogen Co.	Rumford Cogen Co.	CFB	76 MWel	260 MWth
US	Reliant Energy	Shawville Gen. 2	PF	138 MWel	
US	Reliant Energy	Shawville Gen. 3	PF	190 MWel	
US	Associated Electric Co	Thomas Hill En 2	PF	175 MWel	
US	Illinois Power Co (IP)	Vermilion Power 1	PF	75 MWel	

Annex II. Selection of torrefaction plants worldwide

Country	Developer	Technology	TRL	Capacity (tonnes/year)
Austria	Andritz	Rotary drum	TRL 6-7	8,000
Belgium	Torr-Coal B.V.	Rotary drum	TRL 9	30,000
Belgium	CMI NESA	Multiple hearth	TRL 6-7	Undefined
Canada	Airex	Cyclonic bed	TRL 6-7	16,000
Canada	Airex	Cyclonic bed	TRL 4-5	Undefined
Canada	Airex	Cyclonic bed	TRL 4-5	Undefined
Denmark	Andritz / ECN	Moving bed	TRL 6-7	10,000
Finland	Torrec	Moving bed	TRL 6-7	10,000
France	LMK Energy	Moving bed	TRL 6-7	20,000
France	CEA	Multiple hearth	TRL 1-3	Undefined
Indonesia	Hip Lik Green Energy	N/A	TRL 9	100,000
Ireland	Arigna Fuels	Screw reactor	TRL 9	20,000
Netherlands	Horizon Bioenergy	Oscillating belt conveyor	TRL 9	45,000
Netherlands	Topell Energy	Fluidised bed	TRL 9	60,000
Netherlands	Konza Renewable Fuels	Rotary drum	TRL 6-7	5,000
Spain	Grupo Lantec	Moving bed	TRL 6-7	20,000
Spain	CENER	Rotary drum	TRL 4-5	Undefined
Sweden	BioEndev	Screw reactor	TRL 6-7	16,000
UK	Clean Electricity Generation	Oscillating bed	TRL 9	30,000
UK	Rotawave	Microwave	TRL 1-3	Undefined
US	Solvay/New Biomass Energy	Screw reactor	TRL 9	80,000
US	Agri-Tech Producers LLC	Screw reactor	TRL 6-7	13,000
US	Earth Care Products	Rotary drum	TRL 6-7	20,000
US	Integro Earth Fuels, LLC	Multiple hearth	TRL 6-7	11,000
US	River Basin Energy	Fluidised bed	TRL 6-7	7,000
US	Teal Sales Inc	Rotary drum	TRL 9	20,000
US	Agri-Tech Producers LLC	Screw reactor	TRL 4-5	Undefined
US	Terra Green Energy	Multiple hearth	TRL 4-5	Undefined
US	Wyssmont	Multiple hearth	TRL 4-5	Undefined

Annex III. Selection of biogas upgrading plants worldwide

Country	Location	Substrate	Use	Technology	Capacity (Nm3/h)
Austria	Bruck/Leitha	Biowaste	Gas grid	Membrane	1400
Austria	Linz (Asten)	Sewage	Gas grid	Water scrubber	800
Austria	Margarethen	Energy crops manure	Vehicle fuel	Membrane	800
Austria	Häusle (Lustenau)	Biowaste	Gas grid	PSA	750
Brazil	São Pedro da Aldeia	Landfill	Heat	Water scrubber	1200
Canada	Abbotsford BC	manure, biowaste	Gas grid	Water scrubber	800
Canada	Hamilton Ont	Sewage sludge	Gas grid	Water scrubber	800
China	Laocheng	Agricultural	Vehicle fuel	Water scrubber	1250
Denmark	Hemmet	Manure, crops, waste	Gas grid	Chem. scrubber	3000
Denmark	Holsted	Manure, crops, waste	Gas grid	Water scrubber	3000
Denmark	Nordfyn	Manure, crops, waste	Gas grid	Water scrubber	3000
Denmark	Vaarst-Fjellerad	Manure, crops, waste	Gas grid	Water scrubber	2400
Denmark	Hjørring	Manure, straw	Gas grid	Water scrubber	1800
Denmark	Horsens	Manure, slaughterhouse	Gas grid	Water scrubber	1400
Denmark	Skive	Manure, crops, waste	Gas grid	Che. scrubber	1200
Denmark	Hjørring	Manure	Gas grid	Water scrubber	500
Finland	Lahti	MSW, ind biowaste	Gas grid	Water scrubber	1100
Finland	Espoo	Sewage sludge	Gas grid	Water scrubber	750
Finland	Virolahti	MSW, biowaste, crops	Gas grid	PSA	500
France	Lille	Biowaste	Gas grid, fuel	Water scrubber	1400
France	Chagny	MSW	Gas grid	Membrane	950
France	Villeneuve sur Lot	Manure, food waste	Gas grid	Membrane	930
France	Hénin Beaumont	MSW liquid	Gas grid	Water scrubber	600
Iceland	Reykjavik	Landfill gas	Vehicle fuel	Water scrubber	700
Japan	Kobe	Sewage sludge	Vehicle fuel	Water scrubber	700
Japan	Tarumi	Sewage sludge	Vehicle fuel	Water scrubber	700
Netherlands	Dinteloord	Biowaste	Gas grid	Water scrubber	2000
Netherlands	Groningen	Biowaste	Gas grid	Chem. scrubber	1200
Netherlands	Middenmeer	Biowaste	Gas grid	Physical scrubber	1200
Netherlands	Wijster	Biowaste	Gas grid	Chem. scrubber	1200
Netherlands	Alphen ad Rijn	Biowaste	Gas grid	Membrane	1050
Netherlands	Rijsenhout	Biowaste	Gas grid	Chem. scrubber	700
Netherlands	Zwolle	Biowaste	Gas grid	Water scrubber	700
Netherlands	Well	Biowaste	Gas grid	Membrane	600
Norway	Hå/ Grødaland	Biowaste/ sludge	Gas grid	Chem. scrubber	1200
Norway	Tønsberg	Biowaste, manure	Gas grid	Water scrubber	1200
Norway	Oslo/Esval	Biowaste	LBG	Water scrubber	800
Norway	Oslo	Sewage sludge	Vehicle fuel	Chem. scrubber	750
Norway	Drammen	Sludge, biowaste	Vehicle fuel	Chem. scrubber	700
Norway	Fredrikstad	Sludge, biowaste	Vehicle fuel	Chem. scrubber	600
Norway	Lillehammer	Biowaste	Vehicle fuel	Water scrubber	600
Norway	Stavanger	Sludge, biowaste	Gas grid	Chem. scrubber	500
S. Korea	Jungrang	Sludge	Gas grid	Membrane	1500
S. Korea	Daegu (Dalseo)	Biowaste	Vehicle fuel	PSA	1000
S. Korea	Changwon	Sewage sludge	Gas grid	Water scrubber	600
S. Korea	Suyoung	Sewage sludge	Gas grid only	Water scrubber	600

Country	Location	Substrate	Use	Technology	Capacity (Nm3/h)
S. Korea	Wonju	Biowaste, manure	Vehicle fuel	Water scrubber	600
Spain	Madrid	Biowaste	Vehicle fuel	Water scrubber	4000
Switzerland	Bern	Sewage sludge	Gas grid	Chem. scrubber	1500
Switzerland	Zurich	Sludge, biowaste	Gas grid	Chem. scrubber	1400
Switzerland	Münchwilen	Animal by-products	Gas grid	Chem. scrubber	650
Switzerland	Aarberg	Sugar mill	Gas grid	PSA	500
Switzerland	Frauenfeld	Sugar mill	Gas grid	PSA	500
UK	Grants Girvan Phase	Biowaste	Gas grid	Water scrubber	3000
UK	Beecles	Agricultural	Gas grid	Water scrubber	2000
UK	Chittering	Agricultural	Gas grid	Membrane	2000
UK	Grants Glenfiddich	Biowaste	Gas grid	Water scrubber	2000
UK	Howdon	Sewage sludge	Gas grid	Water scrubber	2000
UK	Widnes	Biowaste	Gas grid	Water scrubber	2000
UK	Vale Green 2	Agricultural	Gas grid	Membrane	1800
UK	Avonmouth	Sewage sludge	Gas grid	Water scrubber	1500
UK	Emerald Biogas BtG	Biowaste	Gas grid	Water scrubber	1200
UK	Minworth	Sewage sludge	Gas grid	Water scrubber	1200
UK	Roundhill	Biowaste	Gas grid	Water scrubber	1200
UK	Coupar Angus	Agricultural	Gas grid	Water scrubber	1100
UK	Bay Farm	Biowaste	Gas grid	Membrane	1000
UK	Bishops Cleeve	Biowaste	Gas grid	Water scrubber	1000
UK	Bosworth	Biowaste	Gas grid	Water scrubber	1000
UK	Bromham	Agricultural	Gas grid	Membrane	1000
UK	Cannington	Biowaste	Gas grid	Water scrubber	1000
UK	Castle Eaton	Agricultural	Gas grid	Chem. scrubber	1000
UK	Crouchlands Farm	Agricultural	Gas grid	Chem. scrubber	1000
UK	Davyhulme	Sewage sludge	Gas grid	Water scrubber	1000
UK	Derby	Sewage sludge	Gas grid	Water scrubber	1000
UK	Doncaster	Agricultural	Gas grid	Membrane	1000
UK	Enfield	Agricultural	Gas grid	Membrane	1000
UK	Fairfields Farm	Agricultural	Gas grid	Membrane	1000
UK	Gravel Pits	Agricultural	Gas grid	Membrane	1000
UK	Great Hele	Agricultural	Gas grid	Membrane	1000
UK	Grissan Glasgow	Agricultural	Gas grid	Water scrubber	1000
UK	Helscott Farm	Agricultural	Gas grid	PSA	1000
UK	Hibaldstow	Agricultural	Gas grid	Membrane	1000
UK	Highwood Farm	Agricultural	Gas grid	Membrane	1000
UK	Holkham	Agricultural	Gas grid	Membrane	1000
UK	Illminster	Agricultural	Gas grid	Chem. scrubber	1000
UK	Lake District Biogas	Biowaste	Gas grid	Membrane	1000
UK	Leeming Biogas	Biowaste	Gas grid	Membrane	1000
UK	Manor Farm	Agricultural	Gas grid	PSA	1000
UK	Metheringham	Agricultural	Gas grid	Membrane	1000
UK	Mitcham	Biowaste	Gas grid	Membrane	1000
UK	Peacehill Farm	Agricultural	Gas grid	Membrane	1000
UK	Penans	Agricultural	Gas grid	PSA	1000
UK	Peterhead	Agricultural	Gas grid	Chem. scrubber	1000
UK	Ridge Road	Agricultural	Gas grid	Membrane	1000

Country	Location	Substrate	Use	Technology	Capacity (Nm3/h)
UK	Saltaugh	Agricultural	Gas grid	PSA	1000
UK	Savock	Agricultural	Gas grid	PSA	1000
UK	Sherburn	Biowaste	Gas grid	Membrane	1000
UK	Skeddaway	Agricultural	Gas grid	PSA	1000
UK	Slade Farm	Agricultural	Gas grid	PSA	1000
UK	Stoke Bardolph	Sewage sludge	Gas grid	Water scrubber	1000
UK	Stracathro	Agricultural	Gas grid	PSA	1000
UK	Strongford	Sewage sludge	Gas grid	Water scrubber	1000
UK	Willand	Food waste	Gas grid	Chem. scrubber	1000
UK	Cumbernauld	Biowaste	Gas grid	Membrane	900
UK	Isle of wright	Agricultural	Gas grid	Membrane	900
UK	Scampton	Agricultural	Gas grid	Membrane	900
UK	Tornagrain	Agricultural	Gas grid	PSA	900
UK	Helmdon	Biowaste	Gas grid	Membrane	700
UK	Five Fords	Sewage Sludge	Gas grid	Membrane	600
UK	Fraddon	Biowaste	Gas grid	Membrane	600
UK	Icknield Farm	Agricultural	Gas grid	Membrane	600
UK	Poundbury	Biowaste	Gas grid	Membrane	540
UK	Ebbsfleet	Agricultural	Gas grid	Membrane	500
UK	St Nicholas Court	Agricultural	Gas grid	Membrane	500
US	Detroit, MI	Landfill gas	Gas grid	Water scrubber	5400
US	Renton (WA)	Sewage sludge	Gas grid	Water scrubber	2500
US	San Diego, CA	Sewage sludge	Gas grid	Membrane	1000

Annex IV. Selection of R&D gasification plants worldwide

Project Owner...	Project name	Country	TRL	Outputs
Bio SNG Guessing	Synthesis Demo Guessing	Austria	TRL 6-7	576 t/y SNG
SynCraft	CraftWerk Schwaz	Austria	TRL 4-5	0.1 Mwel power +0.5 MWth
urbas Energietechnik	CHP Demonstrationsanlagen URBAS	Austria	TRL 6-7	0.15 Mwel power +0.3 MWth heat
Enerkem	Synthesis Enerkem Sherbrooke	Canada	TRL 4-5	375 t/y ethanol +475 m3/y methanol +SNG
EP Engineering ApS	Helufsholm CCG - phase A	Denmark	TRL 4-5	0.4 MWe power
Sindal District Heating Company	Dall Energy CHP plant in Sindal	Denmark	TRL 8	0.8 MWel power +5 MWth heat
Volter	Kempele Ecovillage	Finland	TRL 4-5	0.03 MWel power
VTT	Pressurized FB for synthesis gas	Finland	TRL 4-5	0.5 MWth heat
VTT	Dual fluidized-bed steam gasification pilot	Finland	TRL 4-5	0.35 MWth heat
GDF Suez + consortium	Gaya	France	TRL 1-3	0.1 t/y SNG
Agnion Technologies	CHP Agnion Biomasse Heizkraftwerk Pfaffenhofen	Germany	TRL 4-5	6.1 MWel power +32.5 MWth SNG
CHOREN Industries	CHOREN plant Freiberg	Germany	TRL 4-5	53 t/y FT liquids
Wegscheid Demo	Wegscheid Demo	Germany	TRL 6-7	0.125 MWel power +0.23 MWth heat
SEK Koblenz	KSV Koblenz	Germany	TRL 8	0.33 MWel power +0.39 MWth heat
ZAB Balingen	KSV Balingen	Germany	TRL 8	(0.46 MWth heat
ECN	MILENA Gasifier	Netherlands	TRL 4-5	200 m3/h clean syngas
HoSt	CFB Tzum	Netherlands	TRL 6-7	3 MWth heat
Chalmers Univ.	Centre for Indirect Gasification of Biomass	Sweden	TRL 4-5	4 MWth heat
PEGB	SP ETC	Sweden	TRL 4-5	1 MWth heat
Goteborg Energi AB	GoBiGas	Sweden	TRL 8	11,200 t/y SNG
Cortus Energy AB	Probiostal	Sweden	TRL 8	6 MWth heat
Emamejeriet AB	Emamejeriet (Ema dairy)	Sweden	TRL 8	0.04 MWel power +0.1 MWth heat
VVBGC AB	Vaexjoe Vaernamo Biomass Gasification Center AB	Sweden	TRL 6-7	6 MWel power +8 MWth heat+1,000 m3/h syngas
TUBITAK	Synthesis TUBITAK MRC Kocaeli	Turkey	TRL 4-5	0.2 MW SNG
Advanced Plasma Power	BioSNG pilot plant	UK	TRL 4-5	0.06 MWel power+4 kg/h SNG
Go Green Fuels Ltd	GoGreenGas	UK	TRL 8	1,500 t/y SNG
Southern Research Institute	Tech dev lab & pilot plant	US	TRL 4-5	0.002 t/y FT liquids +alcohols+power
INEOS New Planet BioEnergy	INEOS Plant Vero Beach	US	TRL 4-5	6 Mwel power +3.469 m3/h ethanol

Annex IV. Selection of gasification plants worldwide (TRL 9 Commercial)

Country	Project Owner	Project name	Power	Heat
Austria	Biowaerme Eberndorf	CHP Urbas Eberndorf	0.3 MWel	
Austria	Biowaerme Mallnitz GmbH	Urbas Mallnitz	0.25 MWel	0.54 MWth
Austria	Fernwaerme Neumarkt Ges.m.b.H. & Co.KG	CHP Urbas Neumarkt	0.24 MWel	0.58 MWth
Austria	Holzstrom GmbH	CHP Urbas Neukirchen	0.35 MWel	
Austria	SynCraft	CraftWerk Innsbruck	0.261 MWel	0.395 MWth
Austria	SynCraft	CraftWerk Stadl	0.4 MWel	0.615 MWth
Austria	SynCraft	CraftWerk Vierschach	0.3 MWel	0.4 MWth
Denmark	Babcock&Wilcox Volund	CHP B&W Harboore	1 MWel	3.5 MWth
Denmark	Skive District Heating Company	Skive CHP plant	6 MWel	13 MWth
Finland	Jalasjaerven Laempoe	District heating		6 MWth
Finland	Kauhajoen Laempoehuolto	District heating plant		13 MWth
Finland	Kiteen Laempoe	District heating plant		6 MWth
Finland	Lahti Energia	Kymijaervi II	50 MWel	
Finland	Metso Fibre	Bioproduct Mill Aanekoski		87 MWth
Finland	Metso Fibre Oy, Joutseno Mill	Lime kiln gasifier		48 MWth
Finland	Vaskiluodon Voima Oy, Vaasa	Vaskiluodon Voima Biomass Gasification Plant	140 MW	
Germany	Bioenergie Schnellingen	Bioenergie Schnellingen	0.4 MWel	0.518 MWth
Germany	KWS Landshut	KWS Landshut	0.3 MWel	0.45 MWth
Germany	KWS Ostalb	KWS Ostalb	0.3 MWel	0.45 MWth
Germany	Muensterland Energy Gmbh	Muensterland Energy Gmbh	6 MWel	8.6 MWth
Germany	Naturenergie Hersbruck GmbH & Co. KG	Naturenergie Hersbruck GmbH & Co. KG	0.4 MWel	1.1 MWth
Germany	RegaWatt	RegaWatt Abensberg	2 MWel	4.3 MWth
Germany	Stadtwerke Ulm/Neu-Ulm	CHP Stadtwerke Ulm/Neu-Ulm	4.6 MWel	15 MWth
Germany	WUN Bioenergy	WUN Bioenergy	0.36 MWel	0.54 MWth
Italy	Bio&Watt	Bio&Watt	0.3 MWel	
Italy	co-Ver Energy Holding	Lake Maggiore Tecnoparco	0.25 MWel	
Italy	Energia Uno	Urbas Terni	0.199 MWel	
Italy	Guascor Italia	Rossano Calabro (CS)	4.2 MWel	
Italy	Lamprecht	Lamprecht GmH	0.2 MWel	0.32 MWth
Netherlands	Eska Graphic Board	Waste Paper Rejects Gasification		12 MWth
Netherlands	RWE Essent*	Wood gasifier Geertruidenberg	34 MWel	
Switzerland	AEW Energie AG	Pelletvergasser AEW Rheinfelden	0.165 MWel	0.26 MWth
Switzerland	Eomande Energie	Puidoux Woodgasifier	0.89 MWel	4.5 MWth
Switzerland	Holzstrom aus Nidwalden	CHP Pyroforce Nidwalden	1.38 MWel	
UK	ARBRE Energy Limited*	IGCC ARBRE Energy Eggborough	9 MWel	

*idle

Annex V. Selection of R&D Hydrothermal Liquefaction plants worldwide

Project	Project name	Country	Type	Outputs
Licella	Commercial demo plant	Australia	TRL 6-7	bio-oil
Aurora Algae*	Demo	Australia	TRL 6-7	bio-oil
National Research Council		Canada	TRL 4-5	bio-oil (30 t/y)
Pond Biofuels		Canada	TRL 4-5	renewable diesel
Steeper Energy	Continuous Bench Scale	Denmark	TRL 4-5	bio-oil
Aarhus University	Center for Biorefining Technologies	Denmark	TRL 4-5	bio-oil
Seambiotic		Israel	TRL 4-5	diesel-type hydrocarbons
Preem Petroleum		Sweden	TRL 8	diesel-type hydrocarbons
Green Star Products		United States	TRL 4-5	diesel-type hydrocarbons

* idle

Annex VI. Selection of R&D pyrolysis plants worldwide

Project	Country	Status	TRL	Output
CanmetENERGY	Canada	operational	TRL 1-3	bio-oil
ABRITech Quebec	Canada	under construction	TRL 6-7	bio-oil, other syngas
AgriTherm	Canada	commissioning	TRL 6-7	bio-oil, chemicals
Ensyn	Canada	operational	TRL 6-7	bio-oil, chemicals
Ensyn Renfrew	Canada	operational	TRL 8	bio-oil
Ensyn Quebec	Canada	under construction	TRL 8	gasoline fuels
UDT	Chile	operational	TRL 1-3	bio-oil, chemicals
University of Science and Tech. China	China	operational	TRL 4-5	bio-oil
VTT Ltd.	Finland	commissioning	TRL 4-5	bio-oil
Fortum Joensuu	Finland	operational	TRL 6-7	bio-oil
Valmet	Finland	operational	TRL 6-7	bio-oil
Fortum	Finland	operational	TRL 8	bio-oil
Fraunhofer UMSICHT	Germany	operational	TRL 1-3	bio-oil
Fraunhofer UMSICHT	Germany	commissioning	TRL 4-5	bio-oil
KIT bioliq	Germany	operational	TRL 6-7	bio-oil, other
Pytec	Germany	idle	TRL 4-5	bio-oil (150 kg/h)
BTG	Netherlands	operational	TRL 4-5	bio-oil
BTG EMPYRO	Netherlands	operational	TRL 8	bio-oil, steam, power
Alternative Energy Solutions	New Zealand	operational	TRL 4-5	bio-oil
SP ETC	Sweden	operational	TRL 4-5	bio-oil, chemicals
Carbon Trust Pyrolysis	UK	no status	TRL 4-5	bio-oil (30 t/y)
Envergent	US	idle	TRL 4-5	bio-oil
KiOR	US	idle	TRL 4-5	bio-oil
KiOR	US	idle	TRL 1-3	bio-oil
Iowa State University	US	operational	TRL 1-3	bio-oil chemicals
NREL	US	operational	TRL 1-3	bio-oil
University of Idaho	US	operational	TRL 1-3	bio-oil, other
Mainstream Engineering Co	US	under construction	TRL 4-5	bio-oil
Mississippi State University	US	operational	TRL 4-5	bio-oil
Renewable Oil International	US	operational	TRL 4-5	bio-oil
RTI International	US	operational	TRL 4-5	bio-oil
USDA-ARS-ERRC	US	operational	TRL 4-5	bio-oil, chemicals
Virgina Tech	US	idle	TRL 4-5	bio-oil

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