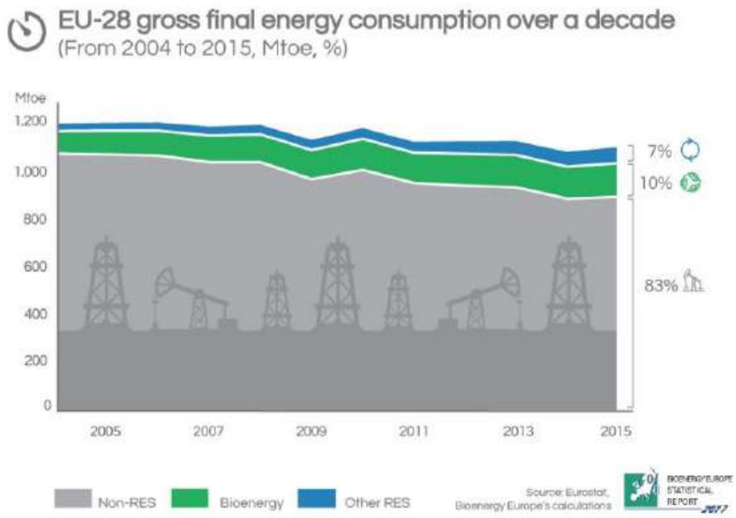
Vision for Bioenergy

Bioenergy represents 61.3% of the renewable energy mix today and will be one of the main drivers to a European net-zero carbon economy. The bioenergy industry is committed today and in the future to the objective of long-term emission reductions by providing innovative heat, power and transport solutions based on biomass.

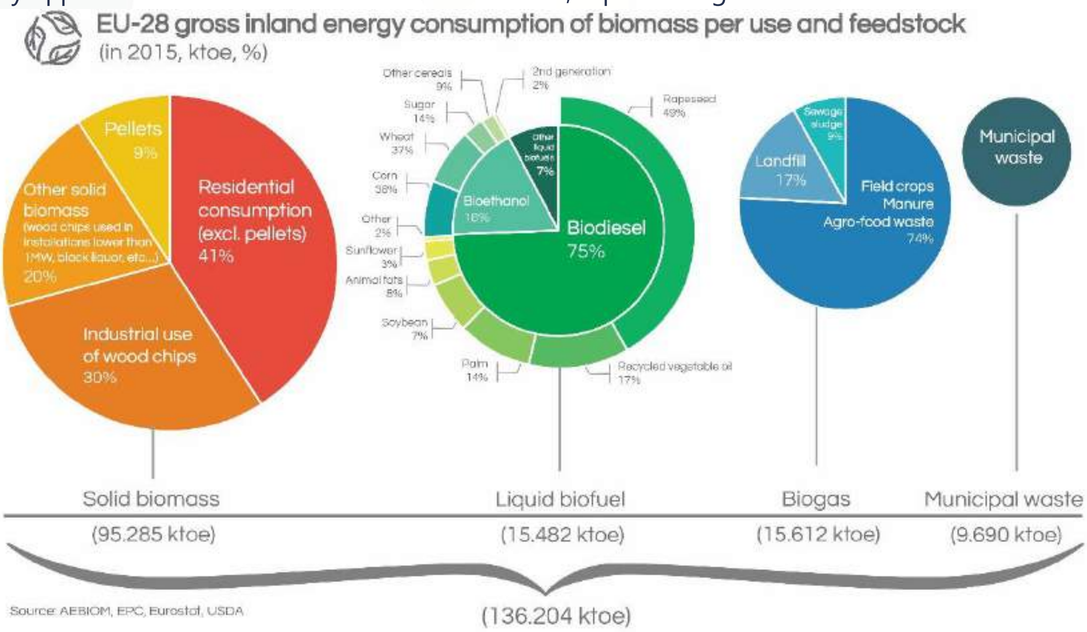
By 2050, based on the sustainably available biomass potential (406 Mtoe; 17 EJ), bioenergy can cover half of the energy demand in Europe if significant reductions are delivered by increasing efficiency of production and reducing the demand for energy by energy efficiency measures. This would represent 1.5 to 2 million jobs in the sector by 2050 and almost 1 billion tons of CO_2 saved through the replacement of fossil fuels. [1] This paper shows, how this important transformation will be possible based on a sustainable supply of biomass and efficient technology solutions in all sectors of the economy.



Bioenergy today

Today, bioenergy represents 10% of the EU-28 final energy consumption in 2015. In 2018, for 43 days the European economy is relying entirely on bioenergy. Looking back, bioenergy consumption has more than doubled since 2000, from 55.4 Mtoe (2.3 EJ) to 112.3 Mtoe (4.7 EJ) in 2015 (final energy consumption).

Solid biomass clearly appears as the main source of fuel consumed, representing 70% of total biomass for energy. Biogas and liquid biofuels account each for around 11% and municipal waste for energy completes the picture with 7%.



[1] The underlying assumptions are developed throughout the specific sections of this document.

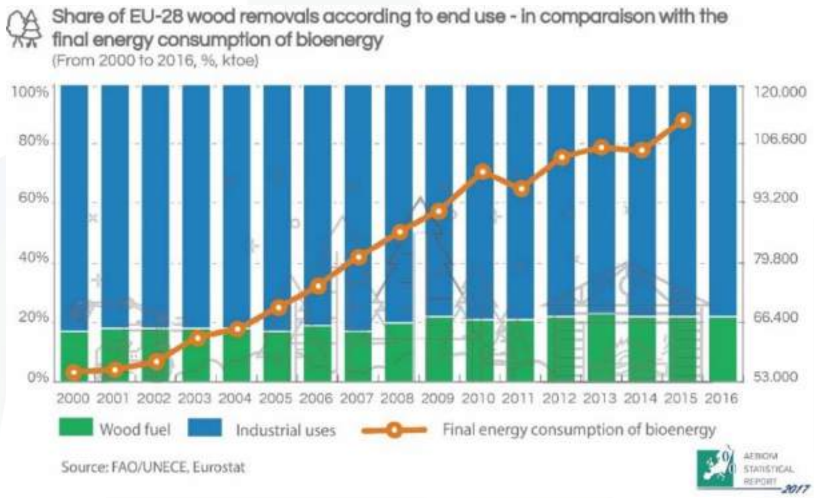
Place du Champ de Mars 2
1050 Brussels
www.bioenergyeurope.org
+32 2 318 41 00
info@aebiom.org
VAT: BE 0871 481 553

Sustainable biomass potential

With 95% locally produced biomass, the growth potential of bio-energy relies essentially on the potential of sustainable biomass resources available in Europe. Scientific research taken into account for mapping the biomass potential by 2050 aims to maintain environmental and climatic conditions such as soil quality, water availability and carbon sinks.

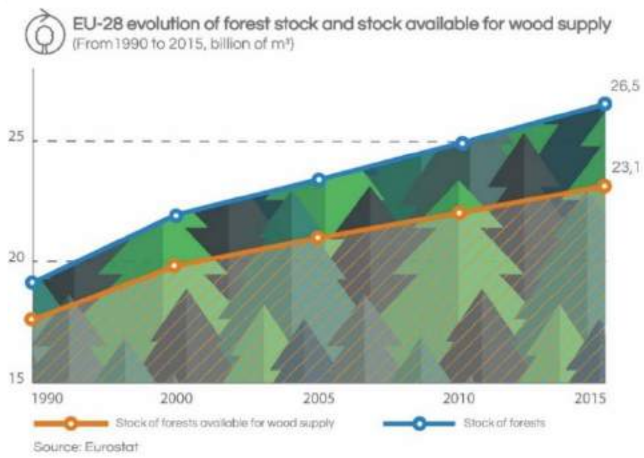
Forest biomass

In 2015, energy production from forest biomass was representing 98.3 Mtoe (4 EJ)[2] in the EU-28. Both for environmental and economic reasons, this is mostly sourced from by-products of forest management operations and the wood industry, such as sawmills. While bioenergy strongly increased in the last 15 years, the percentage of wood removal harvested for energy purposes remained rather stable (*see graph*). This shows that bioenergy sector increasingly relies on wood by-products.



For forest biomass, the increase of potential under current conditions will be limited compared to agricultural biomass (*see section below*). There is strong scientific agreement[3] that the current amount of forest biomass can be slightly increased and depending on actions taken on forest management and criteria applied, there is growth potential up to 143 - 174 Mtoe (6-7 EJ) by 2050.

Forest biomass resources can be increased by sustainable forest management and biomass mobilisation. Over the last quarter of century, the forest stock grew by 32%. This growth relies on two factors: first, forest areas are increasing by 322.800 ha every year in the EU-28. Secondly, the standing volume is growing: on average, only about 63% of the annual forest increment in Europe is actually felled.



In view of a net-zero carbon economy by 2050, two objectives will be pursued with increased forest growth: producing sustainable bio-energy (and other bio-based products) and using forests as a carbon sink. Both objectives can be achieved through sustainable forest management. Based on a solid income for forest holders, forests can be better managed which increases their growth, health and thus their annual CO_2 absorption capacity. A pre-condition offered by the bioenergy sector.

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[2] Bioenergy Europe (formerly AEBIOM) Statistical report (2017): 98.3 Mtoe (3.9 EJ) for solid biomass

[3] Faaij (2018): Securing sustainable resource availability of biomass for energy application in Europe; review of recent literature (quoted in the following: Faaij (2018): Study on biomass potential)

Place du Champ de Mars 2
1050 Brussels

+32 2 318 41 00
info@aebiom.org
VAT: BE 0871 481 553

Agricultural biomass

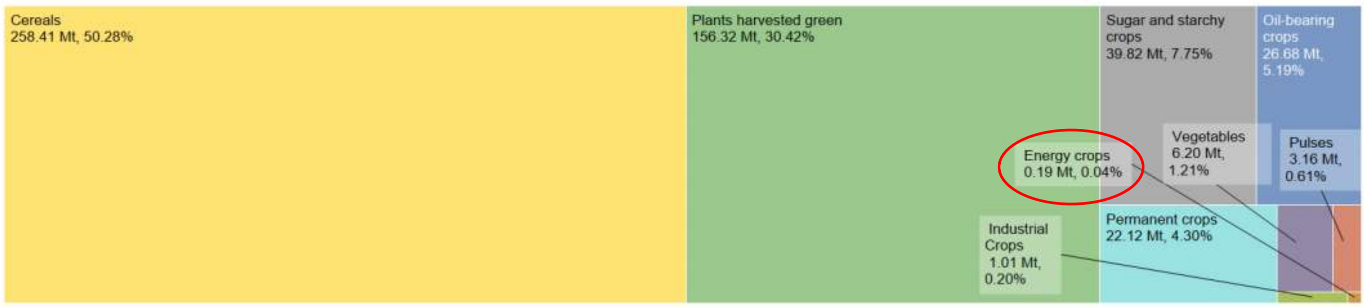
Agricultural biomass includes agricultural residues (solid vegetal residues streams such as straw) and energy crops. For sustainability reasons (*i.e.* biodiversity, soil quality), the deployment of perennial energy crops (both grassy *e.g.* miscanthus and woody *e.g.* willow and poplar), is welcome. At the same time, perennial energy crops represent a long-term investment requiring a stable political framework of support for around 15-20 years. Annual crops give farmers flexibility in the short-term.

Until now, the use of agricultural biomass is still limited in Europe. In 2017, it is estimated that there are around 15,000 ha Miscanthus and 40,000 ha Short Rotation Coppice in the EU.[4] EU-wide statistics on the consumption of agricultural residues for energy do not exist. In the EU, Denmark is the largest consumer of straw for energy. Other countries consuming straw for energy are Hungary, UK and Spain, but volumes are smaller.[5]

Today, around 20 % of the bioenergy feedstock comes from agriculture (26.7 Mtoe; 1.1 EJ)[6]. For 2050, a significant increase in the potential of energy crops and agricultural residues should be developed. Scientific research strongly agrees that agricultural biomass will represent the largest biomass potential in 2050. Given the limited deployment today, variation is significant, ranging from 124 to 444 Mtoe (5.2-18.6 EJ).

Energy crops

Decisive factors regarding land availability for dedicated energy crops are the development of population, food consumption (driven by dietary habits and share of food waste) and improved land management. As can be seen in the diagram, food and feed production accounts for the majority of biomass use in the EU while energy crops accounts for only 0.04% of the total biomass production. If the consumption of meat and the production of food waste is reduced, this could lead to a significant increase of available land for bioenergy production.[7]

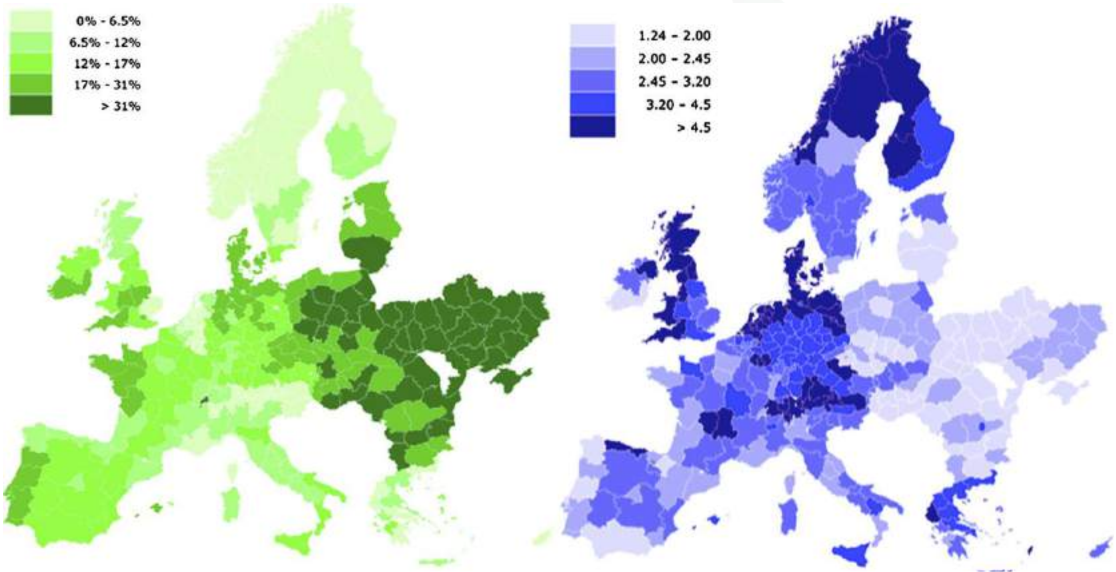


JRC 2018: DISTRIBUTION OF AGRICULTURAL BIOMASS POTENTIAL USE

[4] Bioenergy Europe (formerly AEBIOM) Statistical report (2017): p. 60.
[5] Bioenergy Europe (formerly AEBIOM) Statistical report (2017): p. 56.
[6] Bioenergy Europe: Forestry – The role of biomass, URL: https://bioenergyeurope.org/forestry/
[7] Kallio *et. al.* (2015): Best scenarios for the forest and energy sector – implications for the biomass market, p. 26 ; International Energy Agency (2017): Technology Roadmap. Delivering Sustainable Bioenergy, p. 56.

Place du Champ de Mars 2
1050 Brussels
www.bioenergyeurope.org
+32 2 318 41 00
info@aebiom.org
VAT: BE 0871 481 553

Yet already today there is a lot of land available in Europe where dedicated energy crops could be grown without entering in competition with food production (*see map below*). Especially in Eastern Europe and Baltic States a lot of land is abandoned due to socio-economic factors and would be suitable for biomass production.[8]

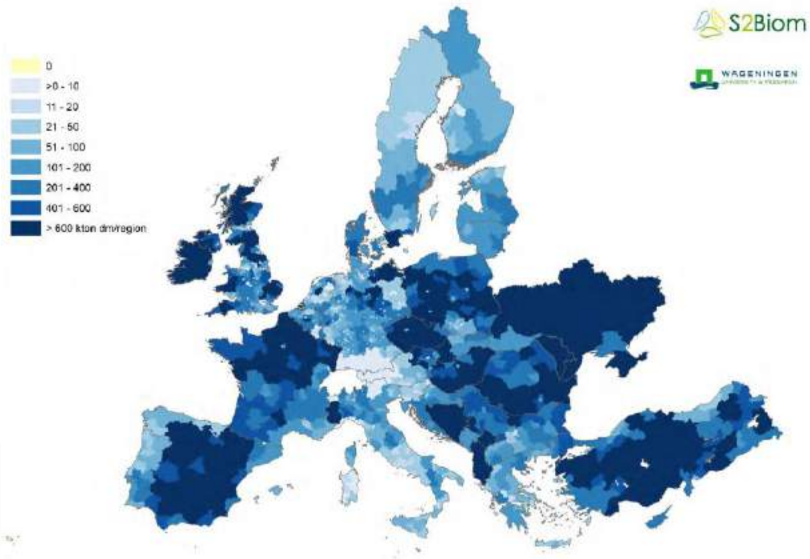


Map of available land and related costs (de Wit et al 2010). On the left: The 'surplus' land potentially available for the production of biomass by 2030 green shades indicate the amount of surplus land as a percentage of the total land). On the right, the production costs for woody crops in 2005 (blue shades indicate the production costs of woody crops)

Agricultural residues

Agricultural residues including straw, stubbles, woody pruning & orchards residues, grassland cuttings not used for feed purposes, biomass from road side verges, by-products and residues from food and fruit processing industry are another source of untapped potential. As can be seen in the graph, most resources are available in countries with a large agricultural sector being complementary with forest biomass which is largely available in Northern Europe.

Straw holds an outstanding place in many Member States. However, some specificities exist: in United Kingdom and Ireland grassland cuttings represent the main potential in terms of agricultural residues and in Southern Europe (especially Spain) agricultural prunings are a non-negligible source of biomass.[9]



MAP OF AVAILABLE RESIDUES IN TON OF DRY MATTER (S2BIOM)

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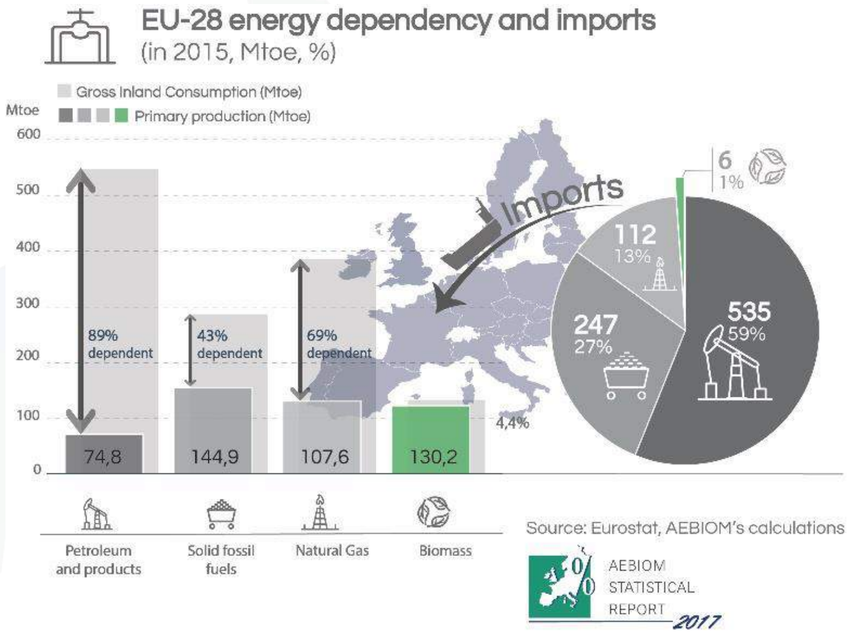
[8] European Commission (2013), Science for Environment Policy. Abandoned farmland widespread in central and eastern Europe, URL: http://ec.europa.eu/environment/integration/research/newsalert/pdf/355na3_en.pdf

[9] S2Biom (2017): Delivery of sustainable supply of non-food biomass to support a "resource-efficient" Bioeconomy in Europe.

Waste

Waste to bioenergy accounted for 15.3 Mtoe (0.6 EJ) in 2015.[10] The potential of waste in 2050 depends on waste treatment decisions. The separate collection obligation of bio-waste introduced by the Waste Framework Directive and stricter limitations of landfills introduced by the Landfill Directive will bring additional potential for waste-to-bioenergy production. However, investment to increase efficiency in the process of energy recovery has to be incentivised via the Waste Framework Directive in order to untap the available potential. In 2050, based on the JRC-EU-TIMES model, the waste-to-bioenergy potential (including biogas production) lies between 40.1 -119.4 Mtoe (1.6-4.9 EJ).[11]



Imports

Bioenergy is a local fuel and Europe should remain the main sourcing area of bioenergy by 2050 to ensure security of supply and limit transport distances. With an energy dependency of 4.4%, bioenergy is far less reliant on imports than fossil fuels (*see graph*).

For some types of biomass such as wood pellets and liquid biofuels raising imports are foreseen in the future. Yet, for the majority of biomass fuels, long transport distances are not a viable solution. Relying increasingly on low-density agricultural biomass (*e.g.* straw) in the future, local solutions will remain a priority. In this vision, the future development of bioenergy is based on the sustainable biomass potential available in Europe, but global and intra-European trade will play a role.

Co-existence and industrial symbiosis with bio-based products

Biomass is not only used for bioenergy, but also for a wide range of bio-based products (*e.g.* paper, panels, construction material and furniture, bio-based chemicals, plastics and textiles). Distribution of biomass resources is following a market-based approach where high-value products such as chemicals and furniture are considered first.

In most cases, bioenergy is produced in industrial symbiosis with other bio-based products. The combination of industrial processes, such as a sawmill or a pulp mill combined with bioenergy production, can increase resource efficiency as residues are used instead of ending up as waste. In the coming years, we can foresee a fast development of technology and products as part of the bio-economy concept. More and more, the production will take place in combinates and bio-refineries with many end products (wood, fibres, textiles, bio-based chemicals, biofuels, composites, nano-cellulose, lignin, hemi-cellulose, biofuels, heat, electricity) and internal flows of products and energy. The combination of several outputs will lead to higher energy savings engaged with optimisation in the

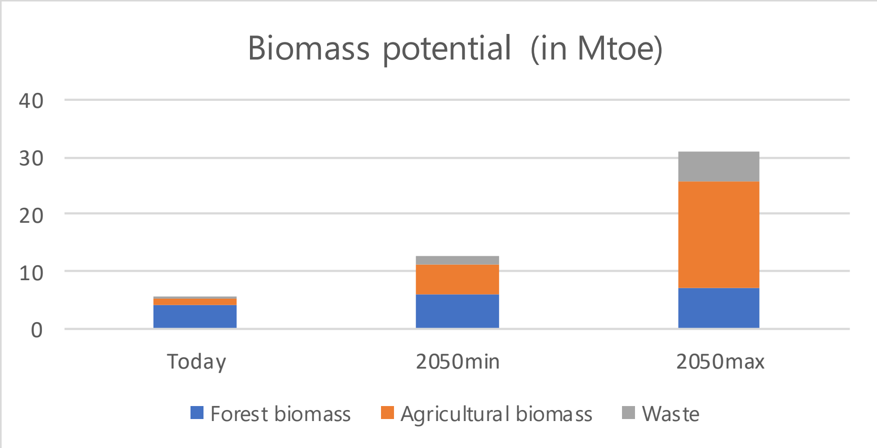
[10] Bioenergy Europe (formerly AEBIOM) Statistical report (2017): p. 53.

[11] Ruiz *et al* (2015): EU TIMES model, Annex VI Biomass potential by feedstock, waste potential includes biogas, agricultural waste, municipal waste, industrial waste sludge, p. 97-130.

production process leading in overall terms to a lower demand and synergetic benefits in better utilization of infrastructures.

The development of the bio-economy will have an impact on the biomass potential for bioenergy. However, it is not said that this impact will be necessarily negative. For instance, increased use of wood for construction purposes will lead to higher amounts of industrial residues available for the bioenergy sector. To give one example, a modern house build from solid wood could be heated 70 years with the by-products from its own construction bringing climate benefits both on the energy and material side.[12] Ongoing trends like digitalisation might further decrease the use of writing paper and increase the need for energy. More integrated processes and biorefineries will increase resource efficiency.

Overall potential



In 2016, the overall bioenergy used was about 140.3 Mtoe (5.7 EJ) (gross inland energy consumption)[13] in the EU-28. Building upon the potentials of different biomass resources (forest biomass, agricultural biomass and waste), the overall potential will be between 307 and 734 Mtoe (12-30 EJ) in EU-28 of the primary energy consumption by 2050.

According to the study on biomass potential by André Faaij[14], considering various constraints by excluding the most expensive biomass categories (86% of biomass at a cost below 5€/GJ) and considering medium agricultural productivity improvement scenarios, **a potential 406 Mtoe (17 EJ) are achievable by 2050**. Still 406 Mtoe (17 EJ) represents a considerable amount in the range of mineral oil in the current European energy mix.

Table: Comparison of biomass used today and biomass potentials in 2050[15] (potential in EU28 + Eastern non-EU European countries).

Sector/Year	Biomass used 2016 (in Mtoe) Gross inland energy consumption	Biomass potential for 2050 (in Mtoe) Primary energy production
Forest	98.3 (4.1 EJ) (70 %)	143 - 174 (5.9-7.3 EJ) (21-34%)
Agricultural biomass	26.7 (1.1 EJ) (19 %)	124– 444 (5.2 -18.6 EJ) (41-56%)
Waste	15.3 (0.6 EJ) (11 %)	40 -119 (1.6-4.9 EJ) (13-15%)
Total	**140.3 (5.8 EJ)**	**307 –737(12.8 -30.8 EJ)**

1 EJ = 23.9 Mtoe (1000 Mtoe = 41.9 EJ, 1 Mtoe = 41.9 PJ, 1 toe = 41.9 GJ,)

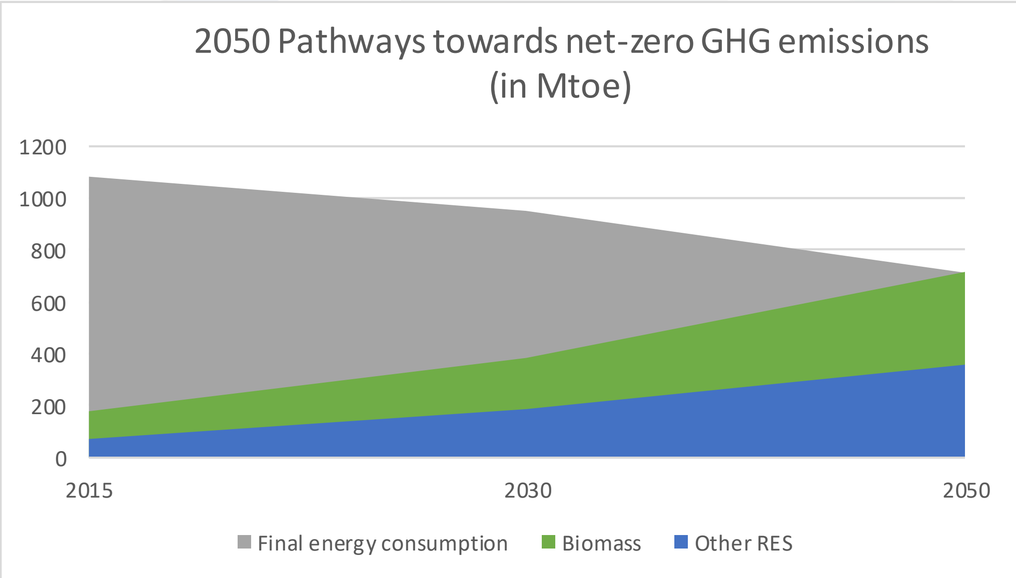
[12] Initiative Power of Wood (Wärme aus Holz): The power of wood video
[13] Bioenergy Europe (formerly AEBIOM) Statistical report (2018), forthcoming.
[14] Faaij (2018): Study on biomass potential.
[15] Based on Faaij (2018): Study on biomass potential.

Place du Champ de Mars 2
1050 Brussels
www.bioenergyeurope.org
+32 2 318 41 00
info@aebiom.org
VAT: BE 0871 481 553

Future development of bioenergy

To achieve a balance between carbon removals and emissions, several parallel developments have to take place. To achieve the GHG emission reduction pathway towards 2050, all renewable energy sources need to experience high growth rates and requires an upward review for the 2030 target to at least 40%. In 2050, the energy system should be reliant on renewable energy. Given the outstanding growth paths of renewables and important cost decreases, very high shares of renewables in 2050 are achievable if there is ambitious, political support.

Significant reductions in the final energy consumption are needed to achieve net-zero carbon economy. Higher efficiency in the energy and industrial production, better insulation of houses, but also change in consumer behavior and political incentives are needed to achieve those reductions.



When it comes to bioenergy, **Bioenergy Europe's vision assumes that bioenergy can sustainably deliver at least 50 percent of EU's final energy demand in 2050**. Based on the above potential analysis, a potential of 406 Mtoe European primary energy is achievable by 2050. If the right political measures are put in place, and imports included, bioenergy could easily provide even more than 50% of the final energy consumption by 2050.

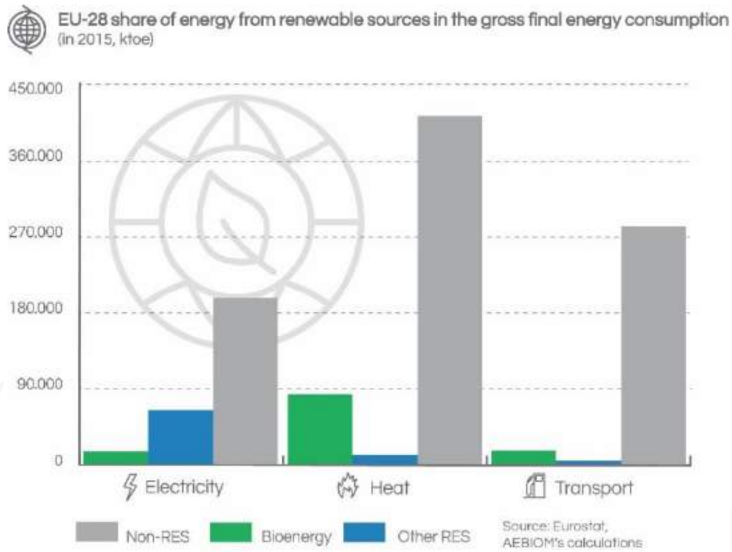
Table: Bioenergy Europe estimation of final energy consumption by 2050

	2015	2030	2050
Final energy consumption[16]	1083 Mtoe (45 EJ)	955 Mtoe (40 EJ)	716 Mtoe (30 EJ)[17]
RES share	17%	40%	90-100%
Bioenergy[18]	112.3 Mtoe (4.7 EJ)	191 Mtoe (8 EJ)[19]	358 Mtoe (15 EJ)
Other RES	70 Mtoe	191 Mtoe	358.5 Mtoe (15 EJ)

16 It should be noted that this table is looking at final energy consumption while the previous table on biomass potential takes primary energy consumption into account
17 Eurelectric, *EU electrification and decarbonization scenario modelling*, May 2018
18 Including imports
19 Based on IRENA *Renewable Energy Prospects for the European Union*, February 2018

Place du Champ de Mars 2
1050 Brussels
www.bioenergyeurope.org
+32 2 318 41 00
info@aebiom.org
VAT: BE 0871 481 553

Renewable energy sources will be deployed in all three energy sectors – electricity, heating & cooling and transport.



So far, renewable energy has strongly increased in the power sector, but the heating & cooling and transport sectors are lagging far behind (*see graph*). Given its current share, bioenergy is well placed to increase the share of renewable energy in those sectors. All three sectors represent opportunities for bioenergy which makes it difficult to foresee the exact distribution among sectors.

Heating & Cooling sector

The heating & cooling sector is the largest sector in terms of energy consumption (about 50% today). Renewable energy is currently representing 18% of the energy mix in this sector and bioenergy represented 89% of the renewable heat (82.9 Mtoe; 3.47 EJ) consumed in the EU-28 in 2015.[20] Looking ahead towards 2050, bioenergy will remain a driver of GHG emission reductions in the heating sector both for the residential and industrial sectors.

Direct renewable heat through biomass represents a great potential to decarbonise the heating system. Bioheat can be provided both at small scale (stoves, boilers) and medium/large scale (Combined Heat & Power plants, Heat only plants) for instance in combination with district heating. In Europe, 75% of the existing building stock is energy *in*efficient. Considering the low renovation rate (between 0.4-1.2% depending on the country)[21], deployment of bioheat in buildings is complementary to energy efficiency measures. With those fully available and deployable technologies, bioheat represents one of the most important solutions to reduce GHG emissions in the building sector.

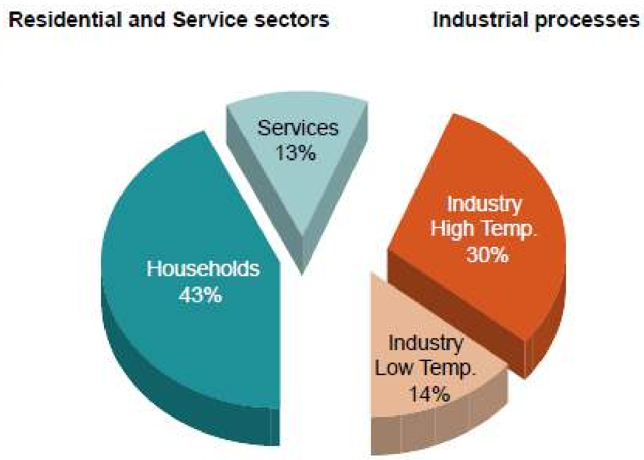


Figure 2 – Distribution of heat by use types in the EU (2006)[22]

In addition, bioenergy is one of the few renewable solutions to decarbonise the industrial sector of our economy. Dedicated heat plants and large-scale biomass CHP installations are capable to reach high temperatures and pressures and are particularly suitable for industrial application as seasonal demand variations do not occur in this sector. Bioheat produced at large scale is often cost competitive with fossil fuel alternatives, can rely on different biomass fuels including waste and by-products and reduces the amount of air emissions. [22] Steam temperatures above >500°C and pressures > 160 Bar can be achieved with solid biomass, depending on the specific case and biomass quality. Research and demonstration projects are ongoing to achieve

[20] Bioenergy Europe (formerly AEBIOM) Statistical report – Key findings (2017), p. 18.
[21] European Commission: Energy – Buildings: URL: https://ec.europa.eu/energy/en/topics/energy-efficiency/buildings
[22] Renewable Heating & Cooling European Technology Platform (2014): Common Implementation Roadmap for Renewable Heating and Cooling Technologies, p. 31.

Place du Champ de Mars 2
1050 Brussels
www.bioenergyeurope.org
+32 2 318 41 00
info@aebiom.org
VAT: BE 0871 481 553

higher temperatures with solid biofuels. With thermal gasification, torrefaction and steam explosion technology, high temperature heat similar to those provided by fossil fuels are achievable.[23]

Electricity sector

With 29% renewable energy in the EU-28 electricity mix, the power sector is currently the main driver of GHG reductions in the European energy system. However, system flexibility and storage remain a challenge for the development of a 100% renewable power system. Growing shares of variable renewables such as wind and solar being integrated in electricity systems result in increased need for balancing services. Bioenergy can offer the flexibility needed by a decarbonized electricity system: biopower is dispatchable and can therefore provide a reliable baseload but can also be used to cover peaks. Besides, short- and mid-term grid balancing, CHP plants running on full capacity when heat demand is high can counterbalance solar PV for which power production goes down during winter time (seasonal balancing).[24]

As it is already the case today[25], the majority of bioelectricity will be generated in combined heat and power plants (CHP). This is reflecting the synergies between renewable energies and energy efficiency. Depending on the local conditions (*e.g.* heat demand) and objectives of biopower (*e.g.* cover peak or base load), biopower-only installations are complementing the production of electricity in CHP plants.

In industrial applications the process variations can be fast and operational flexibility of the energy production unit is a key element and can be provided with modern biomass-based power plants. Both fuel and operational flexibility will be even valuable features in the future electricity markets. The operators can also participate in the electricity market if the price of electricity includes a sufficiently high price for carbon.

Transport sector

With a more and more mobile society, major changes in the transport sector are crucial. So far, the transport sector is lagging far behind in terms of RES deployment (5.24 % without multipliers in EU-28 in 2016). In recent studies, IEA and IRENA[26] have concluded that the importance of biofuels to replace fossil fuels will increase in the coming decades.

For small vehicles, a combination of biofuels together with electrification can drive CO_2 reductions (*e.g.* hybrid cars). Biomass can contribute to a greener electricity mix in order to guarantee that electrification is reducing GHG emissions. For heavy-duty vehicles, ships and airplanes, biofuels will be in most cases the only technical solution due to long investment cycles. Relying on biofuels for transport means that existing fleets can be easily adapted, and a zero-emission economy is not retarded by waiting for the end-of live of a vehicle. In what storage is concerned, biofuels perform better in terms of costs and weight than batteries.

Production of biofuels may be one of the activities of biorefineries but can also take place decentralized on farms and by small and medium enterprises. Carbon captured from Bio-CCS can also be used to produce transport fuel.

[23] See table in Innovation Chapter
[24] International Energy Agency (2017): Bioenergy's role in balancing the electricity grid and providing storage options – an EU perspective, p. 52.
[25] Bioenergy Europe (formerly AEBIOM) Statistical report (2017): p. 23: 58% of biopower is produced in CHP.
[26] IEA (2017) Technology Roadmap. Delivering Sustainable Bioenergy p. 23; IRENA (2018): Renewable Energy Prospects for the European Union, p. 74.

Place du Champ de Mars 2
1050 Brussels

+32 2 318 41 00
info@aebiom.org
VAT: BE 0871 481 553

Looking at the future: Innovation for bioenergy

Modern bioenergy is already a fully developed and commercially deployed source of renewable energy. Modern stoves, residential boilers and CHP plants already achieve very high fuel efficiency levels around 90%[27]. High-quality fuels such as pellets are increasing their market share however the traditional wood-based fuels like forest residue chips being more economical play still a major role. Further energy efficiency increase can be achieved with the replacement of old installations by new technology. To accelerate the deployment rate, renewable energy has to become the default option when replacing old installations. Yet, the polluter pays principle is not sufficiently implemented. Carbon tax are often non-existent and the efficiency of the emission trading system remains to be proven.

Ongoing research and development look at new fuels achieving better fuel quality, higher steam parameters (temperatures and pressure) for industrial processes and more efficient combustion with lower emission values. New integrated technology is combining the production of several outputs offers increased efficiency gains (*e.g.* combination of CHP and pyrolisis oil production). New conversion technologies offer high efficient solutions at small scale (*e.g.* Micro CHP). Another important research field is to increase plant flexibility (e.g. ramp up time, fuel flexibility) and the ability to combust more challenging fuels (*e.g.* waste wood, agricultural biomass).

Non-exhaustive list of latest fuel and conversion technology for solid biomass fuels

Technology	Output	Description	R&D stage
Latest fuel technology			
Torrefaction	Fuel with high calorific value able to replace coal in power plants; potential feedstock for chemical industries; substitute for coke in blast furnaces	Heating biomass to temperatures between 250 – 300 °C in a low-oxygen atmosphere and close to atmosphere pressure.	Ready for commercialisation
Steam explosion	Fuel with high calorific value able to replace coal in power plants; potential feedstock for chemical industries; substitute for coke in blast furnaces	Short thermal treatment with steam and high pressure without oxygen followed by a rapid depressurisation	Demonstration projects
Pyrolysis	Gaseous or liquid fuel with high calorific value. In liquid phase, bio-oil is able to replace heavy and light fuel oil at heat plants or in the production of industrial steam	Thermal degradation (devolatilization) in the absence of an externally supplied oxidizing agent.	First large-scale plants running

[27] Efficiency at nominal heat output

Place du Champ de Mars 2
1050 Brussels

+32 2 318 41 00
info@aebiom.org
VAT: BE 0871 481 553

Liquefaction	Liquid fuel which compared to pyrolysis fuel has a higher liquid yield resulting in a higher calorific value.	Thermochemical conversion in the liquid phase at low temperature and high pressure, usually with a high hydrogen partial pressure and a catalyst.	Pilot phase, early demonstration phase
Thermal Gasification	Syngas which can be used for the production of various products such as substitute natural gas and second-generation biofuels (diesel, kerosene)	Gasification of the feedstock at temperatures of 700°C-1600°C in the presence of a oxidizing agent (air or oxygen/steam)	commercial
Latest conversion technology			
Biorefineries	Various outputs ranging from bio-based chemicals to advanced biofuels, heat and electricity	Solutions to utilize infrastructures and processes for solid/liquid outputs to further use in the same site. Based on pulp mill or petroleum refinery concept, combination of the production of various bio-based outputs increasing resource efficiency	Commercial depending on product outputs
Combined Heat and power ind. micro/small-scale CHP[28]	Production of heat and power from the same fuel in a combined process	High fuel efficiency (above > 85% overall efficiency) as the heat generated by the biofuel combustion is used in a close thermal cycle to produce electricity and heat.	Commercialisation started for micro-CHP, commercial for small and large-scale CHP
Trigeneration	Production of electricity, heat and cold from the same fuel in a combined process	High efficiency (above > 85% overall efficiency) as the heat generated by the biofuel combustion is used in a close thermal cycle to produce electricity, heat and cool through absorption.	Commercial
Stoves and residential boilers	Residential heat	High efficient production of heat (around 90% fuel efficiency) through fixed bed combustion, possibly coupled with gasification and/or condensation.	Commercial
Multifuel solutions	Flexibility in terms of fuels ability to use several fuels in the same	Co-firing of different types of biomass or with other fuels, for instance using a fluidised-bed technology.	Commercial

[28] Micro scale CHP: below < 5kWel in the residential sector, 5-50 kWel in the small industrial sector; small scale CHP:50-250 kWel for industry and district heating.

Place du Champ de Mars 2
1050 Brussels
www.bioenergyeurope.org
+32 2 318 41 00
info@aebiom.org
VAT: BE 0871 481 553

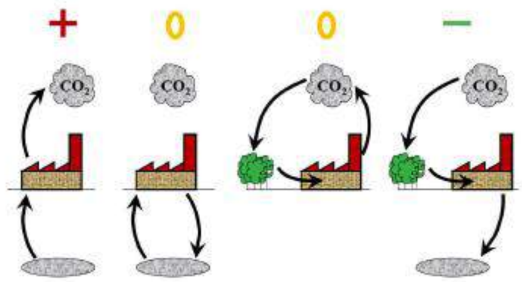
	boiler in any combination		
Fluidised bed technology	Ability to use challenging fuels such as waste wood	Fuel particles are suspended in a hot, bubbling fluidity bed of ash and other particulate materials through which jets of air are blown to provide the oxygen required for combustion or gasification.	Commercial

Sources: Van Loo & Koppejan (2008): Handbook of biomass combustion and co-firing ; WBA Factsheet (2015): Thermochemical gasification of biomass

Greenhouse gas emissions savings and negative emissions

Bioenergy is saving CO_2 through the replacement of fossil fuel combustion. The Renewable Energy Directive foresees greenhouse gas emission savings of at least 80% (for electricity and heating) and 65% (for transport) as of 2026.[29] Applying the JRC methodology to calculate emission savings of bioenergy, in total **365 Mt of CO_2 eq.** have been saved through the replacement of fossil fuels by bioenergy in the EU-28 in 2014.[30] Assuming that the current production of bioenergy is increasing from 140 Mtoe to 406 Mtoe[31]; 5.7 EJ to 17 EJ by 2050, almost **one billion tons of CO_2** will be saved.

CO_2 emission saving through bioenergy might even go one step beyond with the addition of carbon capture and storage given that there is enough sustainable biomass available. In the most ambitious scenarios (*e.g.* IPCC) aiming to limit global warming to 1.5°C, Biomass CCS (Bio-CCS) becomes an almost inevitable solution.[32] While CCS has been deployed in fossil industry, Bio-CCS represents a more interesting and **unique** solution as it produces a double climate benefit: a lock-in with fossil fuels is avoided and more importantly, negative emissions can be achieved though the removal of CO2 from the atmospheric cycle.



CO_2 is indirectly captured from air. During photosynthesis, CO_2 is captured and transformed into biomass. Instead of releasing this captured CO_2 back to the atmosphere during energy production, it can be captured with CCS and thus lead to a negative emission outcome. Up to now, this is unique and could thus play a healing role for our climate.

Bio-CCS technology is readily available, but commercial implementation did not happen yet due a lack of a political framework. To date, a credible mechanism crediting negative emissions is missing: the recent EU ETS has failed to establish a system for the issuing of allocations on the basis of negative emissions. Bio-CCS needs to gain momentum: supportive policies incentivising negative emission technology must be put in place.

[29] Renewable Energy Directive II : Article 26 and Annex VI.
[30] JRC Fossil Fuel Comparator Heat and Electricity, JRC lifecycle emissions data from solid and gaseous fuels.
31 As mentioned above in André Faaij study as the achievable potential by 2050.
[32] IPCC (2014) : 5th Assessment Report, p. 99.

Place du Champ de Mars 2
1050 Brussels

+32 2 318 41 00
info@aebiom.org
VAT: BE 0871 481 553

Following the demonstration phase, bio-CCS could take place in power plants, in large-scale industrial application and in the long-term might take place also in smaller installations. Already today, during the production of ethanol and biogas, concentrated flows of CO_2 can be captured at a relatively low cost. In the near future, CHP plants and biorefineries also represent a promising case of deployment. For transport and storage of CO2, European cross-border networks should be developed.[33]

Social and economic benefits of bioenergy

Bioenergy is the largest renewable energy source in terms of direct and indirect employment[34] accounting for 659,600 jobs in the sectors of solid biomass, biofuels, biogas and renewable waste.[35] By 2050, this number could increase to 1.5 to 2 million jobs based on an increase from 140 to 406 Mtoe (5.7 to 17 EJ) in the production of bioenergy.

Relying on feedstocks from agriculture and forests, biomass is relatively job-intensive in comparison to other types of energy (*e.g.* 10 times more jobs than nuclear energy for each unit of energy produced)[36]. In addition to that, bioenergy is largely produced in rural areas and has thus a positive impact on the income of farmers and forest owners.

Solid bioenergy experienced strong growth in the last years with an increase in turnover from 25 bn € in 2010 to around 32 bn € in 2016 in the EU-28. In 2015, the overall turnover of bioenergy represented 56 bn € in the EU-28.[37] With this amount, the European Union is the global leader in bioenergy. European technology developers and producers in the field of bioenergy are number 1 in research and development in the world generating high-quality jobs and generating exports. Ongoing support for research, development and demonstration projects is needed to keep the EU as a leader in bioenergy.

Compared to fossil fuels which rely largely on imports, import dependency of biomass was about 4.4% in 2015. Relying increasingly on bioenergy will lead to higher energy security in the near future.

[33] This could build upon Norway's plan to establish a CO_2 transport and storage infrastructure integrating EU Member States.
[34] Employment initiated from renewable investments, operation and maintenance activities, production and trading of equipment and biomass feedstock
[35] EurobservER (2017): The state of renewable energies in Europe, p. 124-139.
[36] Biomass counts (2015): Fueling Europe with jobs and innovation, URL: http://www.biomasscounts.eu/wp-content/uploads/2015/03/factsheet-october.pdf
[37] EurobservER (2017): The state of renewable energies in Europe, p. 124-139.

Place du Champ de Mars 2
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www.bioenergyeurope.org

+32 2 318 41 00
info@aebiom.org
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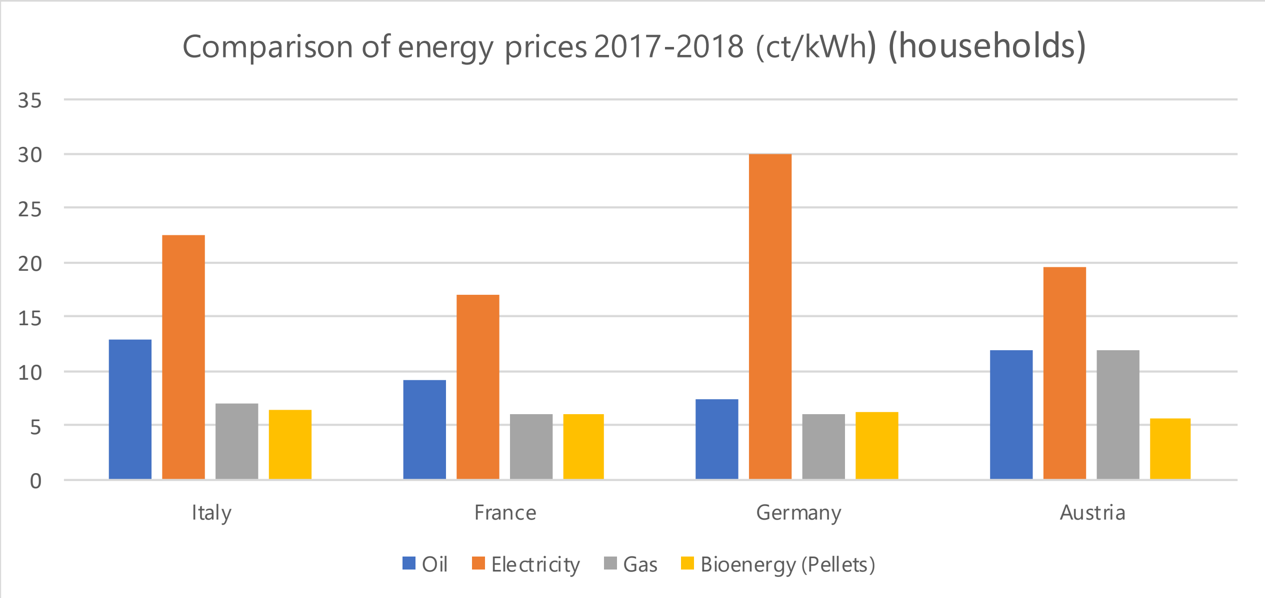
Bioenergy is also beneficial for consumers and can help alleviating energy poverty. When compared to fossil fuel use in the heating sector, biomass is most often a cheaper solution compared to electricity, heating oil and natural gas (*see graph*).



Source: Eurostat, Bioenergy Europe Statistical Report. Prices are given for pellets, other biomass fuels such as wood logs, wood chips are even less expensive than pellets

Place du Champ de Mars 2
1050 Brussels

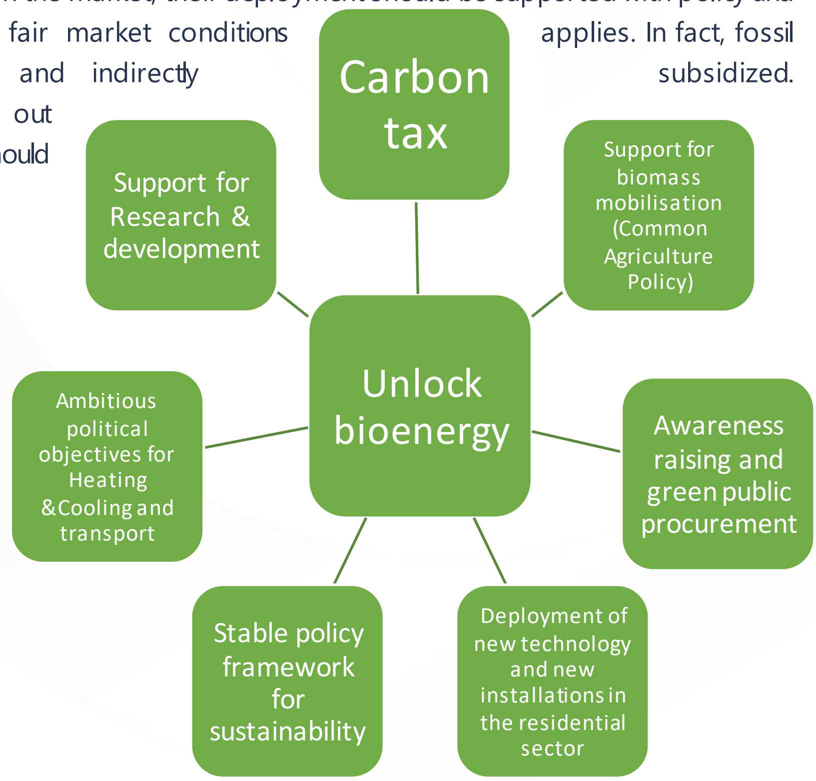
www.bioenergyeurope.org

+32 2 318 41 00
info@aebiom.org
VAT: BE 0871 481 553

Unlocking bioenergy (policy recommendations)

There is sufficient biomass potential and already available and commercially viable technology solutions. To fully untap the bioenergy potential for the 2050 net-zero carbon economy, several key political decisions are needed:

1. Mobilize untapped biomass potential: Today the main biomass potential comes from forests, whereas in the future agriculture (dedicated energy crops and residues) will play a much bigger role. Incentives for farmers and technology providers are needed to improve mobilization, grow feedstock and develop adapted combustion and other technologies.
2. Create incentives to decarbonise the heating and transport sector: The heating and transport sectors are both lagging behind the power sector. Both sectors rely to a large extent on individual consumer decisions. Political incentives and awareness raising (*e.g.* carbon tax) are needed to drive behavioral changes of citizens to increase deployment of low carbon solutions for heating and mobility. To increase energy efficiency, the replacement of old installations by high efficient stoves and boilers in the residential sector need to be fostered by financial support.
3. Ensure reliable power generation and stabilise the grid with bioenergy: The increasing integration of variable renewables with the power grid will place significant pressure on the grid operation. Bioenergy can provide baseload and balancing services. If on one hand, certain technologies can provide faster ramp up times and would hence be able to cover peak loads, they are on the other hand more expensive. For this, sufficient incentives are needed to allow the replacement of fossil fuels by bioenergy in the power sector.
4. Invest in research and development for promising technologies and help market deployment for existing technologies: To a large extent, modern and high efficient bioenergy technologies are already available. Research and development are ongoing for various biomass technologies. For technologies already on the market, their deployment should be supported with policy and financial measures until fair market conditions applies. In fact, fossil fuels are still directly and indirectly subsidized. These should be phased out and a price on carbon should be established.



Definitions

Final energy consumption: Final energy consumption cover energy supplied to the final consumer's door for all energy uses. It is the sum of the final energy consumed in the transport, industrial, agricultural/forestry, fishing, services, household and other unspecified sector. It excludes deliveries to the energy transformation sector and to the energy industries themselves.

Gross final energy consumption: Final energy consumption + consumption of electricity and heat by the energy branch for electricity and heat generation (own use by plant) + losses of electricity and heat in transmission and distribution

Primary energy consumption: primary energy refers to the indigenous production, that is any kind of extraction of energy products from natural sources to a usable form. Primary production takes place when the natural sources are exploited, for example in coal mines, crude oil fields, hydro power plants or fabrication of biofuels. Transformation of energy from one form to another, such as electricity or heat generation in thermal power plants is not included in primary production.

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