Towards an Integrated Energy System:

Assessing Bioenergy's Socio-Economic and Environmental Impact

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This report was commissioned to Deloitte by Bioenergy Europe. Bioenergy Europe is the voice of European bioenergy. It aims to develop a sustainable bioenergy market based on fair business conditions.

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Executive Summary

Bioenergy is a very versatile and flexible solution that can assist the main challenges of achieving climate neutrality by 2050 with job creation and economic growth. Each additional Mtoe of biomass for energy could lead to an impact of 359 million euros in terms of GDP and an employment creation of 7.376 Full-Time Equivalent (FTE), on average, while preventing 2,4 $MtCO_2eq$ emissions due to the replacement of fossil fuels for energy.

Currently, millions of citizens rely on bioenergy to heat their homes, not only through individual heating systems but also through collective systems, such as district heating. Moreover, many industrial processes, especially within wood-related industries, such as the paper and pulp industries, rely on reusing their residues to supply energy to their processes. In the future, the number of citizens and industries that rely on the use of bioenergy will increase as further development of this renewable source is required to achieve the EU emissions targets for 2030 and 2050.

Deloitte has analysed the future role of bioenergy in achieving climate neutrality, as well as its contribution to society considering the socio-economic and environmental impacts not only today but also on the 2050 horizon. The assessment carried out estimates the impact of bioenergy on the economy in terms of GDP and employment creation, paying particular attention to its effect on the rural environment, while also considering the impacts of bioenergy on the mitigation of carbon emissions, the contribution to forest health, the security of the energy supply and the development of a circular economy as well as the complementarities of bioenergy with other renewable energies and the adoption of clean hydrogen solutions.

Economic Growth and Employment Impact

The bioenergy sector's contribution to the economy of the EU27 was estimated by Deloitte using three equivalent approaches, recognised by the European System of National and Regional Accounts (ESNRA)[1]: added value, income and expenditure approaches. The information required by these approaches was gathered from the information that EU companies active in the bioenergy industry disclosed in their financial statements. Additional information was gathered by surveying bioenergy industry players. Information on job creation was calculated based on employment data published by companies in the industry and complementary industry both in their financial statements and in their annual reports. Furthermore, the indirect effects of the bioenergy sector on other sectors of the economy was quantified using input-output tables from the EU27[2].

In 2019, the impact of bioenergy on employment reached 964.258 FTE, with 649.334 and 314.924 FTE mobilized directly and indirectly, respectively. Unlike other renewable energies, which do not need labour to obtain the fuel, biomass is employment intensive as it often needs to be collected, treated and transported prior to its use. Moreover, bioenergy also generates a significant number of jobs in the operation and maintenance of the solutions, the manufacture of equipment, as well as the construction of new generation plants and district heating systems. **In 2019, the operation and maintenance of the different solutions represented 21% of the direct employment created, followed by the manufacture of equipment, representing 11%, and the construction/installation, which accounted for 4% of the direct employment generated.**

It is important to mention that both construction and equipment manufacturing jobs are mobilized through new facilities and installations, unlike the supply of feedstock or the operation and maintenance of the solutions, which are permanent jobs linked to existing facilities.

1 Definitions as given by Eurostat: http://epp.eurostat.ec.europa.eu/statistics_explained/index.php/National_accounts_%E2%80%93_GDP

2 These tables do not include a disaggregated breakdown of the bioenergy sector, so they have been completed on the basis of questionnaires distributed among agents in the sector, in order to identify the sectors from which these goods and services are demanded. Thus, it is possible to estimate the indirect impact of the bioenergy sector on other economic sectors in Europe.

The economic impact of the bioenergy sector in terms of GDP accounted for40.207 million euros in 2019, representing 0,30% of the EU27's GDP: the direct impact reached 24.696 million euros, while the indirect impact represented 15.511 million euros . The impact in terms of GDP of the bioenergy sector in the EU27 was higher than that of sectors such as fishing and aquaculture or coke and refined petroleum products manufacture, and comparable to that of others such as mining and quarrying.

European companies are global leaders when it comes to technological development, manufacturing, and fuel production of bioenergy. In fact, about 74%[3] of the bioenergy technology suppliers are based within the EU. These companies represent a globally competitive industry and have the necessary knowledge and professionals to maintain this leadership as a R&D hub for bioenergy that promotes vibrant commercial activity.

Another way bioenergy creates jobs and supports local economies is through providing new markets for people and companies connected to agriculture and forestry, giving value to previously unused residues and resources. This not only strengthens rural areas by creating more livelihoods allowing for people to support themselves in these areas, but is also an important source of revenue for municipalities. In Europe, 40% of the forest area is owned by municipalities, regional or national governments which means that the sale of forest management residues and resources directly supports state budgets.

Environmental Benefits

Bioenergy is the largest source of renewable energy in the EU27, making up around 59% of the share of renewables in the primary energy production. The bioenergy sector has many synergies with other economic sectors, including the wood-based industries, especially the pulp and paper industries, as well as the agricultural and the agri-food industry, where the utilization of residues as feedstock for energy improves the resource efficiency while increasing marketability of otherwise unprofitable residues that would be waste. This, together with the existing bans on organic waste landfilling in several EU countries values these waste fractions so that they can be re-used for energy purposes, contributing to the development of a circular economy.

At the same time, the use of biomass for energy production also provides an attractive solution for forest management, giving economic value to a low-quality biomass that otherwise would be left on the ground for rotting, which reduces the risk of forest pests and fires.

Furthermore, carbon dioxide emissions emitted by the combustion of biomass is more than compensated by the growth of the forest. **In 2019, the replacement of fossil fuels for energy by biomass prevented 290 MtCO_2eq emissions, equivalent to around 8% of the EU27 GHG emissions. Bioenergy is contributing to the decarbonisation of fossil fuel intensive sectors where carbon emissions are difficult to abate such as the industry and transport sectors.**

By substituting fossil fuels for bioenergy, the primary energy production of bioenergy allowed the replacement of 132 Mtoe from fossil fuels in 2019, reducing the dependence on foreign countries for their energy supply by promoting domestic renewable energy resources.

The above refers only to the replacement of fossil fuels for energy production. However, the impact of the biomass's value chain on reducing emissions is even greater, as before it being used for energy production purposes it already had its own purpose which helped somewhat reduce greenhouse gas emissions. For example[4,5], each cubic meter of wood used as a substitute

3 Bioenergy International (2018): 11th Global Suppliers Directory.

4 Asociación Nacional de Fabricantes de Tableros, Centro de Innovación e Servizos Tecnolóxicos da Madeira de Galicia, Xunta de Galicia (2007): Frente al Cambio Climático: Utiliza Madera.

5 Aalto University (2020): Building cities with wood would store half of cement industry's current carbon emissions.

for other building materials (such as steel and concrete) reduces CO_2 emissions to the atmosphere by an average of 1,1 tCO_2. Moreover, wood buildings could also work as carbon sinks: each cubic meter of wood can store up to 0,9 tCO_2.

Security of Supply

Bioenergy in the European Union is mainly produced utilising local biomass, with an import dependency remaining at 3,7%. The replacement of imported fossil fuels with domestic renewable energy improves the security of the energy supply and reduces the risk of supply problems resulting from the socio-political context in foreign countries.

Additionally, the adoption of bioenergy brings price stability benefits, key for energy security. The cost of biomass for energy proves to be both more stable over time and cheaper than those of fossil fuels. Moreover, a price increase of natural gas results in a price increase in electricity, which, coupled with the difficulty of forecasting prices, puts citizens and industry at risk of facing fluctuating energy costs which can increase energy poverty and decrease the competitiveness of the European industry. For example, when comparing the household price of biomass with other energy commodities, it is observed that the price of pellets, the most expensive type of biomass, remains quite stable, being even and up to four times cheaper than natural gas and electrical heating in all countries.

Moreover, as biomass is the only renewable energy source capable of providing energy in the three primary forms required by society (solid, liquid and gaseous fuels for heat, electricity and transport) it helps diversify the risk from energy disruptions, strengthening energy security.

Future Outlook

Achieving the emission targets for 2030 and 2050 would require further development of bioenergy based on the projections of the European Commission, the International Renewable Energy Agency and the International Energy Agency[6,7,8]. Considering the scenarios reported by the Impact Assessment of the European Commision[6], the average gross inland consumption of biomass for energy would be near 220 Mtoe in 2050, showing an annual increase of about 2% between 2019 and 2050. This annual increase is actually lower than that shown by bioenergy in the last 10 years, which was around 2,6%, showing that the future increase could correspond to a business-as-usual scenario.

The increase in the biomass consumption for energy could serve as a vehicle for job creation and an economic opportunity for countries throughout the European Union. According to the assessment carried out, **each additional Mtoe of biomass for energy would lead to an impact of 359 million euros in terms of GDP and an employment creation of 7.376 FTE, on average.**

The previous is especially important as the current EU imported energy bill is higher than 236 million euros per Mtoe[9]. Therefore, the use of a renewable resource available in the territory, such as biomass, would not only allow the creation of employment and economic growth, but would also allow reducing the energy bill with third countries. Moreover, the transition towards net-zero emissions will lead to unemployment in sectors such as the fossil fuel production, which could be mitigated through the implementation of bioenergy. For example, according to the IEA's Net-Zero Emissions by 2050 (NZE) Scenario, fossil fuel production could lose 5 million job positions by 2030[10].

6 European Commission (2020): Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. Impact Assessment accompanying the document Stepping up Europe's 2030 climate ambition - Investing in a climate-neutral future for the benefit of our people.
7 IEA (2021): Net Zero by 2050, IEA, Paris.
8 IRENA (2020): Global Renewables Outlook: Energy transformation 2050 (Edition: 2020), International Renewable Energy Agency, Abu Dhabi.
9 Own calculation based on data of the European Council on Foreign Relations and Eurostat database.
10 International Energy Agency 2021, accessed 28 September 2021, https://www.iea.org/commentaries/the-importance-of-focusing-on-jobs-and-fairness-in-clean-energy-transitions

The impact on employment in 2050 could reach 1.578.668 FTE, with 1.013.945 and 564.723 FTE mobilized directly and indirectly, respectively. Furthermore, the economic impact of the bioenergy sector in terms of GDP in 2050 could account for 70.105 million euros, representing 0,52% of the current GDP of the EU27. The direct and indirect impact on the GDP would account for 41.338 million euros and 28.768 million euros, respectively.

The increase in employment and GDP compared to 2019 would reach 64% and 74%, respectively. This growth will be led not only by the use of bioenergy for electricity production, but also by the production of biofuels for transport, and the increase of biomass used for heat in the industrial sector. Also, as biomass technology development would evolve with modern appliances that use less fuel for the same heat production, thus being more efficient, there will be a market linked to the replacement of existing old installations with nearly-zero emission modern devices. This market will be led mainly by the residential sector in which, in addition, the traditional use of wood logs used in open fires will be replaced by the use of pellets, chips, or briquettes required by modern equipment.

Furthermore, based on the average gross inland consumption of biomass for energy in 2050 reported by the Impact Assessment of the European Commision[6], the replacement of fossil fuels for energy by biomass could prevent, on average, 487 MtCO_2eq emissions for that year. Hence, each additional Mtoe of biomass for energy could mitigate 2,4 MtCO_2eq emissions due to the replacement of fossil fuels for energy, while creating economic growth and employment.

This impact could be even higher taking into consideration the use of bioenergy together with BECCS (Carbon Capture and Storage technologies). BECCS will enable carbon dioxide removal from the atmosphere, making bioenergy an alternative technology for negative emissions. This will be critical to achieve the Paris Agreement goal as 101 of the 116 scenarios explored by the IPCC in which global warming is kept to 1,5 °C with respect to pre-industrial levels consider these kinds of technologies. In fact, the production of bioethanol, the power sector or industries that require significant heat and electricity in their production processes have a huge potential for BECCS.

Lastly, bioenergy is crucial for achieving the decarbonisation and the sustainability of the energy system in 2050. Bioheat represents a mature and effective solution for decarbonising buildings and industrial sectors in any of its different solutions, being the use of this renewable heat to cover thermal consumptions more efficient than a future switch of thermal consumptions to electric consumptions.

Also, as bioenergy is a dispatchable and flexible power and heat supply, it allows adjusting its production to stabilise the grid under a scenario of high penetration of intermittent renewables. Besides, biomass can easily be stored for when there is no sun or wind, as well as in demand peaks.

In addition, the production of renewable and carbon neutral hydrogen can be found among the many complementarities of bioenergy with other renewable sources. Hydrogen will be an important secondary energy carrier for the future, and it could be obtained from biomass via gasification, electrolysis, etc. paving the way for its clean production.

All in all, bioenergy is key to achieve climate neutrality by 2050, representing an alternative energy source to fossil fuels and a backup energy to balance the intermittency of other renewable sources such as wind and solar. Bioenergy will encompass energy transition with economic growth and employment creation while lowering greenhouse gas emissions particularly in sectors where electrification is difficult and costly (shipping, aviation, medium and high temperature processes and other industrial applications). The use of biomass for energy will allow to continue mitigating the import of fossil fuels, and thereby continue reducing the energy dependence with third countries. Moreover, the bioenergy industry is fully aligned with the net zero emission objectives, being quite ahead of other industries since bioenergy has unique criteria and is under sustainability requirements.

1 The Bioenergy Industry

Bioenergy refers to all types of energy derived from the conversion of recently living organic materials known as biomass, which are available on a renewable basis. Nowadays, biomass used in Europe includes wood from forests, agricultural crops and residues, by-products from wood and the agricultural industry, herbaceous and woody energy crops, municipal organic wastes, manure, and could potentially integrate algae and marine biomass in the future.

The use of biomass constitutes a carbon neutral energy source as carbon emissions derived from its combustion are offset by the carbon dioxide captured through the photosynthesis process of plants. Hence, biomass represents an alternative energy source to fossil fuels, playing an important role in lowering greenhouse gas emissions and achieving a climate neutral economy in 2050 as established in the European Green Deal.

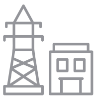
Moreover, there is a need for further development of bioenergy to achieve the EU emission targets for 2030 and 205[11,12,13] particularly in sectors where electrification is difficult and costly (shipping, aviation, medium and high temperature processes and other industrial applications) but also to balance the intermittency of other renewable sources such as wind and solar. However, the mitigation of climate change must go in hand with sustainable development, otherwise negative effects could arise.

The Renewable Energy Directive II (REDII) is the main EU renewable energy policy instrument. According to this Directive, biomass must be produced in a sustainable way to be effective at reducing greenhouse gas emissions. The sustainability criteria that renewable energy sourced from biomass needs to fulfil to minimize possible negative impacts on biodiversity and soil quality, making sure that carbon sinks are effectively maintained, include the following, inter alia:

- Agriculture waste and residues, requiring evidence of the protection of soil quality and soil carbon, and for agriculture biomass, requiring evidence that the raw material is not sourced from highly biodiverse forests.

- Forest biomass, requiring bioenergy generators to demonstrate that the country of origin has laws in place avoiding the risk of unsustainable harvesting and accounting of emissions from forest harvesting. Where such evidence cannot be provided, bioenergy generators need to demonstrate sustainability compliance at the level of the biomass sourcing area.

- New biofuel plants need to deliver at least 65% fewer direct GHG emissions than the fossil fuel alternative. New biomass-based heat and power plants need to deliver at least 70% (80% in 2026) fewer GHG emissions than the fossil fuel alternative.



- Bioelectricity, requiring that large scale plants (above 50 MW) apply highly efficient cogeneration technology, or apply Best Available Techniques (BAT) or achieve 36% efficiency (for plants above 100 MW), or use carbon capture and storage technology.

These criteria are complementary to the safeguards set out by EU climate and environmental legislation, in particular by the Regulation on Land Use, Land Use Change and Forestry 2018/841 (LULUCF).

11 European Commission (2020): Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. Impact Assessment accompanying the document Stepping up Europe's 2030 climate ambition - Investing in a climate-neutral future for the benefit of our people.

12 IEA (2021): Net Zero by 2050, IEA, Paris.

13 IRENA (2020): Global Renewables Outlook: Energy transformation 2050 (Edition: 2020), International Renewable Energy Agency, Abu Dhabi.

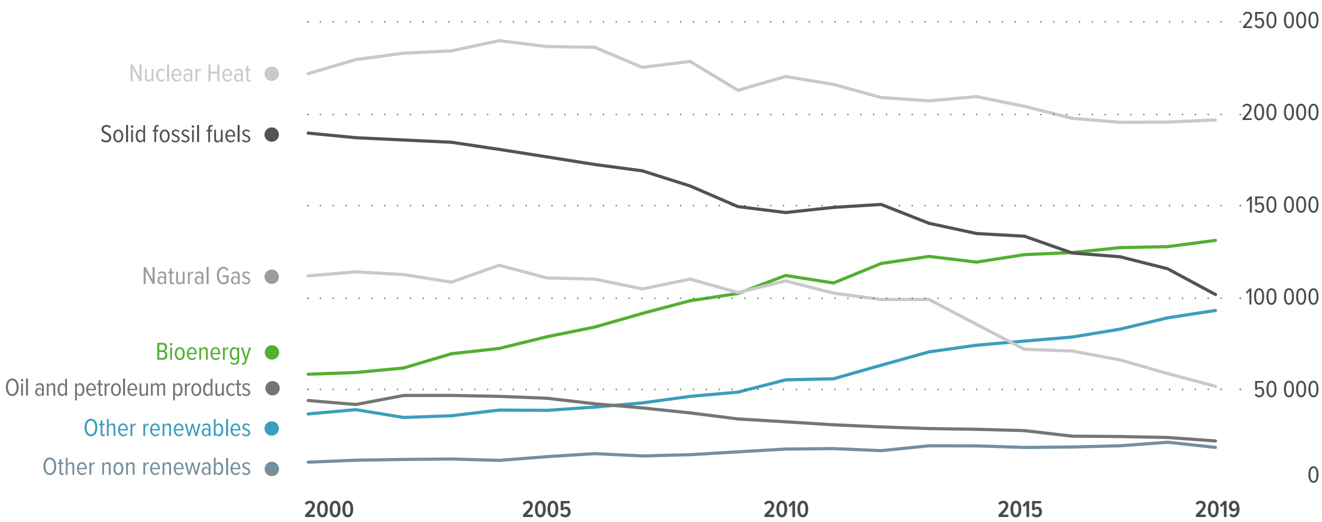
The Land Use, Land Use Change and Forestry Regulation (LULUCF) provides incentives for economic operators to deploy emission-absorbing projects that can be a source of biomass; highlighting as a specific action in the Biodiversity Strategy Action Plan, the Study on the sustainability of the use of forest biomass for energy production and its importance in the environment acting. The regulation makes sure that all sectors contribute to the EU's 2030 emission reduction target, including the land use sector.

Currently, the Renewable Energy Directive revision proposal draft provides updates to strengthen the sustainability criteria for the use of solid biomass for energy and biofuels for transport, considering the economic and environmental impacts of the use of biomass, specifically woody biomass. However, it should be emphasized that bioenergy is mainly produced from process by-flows, residues from forest management operations or wood industries as a result of integrated systems that deliver bioenergy and other forest products. That is, the use of primary biomass for energy comes from low quality sources that cannot be utilized for other purposes, such as forestry residues and dead wood, being bioenergy mainly produced from secondary biomass. Forests are not managed for bioenergy, and biomass for energy is a by-product of the cultivation and management of forests. Also, the use of forest certificates (e.g. PEFC, FSC) helps ensure that woody biomass is sustainable.

Biomass harvested as a result of sustainable forest management guarantees that forests will continue to function as a significant carbon sink and incentives forest health. Furthermore, the accumulation of understory biomass could increase the incidence of forest pests and fires in specific instances. For example, in 2019 a total of 2.028 fires burned an area of 304.147 hectares in 23 countries of the EU[14]. **Appropriate forest management would help control pests and reduce the danger of wildfires, while allowing waste to be recovered through bioenergy.** Besides, biomass is part of the circular bioeconomy, which focuses on the sustainable, resource-efficient valorisation of biomass in integrated, multi-output production chains (e.g. biorefineries) while making use of residues and wastes. This allows renewable energy to be obtained for production processes[15].

Nowadays, biomass is the most important indigenous energy source in Europe[16]. The primary energy production of renewables is the only source increasing within the EU27, being led primarily by bioenergy: from 2000 to 2019 the contribution of this source has increased by 72.694 ktoe; having grown by more than double.

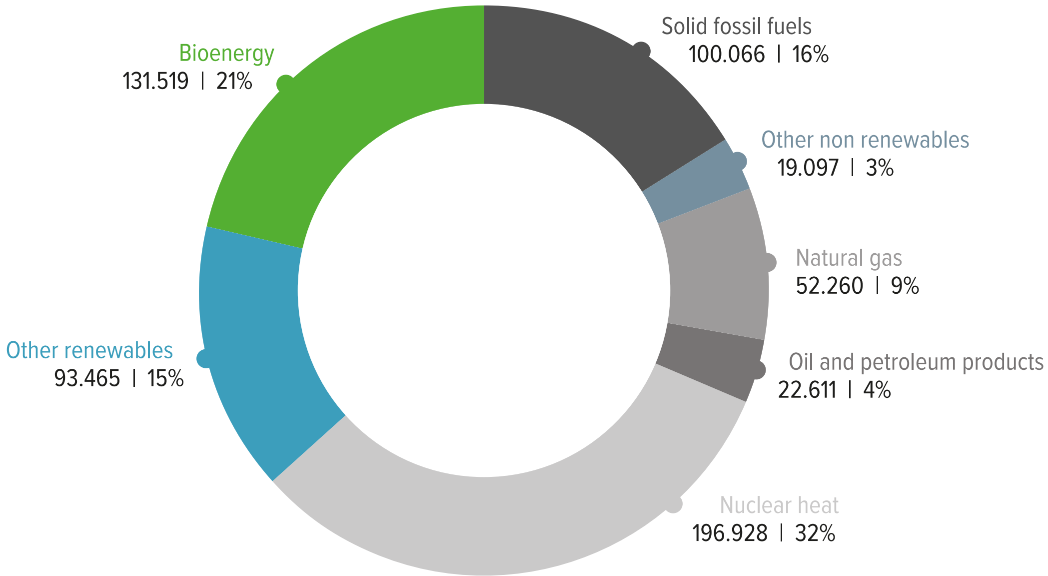
Figure 1. Evolution of primary energy production in EU27 by main fuel (ktoe).



Source: Eurostat database.

14 EFFIS (European Forest Fire Information System)
15 Stegmann P., Londo M. and Junginger M. (2020): The circular bioeconomy: Its elements and role in European bioeconomy clusters, Resources, Conservation & Recycling: X, Volume 6, 2020, 100029, ISSN 2590-289X,
16 Taking into consideration that nuclear heat is reliant on Uranium imports.

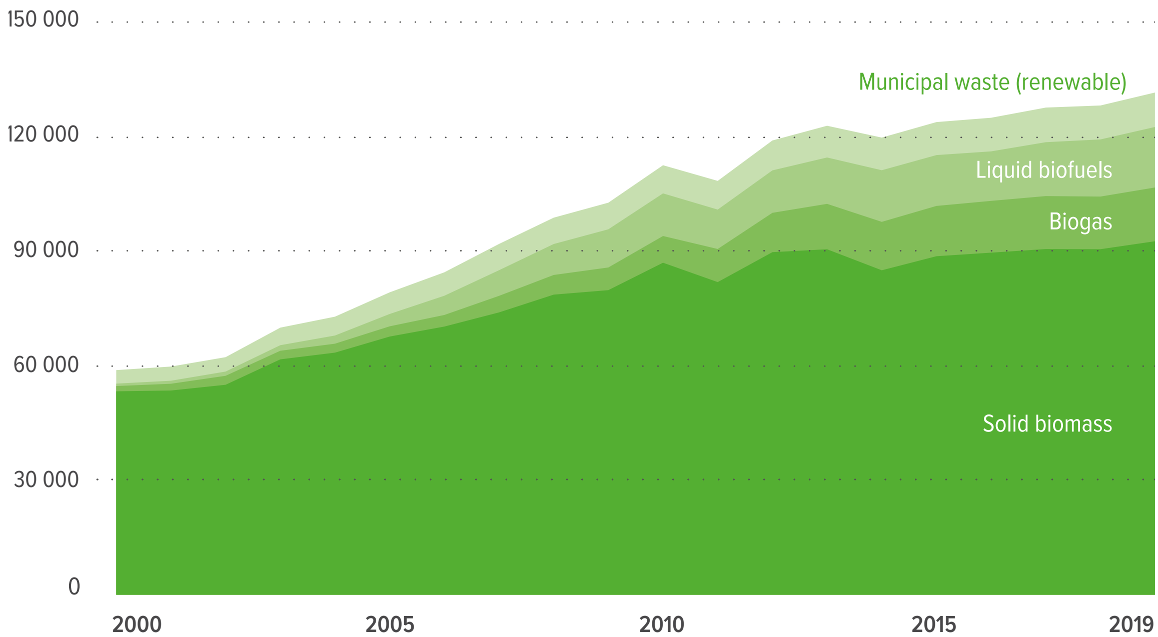
Figure 2. Primary energy production in EU27 in 2019 (ktoe; %).



Source: Eurostat database.

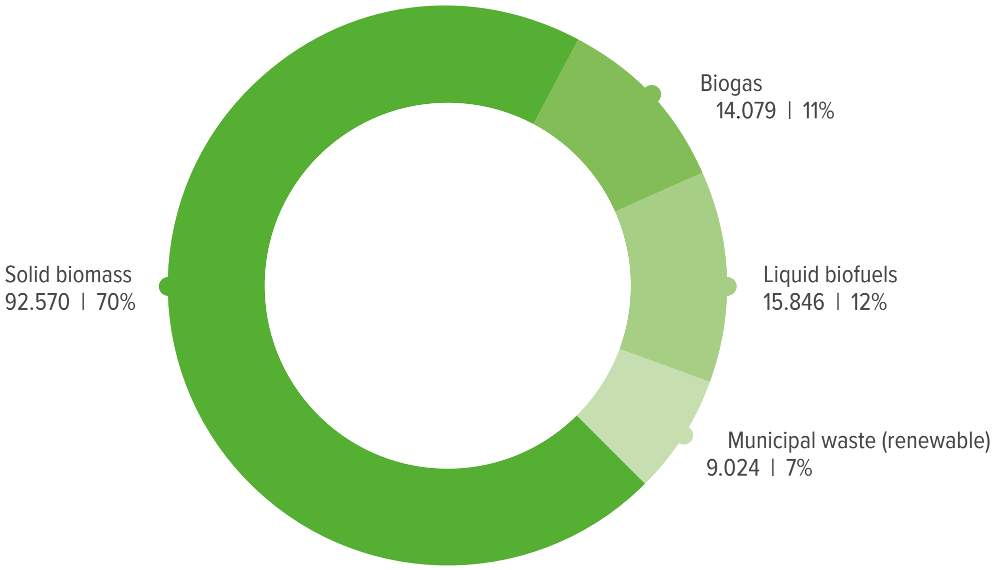
Biomass can be used in liquid forms such as biofuels, in gaseous forms like biogas, or in solid forms, as it is the case when converting wood, agriculture and agro-industrial industry waste and, also, urban organic waste into energy. Solid biomass is the main feedstock used for bio-energy production, accounting for 70% of the total raw material.

Figure 3. Evolution of primary energy production of biomass in EU27 (ktoe).



Source: Eurostat database.

Figure 4. Primary energy production of biomass in EU27 in 2019 (ktoe; %).



Source: Eurostat database.

In terms of gross final energy consumption, bioenergy represents by far the largest source of renewable energy, reaching 115.788 ktoe in 2019 in EU27, equivalent to 11% of all the energy consumed in Europe[17]. Bioenergy can be used in electricity, heating and cooling, and transport, being the only renewable energy source with such potential. In 2019, 74% of bioenergy was consumed as heat, 14% as transport fuel and 12% as electricity.

Therefore, bioenergy offers a large variety of solutions to multiple consumers, each of them playing a relevant role in the decarbonisation of the economy. **The complementarity of bioenergy with other renewable technologies when contributing to the decarbonisation of the economy must be taken into high consideration by government bodies, since the former constitutes a generation source capable of managing the variability of the latter.**

Moreover, more than half of the energy consumed in Europe is imported and this dependence on the imports of fossil fuels may cause energy security problems and weaken Europe's political influence. In this context, a greater use of renewable energy sources will allow Europe to become more energy independent, being able to consume energy that is generated within its own territory. In the case of bioenergy, the import dependency remained at 3,7%[17] in the EU27, in contrast to the 97%[17] for crude oil or 90% for natural gas. The low import dependency shows that bioenergy remains a local source of energy, which also reveals the need for adapted sustainability criteria and quality standards to ensure an operational bioenergy market.

The European Union holds the leadership in terms of technological development, manufacturing, and fuel production of bioenergy, with a globally competitive industry. The manufacturers are setting up as exporters, fulfilling with high manufacturing standards. However, despite the fact that Europe is the market leader in technical knowledge and research matters, the lack of support and incentives from European policies and the lack of a defined political framework may hinder the development of the bioenergy industry: if a stable regulatory framework is not defined, such leadership could be taken away by competing countries.

17 Eurostat database.

CASE STUDY:

Technological innovation in biomass for energy

In recent years, the bioenergy industry has devoted efforts to the development of applications and technologies for the conversion of biomass into energy in order to increase the efficiency of processes, as well as to reduce emissions and improve the functionalities of the equipment.

Increasing the efficiency of the equipment allows increasing energy production reducing the use of biomass, which in turn increases the sustainability of the processes. In addition, technological development has made it possible to obtain equipment with nearly-zero emissions, which has great potential benefits for both the industrial and domestic sectors.

This development takes place thanks to the investment in research and development carried out by the bioenergy industry in Europe, making it a hub for this type of activities. An example of the technological innovation is the combustion technology POLY H.E.L.D., which has been developed by Polytechnik GmbH (Austria).

This technology has extreme air staging, allowing for a low-emission and efficient combustion of various fuels. The dust emissions for wood-based biomass remain lower than 20 mg/Nm^3 at 11% O_2. Besides, a value of 10 mg/Nm^3 can be reached with high quality wood chips.

POLY H.E.L.D. can combust or gasify high-ash fuels with relatively low ash melting points. The system accomplishes these low emission values without additional flue gas purification, which makes it a highly economical solution.

The main characteristics of this solution are as follows[18]:

- Fuel flexibility: Wood chips up to M45, corncobs, straw pellets, and various agricultural residues.
- Efficiency: > 92% (+5% compared to conventional combustion).
- NOx: -25% (compared to conventional combustion).
- Dust: < 20mg/Nm3 (without flue gas purification).
- Output range: 25-100% (also with M45).
- START-STOP within just a few minutes.

The deployment of the technology in Europe requires developing optimal, reliable, and integrated bioenergy supply chains from feedstock cultivation, harvesting, transport, storage to conversion into heat, electricity, and transport fuels. In addition, bioenergy not only generates new jobs directly, but also boosts the creation of specialized, quality jobs throughout its value chain; this has positive economic, social, and environmental impacts at both local and national levels.

Thanks to its ability to create jobs for different work profiles, bioenergy can play a key role in the development of rural areas where a shortage of quality job offers is a pressing problem. Bioenergy can help achieve a sustainable management of natural resources and climate action, a balanced territorial development of rural areas, and improving the competitiveness of forestry and agriculture.

18 POLY H.E.L.D. 2021, Polytechnik GmbH accessed in 13 October 2021, < Poly HELD - Polytechnik>.

Biomass is, therefore, a natural source of renewable energy which can contribute to a more secure, sustainable, and economically advanced future, having the following economic, social, and environmental advantages[19]:

- **Economic:**
  - Reduction of fossil fuel energy dependencies, while creating local value.
  - Addition of value to the local agricultural and forestry inputs.
  - Creation and development of a bio-based industry where the energy required comes from by-products and waste streams.
  - Development of a circular economy.
  - Improvement of the countries' productivity.
  - Creation of export potential.
  - Generation of incomes at a regional and local level (consumption, production, tax revenues).
  - Demand of locally produced capital goods.
  - Development of knowledge and innovation at a regional and local level.
- **Social:**
  - Creation of job opportunities, linking industrial and rural communities.
  - Contribution to reduce energy poverty by offering an affordable renewable solution.
  - Promotion of local development.
  - Creation of specialized jobs, encouraging the generation of knowledge and technological skills.
  - Mitigation of rural depopulation.
  - Contribution to the distribution of energy generation, boosting regional/national energy independence.
  - Production of reliable and decentralised renewable energy for the end consumers.
- **Environmental:**
  - Contribution to achieve EU carbon neutrality by 2050.
  - Creation of new uses for waste, boosting the circular economy.
  - Mitigation of GHG emissions, reducing the impacts of air pollution.
  - Improvement of forest management, lowering the impact of climate change disturbances (forest fires, pests...).

19 FAO (2020): A handbook on a methodology for estimating green jobs in bioenergy. Tools for investigating the effects of bioenergy production on employment at provincial level, Buenos Aires, 124 pp. License: CC BY-NC-SA 3.0 IGO.

2 Objective and Scope of the Assessment

The analysis of the contribution of bioenergy to society cannot be limited to the employment creation and the contribution of bioenergy to the economy as it should also consider the mitigation of carbon emissions, the protection of the environment, the security of energy supply, etc. Hence, the objective of this assessment is to analyse the current impact of bioenergy considering both socio-economic and environmental impacts. The assessment also takes into consideration the future role of bioenergy in achieving EU climate neutrality, assessing socio-economic and environmental impacts in the 2050 horizon.

The scope of the assessment covers the following topics:

- The relevance of bioenergy as an energy input, presenting the current penetration of these solutions and the future relevance according to the smart criteria.
- The positive impact of bioenergy on the European Union's economy and employment, evaluating for each solution the impact on the value chain activities. The information about these impacts will be split according to the following structure:

  - **Bioelectricity:**
    Manufacture of the equipment, construction of the facilities, supply of fuel, and operation of the bioenergy plants.

  - **District heating solutions:**
    Manufacture of the equipment, construction of the district heating infrastructure, supply of fuel, and operation of the bioenergy plants.

  - **Individual heating systems based on biomass:**
    Manufacture of the equipment, installation, supply of fuel, and maintenance.

  - **Biofuels for the transport sector:**
    Manufacture of the equipment, construction of the plants, supply of feedstock, and operation of the biofuel plants.

  The assessment will include the calculation of the impact on the Gross Domestic Product (GDP) and the employment (number of employed professionals) at two levels, attending to the direct and the indirect impact.

- The estimated impact of the bioenergy sector on mitigating GHG emissions, analysing the alternative energy solutions that would have been used if bioenergy was not applied. Other positive environmental impacts will also be evaluated, such as the mitigation of forest fire risk in rural environments.
- The analysis of the positive impact of adopting bioenergy with carbon capture and storage (BECCS) processes from an environmental and economic point of view: the impact on greenhouse gas emissions, the revenues due to carbon sales, and the necessary investment to implement this solution.
- The estimated impact of the bioenergy sector on avoiding imports of fossil fuels, analysing the alternative energy solutions that would have been used if bioenergy was not applied.
- The relevance of bioenergy in the rural economy and its development in Europe, identifying which impacts are located on the rural environment.
- The synergies of bioenergy with relevant economic sectors, such as forestry, agriculture and livestock, as well as the wood industry, considering the circular economy point of view.
- Assessing technical and business approaches to exploit the complementarities between bioenergy and clean hydrogen production.
- Assessing the complementarity of bioenergy with other renewable energies and evaluating the impact of the biopower on the electricity system balance.

3 Economic Growth and Employment

Bioenergy is mainly produced utilising local biomass and its manufacturing value chain is solidly based in the European Union. This results in a significant potential to serve as a vehicle for job creation and economic opportunity for countries throughout the European Union, contributing to rebound the economy and boost a green recovery. These jobs cover a broad range of fields, from scientific research to plant operations, businesses, farming, and manufacturing.

The employment creation and the contribution to the economy are relevant advantages of bioenergy in addition to the avoided carbon emissions, the protection of the environment, the security of energy supply, etc. Hence, bioenergy can assist with the main problems of decarbonisation with job creation, industrial competitiveness, development of rural areas and a strong export industry.

Nowadays, bioenergy solutions represent affordable and trustworthy sustainable energy approaches that include biopower facilities, district heating solutions, individual heating systems based on biomass, as well as the production of biofuels for the transport sector.

The positive impact of bioenergy on the European Union's economy and employment has been evaluated for the different bioenergy solutions, assessing their value chain activities at a direct and indirect level.

The direct impact results from the biomass production and logistics, the construction of facilities and the manufacture of equipment, as well as the operations and maintenance. This includes the necessary labour for biomass production and transportation, construction, operation, and maintenance of plant facilities. At the same time, the activities carried out by the bioenergy industry demand goods and services from other branches of the economy. This indirect impact, or drag effect on the economy, can be evaluated using the European Union input-output tables published by Eurostat[20].

The methodology used for the estimation of the impact of bioenergy on employment in terms of employment and GDP is summarized below (see ANNEX I: Methodology used for the Estimation of the Impact of Bioenergy on Employment and GDP for detailed information):

To calculate the Bioenergy sector's contribution to EU27 GDP, Deloitte used three equivalent approaches, recognised by the European System of National and Regional Accounts (ESNRA)[21]: added value, income and expenditure approaches. The information required by these approaches was gathered from the information that EU companies active in the bioenergy industry disclosed in their financial statements. Besides, additional information was gathered by surveying bioenergy industry players.

The job creation in the different bioenergy industry subsectors was calculated based on employment data published by companies in the industry and complementary industry both in their financial statements and in their annual reports.

Besides, the indirect effects of the bioenergy sector on other sectors of the economy was quantified using input-output models from the EU27.

20 These tables do not include a disaggregated breakdown of the bioenergy sector, so they have been completed on the basis of questionnaires distributed among agents in the sector, in order to identify the sectors from which these goods and services are demanded. Thus, it is possible to estimate the indirect impact of the bioenergy sector on other economic sectors in Europe.

21 Definitions as given by Eurostat: http://epp.eurostat.ec.europa.eu/statistics_explained/index.php/National_accounts_%E2%80%93_GDP

GDP and Employment in 2019

In 2019, the economic impact of the bioenergy sector in terms of GDP accounted for 40.207 million euros, representing 0,30% of the EU27's GDP: **the direct impact reached 24.696 million euros, while the indirect impact represented 15.511 million euros.** The impact in terms of GDP of the bioenergy sector in the EU27 was higher than that of traditional sectors, such as fishing and aquaculture or coke and refined petroleum products manufacture, and similar to that of others such as mining and quarrying.

The greatest direct impact in terms of GDP was derived from the operation and maintenance of the different facilities, reaching 42% of the direct impact generated and accounting for 10.332 million euros. Besides, the supply of feedstock, and the equipment manufacturing represented 38% and 13% of the direct impact on GDP of the bioenergy sector, respectively, while the construction/installation reached 7%.

The impact on employment reached 964.258 FTE in the same year, with 649.334 and 314.924 FTE mobilized directly and indirectly, respectively. It can be observed that bioenergy is intensive in employment, especially in the supply of feedstock, which accounts for more than 50% of the direct employment created. Unlike other renewable energies, which do not require labour to obtain it, biomass often needs to be collected, treated and transported for its use. Thus, the workforce in this part of the sector's value chain is high.

Furthermore, operation and maintenance of the different solutions represented 21% of the direct employment created, with 138.200 FTE, followed by equipment manufacturing, representing 11%, with 70.484 FTE. Construction/installation accounted for 4% of the direct employment generated, reaching 24.798 FTE in 2019.

It is important to mention that both construction and equipment manufacturing jobs are mobilized through new facilities and installations, unlike the supply of feedstock or the operation and maintenance of the solutions, which are permanent jobs linked to existing facilities.

Table 1. Impact of the bioenergy sector in terms of GDP and employment in 2019.

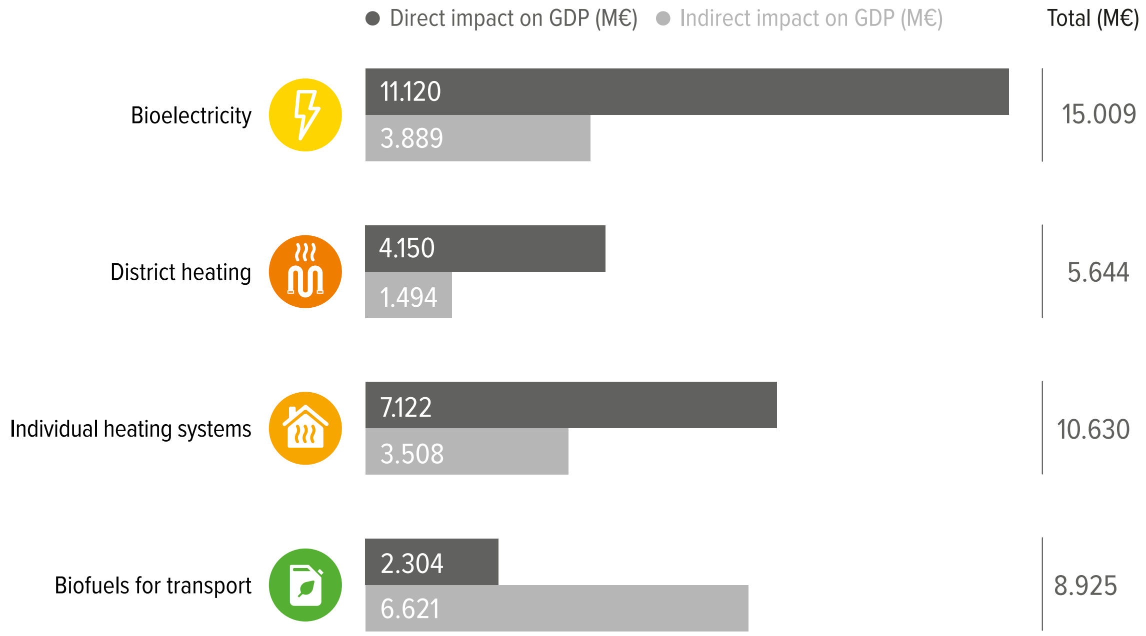
Impact on GDP(M€)	Direct	Indirect	Total
Equipment Manufacturing	3.203	15.511	40.207
Construction	1.738		
Supply of feedstock	9.424		
Operation and maintenance	10.332		
TOTAL	24.696		

Impact on jobs	Direct	Indirect	Total
Equipment Manufacturing	70.484	314.924	964.258
Construction	24.798		
Supply of feedstock	415.852		
Operation and maintenance	138.200		
TOTAL	649.334		

Source: Own elaboration[22].

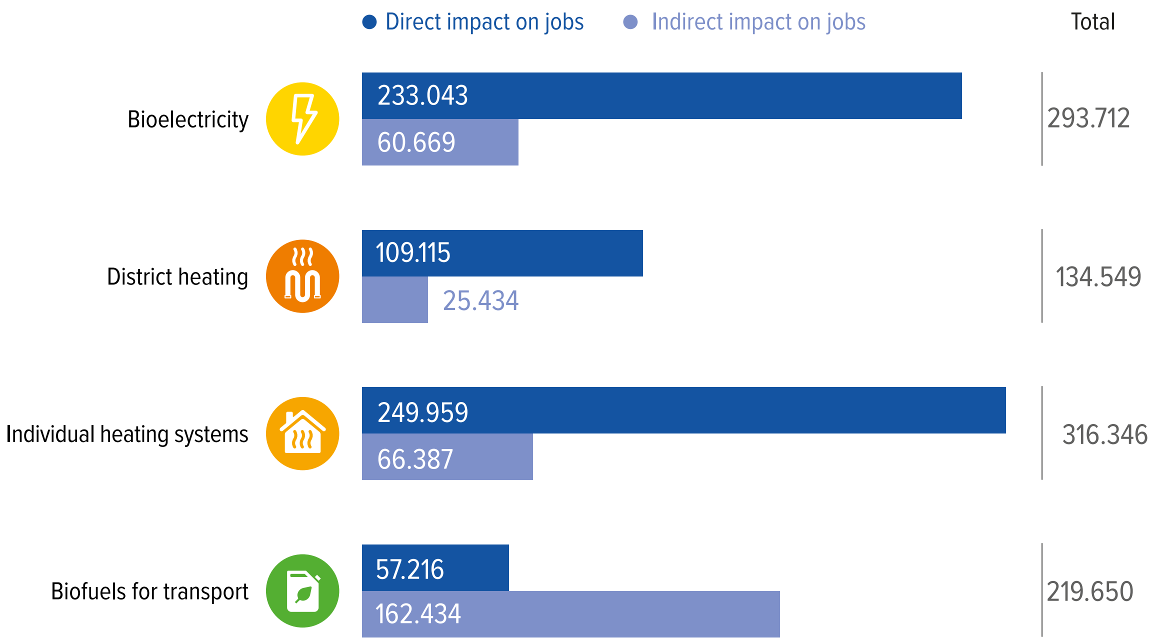
22 See ANNEX I: Methodology used for the Estimation of the Impact of Bioenergy on Employment and GDP for detailed information.

Figure 5. Summary of the impact of the bioenergy sector in terms of GDP in 2019.



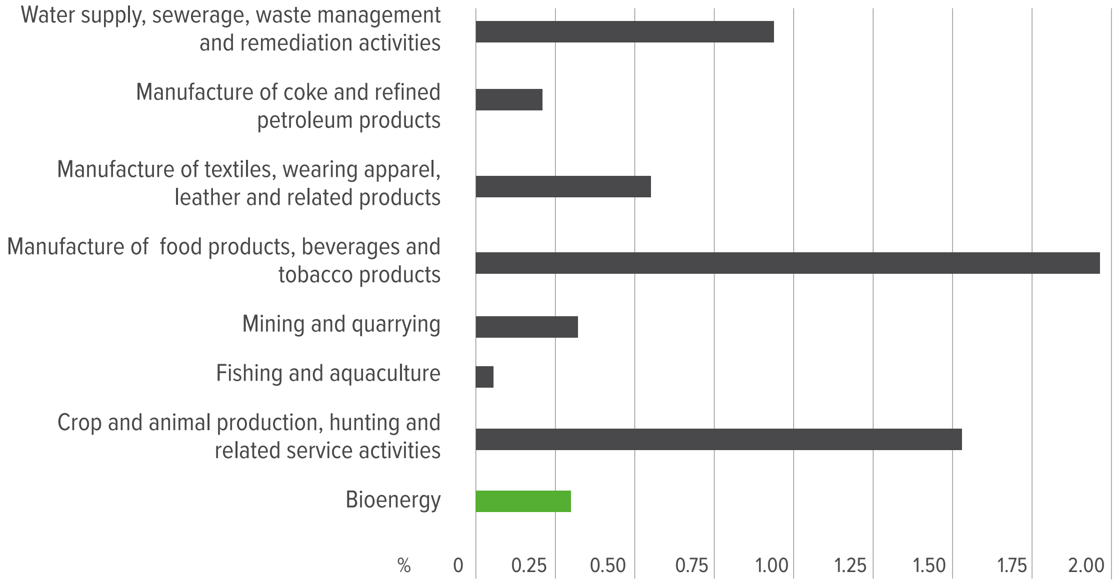
Source: Own elaboration[22].

Figure 6. Summary of the impact of the bioenergy sector in terms of employment in 2019



Source: Own elaboration[22].

Figure 7. Comparison of GDP contribution among different economic branch activities in EU27 in 2019.



Source: Own elaboration and OECD Data.

Attending to the different activities, the disaggregated analysis of the bioenergy sector impact in terms of GDP and employment is presented hereinafter:

- **Bioelectricity:**

  The total electrical capacity from biomass in EU27 in 2019 was 37.038 MW, with 70% of electricity production coming from CHP plants and 30% coming from biopower-only plants[23].

  A biopower-only plant generates electricity by burning biomass, while a combined heat and power (CHP) plant is a facility for the simultaneous production of thermal and electrical energy in one process. **The CHP is one of the best technologies for improving energy efficiency, supporting the penetration of renewables, and providing a more flexible integration in the electricity system as bioelectricity is dispatchable and allows to adjust its production to stabilise the grid.** The total bioelectricity generated by CHP facilities reached 9.935 ktoe, with a production of 10.217 ktoe of derived heat.

  The average annual growing rate of the biopower capacity installed was around 3%[23] between 2018 and 2019. These facilities are operated with different kinds of solid, gaseous and liquid fuels or residues. The solid biomass and the biogas accounts for almost 80% of the fuel input of the biopower plants, with 23.448 and 10.403 ktoe, respectively, in 2019[24]. Besides, the share of municipal waste for electricity generation represents 18%, while the share of liquid biofuels is minimal, accounting for 2%.

  Attending to the manufacture of the equipment, the construction of the facilities, the supply of feedstock, and the operation of the biopower plants, the direct and indirect employment reached 293.712 FTE in 2019. Its economic impact in terms of GDP accounted for 15.009 million euros.

23 Bioenergy Europe (2021): Statistical Report 2021 - Bioelectricity.
24 Municipal waste and liquid biofuels have not been considered in the calculations below.

Table 2. Impact of bioelectricity in terms of GDP and employment in 2019.

Impact on GDP(M€)	Direct	Indirect	Total
Equipment Manufacturing	216	3.889	**15.009**
Construction	445		
Supply of feedstock	3.668		
Operation and maintenance	6.791		
TOTAL	11.120		

Impact on jobs	Direct	Indirect	Total
Equipment Manufacturing	5.811	60.669	**293.712**
Construction	4.642		
Supply of feedstock	153.047		
Operation and maintenance	69.544		
TOTAL	233.043		

Source: Own elaboration[22].

- **District heating solutions:**

  The heat that is distributed to the final consumers through district heating is known as derived heat, which can be produced from Combined Heat and Power (CHP) or heat-only plants.

  Even that most of the district heating plants are still being run with fossil fuels, the share of renewables is increasing. **In 2019, 28% of the energy used for derived heat came from renewables, with bioenergy representing 97% of this 28%**[25].

  In 2019, the gross production of derived bioheat from biomass reached 15.371 ktoe in EU27[25], with solid biomass and biogas representing 74% and 6% of the total respectively. The shares of derived heat from renewable municipal waste and liquid biofuels represented 19% and 1%, respectively. Besides, the average growing rate of these types of biomass between 2018 and 2019 was 5%[25].

  The different activities of the value chain of the district heating solutions cover the manufacture of the equipment, the construction of the district heating infrastructure, the supply of feedstock, as well as the operation of the facilities. The direct and indirect employment derived from the previous activities reached 134.549 FTE in 2019. Its economic impact in terms of GDP accounted for 5.644 million euros.

25 Bioenergy Europe (2020): Statistical Report 2021 - Bioheat.

Table 3. Impact of the biomass district heating solutions in terms of GDP and employment in 2019[26].

Impact on GDP(M€)	Direct	Indirect	Total
Equipment Manufacturing	1.297	1.494	**5.644**
Construction	715		
Supply of feedstock	373		
Operation and maintenance	1.766		
TOTAL	**4.150**		

Impact on jobs	Direct	Indirect	Total
Equipment Manufacturing	34.880	25.434	**134.549**
Construction	10.088		
Supply of feedstock	16.981		
Operation and maintenance	47.165		
TOTAL	**109.115**		

Source: Own elaboration[22].

- **Individual heating systems based on biomass**:

  The individual biomass heating systems and stoves burn wood pellets, chips, or logs to provide warmth in a single room or to power central heating and hot water boilers or systems, offering a cheap and renewable option for heating in the residential sector. Furthermore, biomass boilers are also a perfect sustainable solution for space and process heating in a wide range of industrial and commercial applications including process steam. At this point, it is important to mention that European Union companies are leaders in this technology, manufacturing the equipment according to high standards.

  The consumption of bioheat in EU27 is steadily growing in all sectors, on average by 3% annually since 2000[25], and it is almost entirely based on solid biomass, reaching more than 90% in 2019. The biomass used for heat in the residential sector in EU27 in 2019 accounted for 41.527 ktoe[27], representing almost 50% of the consumption of bioheat. Moreover, the biomass used for heat in the industrial sector and in the commercial and other sectors accounted for 22.479 ktoe and 6.842 ktoe, respectively.

  Attending to the manufacture of the equipment, installation, and supply of feedstock, as well as maintenance, the direct and indirect employment reached 316.346 FTE in 2019. Its economic impact in terms of GDP accounted for 10.630 million euros.

26 The impact derived from the supply of feedstock to CHP district heating is not included in this estimations as it is already covered by the activity "Bioelectricity".
27 This amount refers only to the biomass that is directly used to produce heat within households, excluding heat sup plied through district heating.

Table 4. Impact of the biomass individual heating systems in terms of GDP and employment.

Impact on GDP(M€)	Direct	Indirect	Total
Equipment Manufacturing	1.548	3.508	**10.630**
Construction	434		
Supply of feedstock	4.895		
Operation and maintenance	244		
TOTAL	**7.122**		

Impact on jobs	Direct	Indirect	Total
Equipment Manufacturing	26.390	66.387	**316.346**
Construction	8.390		
Supply of feedstock	210.511		
Operation and maintenance	4.669		
TOTAL	**249.959**		

Source: Own elaboration[22].

It is worth mentioning that the existence of a large share of heat systems still based on non-renewable sources could represent an opportunity for biomass in the decarbonisation strategy, switching from fossil to a renewable solution, and continuing to contribute to the economic growth and employment. Moreover, biomass technology development has also evolved with modern appliances that use less fuel for the same heat production, being more efficient. This means that it is also important to consider the replacement of the existing old biomass installations with the highly efficient, nearly-zero emission, modern biomass installations.

- **Biofuels for the transport sector:**

  Bio-based liquid fuels considered sustainable, such as biodiesel or bioethanol, can be produced from any biological material containing starch, sugars, oil or other types of raw materials; blended with traditional fossil fuels such as diesel or petrol, or as a full substitute for traditional fuels.

  The transport sector consumes 32%[28] of all energy used in the European Union, contributing to the emission of harmful gases into the atmosphere, affecting air quality in large cities and, consequently, the health of the population.

  Also, given the petrol and gas shortage, it is necessary to find and develop alternative solutions to mitigate the problems and offer solutions to the transport industry and the rest of the fuel-demanding sectors, promoting a change in the current energy model.

  In 2019, the final energy consumed from liquid biofuels in the EU27 represented 15.816 ktoe, showing a growth of 4% on average between 2018 and 2019[29].

  The different activities of the value chain of biofuel solutions for the transport sector cover the manufacture of the equipment, the construction of the facilities and the supply of feedstock, as well as the operation of the facilities.

28 IDAE – Ministerio de Industria, Comercio y Turismo (2019): Manuales de Energías Renovables. Biocarburantes en el transporte.
29 Bioenergy Europe (2021): Statistical Report 2021 - Bioheat.

Attending to these activities, the direct and indirect employment reached 219.651 FTE in 2019. Its economic impact in terms of GDP accounted for 8.925 million euros.

Table 5. Impact of the biofuels in the transport sector in terms of GDP and employment in 2019.

Impact on GDP(M€)	Direct	Indirect	Total
Equipment Manufacturing	142	6.621	**8.925**
Construction	144		
Supply of feedstock	488		
Operation and maintenance	1.530		
TOTAL	**2.304**		

Impact on jobs	Direct	Indirect	Total
Equipment Manufacturing	3.403	162.434	**219.651**
Construction	1.678		
Supply of feedstock	35.313		
Operation and maintenance	16.821		
TOTAL	**57.216**		

Source: Own elaboration[22].

Another added advantage of biofuels is their production from used vegetable oils, which in addition to obtaining fuel in a cleaner way, is contributing to the circular economy using residues from industrial processes that, otherwise, would be wasted.

GDP and Employment in 2050

The transition to a climate neutral EU economy by 2050 is at the heart of the European Green Deal presented in 2019. In the Impact Assessment accompanying the document *"Stepping up Europe's 2030 climate ambition"*[30], the European Commission analysed the options related to the level of policy ambition for 2030 to allow for the gradual transition to achieve this objective.

This Impact Assessment considered a series of possible scenarios for 2030 and 2050 that focus on carbon pricing and/or regulatory measures. The scenarios were built around a set of specific policies with the aim of showcasing the specific energy dependencies across different industries to identify sectors where greenhouse gas reductions could potentially be achieved. The scenarios evaluated by the European Commission are as follows:

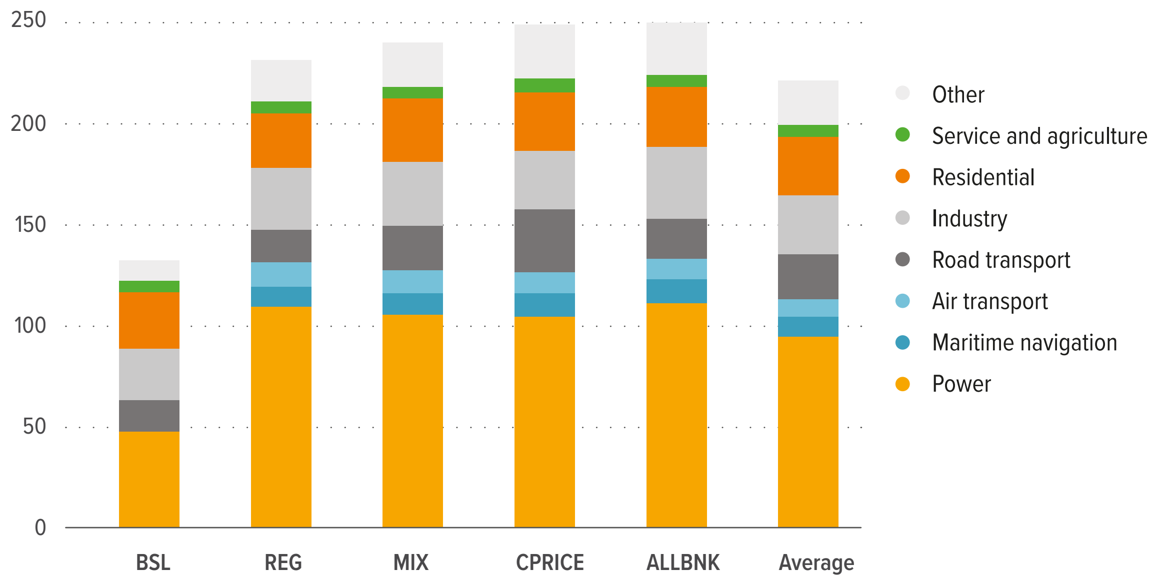
- **BSL:** Achieve the existing 2030 greenhouse gases (GHG), renewable energy systems and energy efficiency EU targets.
- **REG:** Introduce a regulatory-based measure scenario that achieves a reduction of around 55% in GHG's. This scenario assumes a high increase of the ambition of energy efficiency, renewables, and transport policies, while keeping the EU ETS scope unchanged. As a result, it does not expand carbon pricing and relies on other policies.

30 European Commission (2020): Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. Impact Assessment accompanying the document Stepping up Europe's 2030 climate ambition - Investing in a climate-neutral future for the benefit of our people.

- **MIX:** Combines approach of REG and CPRICE to achieve a 55% reduction in GHG's by expanding carbon pricing and increasing the ambition of policies, although the latter to a lesser extent than REG.
- **CPRICE:** Carbon-pricing based scenario that reduces 55% of GHG's assuming the strengthening and further expanding of carbon pricing, either by EU ETS or other carbon pricing instruments. This affects mainly the transport and building sectors combined with low intensification of transport policies while not intensifying energy efficiency and renewable policies.
- **ALLBNK:** Most ambitious scenario in GHG reductions. Based on MIX but further intensifying fuel mandates for the aviation and maritime sectors in response to the extended scope of GHG reductions in these two sectors.

According to the different policy models presented in the Impact Assessment, there is a need for further development of biomass for energy to achieve the EU emission targets for 2030 and 2050. The following figure represents the use of bioenergy for each sector across all the scenarios considered by the European Commission in 2050, as well as the average scenario estimated based on them:

Figure 8. Use of bioenergy by sector in 2050 attending to the different policy scenarios (BSL, REG, MIX, CPRICE and ALLBNK)[30] and the estimated average (Mtoe).



Source: Own elaboration based on European Commission policy scenarios.

According to the average scenario, the gross inland consumption of biomass for energy would be around 220 Mtoe in 2050. While power generation and residential heating nowadays make up most of the biomass demand, the use of biomass in the residential sector is expected to decrease slightly and the power sector would absorb most of the additional demand in bioenergy. On the other hand, the use of biomass for heat in the industrial sector will increase over this period, reaching 31 Mtoe, on average.

It should be noted that even that the consumption in the residential sector may slightly decrease, it does not mean that the final heat produced from biomass will do so. The replacement of old installations by modern units, which have higher efficiencies, will lead to the production of the same amount of energy using less fuel. This means that improving the efficiency of these heating processes can significantly improve the scale of the potential supply and production of bioenergy without increasing the volume of biomass, or even reducing it.

Moreover, the decarbonisation of transport, including not only road but also maritime and air transport, would require advanced biofuels that could be produced at large scales after 2030. Towards 2050, the biomass used to produce biofuels would be increased; but this share does not represent a use greater than 20% of the total use of biomass for energy in any scenario.

As reported by the Impact Assessment of the European Commision[30], there will be an optimisation of the sustainable exploitation of all sources of biomass. The combination of feedstock used to supply the demand in bioenergy in the long term would be characterised by a better mobilisation of agriculture residues. Besides, together with the sustainable extraction of forest residues, the waste sector will represent another significant share of bioenergy feedstock in 2050, derived from a progressive improvement in the industrial and municipal waste collection.

Also, in all scenarios, more than 93% of the bioenergy used in the EU will be produced domestically, showing that the additional consumption will rely mainly on local biomass. The annual increase in the average gross inland consumption between 2019 and 2050 would be around 2%, which is actually lower than that shown by bioenergy in the last 10 years, which was around 2,6%.

This increase in the use of bioenergy derived from the energy transition would imply a growth in the impact on GDP and employment, revitalizing the economy and supporting the creation of green jobs. In 2050[31], the economic impact of the bioenergy sector in terms of GDP could account for 70.105 million euros, representing 0,52% of the current GDP of the EU27. The direct and indirect impact on the GDP would account for 41.338 million euros and 28.768 million euros, respectively. Moreover, the impact on employment could reach 1.578.668 FTE in the same year, with 1.013.945 and 564.723 FTE mobilized directly and indirectly, respectively.

According to the assessment carried out, each additional Mtoe of biomass for energy would lead to an impact of 359 million euros in terms of GDP and an employment creation of 7.376 FTE, on average. This is especially important as the transition towards net-zero emissions will lead to unemployment in sectors such as the fossil fuel production. For example, according to the IEA's Net-Zero Emissions by 2050 (NZE) Scenario, fossil fuel production could lose 5 million positions by 2030[32]. Furthermore, taking into account the current EU imported energy bill, which is higher than 236 million euros per Mtoe[33], it is important to note that the use of domestic biomass for energy would not only allow the creation of employment and economic growth, but would also allow reducing the imported energy bill with third countries.

31 Estimates of the impact on GDP and employment for the 2050 horizon have been made taking into account the elasticity between these variables and the use of biomass for energy in the different activities obtained from the evaluation carried out for 2019 in accordance with the methodology presented in ANNEX I: Methodology used for the Estimation of the Impact of Bioenergy on Employment and GDP.

32 International Energy Agency 2021, accessed 28 September 2021, <https://www.iea.org/commentaries/the-importance-of-focusing-on-jobs-and-fairness-in-clean-energy-transitions>

33 Own calculation based on data of the European Council on Foreign Relations and Eurostat database.

The increase in GDP and employment compared to 2019 would reach 74% and 64%, respectively. This growth will be led not only by the use of bioenergy for electricity production, which would increase by 124% between 2019 and 2050 according to the average scenario, but also by the production of biofuels for transport, and the increase of biomass used for heat in the industrial sector. Also, as biomass technology development would evolve with modern appliances that use less fuel for the same heat production, being more efficient, there will be a market linked to the replacement of existing old installations with nearly-zero emission modern devices. This market will be led mainly by the residential sector in which, in addition, the traditional use of wood logs used in open fires will be replaced by the use of pellets, chips, or briquettes required by the modern equipment.

Moreover, assuming the construction of new combined heat and power facilities to produce heat and electricity, the development of district heating facilities would also evolve during the energy transition, contributing to the impact on GDP and employment of the bioenergy sector. It is worth mentioning that the impact derived from the supply of feedstock is already included under the bioelectricity activities, as most of the derived heat produced comes from these facilities.

Table 6. Impact of the bioenergy sector in terms of GDP and employment in 2050.

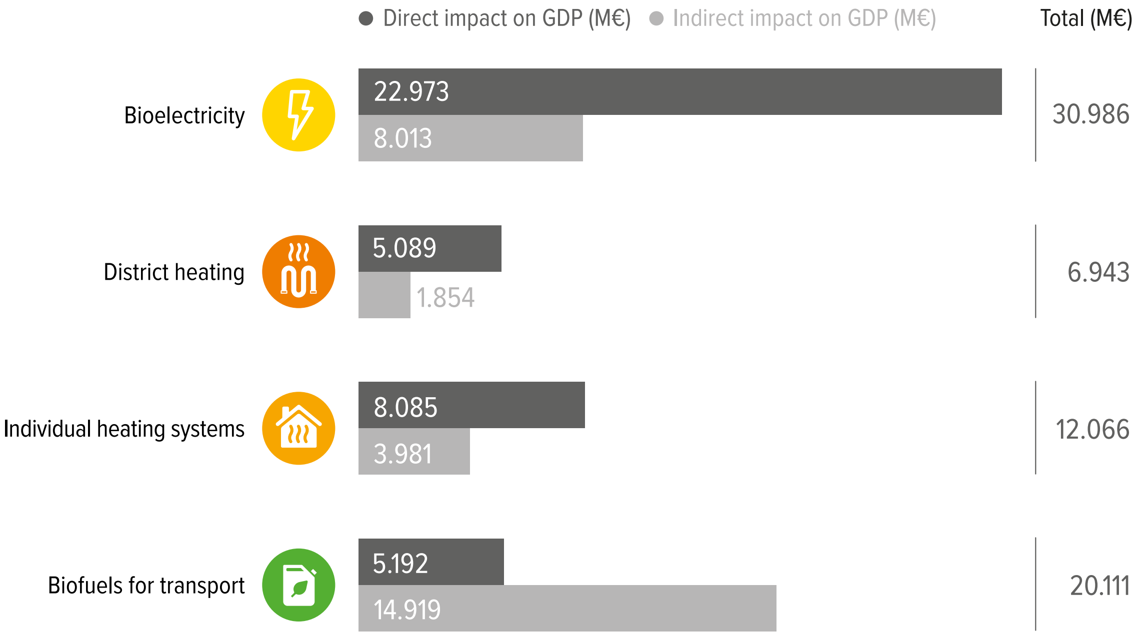
Impact on GDP(M€)	Direct	Indirect	Total
Equipment Manufacturing	22.973	8.013	**30.986**
Construction	5.089	1.854	**6.943**
Supply of feedstock	8.085	3.981	**12.066**
Operation and maintenance	5.192	14.919	**20.110**
TOTAL	**41.338**	**28.768**	**70.105**

Impact on jobs	Direct	Indirect	Total
Equipment Manufacturing	479.194	125.313	**604.507**
Construction	133.547	30.560	**164.107**
Supply of feedstock	283.734	75.357	**359.091**
Operation and maintenance	117.470	333.493	**450.964**
TOTAL	**1.013.945**	**564.723**	**1.578.668**

Source: Own elaboration[34].

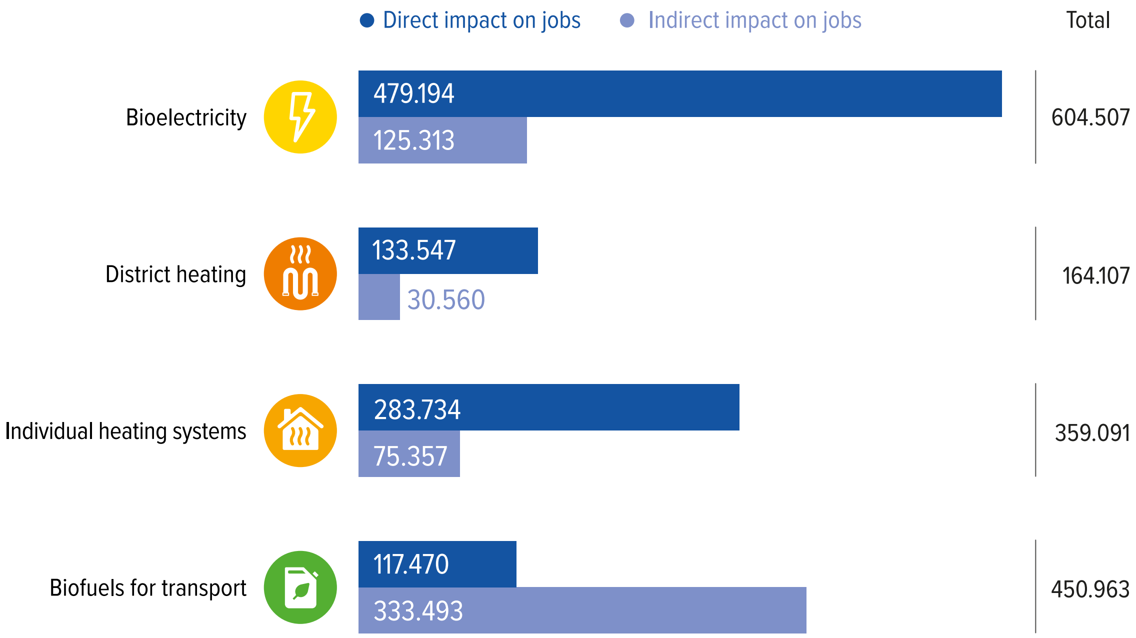
34 See ANNEX I: Methodology used for the Estimation of the Impact of Bioenergy on Employment and GDP for detailed information.

Figure 9. Summary of the impact of the bioenergy sector in terms of GDP in 2050.



Source: Own elaboration[22].

Figure 10. Summary of the impact of the bioenergy sector in terms of employment in 2050.



Source: Own elaboration[22].

Summary:

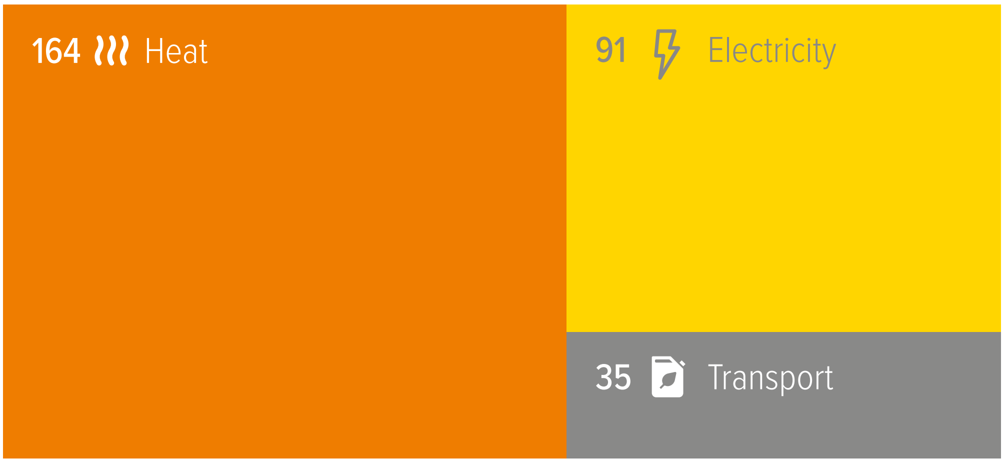
- The employment creation and the contribution to the economy are relevant advantages of bioenergy in addition to the avoided carbon emissions, the protection of the environment, the security of energy supply, etc. Hence, bioenergy can assist with the main problems of decarbonisation with job creation, industrial competitiveness, development of rural areas and a strong export industry.
- In 2019, the economic impact of the bioenergy sector in terms of GDP accounted for 40.207 million euros, representing 0,30% of the EU27's GDP: the direct impact reached 24.696 million euros, while the indirect impact represented 15.511 million euros. The impact in terms of GDP of the bioenergy sector in EU27 was higher than that of traditional sectors such as fishing and aquaculture or coke and refined petroleum products manufacture, and similar to that of others such as mining and quarrying.
- The impact on employment reached 964.258 FTE in 2019, with 649.334 and 314.924 FTE mobilized directly and indirectly, respectively.
- Bioenergy is intensive in employment, more than any other renewable energy, requiring labour to be collected, treated and transported for its use. The workforce in the supply of feedstock accounts for more than 50% of the direct employment created.
- The different policy models of the European Commission show a need for further development of biomass for energy to achieve the EU emission targets for 2030 and 2050. According to the average scenario, in 2050 the gross inland consumption of biomass for energy would be around 220 Mtoe, with biomass imports below 7%.
- In 2050, the economic impact of the bioenergy sector in terms of GDP could account for 70.105 million euros, representing 0,52% of the current GDP of the EU27. The direct and indirect impact on the GDP would account for 41.338 million euros and 28.768 million euros, respectively.
- The impact on employment could reach 1.578.668 FTE in 2050, with 1.013.945 and 564.723 FTE mobilized directly and indirectly, respectively.
- According to the assessment carried out, each additional Mtoe of biomass for energy would lead to an impact of 359 million euros in terms of GDP and an employment creation of 7.376 FTE, on average. This is especially important as the transition towards net-zero emissions will lead to unemployment in sectors such as the fossil fuel production, as well as because bioenergy could help reduce the EU imported energy bill, which is currently higher than 236 million euros per Mtoe.

4 Climate Change Mitigation

Bioenergy deployment offers significant potential for climate change mitigation and adaptation. The mitigation contributes to reduce climate change, involving the reduction of greenhouse gases into the atmosphere. Bioenergy contributes to reduce the sources of these gases, decreasing the use of fossil fuels for electricity, heat, or transport. Likewise, through the complementarity that bioenergy presents for the implementation of other renewable sources that, unlike it, are not manageable, it makes it possible to indirectly contribute to the reduction of greenhouse gas emissions.

Besides, the application of bioenergy with carbon capture and storage can produce energy and decrease the amount of CO_2 in the atmosphere, achieving carbon negative emissions, and mitigating climate change.

Figure 11. GHG savings due to bioenergy in the different sectors in 2019 in EU27 (MtCO$_2$eq).



Source: Own elaboration based on RED II (biomass default values and fossil fuel comparator).

In 2019, bioenergy allowed to save 290 MtCO$_2$eq, equivalent to around 8% of the EU27 GHG emissions or 2,5-fold the annual emissions of Belgium. Bioenergy has contributed to decarbonise sectors such as the industry and transport sectors, which are among the most consuming of fossil fuels. At the same time, bioenergy has mitigated the import of fossil fuels, and thereby reduced the energy dependence with third countries.

In addition, based on the average gross inland consumption of biomass for energy in 2050 reported by the Impact Assessment of the European Commission[35], the replacement of fossil fuels for energy by biomass could prevent, on average, 487 MtCO$_2$eq emissions for that year. Hence, each additional Mtoe of biomass for energy could mitigate 2,4 MtCO$_2$eq emissions due to the replacement of fossil fuels for energy, while creating economic growth and employment.

35 European Commission (2020): Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. Impact Assessment accompanying the document Stepping up Europe's 2030 climate ambition - Investing in a climate-neutral future for the benefit of our people

Case study: Lowering fossil fuel dependency in Finland[36]

An example of the use of bioenergy to replace fossil fuels is the case of the world's largest biomass gasification plant, operated by Vaskiluodon Voima and located in Vaasa (Finland), which started its commercial operation in early 2013.

Valmet, the finish worldwide technology leader, delivered the biomass gasification plant that was built as part of the existing coal-fired power plant and integrated with the pulverised coal boiler. The gasifier feeds the boiler with product gas that is combusted together with coal. The 140 MW gasification plant delivery included a fuel yard, a large-scale belt dryer, a circulating fluidised bed (CFB) gasifier, modification and integration on the existing coal-fired boiler, and an extension to the Valmet DNA automation system with advanced applications.

Through biomass gasification, the plant has been able to lower its CO_2 emissions by approximately 230.000 tonnes per year. The company is now able to replace about 25–50% of the coal with local biomass, depending on the boiler's load. Also, since the boiler can be fuelled solely with product gas, this has been running purely on this biofuel when the load is low during autumn and spring.

Moreover, as the gasifier is fuelled with forest residues, coming from a radius of 100 km around the facility, new jobs were created in the area, boosting the local economy.

Complementing bioenergy with other renewable energies will be key to achieving the decarbonisation commitments of the economy stipulated for 2030-2050. Its integration as a heat producer and as a biofuel will be essential to achieve the decarbonisation of highly polluting sectors, such as the industry and transport sectors.

Moreover, industrial and district heating and cooling covers a range starting from several hundred kW in small heat grids or industries and up to several hundred MW in large towns or industries. In 2050, almost all industrial processes that require heat at high temperatures, which cannot be supplied by solar energy or renewable electricity, will be provided by biomass. Therefore, the increase of thermal share in large-scale CHP plants will be enhanced and power production without cogeneration of heat or heat production without cogeneration of power will be restricted.

Case study: NextGenBioWaste[37]

The objective of NextGenBioWaste was to demonstrate innovative ways of improving the energy conversion and renewable electricity production using municipal solid waste materials and biomass for large-scale supply of renewable electricity and heating/cooling to end-users - at a more competitive cost and improved environmental parameters.

NextGenBioWaste deals with waste and biomass feedstocks and covers the supply chain from fuel preparation, via conversion and residue handling, up to wholesale of energy.

The project was Co-funded by the European Commission under the Sixth Framework Programme, and the consortium comprised seven European utility companies, one technology provider, six R&D providers, and one consultant/engineering company.

36 ExpoBiomasa 2020, AVEBIOM, accessed 13 September 2021, ‹ Lithuania, switching from gas to biomass | Expobiomasa›.

37 NextGenBioWaste 2010, SINTEF ENERGIFORSKNING AS, accessed 13 October 2021, ‹https://www.sintef.no/projectweb/nextgenbiowaste1/›.

Bioenergy is also present within the so-called "eco-neighbourhoods", where energy comes mainly from renewable or recovered energy sources. Over the past 10 years, the number of such projects has increased by 340%. In France, for example, between 2012 and 2015, no less than 39 eco-neighbourhood development projects were launched, representing no less than 55.000 homes.

The actions carried out in these "eco-neighbourhoods" are diverse. For example, in the case of Veolia, which is in the process of setting up a series of collaborations with other organizations to implement the concept, the actions include the use of biomass and optimising the waste collection in the forefront. Besides, the energy management systems employed in these neighbourhoods contribute simultaneously to improve user comfort and preserving the resources consumed.

In line with the above, it is important to note that it is estimated that 30% of CO_2 emissions in the European Union come from buildings. The use of wood for the construction of buildings, as long as the wood comes from forests where sustainable and accredited management is carried out, could mitigate CO_2 emissions derived from construction with other materials such as steel and concrete[38,39]: each cubic meter of wood used as a substitute for other building materials reduces CO_2 emissions to the atmosphere by an average of 1,1 tCO_2. Moreover, wood buildings could also work as carbon sinks: each cubic meter of wood can store up to 0,9 tCO_2.

In addition, the residues derived from the construction of wood buildings, as well as those obtained at the end of their useful life, could in turn be used for the production of bioenergy. Hence, biomass would help mitigate climate change not only through the substitution of fossil fuels for energy production but also by reducing CO_2 emissions derived from construction with other materials.

Moreover, Bioenergy Carbon Capture and Storage (BECCS) and biochar are key carbon-negative technologies to reach the Paris Agreement's objectives. BECCS combines biomass energy applications with the capture and storage of CO_2, thus providing net removal of CO_2 from the atmosphere. As bioenergy is integrated in numerous industrial sectors, bioenergy carbon capture and storage is a versatile technology that can be applied to energy generation and to different installations (in cement, ethanol, pulp and paper among others) using biomass as feedstock. Due to its promising results, this technology is more detailed in the Chapter "Bioenergy with Carbon Capture and Storage Processes".

The biochar is defined as carbonised biomass obtained from sustainable sources and sequestered in soils to sustainably enhance their agricultural and environmental value under present and future management. The biochar aims to fight against climate change as it keeps biogenic carbon from the atmosphere, by sequestering it, in soils for several centuries. Besides, biochar constitutes a certifiable carbon capture utilization and storage (CCUS) solution while generating major co-benefits in favour of sound and sustainable agriculture, the preservation of natural capital, soils, ecosystems, and water resources.

Bioenergy also provides an attractive solution to foster the sustainable forest management, giving economic value to low-quality biomass that otherwise would be left on the ground for rotting, such as tops, branches, thinnings, etc. The development of a sustainable forest management contributes to mitigate the impact of climate change, which affects forest ecosystems negatively, increasing the frequency and intensity of extreme events, such as pest and disease outbreaks, wildfires and windstorms.

38 Asociación Nacional de Fabricantes de Tableros, Centro de Innovación e Servizos Tecnolóxicos da Madeira de Galicia, Xunta de Galicia (2007): Frente al Cambio Climático: Utiliza Madera.

39 Aalto University (2020): Building cities with wood would store half of cement industry's current carbon emissions.

Then, the cellulosic feedstocks, the increased end-use efficiency, the improved land carbon-stock management and residue use, and the carbon dioxide capture and storage from bioenergy are promising options to fight against climate change, mitigating its impact as well as adapting to its effects.

Summary:

- In 2019, the replacement of fossil fuels for energy by biomass prevented 290 MtCO_2eq emissions, equivalent to around 8% of the EU27 GHG emissions. Bioenergy has contributed to decarbonise sectors such as industry and transport, which are among the most consuming of fossil fuels.
- In 2050, the use of biomass for energy replacing fossil fuels could mitigate 487 MtCO_2eq emissions, considering the average consumption of biomass for energy reported by the Impact Assessment of the European Commission.
- In 2050, almost all industrial processes that require heat at high temperatures, which cannot be supplied by solar energy or renewable electricity, will be provided by biomass in replacement of fossil fuels. Therefore, the increase of thermal share in large-scale CHP plants will be enhanced and power production without cogeneration of heat or heat production without cogeneration of power will be restricted.
- Bioenergy also helps decarbonise the domestic sector, being also present within the so-called "eco-neighbourhoods", where energy comes mainly from renewable or recovered energy sources. For example, in France, the number of such projects has increased by 340% in the last 10 years.
- Each cubic meter of wood used as a substitute for other building materials reduces CO_2 emissions to the atmosphere by an average of 1,1 tCO_2, as long as the wood comes from forests where sustainable and accredited management is carried out. Moreover, wood buildings could also work as carbon sinks, with each cubic meter of wood storing up to 0,9 tCO_2. Hence, biomass would help mitigate climate change not only through the substitution of fossil fuels for energy production but also by reducing CO_2 emissions derived from construction with other materials.
- BECCS and biochar are key carbon-negative technologies helping to fight against climate change to reach the Paris Agreement's objectives. BECCS is the most mature and combines biomass energy applications with the capture and storage of CO_2, thus providing net removal of CO_2 from the atmosphere. Moreover, biochar aims to fight against climate change as it keeps biogenic carbon from the atmosphere, by sequestering it, in soils for several centuries.

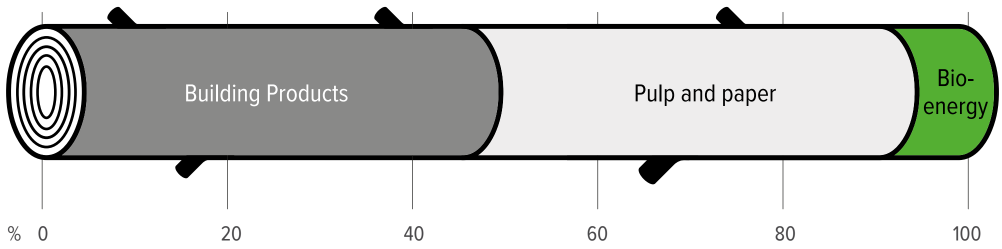
5 Forest Health

Solid biomass accounts for 70% of the bioenergy employed for primary energy production, being the main source of biomass used for this purpose. Moreover, the use of woody biomass over the last 20 years has increased by 74%, reaching 93 Mtoe in 2019[40].

The foregoing places forests as the main producers of resources used in bioenergy, being forestry the sector that best reflects the impact of this energy source. However, forests are not cut down specifically to generate biomass. Forest biomass for bioenergy is typically obtained from forests managed for multiple purposes, in this sense, stems that meet quality requirements are used to produce high value products such as sawn wood and wood panels, while residues from forestry operations (tops, branches, thinnings, and wood that is unsuitable for lumber) and wood processing residues are used for energy production.

The following figure shows that the resources taken directly from forests for bioenergy production are minimal, with more than 90% of the total of a harvested tree used for building materials or pulp and paper products.

Figure 12. The yield of different products (% of wood volume) from a harvested tree trunk.*



**Tree stumps and roots remain in forest for biodiversity. Treetops and branches are sometimes used for bioenergy.*

Source: Stora Enso.

In parallel to the increase in bioenergy production from forest biomass, there has also been, on a European scale, an increase of forest area, forest stock and forest biodiversity. Between 1990 and 2020, forest area has increased by about 468.000 hectares each year, which corresponds to the area of about 1,24 football fields per minute. The forest stock[41] over the same period showed an increase of 42%, reaching 27,35 billion m^3 in 2020[42].

These increases show that bioenergy is not a cause of deforestation in European forests. However, climate change affects forest ecosystems negatively by making forests less resilient to disturbances, such as the frequency and intensity of pest and disease outbreaks, wildfires and windstorms.

40 Eurostat database.
41 The total amount of m^3 of biomass present in forests.
42 FOREST EUROPE (2020): State of Europe's Forests 2020.

The implementation of smart forestry techniques, allowing the coupling of production and conservation, could contribute to maintain forests resilient to face climate change. According to the IPCC[43], a sustainable forest management strategy aimed at maintaining or increasing forest carbon stocks, while producing an annual sustained yield of timber, fibre or energy from the forest, will generate the largest sustained mitigation benefit in the long term.

Thinning is an effective and powerful forest management tool that promotes tree growth and restores forest health[44]. When thinning, forest operators remove slower-growing or defective trees to provide more space for the remaining trees to grow. Also, pruning is a silvicultural operation that can improve the health of forests. While pruning is usually done to produce knot-free timber on the lower part of the stem of a tree, it can also be used to remove dead and diseased branches and prevent disease infections in some cases. For example, in white pine stands, pruning can help prevent white pine blister rust infections by removing the most vulnerable infection sites. Moreover, pruning can improve air circulation within a stand, which can help reduce fungal disease[44].

On the other hand, accumulating understory biomass could also increase the incidence of forest pests and fires. Forest management is not always cost-effective, and due to rural depopulation and difficult terrain it is also sometimes neglected. The use of biomass for energy production provides an attractive solution for forest management, giving economic value to a low-quality biomass that otherwise would be left on the ground for rotting, while preventing forest pests and fires.

Forest fires deliver vast amounts of greenhouse gas emissions into the atmosphere and directly contribute to the outflow of mineral nutrients, the destruction of the soil's organic layer, changes in the water's infiltration rates causing erosion, soil loses and landslides. In addition, recurrent fires, most notably in southern areas of Europe where drought periods appear, have been reported to lead to permanent desertification of the region. The fire's effect on the lands soil disturbs its ability to re-grow vegetation significantly and the disturbance impacts on soils can last up to at least 80 years, where the region's biodiversity is drastically hindered.

The annual reports produced by the EFFIS (European Forest Fire Information System) represent the impact of fires on the different EU member countries. As such, in 2019, a total of 2.028 fires, larger than 30 hectares, were recorded using satellite imagery, burning an area of 304.147 hectares in 23 countries as shown in the table below. The total amount of CO_2 emitted into the atmosphere caused by these fires are estimated in 12,63 million tonnes[45].

43 Nabuurs G.J., Masera O., Andrasko K., Benitez-Ponce P., Boer R., Dutschke M., Elsiddig E., Ford-Robertson J., Frumhoff P., Karjalainen T., Krankina O., Kurz W.A., Matsumoto M., Oyhantcabal W., Ravindranath N.H., Sanz Sanchez M.J., Zhang X. (2007): Forestry. In Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Metz B., Davidson O.R., Bosch P.R., Dave R., Meyer L.A. (eds)], Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

44 Forestry Commission UK (2011): Thinning Practice - A Silvicultural Guide

45 Estimations extrapolated from a study conducted in Galicia (Spain) - Universidad de Vigo (2007): Cálculo de las emisiones de CO_2 por los incendios de 2006 en la provincia de Pontevedra (Galicia) – which reported that for an area of 40.943 hectares burnt in 2006, 1,7 million tonnes of CO_2 were emitted into the atmosphere alongside other GHG's as well. This, of course, is data which is accurate for this specific case as there are many factors (biomass, wood type, soil characteristics, vegetation) that account for the share of the different greenhouse gases emitted by each individual fire.

Table 7. Impact of fires on the different EU member countries in 2019. Source: EFFIS[46].

Countries	Hectares burnt, 2019	Fires (+30ha), 2019
Austria	38,1	1
Belgium	314,9	4
Bulgaria	13.827,9	90
Croatia	11.959,8	75
Cyprus	625,4	6
Czech Republic	52,5	2
Denmark	107,7	2
France	45.234,6	370
Germany	2.054,5	14
Greece	11.111,6	70
Hungary	601,7	10
Ireland	2.895,5	23
Italy	39.655,4	448
Latvia	49,4	1
Lithuania	235,3	4
Netherlands	20,8	1
Poland	181,8	6
Portugal	34.661,4	222
Romania	73.444,2	242
Slovakia	24,6	1
Slovenia	105,9	2
Spain	66.405,6	424
Sweden	538,4	10
Total	**304.147**	**2.028**

Via a better control of forests, bioenergy is a solution that could contribute to the mitigation of these wildfires and the improvement of forest health. The use of the residual biomass from thinning and pruning adds a lifecycle where energy can be produced from biomass that alternatively would be wasted. This is also directly relevant to the introduction of bioenergy within the agriculture industry, where many waste products from agricultural lands is composed of

46 San-Miguel-Ayanz, J., Durrant, T., Boca, R., Maianti, P., Libertá, G., Artés-Vivancos, T., Oom, D., Branco, A., de Rigo, D., Ferrari, D., Pfeiffer, H., Grecchi, R., Nuijten, D., Leray, T. (2020): Forest Fires in Europe, Middle East and North Africa 2019, EUR 30402 EN, Publications Office of the European Union, Luxembourg, 2020, ISBN 978-92-76-23209-4, doi:10.2760/468688, JRC122115.

dry vegetation which, if not treated properly, can trigger wildfires. Even so, common practices within the agriculture industry to eliminate waste is to purposely create a controlled fire where the waste products are burnt. Bioenergy provides a successful solution to these problems where agricultural waste can be re-used for profit, where GHG emissions are reduced significantly along with the risk of wildfires occurring.

Furthermore, increasing the economic value of forest management and control activities could result in migration of population to rural areas, while reducing the risk of wildfires in the region. This is an important aspect to consider knowing that in recent decades, migration of population has noticeably been from rural to urban areas, due to the existence of higher economic activities.

Summary:

- Forests are the main producers of resources used in bioenergy as 70% of the bioenergy employed for primary energy production is solid biomass. However, forests are not cut down specifically to generate biomass, being the market for raw materials in the sectors that rely on forest resources regulated by the cascade principle: bioenergy is mainly produced from secondary biomass, which results from the activity of other industries and not taken directly from the forest.
- The increase in the use of woody biomass over the last 20 years has taken place in parallel with an increase of forest area, forest stock and forest biodiversity, which shows that bioenergy is not a cause of deforestation in European forests.
- Climate change affects forest ecosystems negatively by making forests less resilient to disturbances, such as the frequency and intensity of pest and disease outbreaks, wildfires and windstorms.
- Forest fires deliver vast amounts of greenhouse gas emissions into the atmosphere and directly contribute to the outflow of mineral nutrients, the destruction of the soil's organic layer, changes in the water's infiltration rates causing erosion, soil loses and landslides. Via a better control of forests, bioenergy is a solution that could contribute to the mitigation of these wildfires and the improvement of forest resiliency to face climate change (disturbances such as forest pests).
- The use of biomass for energy production provides an attractive solution for forest management, giving economic value to a low-quality biomass that otherwise would be left on the ground for rotting, while preventing forest pests and fires.
- Increasing the economic value of the forest management and control activities could result in migration of population to rural areas, while reducing the risk of wildfires in the region.

6 Bioenergy with Carbon Capture and Storage Processes

Bioenergy is derived from biomass, which is a renewable energy source and serves as a carbon sink during its growth. Hence, biomass represents an alternative energy source to fossil fuels, playing an important role in lowering greenhouse gas emissions in industries such as power generation.

Taking into consideration that bioenergy is carbon neutral, its use, together with Carbon Capture and Storage (CCS) technologies, enables carbon dioxide removal from the atmosphere, making bioenergy an alternative technology for negative emissions.

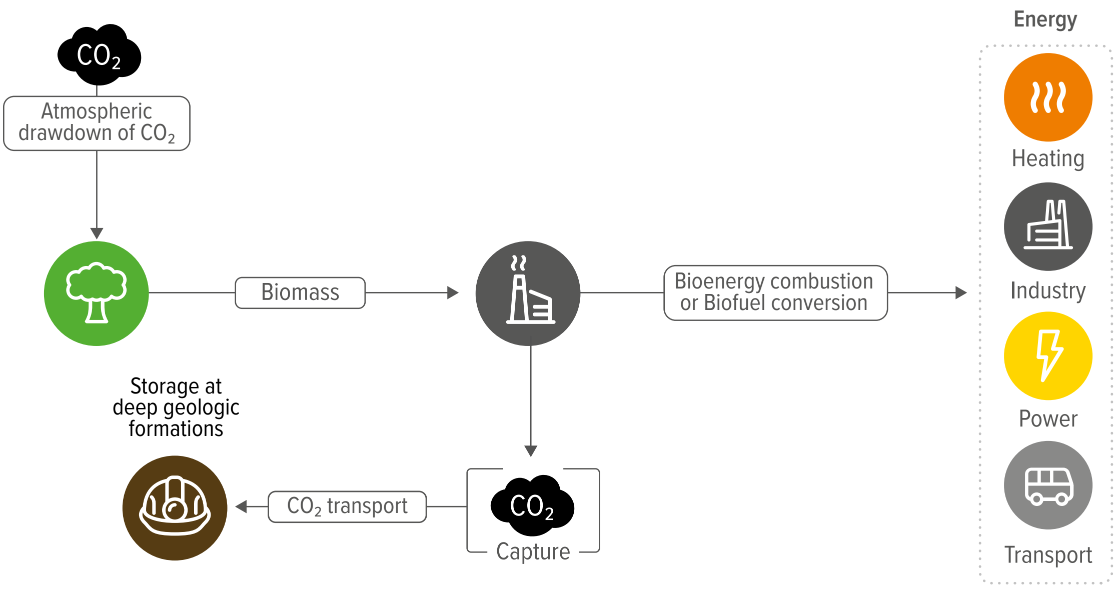
Such technologies are considered critical to achieving the Paris Agreement goals: of the 116 scenarios explored by the Intergovernmental Panel on Climate Change (IPCC) in which global warming is kept to 1,5 °C of pre-industrial levels (more ambitious than the Paris Agreement's 2 °C), 101 use negative emission technologies.

Among the different technologies that can contribute to achieve negative emissions, such as promoting and developing carbon sinks or boosting ocean plants' productivity, **Bioenergy with Carbon Capture and Storage (BECCS) is the most scalable negative emissions technology available today, emerging as the best solution to decarbonise emission-intensive industries while removing CO_2 from the atmosphere and generating electricity or heat.**

Hence, BECCS involves the utilisation of biomass as an energy source and the capture and permanent storage of the CO_2 produced during the conversion of biomass into energy. However, due to the variety of industries, biomass feedstocks and energy conversion processes, there is no singular definition of BECCS, and achieving negative emissions requires that the CO_2 stored must be greater than the CO_2 emitted during the biomass production, transport, conversion, and utilisation. The overall process involves the following:

1. Sustainably managed forests, agricultural and energy crops absorb carbon dioxide from the atmosphere through photosynthesis as plants grow.
2. Biomass is transported to the conversion facility.
3. Biomass is combusted or converted into biofuel using digestion/fermentation processes.
4. Carbon dioxide produced during combustion or conversion is captured and stored.

Figure 13. Bioenergy and carbon capture and storage (BECCS) schematic.



The basics of BECCS to achieve negative emissions rely on carbon capture and storage (CCS), a broader technology group. CCS is already a proven technology, with the first carbon capture and storage facility having started its operations in 1972 in the United States as part of an EOR project. The CCS processes comprise capture, transportation, and geological storage of CO_2.

- Capture: it involves a post-combustion separation of CO_2 from other gases produced at industrial installations or power plants.
- Transportation: it usually involves the compression of CO_2 into its denser or liquid form and transmission from the capture location to the storage facility, which can be achieved through pipelines, ships, or using road or rail tankers.
- Geological storage: it involves the injection of CO_2 in dense or liquid form into sub-surface rock formations normally at depths of one kilometre or more.

The individual technologies to utilise biomass to produce energy or fuel, as well as the capture, transport, and storage of CO_2 are active in commercial facilities around the world. At a worldwide level, most of the BECCS facilities are related to biofuels production, with the United States and bioethanol plants at the top. In Europe, there are two examples of BECCS in relation to the production of bioethanol, Alco Bio Fuel (ABF) bio-refinery CO_2 recovery plant and Cargill wheat processing CO_2 purification plant, located in Belgium and United Kingdom respectively and with a capture capacity of 100.000 tpa of CO_2[47].

Besides, bioenergy with carbon capture and storage is increasingly being explored and deployed around the world at heat and power stations, factories, and waste-to-energy plants as they aim to achieve net zero through negative emissions. In Europe, Sweden, Norway, Denmark, and United Kingdom all have projects either piloting or developing BECCS with the aim of achieving negative emissions to reach their net zero climate goals.

In January 2019, the first post-combustion pilot of CO_2 capture in Europe at the Drax Power Limited power plant in the UK started its operations. Since December 2019, Stockholm Exergi, which is the energy utility responsible for the Swedish capital's heating, cooling, electricity, and waste processing services, has trialled BECCS at its Combined Heat and Power plant in the Värtan area of Stockholm, where it calculated there is potential to capture 800.000 tonnes of CO_2 per year. Also, i s, further facilities are planned for the coming years in Europe, North America, and Japan.

Hence, there is an enormous potential for BECCS in different areas, such as its application in the production of bioethanol or its use in industries that require significant heat and electricity in their production processes. The power sector also has a huge potential for achieving negative emissions. For example, bioelectricity supplied about 37,04 GW[48] for UE27 power generation in 2019; today, 37,04 GW could result in significant carbon dioxide reductions if it is captured and stored.

47 Global CCS Institute (2019): Bioenergy and carbon capture storage.
48 Bioenergy Europe (2021): Statistical Report 2021 - Bioelectricity

CASE STUDY:

Drax BECCS[49]

Drax Power Limited operates two pilot BECCS facilities at the Drax Power Station in North Yorkshire, UK, with plans for commercial-scale capture as of 2027. The 3,9 GW Drax Power Station, which provides around 6% of the country's electrical supply, has converted four of its six generating units from coal to biomass (sustainably sourced wood pellets). In doing so, it has become Europe's largest decarbonisation project and the UK's single largest source of renewable electricity: each unit, with a capacity of around 650 MW, would consume about 2,3 million tonnes of biomass yearly, while producing 4,2 TWh of electricity.

The first pilot CO_2 capture facility started operating in 2019, using capture technology from C-Capture. The project has the capacity to capture up to one tonne of CO_2 per day. The second pilot started in 2020 using technology from Mitsubishi Heavy Industries, capturing around 300 kg of CO_2 per day to test the companies' technology with biomass flue gases. The project is currently releasing small quantities of CO_2 from its pilot operations after its capture and has planning consent to provide CO_2 for use with several partner companies. The long-term plan for the full-scale plant is for permanent geologic storage.

The commercial scale BECCS project from Drax would be part of the proposed Zero Carbon Humber CCUS hub in the UK. If all four units of Drax Power Station were converted, it could generate up to 16 million tonnes of negative emissions every year (by comparison, the Humber Estuary industrial cluster generates around 14 million tonnes of CO_2 each year), becoming the anchor for a wider CCU and CCS network in the Humber Estuary region – the UK's largest cluster of industrial emitters.

CASE STUDY:

Fortum Oslo Varme waste to energy plant[50]

Since 2018, the waste to energy plant located in Klemetsrud, Oslo, is 50% owned by the city of Oslo and 50% owned by Fortum Oslo Varme (FOV), which is the current operator of the facility.

The FOV waste to energy plant processes about 400.000t of Municipal Solid Waste (MSW) per year in 3 lines. The MSW is made of approximately 1/3 household waste, 1/3 commercial and industrial waste and 1/3 refuse derived fuel imported from the UK. This facility produces about 700 GWh of district heat and 150 GWh of electricity per year.

In 2019, FOV ran a pilot campaign of Carbon Capture and Storage. This pilot was preceded by feasibility studies and other campaigns that started in 2015. The technology employed is based on a post-capture solution using amine (Shell/Cansolv technology). The amine technology was selected because it is the most advanced and proven technology for large combustion applications, even though experience with waste to energy is still limited.

49 DRAX 2021, accessed 6 September 2021, <https://www.drax.com/carbon-capture/negative-emissions-techniques-technologies-need-know/>.
50 IEA Bioenergy (2021): Deployment of bio-CCS: case study on Waste-to-Energy - Fortum Oslo Varme (FOV), Oslo, Norway.

The pilot processed a 0,3% exhaust gas slip stream for a combined duration of over 5000 hours. Extensive analysis work was carried out during the test period which ended in December 2019. In summary, the CO_2 capture efficiency was good, achieving 90%, and the CO_2 purity was as expected. The pilot campaign did not yield unexpected or alarming results.

The FOV project has been initiated as part of a broader ambition of the city of Oslo to reduce its GHG emissions by 95% in the 2009-2030 period. The FOV facility is the city's largest single emission source, and therefore it is considered as a perfect candidate to implement a full-scale deployment of CCS, with funding being now the key factor determining if the plant comes online in 2024.

CASE STUDY:

HOFOR Amager CHP[51]

HOFOR (short for Hovedstadsområdets Forsyningsselskab) is Denmark's largest utility and is owned by the City of Copenhagen, which has set a target for itself to be a carbon-neutral city by 2025, with bio-CCS being explored as one tool to achieve this.

The city is about to initiate pilot trials into deploying CCS at one of its waste to energy facilities. The waste to energy plant is located right next to the site hosting HOFORs CHP operations, and HOFOR has also started to investigate options for CCS deployment.

The waste to energy facility mentioned above operates two biomass-fired CHP units. Amager power plant's Unit 1 (referred to as AMV1) can produce 250 MJ/s of heat and 68 MW of electricity, with an annual wood pellet consumption of roughly 250.000 tonnes. The new wood chip-fired unit (AMV4) has a heat production capacity of 400 MJ/s and an electrical capacity of 150 MW. This is anticipated to use roughly 1,2 million tonnes of wood chips per year.

The investigations regarding carbon capture and storage carried out by the HOFOR includes AMV4. If carbon capture was implemented on the new wood chip-fired unit, nearly 1,1 $MtCO_2$ could be captured per year.

However, it is too early to say what technologies HOFOR would potentially select for carbon capture and storage as the company has no concrete plans to implement it at this point. In any case, the emphasis is being placed on technologies that have a high technology readiness level.

51 IEA Bioenergy (2021): Deployment of bio-CCS: case study on bio-combined heat and power - HOFOR Amager CHP, Copenhagen, Denmark.

Summary:

- Negative emission technologies are considered critical to achieving the Paris Agreement goals. Among the different alternatives, such as promoting and developing carbon sinks or boosting ocean plants' productivity, BECCS is the most scalable negative emissions technology available today, emerging as the best solution to decarbonise emission-intensive industries while removing CO_2 from the atmosphere and generating electricity or heat.
- BECCS involves the utilisation of biomass as an energy source and the capture and permanent storage of the CO_2 produced during the conversion of biomass into energy.
- BECCS is increasingly being explored and deployed around the world as it has an enormous potential in different areas, such as its application in the production of bioethanol or its use in industries that require significant heat and electricity in their production processes. The power sector has also a huge potential for achieving negative emissions. For example, bioelectricity supplied about 37,04 GW for EU27 power generation in 2019; today, 37,04 GW could result in significant carbon dioxide reductions if it is captured and stored.
- In Europe, Sweden, Norway, Denmark and United Kingdom all have projects either piloting or developing BECCS with the aim of achieving negative emissions to reach their net zero climate goals.

7 Energy Dependency

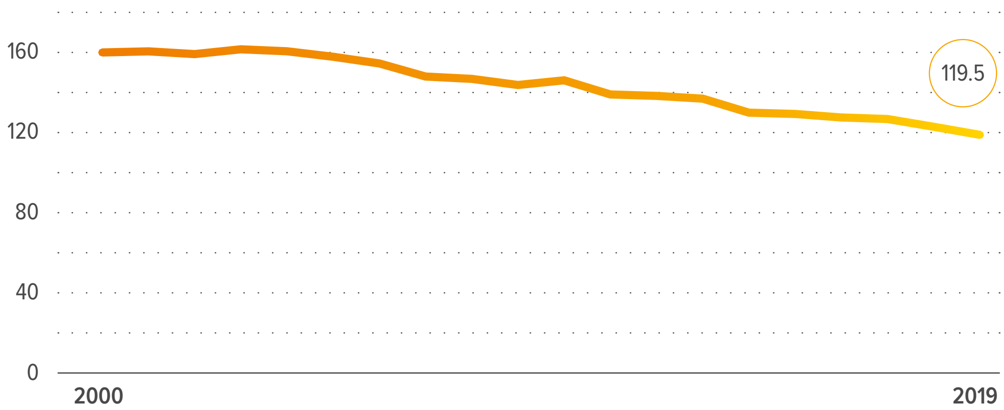
Fossil and non-renewable fuels still dominate the European energy landscape: in 2019, the primary energy production from these fuels accounted for 63%, reaching 391 Mtoe. Moreover, the energy import dependency of these fuels is extremely high in Europe, exceeding 96% for oil and petroleum and close to 90% for natural gas[52].

On the contrary, renewable energies accounted for 37% of the primary energy production in 2019[52]. Of this, bioenergy represented 59%, replacing energy from fossil fuels to a value of 132 Mtoe. Bioenergy has been leading the growth of renewable energies in the primary energy production within EU27: from 2000 to 2019 the contribution of this source has been increased by 72.694 ktoe; having grown more than double. Besides, its import dependency remained at 3,7%[52] in the EU27.

In addition to contributing positively to lowering greenhouse gas emissions as a carbon neutral energy source, the use of bioenergy allows to reduce dependence on foreign fossil fuels by taking part of renewable resources available in the territory. Bioenergy can be used as power, heat and fuels for transport that would otherwise be covered by fossil fuels.

Europe's dependence on foreign countries for the supply of fossil fuels can lead to supply problems due to the socio-political context in those countries. It is essential to guarantee the security of energy supply to the citizens, and this is also a fundamental requirement for industrialized societies, where supply interruptions would create economic losses: in 2019, the energy intensity of the EU27 reached 119,5 toe per million euros of GDP in chain linked volumes (2010)[53] and, therefore, each tonne of oil equivalent not supplied would have resulted in an economic loss of 8,4 thousand euros (2010)[54]. Hence, the energy supply security can profit from bioenergy as it is a renewable resource available in the territory, mitigating the dependence on imported fossil fuels.

Figure 14. Energy intensity of GDP in chain linked volumes (2010) for EU27 (toe/M€).



Source: Eurostat database.

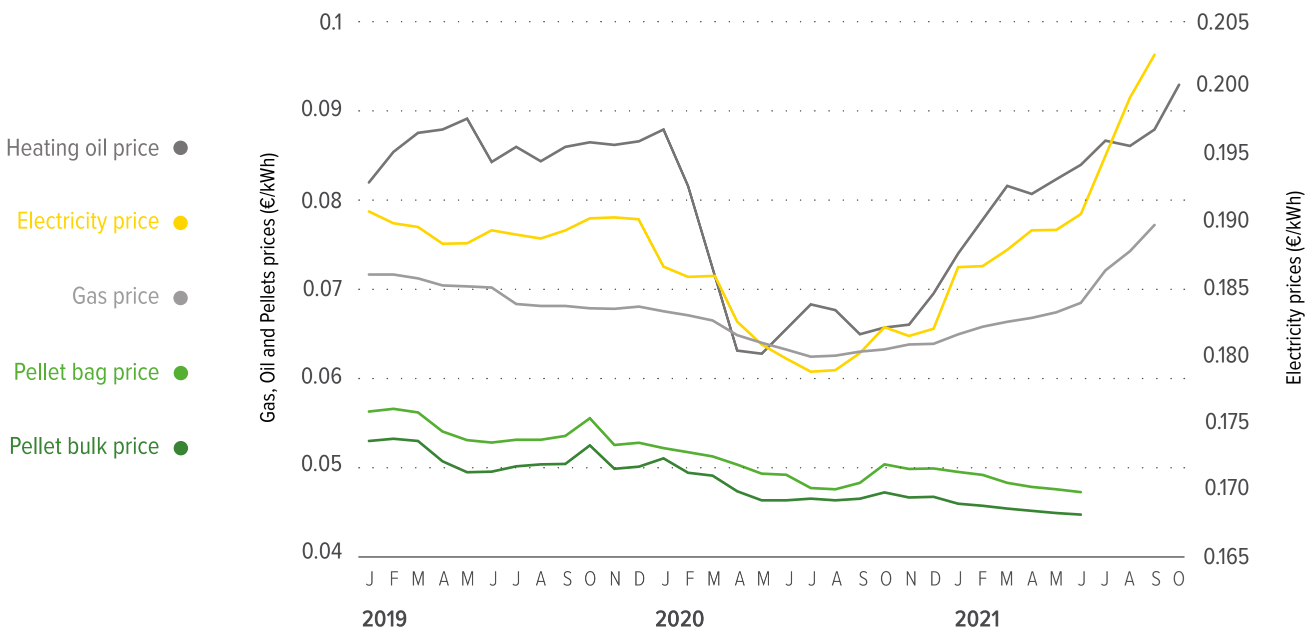
52 Eurostat database.
53 GDP is in constant prices to avoid the impact of inflation, with a base year of 2010.
54 The cost of an energy interruption can be assessed through the use of an economic indicator for energy supply security. For example, while energy intensity is defined as the amount of energy used to produce a given level of output, its inverse could be understood as the economic loss arising from an energy interruption

At a time of fluctuating fuel prices, renewable energy can offer, in addition to environmental benefits, a greater stabilisation of electricity costs. The volatility of fossil fuel prices, coupled with the difficulty of forecasting them, puts citizens and industries at risk of facing fluctuating energy tariffs, which increases the energy poverty and decreases the competitiveness of the European industry. So much so that electricity is the commodity that shows the highest fluctuation in its price as it depends on the technology used for its production. For example, a very high share of gas in the power mix of the EU results in the extreme price increase of this commodity to the wholesale electricity price.

However, biomass is excluded from the global commodities price fluctuations, being locally sourced in the EU. The previous, together with the fact that carbon released when solid biomass is burned will be re-absorbed during tree growth, guarantee that sustainable biomass will remain an affordable source of energy, actively contributing to decrease the energy poverty rate in the EU. For example, when comparing the price of biomass with other energy commodities for households, it is observed that the price of pellets, the most expensive type of biomass, remains quite stable, and up to four times cheaper than natural gas and electrical heating in all countries.

Moreover, biomass contributes to energy diversification as is the only renewable energy source capable of providing energy in the three primary forms required by society: solid, liquid and gaseous fuels for heat, electricity and transport. Reducing the dependence on a single form contributes to mitigate energy disruptions and strengthens energy security.

Figure 15. Evolution of price of biomass compared with other energy commodities.



Source: Bioenergy Europe, Household Energy Price Index (HEPI).

Although there are other renewable energies that also make it possible to reduce energy dependence on fossil fuels, bioenergy stands out for being a technology with a mature state of development, capable of responding to the requirements of the energy systems. Furthermore, bioenergy constitutes a manageable and storable source of energy, making it an ideal candidate for fossil fuel replacement. Likewise, its use makes it possible to reduce the dependence on the availability of solar and wind resources to produce energy.

Moreover, a clear example of how bioenergy contributes to reducing energy dependence on fossil fuels is the case of Lithuania, which is shown below. Bioenergy emerges as a solution for improving energy supply security, reducing foreign energy dependency, increasing economic development, and maintaining the balance between environment and sustainability.

CASE STUDY:

Lithuania, reducing emissions and becoming energy independent[55]

As part of the Nordic Baltic region of Europe, for Lithuania and its population of 3 million people, the dependence on imported fossil fuels from Russia was an economic and political challenge. In 2014, when the country became an EU member state, the price for imported gas increased due to geopolitical reasons, regardless of the market situation.

The country presents one of the highest amounts of biomass per capita of the European Union, with forests covering 33,2 % of the country (2,2 million ha). Taking into consideration the existing potential of this renewable resource and the energy dependence situation with third countries to import fossil fuels, Lithuania started an energy transition towards renewable energies.

From 2000 to 2014, the use of bioenergy in the district heating sector increased from 2% to 65%, thus surpassing the biomass used in district heating to imported gas.

As a result, the transition from imported gas to local biomass fuel resulted in the reduction of CO_2 emissions, as well as in a cost reduction for consumers, while creating new jobs and sustainable economic growth.

Summary:

- The European energy landscape is still dominated by fossil and non-renewable fuels, presenting an energy import dependency which is extremely high, exceeding 90% for oil and petroleum and 80% for natural gas.
- Bioenergy emerges as a mature technology for improving energy supply security, reducing foreign energy dependency, increasing economic development, and maintaining the balance between environment and sustainability. In 2019, bioenergy primary energy production replaced 132 Mtoe of energy from fossil fuels.
- Bioenergy can reduce the dependence on foreign fossil fuels by taking part of the renewable resources available in the territory (presenting an import dependency lower than 4% in the EU27). Moreover, bioenergy can be used as power, heat and fuel for transport that would otherwise be covered by fossil fuels.
- The energy supply security can profit from bioenergy as it mitigates the dependence on foreign countries for the supply of fossil fuels, avoiding supply problems due to the socio-political context in those countries.
- The adoption of bioenergy brings with it the price stability benefits. The costs of biomass prove to be more stable and cheaper over time not only for industrial consumers but also for domestic users, compared to the rising or fluctuating prices of electricity and fossil fuels.

55 ExpoBiomasa 2020, AVEBIOM, accessed 13 September 2021, < Lithuania, switching from gas to biomass | Expobiomasa >.

8 Rural Environment

Biomass constitutes a renewable energy source of natural and local origin. Using various biological and thermal processes such as anaerobic digestion, combustion, gasification or pyrolysis, the agricultural wastes can be converted into biofuels, heat or electricity, which contributes to a sustainable development not only in economic and social terms, but also environmentally.

Due to the abundance of biomass in rural areas, these are positioned as the origin of the bioenergy value chain, being key for the development of the sector. The type of biomass available directly affects the technology used for its conversion, as well as the location of the plants. For example, in the case of biogas plants, the conversion plants are often located near abundance of manure due to the transportation costs of the biomass used. However, in other cases, such as solid biomass to produce heat and/or electricity, the distances are greater, with the conversion facilities located closer to the point of consumption. In any case, considering economic and environmental sustainability criteria, the industry tends to approach the rural environment as this allows reducing the transport costs of the biomass.

Therefore, the start of the activities linked to the bioenergy sector has its origin in rural areas, with sustainable forest management and agriculture. These activities can mobilize along the value chain both equipment and component manufacturers, builders and plant operators, facilities maintenance services, as well as the final consumers of this resource in their homes.

Unlike other renewable energies, which do not need labour to obtain the fuel, biomass often needs to be collected, treated and transported for its use, being intensive in employment: the production of biomass for bioenergy uses created more than 415 thousand FTE in 2019 in EU27, representing more than 50% of the direct employment generated by the bioenergy sector.

In addition to reducing the dependency on fossil fuels and helping mitigate carbon emissions, bioenergy can then create jobs and support local economies through to the collection, treatment and transport of biomass, as well as provide new markets for people and companies connected to agriculture and forestry, strengthening rural areas and helping population settlement. Moreover, the benefits of bioenergy on rural environments allows preserving the high quality of life of these areas as well as the local control and a clean environment to keep it a good place to live.

In the EU, about 60% of forest area is privately owned and 40% is public, being the latter owned by municipalities, regional or national governments[56]. Hence, it is important to note that bioenergy can also support state budgets.

In addition, while bioenergy contributes to the valorisation of forest residues, thinning out dead trees from overcrowded forests, by-products of forest management such as limbs, treetops, needles, leaves, etc. improves the health of the trees that remain in the forest, helping control forest pests and other diseases, as well as reducing the incidence of wildfires.

A set of living examples of the positive effects across the European Union are presented on the following pages.

56 EFI Forest Policy Research Network (2021): Who owns the forests and how are they managed?

CASE STUDY:

Bioenergy, the key for a sustainable forest management in Estonia[57]

Nowadays, in Estonia there is 40% more forest land than 60 years ago, and half of the country (2 million ha) is covered with trees. The Estonian State Forest Management Centre (RMK) manage nearly half of the forestry areas.

The shift from fossil energy towards bioenergy is widely supported by Estonians, with wood being the largest alternative to non-renewables in Estonia. Every year, around 15% (about 600.000 m^3) of the wood harvested by Estonian state forests is used for bioenergy. This wood is mainly derived from silvicultural thinning and regeneration fillings and it is not suitable for other purposes such as construction or furniture production.

Using wood for heating has been a long tradition in Estonia and it has become the country's main renewable energy source – already 89% of renewable energy used in Estonia is based on wood. This amounts to 2,1 million m^3 a year, or some 20% of the country's total annual cuttings. The demand for this renewable energy source, especially in the form of pellets, is growing. Low-quality wood is consumed mainly by heating plants and CHP installations. The demand for firewood for households in local markets should also not be underestimated. Wood energy allows consumers to save around 20-30% on their energy bills.

It should be noted that sufficient demand for lower-quality wood assortments and forest residues for bioenergy use supports the economic viability of forestry and incentivises the silvicultural important but often costly tending of young forests. Timely tending is necessary to grow timber assortments for use in high value-added products such as furniture and construction materials. Therefore, the bioenergy sector enlarges the customer base for forest products, by creating demand for low quality wood and forest residues, and thus encourages the efficient use of all raw materials resulting from silvicultural operations in state forests.

CASE STUDY:

Rural areas and bioenergy, an example for sustainable growth in Italy[58]

Coradai S.r.l., in Valdaone (Trento), is a family-owned company specialised in wood activities. The company is committed to giving new life to waste through obtaining wood chips from secondary raw materials, in addition to managing the lots from which it provides logs to local sawmills.

Removing waste from forests mitigates the attraction of parasites than can also infect the healthy plants around, facilitating the growth of new trees and producing quality wood chips for local consumption.

The waste is obtained through a biomass management platform that was created with a local partner. By employing a mini cogeneration plant that produces 90 kW of electricity and 210 kW of thermal energy, the company can guarantee the correct dryness of the wood chips which they supply to three large power plants and other medium-sized plants including schools, hotels, and two greenhouses.

57 European Bioenergy Day 2020, Eustafor, accessed 30 August 2021, ‹Wood fit for purpose in Estonia – European Bioenergy Day›.

58 European Bioenergy Day 2020, AIEL, accessed 30 August 2021, ‹Circular economy - giving new life to waste – European Bioenergy Day›.

All the consumers of the wood chips from Coradai are located within a radius of a few dozen kilometres from the production site, proving that the company's focus activity is in the south-western Trentino region. On the other side, the 10 Coradai employees live close to the company's headquarters. An extra benefit of the company's regional focus is that local businesses strongly benefit from this activity, especially the maintenance of vehicles, spare parts, and other services that are almost exclusively local suppliers.

Bioenergy allows Coradai to protect the natural heritage of Trentino, while creating opportunities for employment and incomes.

Olive oil residues, an untapped source of energy in Greece[59]

Olive groves are also one of the most iconic features of Mediterranean landscapes, comprising a total area of around 4,6 million ha in the European Union in 2017[60]. A lesser known fact, however, is the enormous amount of biomass generated through the pruning operations of the olive trees. An untapped source of energy that "AGROinLOG" project (funded from the European Union's Horizon 2020) aims at converting.

The "AGROinLOG" project seeks to demonstrate the IBLC concept in three agro-industries (cereal processing, animal feedstock and olive oil processing) around Europe and to replicate the concept in other agro-industrial sectors. The olive oil sector demonstration is based around one of the leading companies in the sector in Greece, NUTRIA S.A.

The demonstrative aspects of the project foresee the mechanised harvesting of olive tree pruning around Agios Konstantinos in Central Greece, where NUTRIA is located. The harvested, chipped biomass can lose its residual moisture through treatment at the rotary dryers of pomace milling facilities, and then is either sold on the market as dried chips or further processed and turned into pellets.

The validation of the solid biofuels produced will be performed through combustion tests in commercial boilers or specialised laboratories. Considering the local availability of olive tree pruning, it is estimated that up to 8.000 tons of upgraded biomass fuel can be brought into the market on a yearly basis. Overall, the application of the IBLC concept to a Greek olive oil industry is expected to widen its business orientations, increasing its annual turnover while also promoting the concepts of a circular economy and a sustainable rural development.

59 European Bioenergy Day 2020, CERTH, INOSO-PASEGES and AGROinLOG, accessed 30 August 2021, <Managing olive oil residues in Greece – European Bioenergy Day>.
60 Eurostat database.

CASE STUDY:

Biomass district heating solutions, warming up Croatia[61]

Pokupsko, a municipality in north-western Croatia near the Kupa River, is covered by a 70% of forested areas. The 2.500 residents of this municipality are accustomed to living in harmony with nature, a fact of life supported by the municipality's aims for sustainable development. This has been achieved by investing in projects and maximising the utilisation of financial incentives from both national and EU funds.

In the last 10 years, several energy efficiency and renewable energy related projects have been implemented, having visible impacts on the residents' quality of life. One of those projects was the establishment of a biomass district heating plant to provide heat to public and commercial buildings, as well as households located in the centre.

The construction of the communal biomass heating plant has increased the quality of life of the residents; instead of having to chop wood into logs and light old wood furnaces manually, heat is now readily available by simply pressing a button.

Not only is the price of this heat cheaper than fossil fuel, but the regulation system also enables each customer to define the desired comfort level and monitor the heat consumed. One of the main beneficiaries of the new biomass heating plant is an elementary school in Pokupsko. Through a wide range of activities, the students of this school are instilled with respect for nature preservation and environmental protection.

The biomass heating plant in Pokupsko also provides a strong positive social component, as part of the revenues from the heating are used for scholarships for local children. The Municipality of Pokupsko has been the key driving force of this project by recognising the benefits and actively participating in the project's implementation, educational and promotional activities, and providing feedback, leaving them with more interest to pursue future projects.

Summary:

- Biomass constitutes a renewable energy source of natural and local origin. Due to its abundance in rural areas, these are positioned as the origin of the bioenergy value chain, being key for the development of the sector.
- Unlike other renewable energies, which do not need labour to obtain the fuel, biomass often needs to be collected, treated and transported for its use, being intensive in employment: the production of biomass for bioenergy represented more than 50% of the direct employment generated by the bioenergy sector in 2019.
- Bioenergy not only creates jobs and support local economies through the collection, treatment and transport of biomass, but also provides new markets for people and companies connected to agriculture and forestry, strengthening rural areas and helping population settlement.
- Bioenergy can also support state budgets as 40% of forest area is owned by municipalities, regional or national governments.
- Sustainable forest management and agriculture linked to bioenergy could help control forest pests and other diseases, while reducing the incidence of wildfires in rural areas.

61 European Bioenergy Day 2020, Bioenergy Europe, accessed 30 August 2021, <Croatian bioenergy village – European Bioenergy Day>.

9 Circular Economy

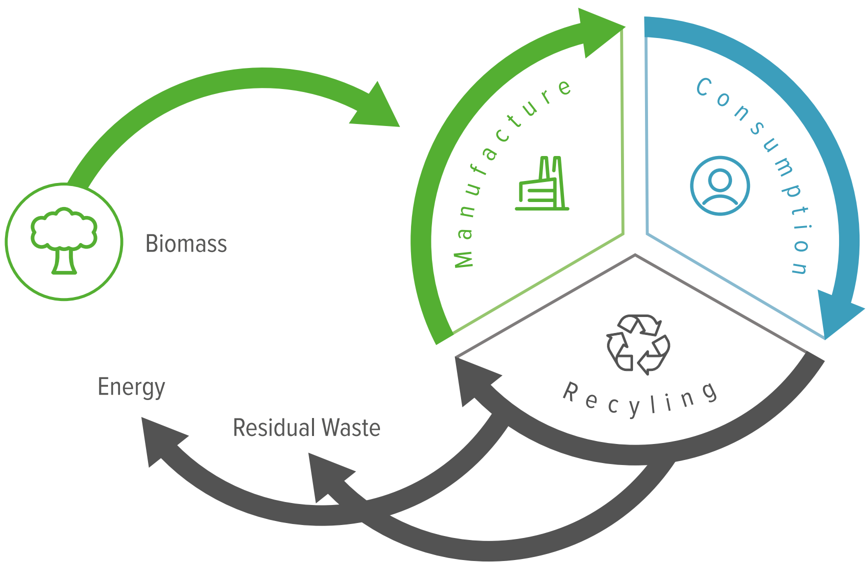
A circular economy relies on the value of resources being maximised indefinitely, avoiding as far as possible the production of unrecoverable waste. However, the current production system is based on high demand for raw materials and conventional energy consumption, jeopardising future production, and discarding valuable resources.

A transition towards a circular economy is essential for achieving sustainability. However, going away from linear production requires renewable resource production systems and their reuse or reconversion to create new products with added value with a longer life cycle, using transformation methods such as combustion, gasification, pyrolysis, fermentation, co-combustion, or a mixture of these.

Biomass is highly significant in a circular economy in terms of material products and the provision of energy. It can be used to obtain biofuels and bioproducts for their final use in heating and cooling systems, the generation of electricity, as well as the development of sustainable biofuels for transport.

Bioenergy represents just one part of the wider biomass system that supports the basic needs of the population by providing food, feed, fibre, fine chemicals and fertilisers. Even so, bioenergy can strengthen the whole biomass system by creating revenue streams for residues and waste generated along supply chains that would otherwise be burned onsite, wasted or disposed.

Figure 16. Bioenergy circular economy production system.



Moreover, a truly circular economy demands a comprehensive approach to resource efficiency that not only addresses the use of raw materials, but also energy sources. Transitioning to renewables is key to creating a circular economy and achieving the goals of the Paris Agreement.

In the circular economy, bioenergy technologies process waste into energy products and capture nutrients for application to farmland, closing the nutrient loop, maintaining productivity and preserving nutrient resources. For example, slow pyrolysis of biomass produces combustible gas and biochar for use as a soil amendment[62]. Thus, bioenergy can contribute to generate positive environmental and social impacts, through the efficiency of resources, access to energy and the generation of employment and wealth.

In relation to the existence of waste and residues, banning its landfill can foster the circular economy[63]. For example, implementing or introducing landfill bans for certain recyclable waste streams, such as biodegradable waste, paper, glass, metal, wood, textiles, plastic, etc. The bans play a "market-making" role and ensure that valuable waste fractions remain available for re-use or for energy purposes, rather than being dumped into a landfill[64]. In Europe, a number of countries have bans on waste by type: Denmark has a ban on the landfilling of waste suitable for incineration, Germany has a ban on municipal waste that is recoverable, and Sweden has a ban on landfilling wood waste to encourage its use for energy.

Figure 17. Landfill ban on organic waste or non-pretreated MSW.

Source: BioReg[65].

62 Brandão M., Lazarevic D. and Finnveden G. (2020): Handbook of the Circular Economy, chapter 29, pages 382-395, Edward Elgar Publishing.

63 Nordic Council of Ministers (2021): *How can the Nordic mix of policy instruments become more effective?*

64 European Commission (2016): *The efficient functioning of waste markets in the European Union legislative and policy options.*

65 Absorbing the Potential of Wood Waste in EU Regions and Industrial Bio-based Ecosystems – BioReg (2018): D1.1 European wood waste statistics report for recipient and model regions.

Thus, the bioenergy sector has many synergies with other economic sectors, especially the wood industry. Bioenergy enables forest management by covering the costs of traditionally loss-making forestry activities, allowing the energy use of logging residues as a by-product of a final felling without negative effects on wood production or the harvesting of energy wood from young stands, improving the growth of the remaining trees. Hence, bioenergy contributes to the sustainable management of forests, which is an essential source of biodiversity and carbon storage.

CASE STUDY:

TORERO Project - TORrefying wood with Ethanol as a Renewable Output: large-scale demonstration[66]

The TORERO Project has received funding from the European Union's Horizon 2020 - Research and Innovation Framework Programme and the consortium consists of the full value chain, industry ArcelorMittal and Renewi, two expert research organisations, Joanneum Research and Chalmers Technical University, and a torrefaction technology supplier, TorrCoal.

The aim of TORERO Project is to demonstrate a cost, resource, and energy efficient technology concept for producing bioethanol for use in the transport sector from a wood waste feedstock, fully integrated in a large-scale, industrially functional steel mill:

- Wood waste is converted to biocoal by torrefaction.
- Biocoal replaces fossil powdered coal in a steel mill blast furnace.
- Carbon monoxide in blast furnace exhaust fumes is microbially fermented into bioethanol.
- Material and energy loops of the process are closed to a very large degree.

Every steel mill that implements this concept will be able to produce at least 80 million litres of bioethanol per year. The project creates a value chain for wood waste, which currently has no attractive applications.

Moreover, the technology concept is open ended and, in the future, stakeholders may replicate the concept with other feedstocks and for producing other types of fuels. The Torero Project's business case will produce a competitive process for non-food feedstock bioethanol production.

It is worth mentioning that the OPEX of Torero is 1/3 lower, with a same CAPEX, compared with the current first-generation production based on cellulosic bio-ethanol solution.

Most importantly, together with sister project Steelanol, TORERO is the only H2020 project to demonstrate a biofuel production process that is integrated in an existing, fully functional large-scale industrial facility. All other H2020 solutions will need to be newly built if they ever reach full industrial scale. This means that TORERO is an add-on technology that can be used to upgrade existing facilities of the steel sector, an industry that is actively scouting for technological solutions to make its production processes more sustainable.

66 TORERO 2020, accessed 7 October 2021, <Torero - fuelling a sustainable future>.

In the case of the pulp and paper industries, biomass is also the main feedstock and there are synergies with the bioenergy sector. The pulp and paper industry produces a stable flow of residues to be used for added-value bioenergy products, which creates a good base for circular economy development. At the same time, the utilization of residues as feedstock for energy improves the resource efficiency of the industries.

An example of the previous is the use of all the resources obtained from the forestry sector, of which, with the activity dedicated to bioenergy, implies a total use of forest resources. The same happens in the case of the agricultural sector. The agricultural wastes for bioenergy are produced along with crops and require no extra land or efforts. So far, agricultural waste has been treated as waste, which was either ploughed in fields or burnt away. The conversion of this waste into energy is not only a step towards a greener and sustainable future but also economical.

In addition, urban areas and the agri-food industry generate a large amount of organic waste and residues that are potential for reuse in new by-products. These wastes can be treated in biogas production plants instead of their disposal or storage in landfills, reducing water pollution in the event of possible spills and the emission of methane into the atmosphere. Besides, valuable nutrients are obtained that can be used as fertilizers for the soil or green energy.

Bioenergy production is an economic opportunity for these sectors, increasing marketability of otherwise unprofitable residues that would be wasted, which plays a role in all countries. Likewise, the sustainable bioenergy systems advance the circular economy and decarbonisation of energy supply through a sustainable biomass supply, an appropriate management of biomass residues, and the synergies among the different sectors with energy generation.

Lastly, a set of examples of companies that contemplate a circular economy approach in their activity can be found below:

CASE STUDY:

Stora Enso[67]

Stora Enso develops and produces solutions based on wood and biomass for a range of industries and applications worldwide, leading in the bioeconomy sector and supporting the customers in meeting demand for renewable eco-friendly products.

The company is integrating its core circular design principles into its processes and product management. These principals include designing out waste, of which an aspect is maximising the net value of residuals from Stora Enso's value chains.

An example of this is how the company utilises the wood shavings, dry chips and sawdust from its sawmilling lines to produce wood pellets. These pellets are used for residential and commercial heating, as well as in horse bedding. By controlling the entire pellet value chain – from sustainably managed forests through to carefully controlled pellet pressing operations – Stora Enso ensures high quality, renewable energy, and animal care solutions for customers throughout Europe.

The company is ramping up its circular ambitions. In 2021, Stora Enso announced its aim to offer 100% regenerative products and solutions by 2050. Being regenerative means shifting its sustainability goals from minimizing negative environmental impacts to becoming a net positive contributor within the focus areas of climate, circularity and biodiversity.

67 Stora Enso 2021, accessed 22 September 2021, <https://www.storaenso.com/en/about-stora-enso>.

CASE STUDY:

Valmet[68]

Valmet is the world's leading developer and provider of technologies, automation and services for the pulp, paper, and energy industries.

The fundamental idea of a circular economy is embedded in Valmet's mission: converting renewable resources into sustainable results.

The circular economy is part of Valmet's solutions for pulp, paper and energy production. Through its technology, automation and services offering, Valmet enables customers to apply a circular economy in their operations. For example, in October 2019, Valmet was the first company in the world to launch roll covers based on biomaterials and recycled materials for board, paper, tissue and pulp making.

Moreover, in the own company operations, Valmet is constantly improving the processes to increase resource efficiency and maximizing the use of recycled materials in its technology offering.

CASE STUDY:

Dalkia[69]

Dalkia develops alternative renewables, such as biomass, geothermal, biogas and recovered energies.

The company uses waste conversion techniques to obtain biogas through the biological decomposition or fermentation of organic waste through anaerobic digestion. Its techniques support the energy transition towards sustainable energy generation methods, allowing the development of a circular economy of waste everywhere, reducing distribution costs.

Summary:

- Biomass is highly significant in a circular economy in terms of material products and the provision of energy. It can be used to obtain biofuels and bioproducts for their final use in heating and cooling systems, the generation of electricity, as well as the development of sustainable biofuels for transport.
- Bioenergy is responsible for providing added value to the waste and residues within the circular economy, allowing renewable energy to be obtained for production processes while it can also capture nutrients for farmland applications, closing the nutrient loop, maintaining productivity and preserving resources.
- The bans on organic waste landfilling existing in several EU countries can foster the circular economy, ensuring that valuable waste fractions remain available for reuse or for energy purposes.
- Thus, the bioenergy sector has many synergies with other economic sectors, including the wood-based industries, especially the pulp and paper industries, as well as the agricultural and agri-food industries, where the utilization of residues as feedstock for energy improves the resource efficiency of the sectors while increasing marketability of otherwise unprofitable residues that would be waste.

68 Valment 2021, accessed 22 September 2021, <https://www.valmet.com/about-us/>.
69 Dalkia 2021, Groupe EDF, <https://www.dalkia.com/about-us/missions/>.

10 Sector Integration and Adoption of Clean Hydrogen Solutions

Image courtesy of Turboden

The EU aims to be climate-neutral by 2050, achieving an economy with net-zero greenhouse gas emissions, and the reduction of emissions in the energy sector has been established as a priority to achieve this objective. The clean energy transition in Europe presents the challenge of restructuring this sector using renewable technologies. In this context, bioenergy can play a key role, as most of the countries have biomass resources available, being an energy supply option available in all Member States.

Biomass is not only a versatile energy source, which can be used for producing power, heat, liquid and gaseous fuel, but also serves as feedstock for materials and chemicals. Furthermore, the complementarity of bioenergy with variable renewable energies, such as solar and wind, stands out, being an alternative energy to the use of fossil fuels, within the framework of the decarbonisation process.

In this sense, it is important to highlight the rise and need of the hybrid renewable energy systems, consisting of two or more renewable energy sources combined to provide increased system efficiency as well as greater balance in energy supply. In addition, the hybrid installations can have storage systems for generated and unused energy.

In the case of obtaining bioenergy through biomass, the most common form of hybridization is its combination with solar thermal energy. Solar thermal hybridization with bioenergy allows to cover thermal needs, being used in HSW (Hot Sanitary Water) or heating systems, boosting the development of district heating systems. The hybridization of both resources allows to cover all needs, overcoming the discontinuity of operation of solar energy as a function of irradiation.

Besides, another form of hybridization that stands out is the combination of heat pumps and biomass boilers. For larger systems above 50 kW output, the investment is relatively low compared to other cascade heating systems, as well as the space requirements. This hybrid system works with 100% renewable energy and is still more efficient than a pellet heating system or a heat pump on its own. Even if the solution is particularly worthwhile for new builds, it is also an option when refurbishing apartment blocks as the biomass boiler can provide the high flow temperatures required on cold days. Moreover, the heat pump offers additional benefits in summer as it can be used in reverse operation for cooling.

CASE STUDY:

Heat and electric power production from solar thermal energy and biomass[70]

Turboden, a Mitsubishi Heavy Industries group company, is an Italian firm and a global leader in the design, manufacture, and maintenance of Organic Rankine Cycle (ORC) systems, highly suitable for distributed generation.

Brønderslev Forsyning is the district heating company of the city of Brønderslev, located in Denmark. This company is owned 100% by the city municipality and the district heating network supplies about 4.600 customers, with a length of around 140 km.

The goal of Brønderslev Forsyning was to build one of the most innovative plants at a technological level combining solar thermal and biomass as heat sources. Using the Turboden ORC system, the company could overcome the challenge to find an energy production system that could follow the variations in thermal power due to different heat sources with peaks and discontinuities during the day.

Turboden supplied an ORC system of about 3,8 MWe fed by thermal oil coming both from the 2 biomass boilers and the concentrated solar field (40 rows of 125 m parabolic through loops). Part of the thermal power from CSP is used directly to heat up district heating water.

70 Turboden 2021, accessed 6 September 2021, ‹ORC system for Brønderslev Forsyning | TURBODEN›

CASE STUDY:

Combining heat pumps with wood pellet boilers[71]

Hoval, a Liechtenstein heating appliances company, has combined heat pumps with wood pellet boilers to create a system tailor-made for apartment blocks in Brissago, Switzerland. The three apartment buildings, each of which contains eight apartments, were built in 2013.

The air/water heat pump and a wood pellet boiler were brought together here for the first time. In spring and autumn, the Belaria heat pump copes perfectly well on its own. In the depths of winter, the BioLyt wood pellet boiler supplies the heat. And the rest of the time, the two units share the work between them. The pellet boiler covers 60-65% of the annual demand of 150.000 kWh, while the heat pump covers 35-40%.

In this system, each unit neutralises any potential weak points of the other unit: the pellet boiler does not have to keep switching on and off during spring and autumn, which would only reduce its efficiency, and there is no need for it to struggle in low-load operations. For its part, the heat pump, which would otherwise reach its limits at low outside temperatures and consume excessive amounts of power, can relax, and let the pellet boiler take over.

The underlying principle of hybrid energy sources is the complementary nature of their energy generation patterns. Considering the renewable electricity production, biomass will be the backup energy for intermittent renewables like wind and solar, along with storage, increasing the system's reliability. Hence, bioenergy is complementary with the long-term power system development marked by increased share of intermittent power production. Moreover, bioenergy is flexible, not site-specific, and an affordable technology, which could even be linked with carbon capture and storage solutions to achieve negative emissions.

Besides, the biomass Combined Heat and Power (CHP) systems combine electricity generation with the production of heat, for example for district heating. The residual energy from electricity generation is then used to heat water which is circulated in city-wide pipeline networks to provide heating for homes, industries and offices. The use of this renewable heat to cover thermal consumptions is more efficient than a future switch of thermal consumptions to electric consumptions.

CASE STUDY:

How can bioenergy enable large renewable energy penetration?

The low-carbon transition, in line with the European Commission's proposed long-term strategy with the net-zero target by 2050 will require a large increase in electricity, especially for low-carbon solutions in mobility, heating and cooling and the decarbonisation of energy-intensive industries.

Considering the electrification of a European country with a population of more than 11,5 million as a case study, the complementary of the bioenergy and other renewable energies has been assessed. The power generation that would need to be installed has been evaluated considering a level of penetration of renewable energies that allows to cover the total electricity demand based on the following assumptions:

- The total load of the electricity system[72] in 2050 would be 102,9 TWh, taking into consideration a Scenario of high renewable penetration. This Scenario shows a 21,08% increase compared to 2019 and has a 16,5 GW peak demand.

71 European Bioenergy Day 2020, EHI, accessed 30 August 2021, ‹ When a pellet boiler met a heat pump… – European Bioenergy Day›.
72 The total load includes all the electrical loads on the transport grid and on the distribution systems connected to it. It also considers the estimated power losses.

- A simultaneous import capacity from the interconnections with neighbouring electrical systems of 6.500 MW.

The assessment has been carried out through an hourly simulation of the generation dispatch and two different Scenarios have been defined to achieve the renewable energy coverage of the demand:

A. This Scenario takes only into account the installation of wind power (land and offshore) and photovoltaic solar (terrestrial and on roofs) to achieve the objective of 100% renewables, together with the installation of energy storage systems[73].

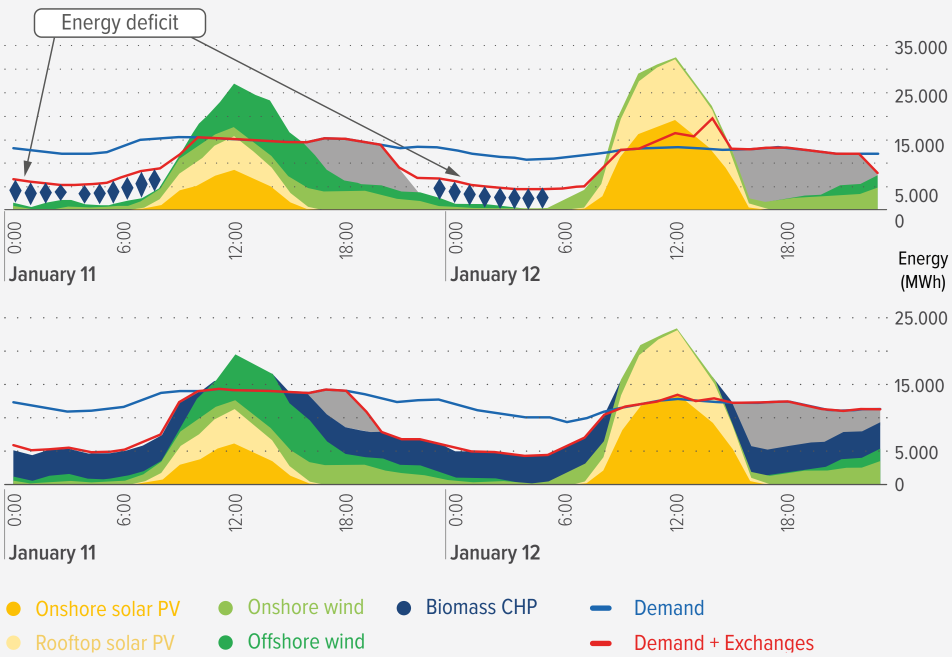
B. This Scenario considers the application of bioenergy in the future coverage of the electricity demand, considering not only the production of electricity but also heat.

   The total load of the electricity system in 2050 under this Scenario would be 98,8 TWh, assuming that bioenergy will be used to satisfy the thermal needs under the consumption of Scenario A by a value of 4,1 TWh. This implies a reduction of the electricity demand to be covered by the renewable energies stated in Scenario A.

   Furthermore, an installed biomass CHP capacity of 3 GW is assumed for 2050, considering that the current installed biomass facilities and gas CHP facilities in the country switched to this technology.

The renewable energy capacity installed in Scenario A reached 196 GW and would be even higher if the interconnections capacity were not considered. Even with this level of installed capacity, it is not possible to attend the total demand of the system when there is a lack of wind and solar resources. An energy mix based on wind and solar photovoltaic technologies presents high volatility and requires backup capacity, otherwise there could be energy deficits. For example, as shown in the figure below, the lack of wind and solar resources makes it impossible to meet the demand during the winter peak under Scenario A.

Figure 18. Generation dispatch derived from the solution of Scenario A and B in 2050 (January: peaks of winter).



Source: Own elaboration.

73 Demand adjustment is carried out through an equitable distribution between the different technologies.

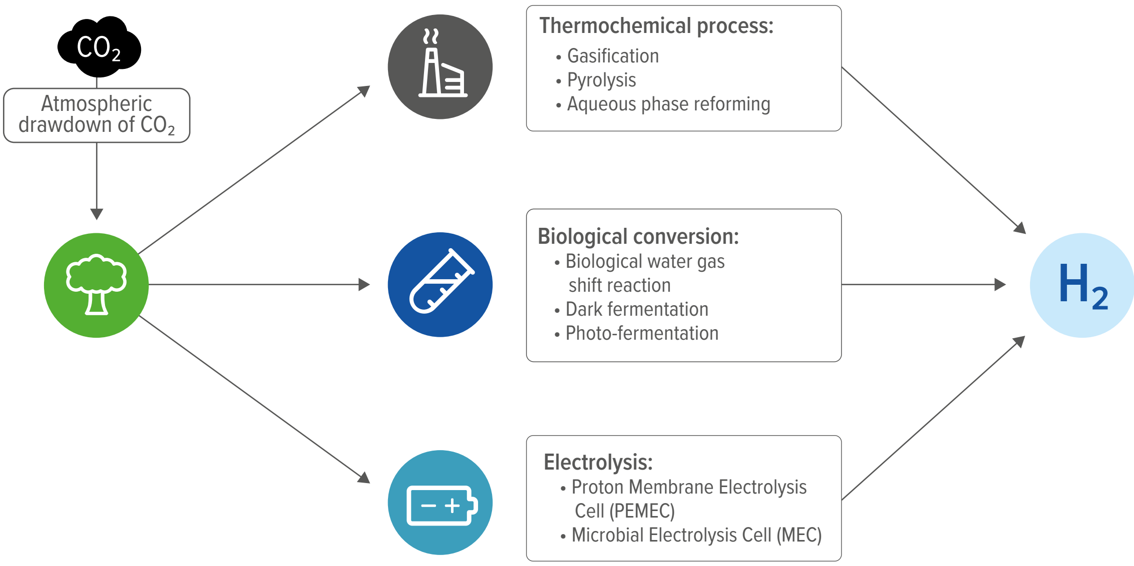
Energy storage systems could be used to attend that demand, however, the capacity required would be very high due to the high volatility of the generation and its seasonal behaviours: summer presents the highest production, while winter usually shows problems to cover the demand. Besides, if the generated energy cannot be exported, or stored, it would be lost.

Scenario B shows that biomass CHP allows attending the winter peak demand as it is a renewable manageable technology. Also, the electricity demand peak is reduced[74] since part of the thermal consumption is assumed by bioenergy, reducing the stress of the electrical system and the power necessary to meet these peaks.

Bioenergy makes it possible to adapt the generation curve to the consumption curve. Likewise, biomass is a resource that can be easily stored, being able to work as an energy vector to be used when needed. Furthermore, in the absence of interconnections with other electricity systems, the situation would be even worse. Hence, the use of bioenergy also avoids energy dependence, providing manageability and flexibility to the energy system.

On the other hand, taking into consideration that clean hydrogen is currently enjoying an unprecedented political and business momentum, with the number of policies and projects around the world expanding rapidly, it is also worth mentioning its complementarity with biomass[75]:

Figure 19. Main routes for hydrogen production from biomass.



The thermochemical conversion is the most advanced technology for hydrogen production from biomass. The process was established based on similar methodologies performed on biofuels, such as biomethane, adapted from steam methane reforming (SMR). The three primary thermochemical routes are gasification, pyrolysis, and aqueous phase reforming.

74 The peak demand under the Scenario B is 15,8 GW, 0,7 GW lower than in Scenario A.
75 T. Lepage, M. Kammoun, Q. Schmetz, A. Richel (2021): Biomass-to-hydrogen: A review of main routes production, processes evaluation and techno-economical assessment, Biomass and Bioenergy, Volume 144, 105920, ISSN 0961-9534.

Furthermore, the biological conversion can be divided into three categories: biological water gas shift reaction, dark fermentation, and photo-fermentation. Each process depends on the nature of the enzymes used to catalyse hydrogen formation. Commonly, microorganisms, such as micro-algae and cyanobacteria, produce the enzymes required to synthesise hydrogen. Unlike the thermochemical processes, biological conversion takes place at lower temperatures (30–60 °C) and pressures (1 atm), decreasing the energy cost[75].

Moreover, there is also the option of obtaining hydrogen by biomass electrolysis. This methodology allows a production of hydrogen that is adjustable to the amount and type of biomass available. For example, this route for hydrogen production allows the reuse of wastewater streams from industry, achieving an added value for these wastes by obtaining molecules with energy power.

The electrolysis of biomass allows to produce hydrogen of high purity, efficiently and cleanly, using electrical energy of renewable origin. Furthermore, this method does not generate carbon gases (CO, CO_2), since the electro-oxidation products are liquid organic currents which are easily separable from the hydrogen produced. By means of this method of obtaining hydrogen through wastewater, it can be used as an energy vector such as fuel to supply the energy needs or used in the associated processes in refineries to obtain biofuels.

Hence, the contribution of biomass to green energy production will be key to achieving electricity coverage rates in complementarity with other renewable energy resources and to achieve carbon neutral economies.

Summary:

- Biomass is not only a versatile energy source, which can be used for producing power, heat, liquid and gaseous fuel, but also serves as feedstock for materials and chemicals.
- Bioenergy presents complementarities with other renewable energies. The use of hybrid renewable energy systems, such as bioenergy with solar thermal energy or heat pumps provides increased system efficiency as well as greater balance in energy supply.
- Biomass Combined Heat and Power (CHP) systems combine electricity generation with the production of heat, for example for district heating. The use of this renewable heat to cover thermal consumptions is more efficient than a future switch of thermal consumptions to electric consumptions.
- An energy mix based on wind and solar photovoltaic technologies presents high volatility and requires backup capacity. Biomass could be the backup energy for these technologies, along with storage, increasing the system's reliability.
- Bioenergy is flexible, not site-specific, and an affordable technology, which could even be linked with carbon capture and storage solutions to achieve negative emissions.
- Hydrogen will be an important renewable secondary energy carrier for the future. Even that most of the hydrogen today is predominantly produced from fossil fuels, biomass can be an alternative to produce renewable and carbon neutral hydrogen via gasification, electrolysis, etc.

11 Policy Recommendations

The main policy recommendations derived from the assessment are:

1. **EU member countries should establish control measures to prevent the accumulation of forest residues, encouraging the use of waste to energy.**

   Sustainable forest management requires cleaning and thinning forests to boost the health of the trees and reduce the risk of wildfires. Utilizing these waste streams for bioenergy valorises these residues and helps mitigate climate change while maintaining or improving forest biodiversity and ecosystem condition. As forests are not managed for bioenergy, the sustainable use of biomass for bioenergy does not contribute to the deforestation of forests.

2. **Synergies between bioenergy and the industries linked to forestry and agriculture should be promoted.**

   Bioenergy contributes to a sustainable development of rural areas. It not only reduces the dependence on fossil fuels and helps mitigate carbon emissions, but also creates jobs and supports local economies by providing new markets for people and companies connected to agriculture and forestry, strengthening rural areas, and helping rural settlements.

3. **EU National Energy and Climate Plans should consider biomass not only as a mean of transition between conventional and other renewable energies.**

   Bioenergy is a market ready technology that is already working towards achieving the climate objectives set by the European Commission. As the only renewable energy source with mandatory sustainability requirements by law, it is a reliable solution to achieve decarbonisation.

4. **EU National Energy and Climate Plans should promote to cover thermal consumptions with bioheat and consider biopower as a backup energy for intermittent renewables to increase the system's reliability.**

   Bioenergy is crucial for the decarbonisation and the sustainability of the energy system. So far, bioheat represents a mature and effective solution for decarbonising the buildings and industrial sectors in any of its different solutions (district heating, individual heating systems, etc.). Moreover, in district heating systems, fuel switching from fossil fuels to renewable energy needs to be promoted and supported as well as the creation of new bioheat district heating.

   Furthermore, bioenergy is a dispatchable and flexible power supply, allowing to adjust its production to stabilise the grid under a scenario of high penetration of intermittent renewables. Biomass can easily be stored for situations when there is no solar or wind resources available, as well as in peaks demands.

5. **Circular bioeconomy should be fostered by the EU considering bioenergy to make use of residues and wastes while optimizing the value of biomass over time.**

   A bio-based economy relies on the production of renewable biological resources and the conversion of these resources into value added products. Residues should be utilized as much as possible to increase circularity with the remaining waste used for bioenergy.

   Bioenergy facilitates the emergence of a bio-based economy. Today, refineries are already processing oil into many different molecules with various uses. The biorefineries of tomorrow will utilize biomass to produce bio-composites and textiles too, but inevitably there will still be residues that can still create value by producing process steam, biofuels or biochar.

   Thus, a circular bioeconomy guarantees the energy supply, mitigates the effects of climate change, and reduces the use of fossil fuels.

6. **The EU should promote an industrial approach for bioenergy focused on the extensive existing R&D expertise.**

   Companies based in the European Union are leaders in terms of technological development, manufacturing, and fuel production in bioenergy. Europe's wealth of knowledge and bioenergy professionals ensures a globally competitive industry on the cutting-edge of innovation.

   Europe should have a long-term industrial approach to maintain this leadership as a R&D hub for bioenergy that promotes vibrant commercial activity.

7. **The development of technologies like Bioenergy with Carbon Capture and Storage (BECCS) requires a robust regulatory framework and R&D support to flourish.**

   BECCS has incredible potential as it produces energy while decreasing the amount of CO_2 in the atmosphere thereby achieving carbon negative emissions. Although there are already several existing projects in the EU, a robust regulatory framework is needed to help promote and mainstream this revolutionary technology.

8. **A switch to renewables requires the support of authorities to phase out of subsidies to fossil fuels and to reformulate the EU Emissions Trading Scheme (ETS).**

   The total number of allowances available should be decreased in order to achieve a higher carbon pricing which will promote the use of renewable technologies. To maximize the effectiveness of the EU ETS, it is essential that the transport sector does not fall outside the Scheme.

9. **European Member Countries and European institutions should agree on a stable European regulatory framework for bioenergy.**

   Bioenergy is paving the way for other energy sources in sustainability certification in the EU. This verification will maximize the environmental benefits by setting minimum standards for the whole supply chains, independently of the biomass origin.

   Changes in the regulatory framework for bioenergy, such as modifications of the sustainable criteria, could harm investments. Therefore, European institutions should avoid regulatory changes and legal uncertainty that holds back investments.

12 Conclusions

The contribution of bioenergy to society goes beyond the impact on the creation of employment and wealth, but also contributes to mitigating climate change, protecting forest health, increasing security of the energy supply, etc. This assessment has analysed the current impact of bioenergy considering both socio-economic and environmental impacts, while taking into consideration the future role of bioenergy in achieving climate neutrality in the 2050 horizon.

Biomass for energy can contribute to the development of a truly circular economy due to the many synergies it presents with other economic sectors, including the wood-based industries, especially the pulp and paper industries, as well as the agricultural and agri-food industries. The utilization of residues as feedstock for energy in these industries improves the resource efficiency while increasing marketability of otherwise unprofitable residues that would be waste. Also, the use of biomass for energy production provides an attractive solution for forest management, giving economic value to low-quality biomass that otherwise would be left on the ground for rotting, whilst preventing forest pests and fires.

Considering the needs for further development of bioenergy to achieve the emission targets for 2050[76,77,78], the economic impact of the bioenergy sector in terms of GDP could account for 70.105 million Euros that year, representing 0,52% of the current GDP of the EU27. At the same time, the impact on employment could reach 1.578.668 FTE.

Hence, **each additional Mtoe of biomass for energy could lead to an impact of 359 million euros in terms of GDP and an employment creation of 7.376 FTE, on average.** This is particularly important as the transition towards net-zero emissions will lead to unemployment in sectors such as the fossil fuel production sector. Moreover, considering that the current EU imported energy bill is higher than 236 million euros per Mtoe[79], the use of inland biomass for energy would not only allow the creation of employment and economic growth, but would also help reduce the energy bill with third countries.

Bioenergy is not only employment intensive in the collection, treatment and transport of biomass, but it also generates a significant number of jobs in the operation and maintenance of the solutions, the manufacture of equipment, as well as the construction of new generation plants and district heating systems. Moreover, European companies are global leaders when it comes to the technological development, manufacturing, and fuel production of bioenergy, with 74%[80] of the bioenergy technology suppliers based within the EU.

These companies represent a globally competitive industry and have the necessary knowledge and professionals to maintain this leadership as a R&D hub for bioenergy that promotes vibrant commercial activity. However, the lack of support and incentives from European policies and the lack of a stable regulatory framework may hinder maintaining this position in the future, being the leadership taken away by competing countries.

The bioenergy industry is fully aligned with the net zero emission objectives, being quite ahead of other industries since bioenergy has unique criteria and is under sustainability requirements. Based on the average gross inland consumption of biomass for energy in 2050 reported by the

76 European Commission (2020): Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. Impact Assessment accompanying the document Stepping up Europe's 2030 climate ambition - Investing in a climate-neutral future for the benefit of our people.

77 IEA (2021): Net Zero by 2050, IEA, Paris.

78 IRENA (2020): Global Renewables Outlook: Energy transformation 2050 (Edition: 2020), International Renewable Energy Agency, Abu Dhabi.

79 Own calculation based on data of the European Council on Foreign Relations and Eurostat database.

80 Bioenergy International (2018): 11th Global Suppliers Directory.

Impact Assessment of the European Commission[81], the replacement of fossil fuels for energy by biomass would prevent, on average, 487 $MtCO_2eq$ emissions that year. Hence, each additional Mtoe of biomass for energy could mitigate 2,4 $MtCO_2eq$ emissions due to the replacement of fossil fuels, contributing to decarbonise sectors such as the industry and transport sectors, which are among the most consuming of fossil fuels.

According to the Impact Assessment[76], the biomass imports will be lower than 7% in all the different scenarios evaluated. Thus, bioenergy will contribute to improve energy supply security, avoiding supply problems due to socio-political issues in foreign countries, and bringing price stability benefits as the costs of biomass for energy prove to be stable over time, compared to the rising or fluctuating costs of fossil fuels and electricity.

Bioheat represents a mature and effective solution for decarbonising buildings and industrial sectors in any of its different solutions (district heating, individual heating systems, etc.). In 2050, almost all industrial processes that require heat at high temperatures, which cannot be supplied by solar energy or renewable electricity, will be provided by biomass in replacement of fossil fuels. Therefore, the increase of thermal share in large-scale CHP plants will be enhanced and power production without cogeneration of heat or heat production without cogeneration of power will be restricted

Furthermore, the use of Bioenergy with Carbon Capture and Storage in different sectors, such as its application in the production of bioethanol, the power sector or industries that require significant heat and electricity in their production processes, will enable to obtain negative emissions. This will be critical to achieve the Paris Agreement goal as 101 of the 116 scenarios explored by the IPCC in which global warming is kept to 1,5 °C with respect to pre-industrial levels consider these kinds of technologies.

In addition, biomass can contribute to the development of the green hydrogen economy. This renewable and carbon neutral gas can be obtained from biomass through different routes, such as gasification or electrolysis, and can also contribute to decarbonise sectors which do not have green alternatives.

Bioenergy also represents a dispatchable and flexible power supply, which means that its production can be used to stabilise the grid under a scenario of high penetration of intermittent renewables. Hence, biomass could be the backup energy for these technologies, along with storage, increasing the system's reliability.

All in all, the use of biomass for energy is key to achieve the decarbonisation and the sustainability of the energy system in 2050, allowing to fulfil the EU's climate ambitions. Bioenergy can assist with the main challenges of decarbonisation with job creation and economic growth, while reducing the EU imported energy bill. The European Union has the necessary indigenous resources to be able to respond to this challenge, as well as the necessary mechanisms to ensure the sustainability of the processes, with biomass being the only renewable energy source subject to sustainability criteria. The use of biomass for energy allows reducing energy dependence with third countries, improving energy security and increasing energy price stability. Moreover, the sustainable use of biomass for energy makes it possible to contribute to the sustainable management of forests, while preventing forest pests and fires.

81 European Commission (2020): Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. Impact Assessment accompanying the document Stepping up Europe's 2030 climate ambition - Investing in a climate-neutral future for the benefit of our people.

Annex

ANNEX I: Methodology used for the Estimation of the Impact of Bioenergy on Employment and GDP

The positive impact of bioenergy on the European Union economy and employment has been evaluated for the different bioenergy solutions, assessing their value chain activities, at a direct and indirect level.

The direct impact results from the operation and construction of the facilities and the manufacture of the equipment, as well as the biofuel production and transportation. This includes the labour necessary for biomass production, construction, operation, and maintenance of facilities plant and for transporting the biomass. At the same time, the activities carried out by the bioenergy industry demand goods and services from other branches of the economy. This indirect impact, or drag effect on the economy, can be evaluated using the European Union input-output tables published by Eurostat[82].

The methodology used for the estimation of the impact of bioenergy on employment in terms of employment and GDP is summarized below:

- **Calculating the bioenergy sector's direct contribution to GDP:**

  Bioenergy sector is made up of companies that carry out a wide range of different activities integrated in the value chain of the industry. The activities of the sector have been split according to the following structure, considering the:

  - Production of electricity from biopower plants;
  - Supply of heat and power applying district heating solutions;
  - Heating systems based on biomass;
  - Use of biofuels in the transport sector.

  For each of these activities the following subsectors were taken into consideration:

  - Equipment manufactures;
  - Construction / Installation developers of the Bioenergy plants;
  - Supply of feedstock companies;
  - Operation and maintenance services companies.

  EU companies active in Bioenergy industry were identified and their financial statements analysed for the 2018-2020 period.

  To calculate the Bioenergy sector's contribution to EU27 GDP, Deloitte used three equivalent approaches, recognised by the European System of National and Regional Accounts (ESNRA)[83]: added value, income and expenditure approaches.

  The **Value added** is defined as the value of all newly generated goods and services minus the value of all goods and services consumed in their creation; the depreciation of fixed assets is not included; to obtain GDP at market prices.

82 These tables do not include a disaggregated breakdown of the bioenergy sector, so they have been completed on the basis of questionnaires distributed among agents in the sector, in order to identify the sectors from which these goods and services are demanded. Thus, it is possible to estimate the indirect impact of the bioenergy sector on other economic sectors in Europe.

83 Definitions as given by Eurostat: http://epp.eurostat.ec.europa.eu/statistics_explained/index.php/National_accounts_%E2%80%93_GDP

The **Income approach** includes salaries and other money spent on employees, net taxes on production and imports, gross operating surplus, and mixed income. The income approach shows how GDP is distributed between different participants in the production process.

The value added and income approaches were used to estimate the sector's contribution to GDP, using the information that companies disclosed in their financial statements. Additional information was gathered by surveying Bioenergy industry players.

The calculation based on the **expenditure approach** requires to estimate the sector's exports and imports. This estimation has been carried out based on the information available in the financial statements.

- **Indirect contribution to GDP:**

The different subsectors of the Bioenergy industry purchase from, and provide services to, other sectors of the economy, having an indirect impact on GDP, that is quantified using input-output models from the EU27[84].

Currently, the input-output models from the EU do not break the Bioenergy sector into subsectors, so it is necessary to evaluate the interrelationships with other economic sectors separately. In order to achieve this, a questionnaire was prepared and completed by surveying bioenergy industry players of the different subsectors of the industry.

The indirect effects of an industry on other sectors of the economy can be quantified from the matrix of technical coefficients and the Leontief inverse matrix. To calculate indirect impact on GDP is required the following information:

1. Obtain the latest EU Input-Output tables (2020) from Eurostat and access the "Symmetric Input-Output Table for domestic output at basic prices".

2. Questionnaires were developed to incorporate the breakdown of the bioenergy industry players. The intermediate consumption flows between the sub-sectors (equipment manufacturers, construction / installation developers, suppliers of feedstock and operation and maintenance services companies) and other economic activities were then quantified.

3. The information collected from the questionnaires of the Bioenergy sector and the other economic sectors were introduced into the matrix.

    a. Technical coefficients matrix was drawn up. This measures the relative importance of each industry in the total production of another subsector.

    b. A Leontief inverse matrix was drawn up. This measures the indirect impact of a sector on another economic activity through the multiplier effect that a sector has on the intermediate production of another.

    c. Income multipliers were calculated. These measure the existing relation between gross added value (contribution to GDP) and total production. This set of indicators, multiplied by the intermediate production, quantifies the indirect impact that an increase of €1 in the Bioenergy sector's contribution to the EU's GDP has on the GDP of the rest of the economy.

84 An input-output model is a quantitative economic technique that captures the correlations between different branches of an economy or among branches of different and even competing economies.

4. Indirect impact of bioenergy sector is estimated by multiplying the expenses in goods and services by the multipliers of each economic activity.

- **Calculating the bioenergy sector's direct and indirect job contribution:**

  The job creation in the different Bioenergy industry subsectors, as well as related economic sectors was calculated based on employment data published by companies in the industry and complementary industry both in their financial statements and in their annual reports.

  1. Direct employment is calculated by adding the number of jobs reported in each Bioenergy company's financial statement or annual report.

  2. Indirect employment has been estimated considering the economic activity generated by Bioenergy in other sectors using indices of productivity per employment calculated in the Input-Output tables.

Glossary

°C	Celsius Degree
atm	Atmosphere
BAT	Best Available Techniques
BECCS	Bioenergy with Carbon Capture and Storage
CAPEX	Capital Expenditure
CCS	Carbon Capture and Storage
CCU	Carbon Capture and Utilization
CCUS	Carbon Capture Utilization and Storage
CFB	Circulating Fluidised Bed
CHP	Combined Heat and Power
CO	Carbon Monoxide
CO_2	Carbon Dioxide
EFFIS	European Forest Fire Information System
ETS	Emissions Trading Scheme
EU	European Union
EU27	27 European Union Countries
FOV	Fortum Oslo Varme
FSC	Forest Stewardship Council
FTE	Full-Time Equivalent
GDP	Gross Domestic Product
GHG	Greenhouse Gases
H_2	Hydrogen
ha	Hectare
HSW	Hot Sanitary Water
IPCC	Intergovernmental Panel on Climate Change
LULUCF	Land Use, Land Use Change and Forestry
M€	Million Euros
MSW	Municipal Solid Waste
NZE	Net-Zero Emissions
OPEX	Operational Expenditures
ORC	Organic Rankine Cycle
PEFC	Programme for The Endorsement of Forest Certification
R&D	Research and Development
REDII	Renewable Energy Directive II
SCR	Selective Catalytic Reduction
SMR	Steam Methane Reforming
SNCR	Selective Non-Catalytic Reduction
tCO_2	Tonne of CO_2
TOE	Tonne of Oil Equivalent
TPA	Tonnes per Annum

Deloitte.