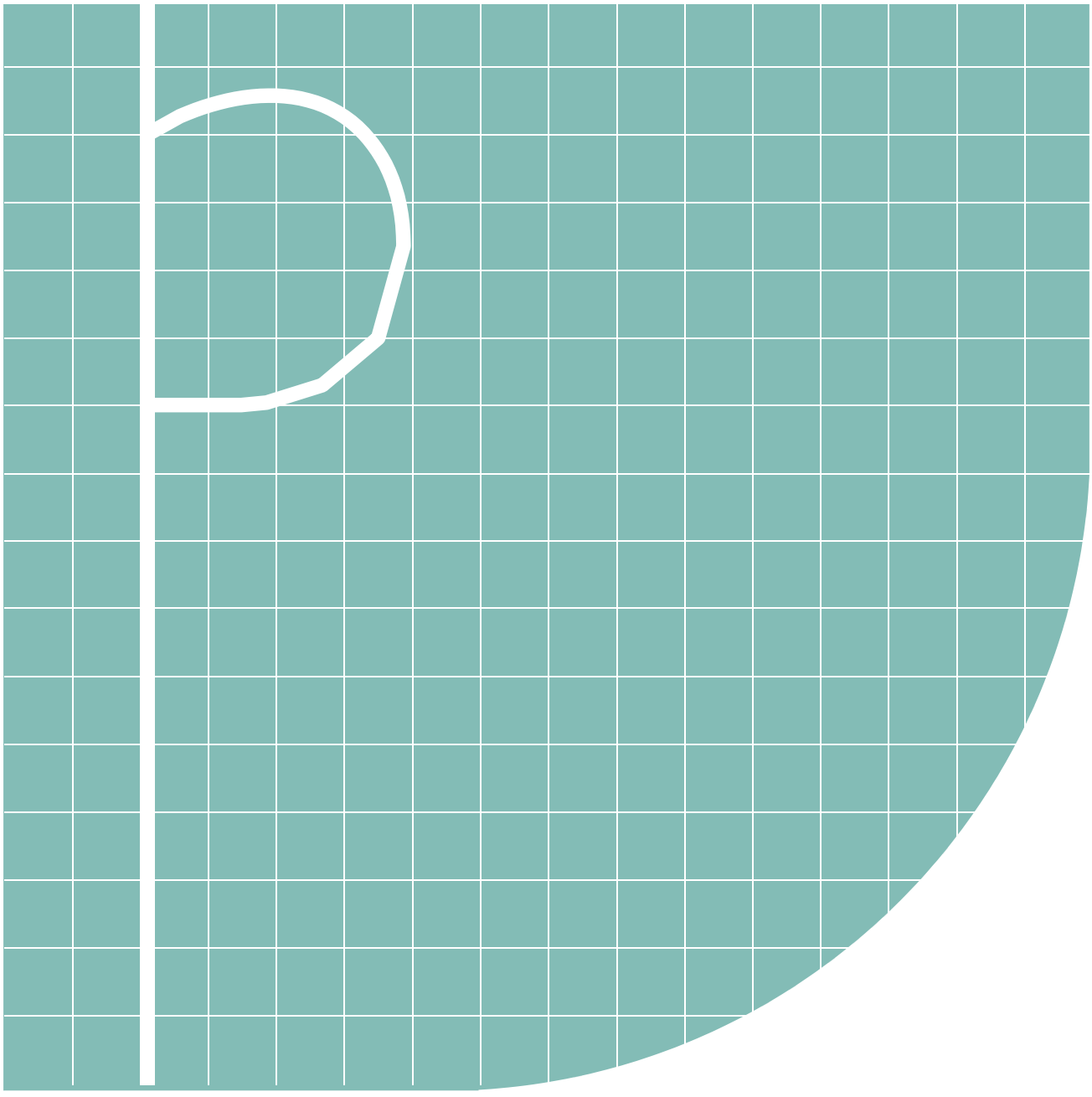
#19

Paper Bioenergy

Agricultural bioenergy as a driver of the energy transition



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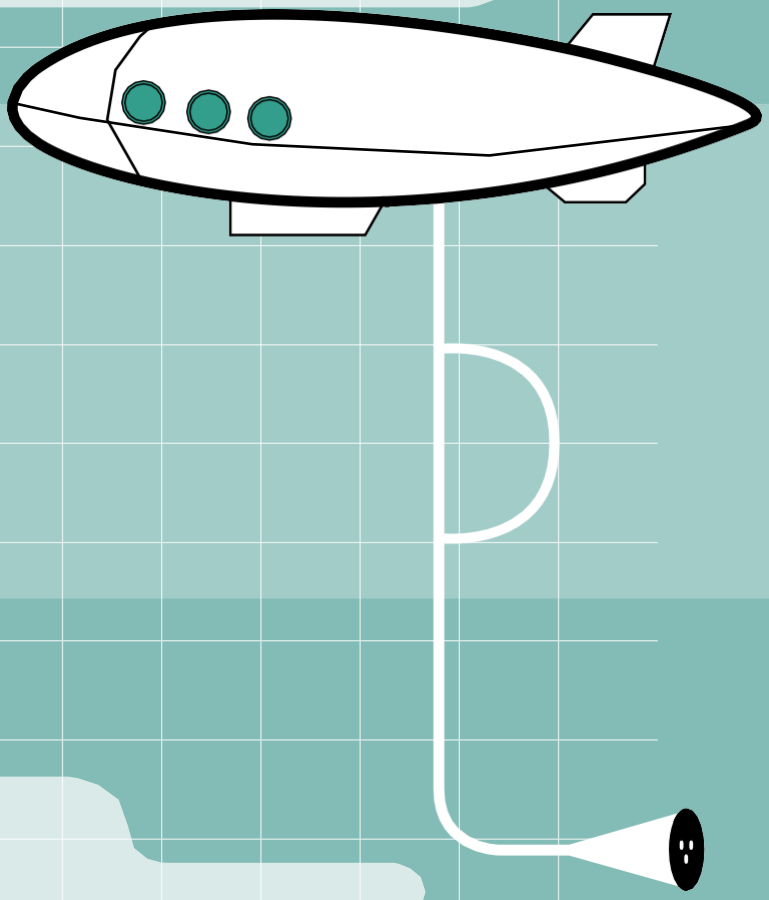
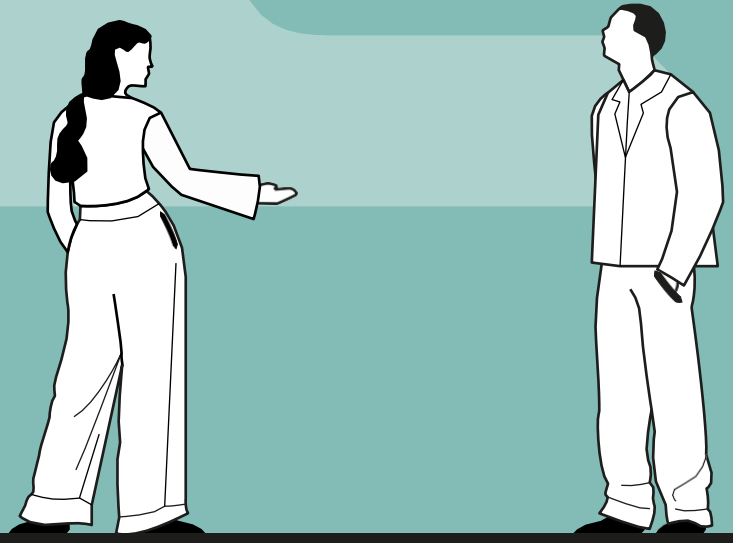


In the field of renewable energies, bioenergy is taking on an increasingly decisive role, including in terms of easing energy supply pressures. They form part of a rapidly expanding sector and, as a whole, give rise to a multitude of opportunities. Let's try to understand more together.

We consistently hear talk of the ecological transition. What is the role of bioenergy?



Abstract

- Bioenergy is the branch of renewable energies consisting of biomass or organic substances. They can be defined as the set of technologies that can be used for the production of energy (electricity and thermal) or energy carriers (fuels) through biomass transformation processes. In a context characterised by the vulnerability of energy supplies, bioenergy is a topic of extreme interest since it allows to alleviate energy needs in the form of electricity, heat and fuels.

- Worldwide, in terms of energy contained in biomass, bioenergy represents 54% of total renewable energy, up by 5% in 2022, and equal to 10% of total energy sources.

- In Italy, bioenergy represents an important share of renewable energies, equal to 48.8% of energy consumption from renewable sources, playing a crucial role in easing energy supply pressures . Bioenergy sources can be of various origin, mainly agricultural and urban, but the major part derives from the agricultural sector.

- The productive potential of the agro-livestock sector accounts for just under half (roughly 45%) of total bioenergy. In terms of electricity production, the contribution of the primary sector, including the traditional use of biomass, represents 5.2% of the Italian total and circa 13% of electricity production from renewable sources.

- The most interesting feedstock for the agricultural sector is animal manure which, through anaerobic digestion, is decomposed and transformed into biogas (a mixture of methane and carbon dioxide), one of the main bioenergy productions chains.

- Out of a total of approximately 3,000 electricity production plants installed in Italy and powered by bioenergy, as much as 72% is either directly or indirectly attributable to the agricultural sector. In particular, with regard to the production of biogas, there are 688 plants that reuse animal waste and 1,105 that use digestate from agro-forestry activities.

- Europe boasts significant biogas production records, with 19,000 plants, primarily located in Germany, Italy, France, and the United Kingdom. Italy, with its 2,200 operating plants, ranks second in Europe and
fourth globally after Germany, China and the United States.

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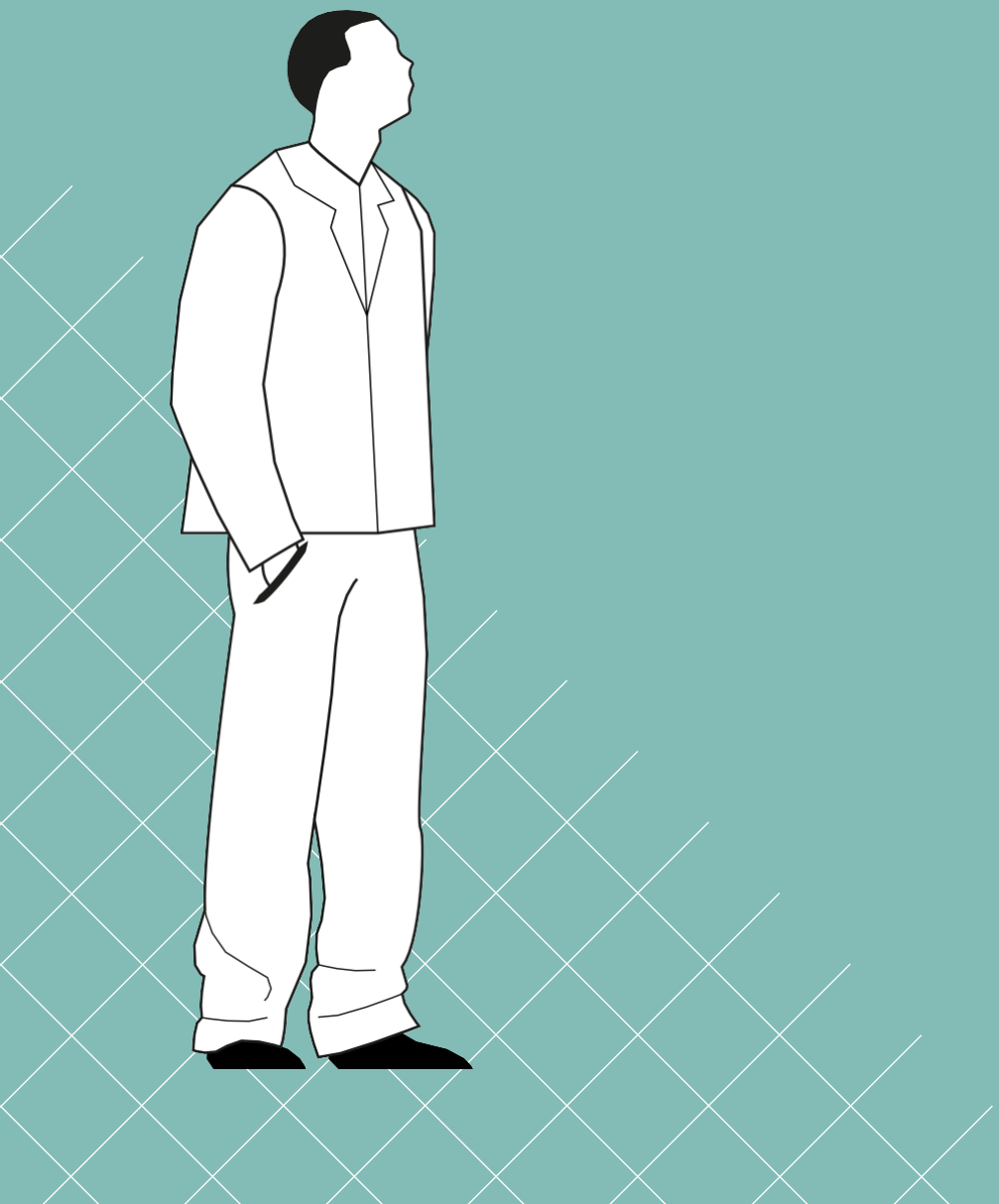

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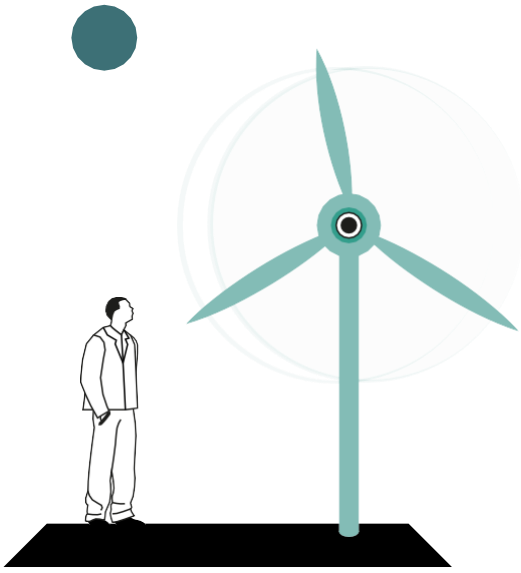


1. Renewable energies

Renewable energy is energy produced from sources that are exhaustible, such as the sun and wind, unlike energy that comes from limited and exhaustible sources such as fossil fuels (for example, coal and oil).
According to various sources, renewable energies can be classified as follows:

- solar energy;
- wind energy;
- hydroelectric energy;
- marine energy;
- geothermal energy;
- biomass energy (bioenergy).

We can state that renewable energies come from potentially unlimited sources and that, in terms of carbon dioxide production, they have a lower impact than fossil sources. In view of this, within the political strategy aimed at the energy transition process, renewable energies are considered the present and future of global energy production in terms of consumption and uses, expressing the importance of these sources in mitigating and combating climate change. For example, compared to electricity produced from conventional sources, renewable energy allows a drastic reduction in the levels of climate-altering gas emissions [1]. Today, many countries around the world share the need to produce more and more green energy and to abandon conventional sources. According to data based on the latest report by the International Renewable Energy Agency (IRENA), in 2019 renewables accounted for three quarters of the world's new energy capacity, with more than a third of the total production of

electricity [2]. It is therefore expected that the cumulative capacity of electricity from renewable sources, in the European continent alone, will increase by almost 60% (+425 Gigawatts - GW) between 2022 and 2027, more than double the previous five-year period (2016-2021).

Among renewables, photovoltaics leads the way towards the broadest change, followed by onshore wind [a], offshore wind [b], bioenergy and hydropower. In Europe, the energy transition has begun in numerous countries with an increase in countries announcing their commitment to achieve net zero emissions in the coming decades. In addition to the benefits – due to a proven lower environmental impact – it is also necessary to note the difficulties that are still being encountered with respect to production costs and the usability of renewable energies by consumers.

2.

2. Bioenergy

Among the various renewable energies, bioenergy production, i.e., energy generated from biomass, has aroused much interest in recent years. The term biomass is defined, according to Directive 2009/28/EC of the European Parliament and Council on 23 April 2009 [3], as

'the biodegradable part of products, waste and residues of biological origin from agriculture (including plant and animal substances), forestry and related industries, including fishing and aquaculture, as well as the biodegradable part of industrial and urban waste'. Biomass therefore includes all those products deriving from agricultural crops and forestry (including residues from agricultural and forestry processes), biodegradable waste from agri-food products intended for human consumption or animal husbandry, and all organic products deriving from the biological activity of animals [4]. Depending on the various conversion processes (thermochemical, biochemical, or physico-chemical), biomass can be used to obtain electricity, heat, and biofuels [5]. Biomass, as a renewable source from the agricultural sector, can be obtained through the recovery of residual raw material (for example, livestock waste or pruning waste) and, if planned within company management, also through the rotation of food crops with second-harvest crops aimed at producing not only food raw materials but also energy.

This type of management can be placed within crop rotation [c], thus including second-harvest crops (the so-called "cover crops") that allow soil covering

to be maintained for a greater number of months throughout the year. Moreover, the cultivation of crops dedicated to energy purposes can also take place on land that is not suitable for food production. Compared to other sectors, the agro-forestry sector is perhaps the most diverse in terms of choice of sources.

In fact, within the context of uses, it is always worth taking into account the multiple interactions between the different production chains, so as not to create competition between food crops and production for energy purposes. In fact,

the growing food needs of the world's population, which in 2050 will reach 10 billion people according to FAO estimates,

pushes to enhance energy crops, in areas that are not suitable for food production to avoid conflicts with the objectives of food security at a global level. Furthermore, today's call for the development of energy crops is also reflected in legislation, starting specifically with the need to avoid taking land away from food production.

3.

3. The regulatory framework

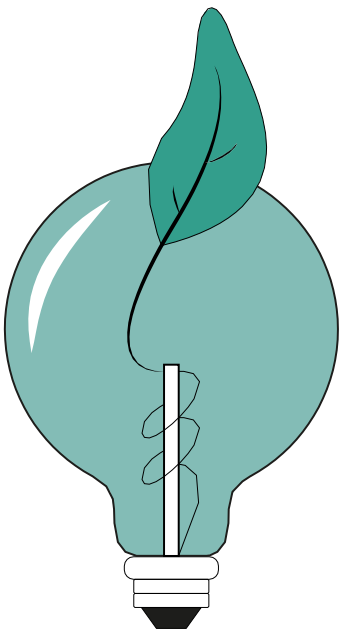
The starting point of the European regulation on the promotion of energy from renewable sources is the publication of the European Commission's White Paper entitled "*Energy for the future: renewable energy sources*" dated 1997, with which it sets the goal of reaching 12% of energy produced from renewable sources in the European territory by 2010. With this initial transitional step, the Commission estimated what the European energy needs were for the next thirty years, outlining a scenario in which dependence on imported energy sources would grow to 70%, thus making a change of course in energy production and distribution inevitable. It was on the basis of the White Paper and the Kyoto Protocol (discussed in more detail in chapter 8) that Directive 2001/77/EC "*on the promotion of electricity produced from renewable energy sources in the internal electricity market*" was promulgated in Europe. This directive initiated an actual energy transition process for all Member States through a major reform of the legislative framework consistent with European and international energy objectives. In order to align with international objectives, the association between green energy and agriculture was strengthened with the introduction in early 2003 of Directive 2003/30/EC on the "*promotion of the use of biofuels or other renewable fuels for transport*" [d]. Specifically, Article 2 of the directive introduces the concept

of biomass and biofuel for the first time. In this way, Europe establishes the fundamental role of agriculture among the official sources of energy production of the new century. Legal developments have pushed for greater detail in regulatory aspects and a greater involvement of all Member States in the commitment and remodulation of energy production according to increasingly renewable sources that have less impact on the entire ecosystem. The evolutionary process is highlighted by Directive 2018/2001[6] (RED II), legally binding since June 2021, which sets an EU-wide target of a 32% share of renewable energy in total energy consumption by 2030, establishing:

- a common framework for the promotion of energy from renewable sources;
- a binding target for the overall share of energy from renewable sources in the Union's gross final energy consumption in 2030;
- financial support - for electricity from renewable sources - for self-consumption of such electricity, the use of energy from renewable sources in the heating and cooling sector and in the transport sector, regional cooperation between Member States and between Member States and third countries, guarantees of origin, administrative procedures, along with information and training;
- sustainability and greenhouse gas emissions reduction criteria for biofuels, bioliquids and biomass fuels.

In compliance with legal changes and in response to the energy aspects of the EU's climate transition as part of the "Fit for 55" package [e], the new Directive (EU) 2023/2413 [7] (RED III) was published in October 2023. Its objectives include streamlining permit procedures, while also establishing the ambitious target of a 42.5% renewable energy share by 2030, compared to the previous 32% under RED II. The desirable outcome of the EU is not to limit itself to the mere identification of percentages in energy shares, but to bring about a significant change towards a more sustainable and efficient energy future.

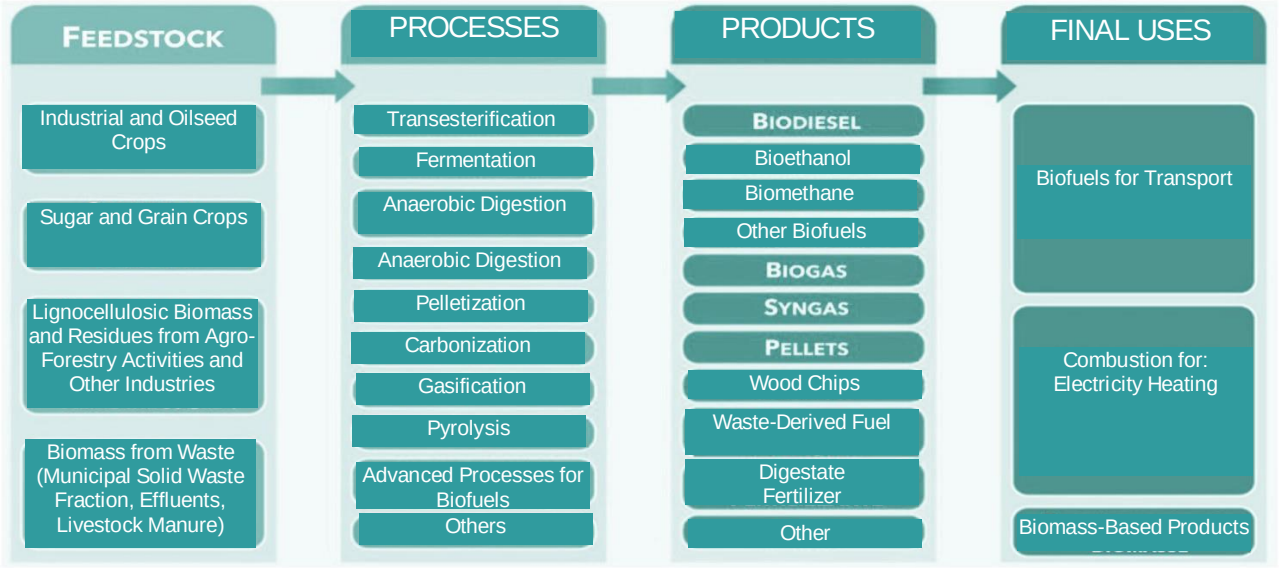
4.



4. State of the art in bioenergy

Bioenergy is the branch of renewable energy consisting of biomass – or organic substance – in a solid, liquid or gaseous state. Bioenergy can also be defined as the set of technologies that can be used for the production of energy (electrical and thermal) or energy carriers (fuels) through biomass transformation processes. They can cover energy needs in the form of electricity, heat and fuels for transport. Bioenergies as a whole therefore give rise to a very articulated reality and, based on how they are considered, they allow a multiplicity of inter-sectoral aspects: they include many raw materials (feedstock), they are involved in conversion processes and energy applications, and they interact closely with the agricultural-forestry sectors and urban and industrial waste management.

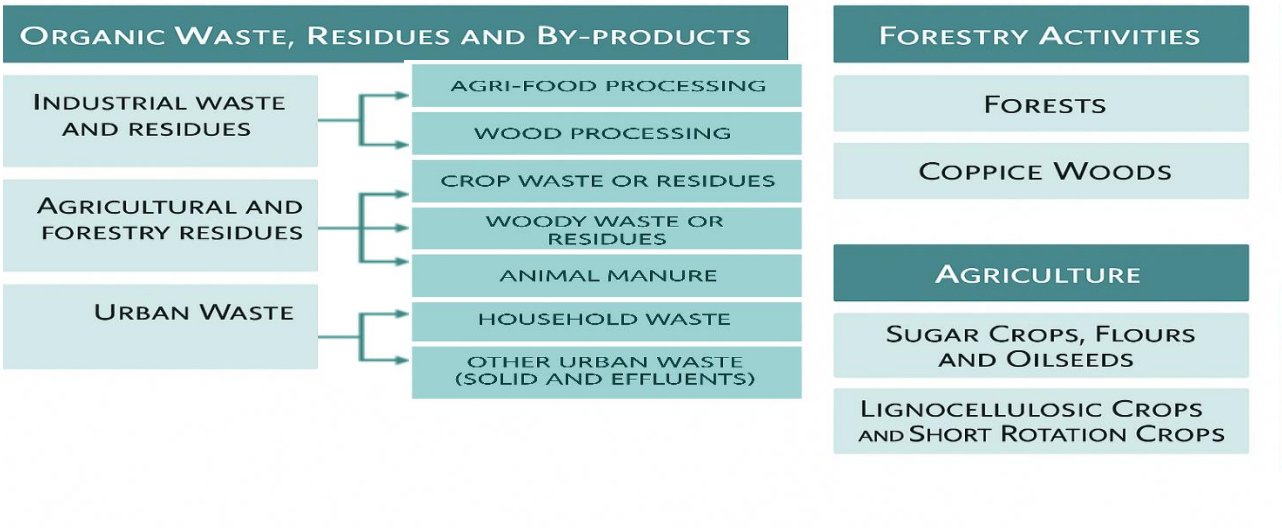
Tab 4.1 – Feedstock, processes, products and uses



Sources: Elaboration by Divulga based on IEA-International Energy Agency sources (ieabioenergy.com)

Within this context, it should be noted that a wide range of conversion technologies is continuously developing and offers prospects for improving efficiency, reducing costs and improving environmental performance. In order to have a complete overview of the bioenergy sector, in this chapter we will use an approach that starts with the classification of the sources – so as to consider the potential of bioenergy compared to the other forms of energy – and then goes on to consider uses and consumption with the aim of quantifying the practical contribution that these sources of energy have in our lives and in our activities. Bioenergy sources can be of various origin (mainly agricultural and urban), yet the predominant part refers to the agricultural sector. This aspect is certainly also relevant for energy production through the reuse of animal waste and the exploitation of waste biomass.

Tab. 4.2 – Waste biomass



Sources: Elaboration by Divulga based on IEA-International Energy Agency sources

Bioenergy sources can also be classified in terms of the transformation processes of the raw material used:

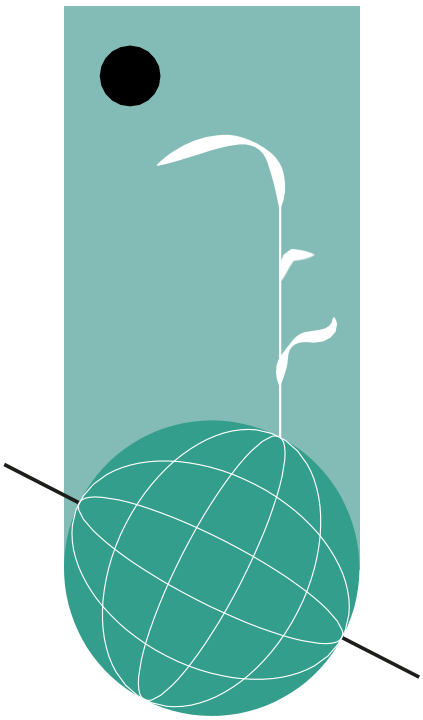
- solid biomass: agricultural parts, forestry and solid urban waste parts;
- bioliquids: crude vegetable oils and other liquids (waste water);
- biogas: from animal manure, from organic and sludge waste.

Biogas in particular is an energy product derived from anaerobic digestion or fermentation processes that can be used directly to produce energy (electrical or thermal) or refined to obtain biomethane, an energy carrier that also falls within the growing sector of biofuels or biofuels for transport, which can be in either liquid form (biodiesel, bioethanol, etc.) or gaseous form (biomethane). Consequently, the most important bioenergy "supply chains" – seen from the point of view of uses – are represented by the production of:

- heat from solid biomass (civil and industrial uses);
- electricity from solid biomass, biogas and bioliquids;
- liquid biofuels (biodiesel, hydrotreated vegetable oil / HVO, ETBE methanol) from dedicated crops;
- biomethane from fermentable biomass.

As a result, in order to define a complete overview of bioenergy at a global and national level, it is useful to organise the data in an integrated manner, referring to the sources while taking into account the uses and consumption.

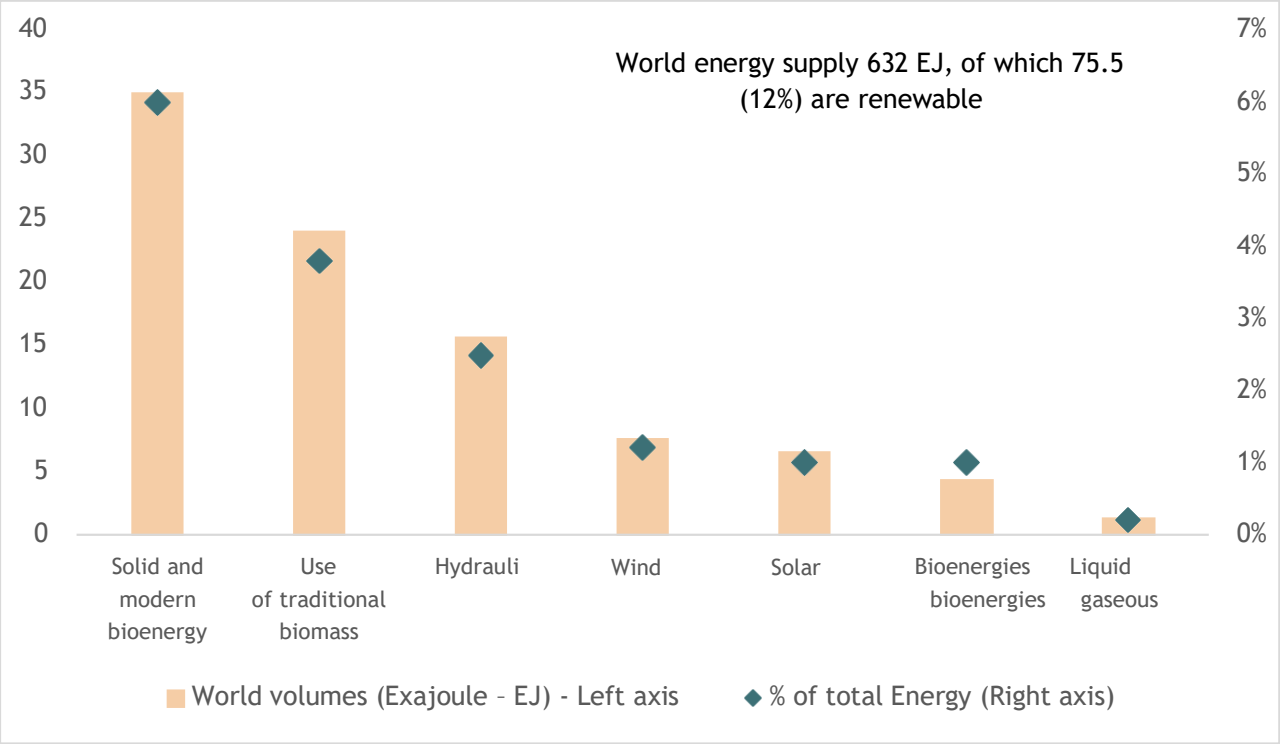
5.



5. The numbers worldwide

Worldwide, from a point of view of the energy contained in biomass – expressed in exajoules (EJ) and which for simplicity we will refer to as “volumes” – the share of bioenergy in total renewable energy is equal to 54% and amounts to over 40 exajoules (EJ), which correspond to approximately 11.1 billion megawatt hours (MWh) [8], with a 5% growth trend in 2022. We must also add to these volumes the 24 EJ (equal to approximately 6.67 billion MWh) deriving from the traditional use of biomass (for example, the combustion of forest products such as pellets, wood chips, charcoal, etc.).

Graph 5.1 – World volume of renewable energy - 2022



Sources: Elaboration by Centro Studi Divulga based on IEA data

Overall, the share of bioenergy in total energy sources is roughly 10% [9].

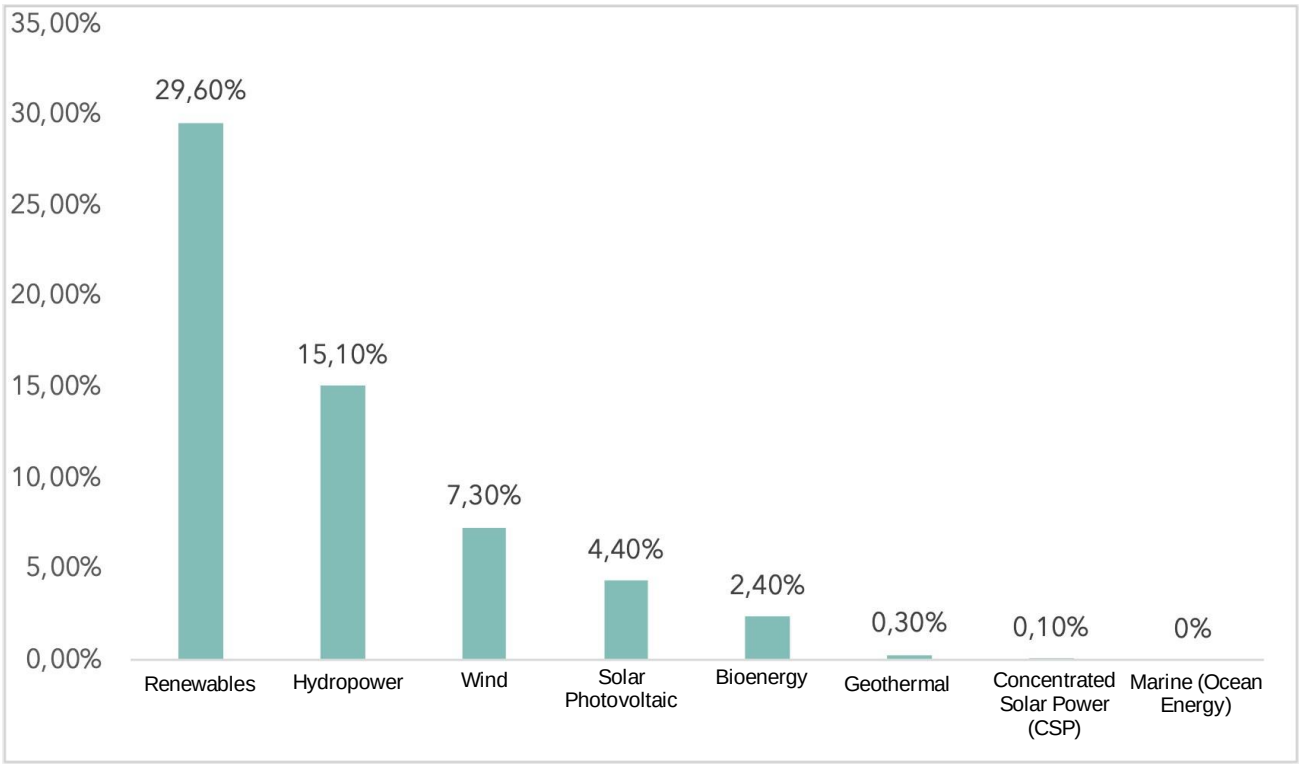
When analysing its share in energy consumption, bioenergy plays a fairly significant role worldwide. Excluding their use in energy-intensive industrial sectors, the IEA has estimated that the energy mix of so-called "light industry" (with low energy intensity) already requires14% of consumption based on bioenergy at a global level [10]. In the electricity generation sector, bioenergy accounts for 168 Gigawatts (GW) of installed power [f] for an annual world production of 687 Terawatt hours (TWh) which corresponds to approximately 8% of electricity production from renewable sources and 2.4% of the total. In a scenario without incentive policies and with constant technology, the forecasts for the coming years indicate an average annual growth rate by 2030 (Compounded Average Annual Growth Rate - CAAGR) of 4.1% for installed capacity and 5.7% for production [11].

Tab. 5.1 – Share of renewables and bioenergies in the electricity sector - 2022

	Prod. Electrical energy (Twh)	CAAGR as at 2030 (%)	Weight: %	Power installed (Gigawatt - GW)	CAAGR as at 2030 (%)	Power installed (in %)
Total electricity production	29,033	2.7	100%	8,643	6.4	100%
Renewables	8,599	8.8	29.6%	3,629	11.4	42%
Solar Photovoltaic	1,291	19.6	4.4%	1,145	19.3	13.2%
Wind	2,125	11.9	7.3%	902	10.9	10.4%
Hydraulic	4,378	1.6	15.1%	1,392	1.5	16.1%
Bioenergies	687	5.7	2.4%	168	4.1	2%
Highly-concentrated solar	16	14.4	0.1%	7	11.3	0.1%
Geothermal	101	7.1	0.3%	15	7.4	0.2%
Marine	1	24.0	0%	1	17.2	0%

Sources: Elaboration by Centro Studi Divulga based on IEA data

Graph 5.2 – Share % of renewables and bioenergies in the electricity sector - 2022



Sources: Elaboration by Centro Studi Divulga based on IEA data

With regard to fuels, considered from the point of view of world consumption, biofuels today represent only 2.5% of liquid fuel consumption, with a projected increase of 4.4% per year between now and 2030 (CAAGR) [12] and with the use of solid biomass substantially unchanged. With regard to biogas and biomethane, which represent the smallest share (0.6%) of final "bioenergy" consumption (and 6.6% in terms of overall bioenergy volumes), the estimated potential growth by 2030 would be very rapid, exceeding an average annual rate of 13%, demonstrating the growing interest in this type of product, particularly in Europe.

Tab. 5.2 – Bioenergy in global energy consumption - 2022

	World Energy Consumption (EJ)	CAAGR to 2030 (%)	Focus on Transport (EJ)	CAAGR to 2030 (%)
Electricity	89	2.5	1.5	15
Liquid Fuels	172.3	0.9	109.6	0.8
Bio-fuels	*4.3*	*4.4*	*4.1*	*4.3*
Petroleum Derivative Products	*168*	*0.8*	*105.5*	*0.6*
Gaseous fuels	71	1.2	5.3	1.1
Biogas/Biomethane	*0.25*	*13.3*	*0.09*	*9.7*
Hydrogen	*0*	*58.3*	*0*	*5.7*
Natural Gas	*70*	*1.1*	*5.2*	*0.6*
Solid fuels	93	-0.4	---	---
Bioenergy (biomass)	40	-0.6	---	---
Coke	52	-0.2	---	---
Thermal	15	1.1	---	---
Total Final Consumption	442	1.1	116	1.1

Source: Elaboration by Centro Studi Divulga based on IEA data

6.

6. Bioenergy in Italy

In Italy, bioenergies represent a significant share of renewable energy and as such plays a crucial role in easing pressures on energy supply. To get an idea of their importance, it is worth considering that a total of 48.8% of energy consumption from renewable sources (electricity, heat and biofuels) occurs thanks to the use of bioenergies [13].

Tab. 6.1 – Gross Final Consumption of energy from renewable sources in Italy - 2021

	Mtoe (millions of tonnes of oil equivalent)	Weight %
Electrical Sector	10.21	44.5%
Hydraulic	*4.17*	*18.2%*
Wind power	*1.75*	*7.6%*
Solar	*2.15*	*9.4%*
Geothermal	*0.51*	*2.2%*
Bioenergies	*1.63*	*7.1%*
Thermal Sector	11.18	48.8%
Geothermal	*0.14*	*0.6%*
Solar (thermal)	*0.25*	*1.1%*
Bioenergies	*8.01*	*24.9%*
Energy	*2.78*	*12.1%*
Transport Sector (biofuels)	1.55	6.8%
TOTAL	22.93	100%

Sources: Elaboration by Centro Studi Divulga based on GSE/Terna data

With regard to the electricity sector in 2021, the gross production of energy from renewable sources, equal to 116.3 million MWh, was 40.2% of the total production, with bioenergies that accounted for 16.4% (19.1 million MWh). 41.4% of the plants are fuelled by solid biomass, 35.4% with biogas and the remaining 23.2% with bioliquids [g].

Tab. 6.2 – Electricity production and power of plants fuelled by renewable sources - 2021

	Production (millions of megawatts per hour)	Weight %	Power installed (megawatts)	Weight %
Renewables	116.3	100%	57,979	100%
Hydraulic	45.4	39%	19,172	33.1%
Wind power	20.9	18%	11,290	19.5%
Solar	25.0	21.5%	22,594	39%
Geothermal	5.9	5.1%	817	1.4%
Bioenergies	19.1	16.4%	4,106	7.1%
Solid Biomass (*)	*6.8*	*5.8%*	*1,700*	*2.9%*
Biogas	*8.1*	*7.0%*	*1,455*	*2.5%*
Bioliquids	*4.1*	*3.5%*	*951*	*1.6%*
% Renewables of total	40.2%	---	---	---

(*) Includes the biodegradable part of municipal solid waste.

Source: Elaboration by Centro Studi Divulga based on GSE/Terna data

At the end of 2021, there were approximately 3,000 bioenergy-powered electricity generation plants, an increase of 1.4% compared to the previous year (+41 plants), with an installed capacity of 4,106 MW (equal to 7.1% of the total renewable energy capacity). 46.6% (8,890 MWh) of the energy produced by bioenergy is generated by plants with a capacity greater than 10 MW, 40.8% by those with a capacity less than 1 MW, and the remaining 12.6% by plants belonging to the intermediate class (1–10 MW).

Tab. 6.3 – Plants powered by bioenergy - 2021

Power classes	Number of plants	Installed power (in %)	Power generation (thousands of MWh)
≤ 1 MW	2,639	32.7%	7,778
1 MW - 10 MW	289	19.6%	2,402
> 10 MW	66	47.7%	8,890
Total	2,985	100%	19,071

Source: Elaboration by Centro Studi Divulga based on GSE/Terna data

With regard to national distribution, both the number of bioenergy-powered plants (73.5% of the national total) and the percentage of installed capacity (62.7%) are concentrated in the regions of Northern Italy. Lombardy, in particular, is the region with the highest figure (roughly 946 MW), followed by Emilia Romagna (648 MW): taken together, the two regions account for 38.8% of the total national data. In Central Italy, the most relevant capacity figure is found in Lazio (169 MW), whereas in the South, Puglia and Campania account for (332 MW and 239 MW) respectively.

Tab. 6.4 – Plants powered by bioenergy throughout the Regions - 2021

	Number	Power (megawatts)	Weight % (installed power)	Production (thousands of MWh)
Lombardy	773	945.5	23%	4,231.4
Emilia Romagna	340	647.6	16%	2,960.3
Veneto	401	372.4	9%	2,011.4
Piedmont	330	346.6	8%	1,861.5
Puglia	75	332.4	8%	1,450.9
Campania	97	239	6%	1,135.0
Calabria	47	200.8	5%	1,343.6
Lazio	118	168.5	4%	635.9
Tuscany	143	161.5	4%	518.3
Friuli Venezia Giulia	138	140.5	3%	836.3
Sardinia	41	112.5	3%	561.6
Trentino Alto Adige	194	95.3	2%	352.2
Basilicata	34	82.6	2%	255.1
Sicily	44	74.1	2%	244.6
Umbria	77	48.5	1%	216.4
Molise	11	46.1	1%	160.8
Marche	69	36	1%	143.3
Abruzzo	34	30.7	1%	114.5
Liguria	11	22.5	1%	26.6
Valle d'Aosta	8	3.1	0%	10.7
ITALY	2,985	4,106	100%	19,070.8

Source: Elaboration by Centro Studi Divulga based on GSE/Terna data

With regard to the thermal sector, on the other hand, roughly one-fifth (19.7%) of consumption comes from renewable energy sources (equal to 10,896 Ktoe - tonnes of oil equivalent) with bioenergy accounting for approximately 73.5% [h]. The most widely used is solid biomass (6,777 Ktoe of direct consumption and 384 Ktoe derivatives from cogeneration or district heating systems) while only a small portion of the demand is covered by the biodegradable organic part (482 Ktoe) and biogas (326 Ktoe).

Tab. 6.5 – Thermal Sector – Energy from renewable sources - 2021

	Ktoe	Direct consumption	Gross production of derived heat
Geothermal	141	115	26
Solar	247	247	0
Bioenergy	8,010	7,171	839
Biodegradable part of waste	*482*	*359*	*123*
Solid Biomass	*7,161*	*6,777*	*384*
Bioliquids	*41*	---	*41*
Biogas	*326*	*35*	*291*
Ambient energy (*)	2,498	2,498	---
Cooling for EU target purposes on RES (Renewable Energy Sources)	*283*	*283*	---
Actual total	10,896	10,031	865
Total for EU target (RED directives)	11,176	10,314	861

(*) Cooling, heating and DHW (Domestic Hot Water) - heat pumps

Source: Elaboration by Centro Studi Divulga based on GSE/Terna data

In the biofuels sector (biodiesel, biogasoline, biomethane), in 2021, release for consumption was over 1.7 million tonnes, corresponding to 1,552 Ktoe, an increase of 15.2% compared to 2020 (+14.5% in physical terms). In this sector biomethane (136 Ktoe equal to 116.8 thousand tonnes of product placed on the market) has seen a growth of over 66% over the previous year, although it represents only 8.8% of the total energy and 6.8% in volume.

Tab. 6.6 – Biofuels released for consumption - 2021

	Quantity (tonnes)	Energy (ktoe)	Var. % 2021/2020
Biodiesel (*)	1,571,059	1,388.4	11.5%
Biomethane	116,792	136.5	66.5%
Bio-ETBE (**)	31,449	27.0	35.2%
Bioethanol	74.77	0.0	382.2%
Total	1,719,374	1,552.0	15.2%

(*) Including hydrotreated vegetable oil and Fischer-Tropsch Diesel
(**) 37% of the ETBE fuel is considered renewable: an organic compound derived from ethyl and isobutyl alcohol, which can be integrated into petrol.

Source: Elaboration by Centro Studi Divulga based on GSE/Terna data

7.

7. Bioenergy from agricultural sources

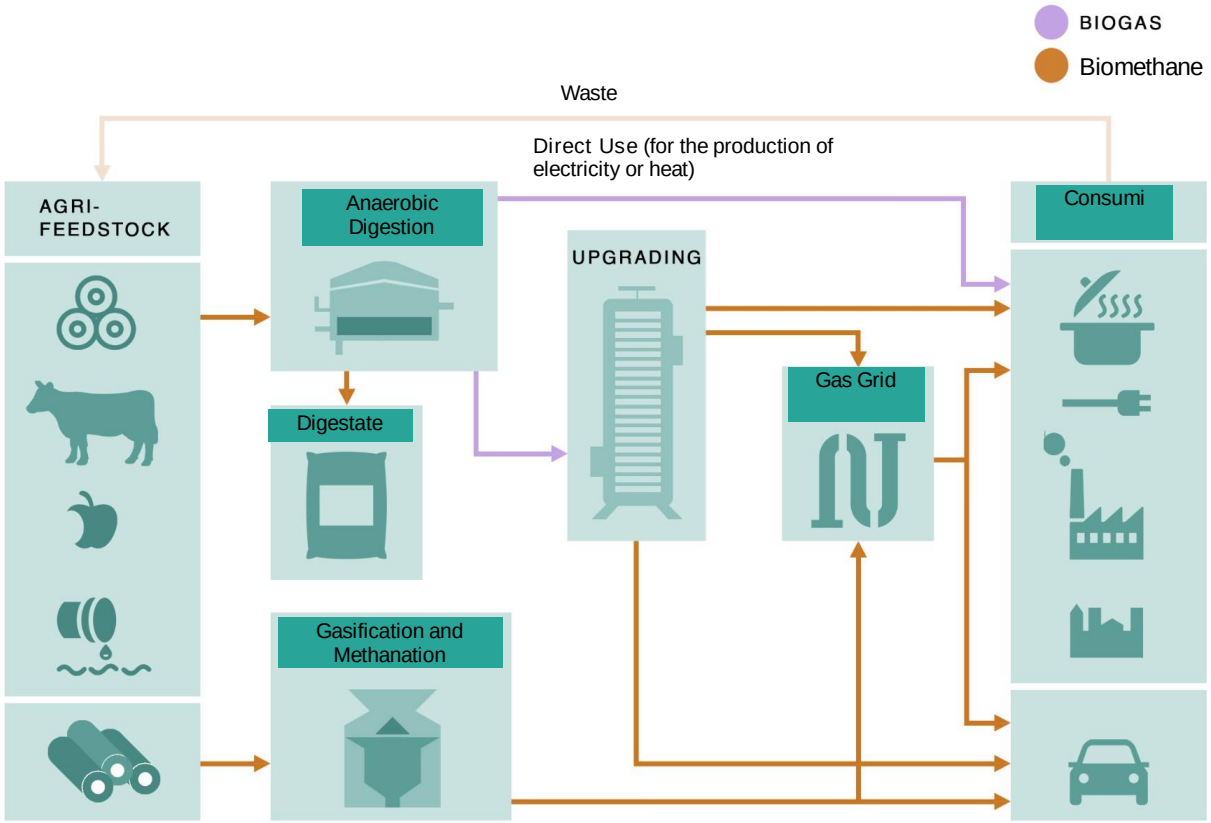
7.1 Waste that becomes value

The main source of biomass for the production of renewable energy is the agricultural (including livestock) and forestry sectors. In particular, the bioenergy sources from the agricultural and forestry sector are animal manure and plant biomass derived from dedicated crops (agricultural and forestry) and residues. Undoubtedly, the most interesting feedstock for the agricultural sector [i] is animal manure, which, through anaerobic digestion [j], is decomposed and transformed into biogas (a mixture of methane and carbon dioxide), which is one of the main Italian bioenergy supply chains.

The biogas produced (both raw and refined) can be used for:

- direct combustion in a boiler (production of thermal energy);
- cogeneration (combined thermal and electrical energy production);
- production of biomethane for placing into the grid or for transport through the elimination of carbon dioxide.

Fig. 7.1.1 – Biogas and Biomethane production pathways

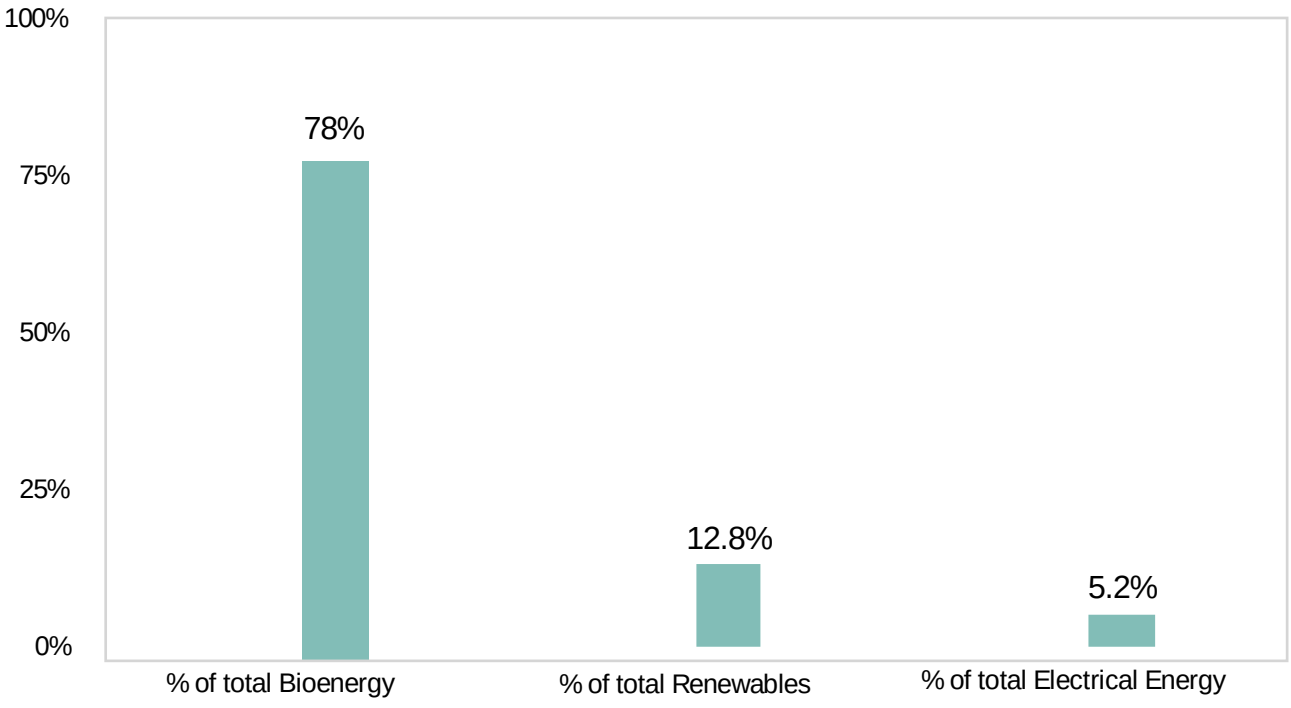


Source: Elaboration by Centro Studi Divulga based on IEA sources

7.2 The key numbers

The productive potential of the agri-livestock sector accounts for just under half (roughly 45% of the installed power) of the total bioenergy, however only 3.2% of the general power of the electricity-generating plants from renewable energy sources. If biomass (forest products) were also to be taken into consideration, the relative weight would rise to 64% of installed power of the total bioenergy and 4.5% of renewables. In terms of electricity production, the contribution of the primary sector, including the traditional use of biomass, represents 5.2% of the Italian total and circa 13% of electricity production from renewable sources.

Graph 7.2.1 - Impact of agricultural bioenergy in Italy on electricity production - 2021



Source: Elaboration by Centro Studi Divulga based on GSE/Terna data

Out of a total of roughly 3,000 plants for the production of electricity installed in Italy and powered by bioenergy, it is estimated that as much as 72% can be directly or indirectly linked to the agricultural sector. In particular, with regard to the production of biogas, there are 688 plants that reuse animal manure and 1,105 are powered by digestate from agro-forestry activities.

Tab. 7.2.1 – Electricity production plants powered by Bioenergy - 2021

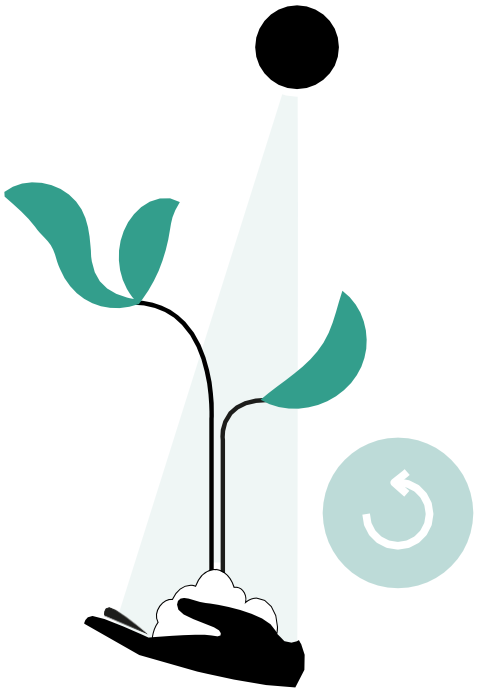
	Number	Power (MW)	Production (thousands of MWh)
BIOMASS (solid)	454	1,699.6	6,837.8
Biodegradable urban part (MSW)	*60*	*919.7*	*2,308.3*
Other biomass	*394*	*779.9*	*4,529.5*
BIOGAS	2,261	1455.1	8,124.2
Waste	*386*	*382.9*	*1,058.6*
Sludge	*82*	*46.7*	*124.0*
Animal manure	*688*	*249.4*	*1,296.9*
Agro-forestry activities	*1,105*	*776.1*	*5,644.6*
BIOLIQUIDS	454	951.4	4,108.8
Crude vegetable oils	*358*	*812.3*	*3,469.4*
Others	*96*	*139.1*	*639.4*
Total BIOENERGY	2,985	4,106	19,070.8

Source: Elaboration by Centro Studi Divulga based on GSE/Terna data

7.3 EU records

In 2022, Europe was the largest producer of biogas, with 19,000 plants located mainly in Germany, Italy, France and the United Kingdom. Italy, with its 2,200 operating plants – of which just over 1,730 produce agricultural biogas (78%), i.e. biogas resulting from the codigestion of livestock effluents with agricultural waste (agricultural and agro-industrial residues, energy crops) – ranks second in Europe and fourth worldwide after Germany, China and the United States [14]. Moreover, the product exiting the fermenters is still rich in organic material and nutrients and can be used as a fertiliser. In fact, from a composition viewpoint, the remaining organic substance is more stable, as is the content of macro and microelements; for example nitrogen, which changes from its organic form to ammoniacal form, is more easily assimilated by plants [k].

8.



8. The role of bioenergy in the circular economy

The Kyoto Protocol – which was adopted in 1997 and entered into force in 2005 – constitutes the first multilateral agreement towards the creation of more concrete instruments for reducing greenhouse gas emissions into the atmosphere [15], thanks to appropriate measures and policies such as the production of electricity from renewable sources, the issuing of standards for the thermal insulation of homes, and the promotion of public transport, to name just a few. Starting with the Kyoto Protocol, followed in 2015 by the Paris Protocol, the energy issue has become part of a broader framework within the 2030 Agenda (adopted in September 2015), through the complex system of sustainable development. In order to achieve these objectives, the legislative package, dubbed "Clean Energy for All Europeans," was approved at European level between the end of 2018 and the beginning of 2019. Within this regulatory framework is Directive (EU) 2018/2001/EU [6], better known as RED II, which establishes a common framework for the promotion of energy from renewable sources in the EU: it sets a binding share of 32% of total energy produced from renewable sources in the European Union's gross final consumption. In achieving these goals, the EU's proposals include the concept of a circular economy, which intensifies the sustainable approach on issues relating to the use of common energy resources, the containment of global warming, and the management of overall energy sources. The circular economy paradigm is based on 5 pillars, which can exist either

individually or in combination with each other and which concern: sustainable resources, the product as a service, sharing platforms, the extension of a product's useful life, and the new life cycles of primary and waste products. This type of economy is therefore based on basic concepts such as recycling, reuse, the regeneration of products and materials, as well as the promotion and creation of long-lasting products [16]. It is a production and consumption model that involves sharing, repairing, refurbishing, reusing and recycling existing materials and products. In this way, the life cycle of products is extended [17], thus helping to reduce waste to a minimum while transforming some materials from "waste" into "resources" [18].

On this basis, the European Union has recognised the adoption of this model as a strategic priority for member countries and as an opportunity for growth and development in terms of competitiveness, innovation, the environment and employment [19]. It is within this context that renewable energies become a key component for the production of circular products and resources, including the way in which plants for the transformation of energy are designed, manufactured, built and managed and how their possible conversion with respect to the use of conventional sources is addressed.

Today, talking of circular economy – linked to renewable resources and the energy transition – means touching on a focal point of the international debate on environmental and social development, for which it is crucial to protect the environment without limiting economic evolution, also from the perspective of protecting territories and communities. Therefore, renewable energies – and in particular bioenergy – within the circular economy can play a crucial role with multiple positive effects, in promoting the growth of virtuous models in support of communities, territories and fair and sustainable production chains. Bioenergy is capable of reconciling economic development with environmental safeguarding while increasing employment. Furthermore, it enables to comprehensively address the interconnected challenges of natural resource scarcity, food security, dependence on fossil fuels and climate change, while achieving sustainable economic growth.

9.

9. Agriculture, bioenergy and the circular economy

The importance of combining efficient use of resources with environmental protection is evident today, both at the European and global levels. Thanks, in part, to technological innovations, agriculture is now increasingly engaged in a radical transition towards a circular, solid and resilient system based on production processes that improve the sustainability of agricultural activity.

As a result, even agriculture, within the circular economy, becomes a system in which waste is reused and regenerated, thus becoming resources. The goal is not only to reduce waste but to create added value for the entire supply chain [20]. In the transition process, the conversion to a "no-waste-economy" is becoming essential, one that feeds on what it produces, with not only environmental but also economic and social benefits. Over the last century, it is estimated that a total of 60% of the original organic matter has been lost, with 52% of the soils in a state of degradation [21]. This phenomenon, in addition to reducing the fertility of agricultural soils, has contributed to the increase in greenhouse gases in the atmosphere.

Within this perspective of virtuous recycling, the full recovery of waste – industrial, agri-food or urban – used in the production of biofuels for the decarbonization of transport through the conversion of refineries is increasingly gaining ground[22]. Among these innovative pathways, aimed at reducing the risk of further soil degradation processes and at the same time supporting the

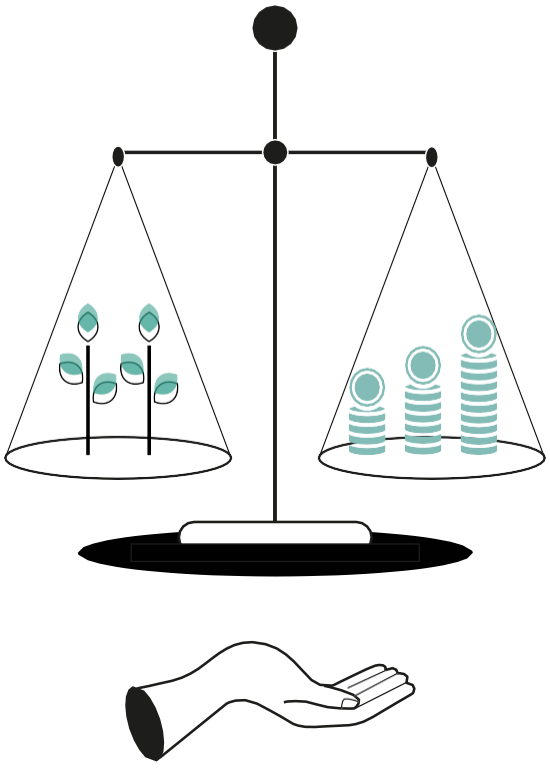
production of green energy, the European Union has launched initiatives on the use of land that is unsuitable for food production (exhausted quarries and open pit mines, landfills or abandoned industrial sites), for the production of biomass for energy use, representing a "win-win" solution. Among the most important experiences at an international level is the European Life Ecoremed project [23], which identified the common reed (Arundo donax) as the species most adaptable to levels of physical soil degradation and capable of producing large quantities of lignocellulosic biomass even in conditions of very low fertility. Castor oil has also been found to be very resistant to environmental stresses and is capable of producing interesting quantities of oil that can be used for green chemistry or for the production of biodiesel [24], on soils that are not useful for food production. Cover crops should also be included in this context, mainly used to manage the erosion and fertility of soil, water quality, and weeds. Indeed, virtuous management of cover crops on farms could provide a source of biomass for the production of bioenergy [25] (for example, biofuels and biodiesel). In Italy alone, it is estimated that by exploiting areas unsuitable for food production, such as landfills or abandoned industrial sites, up to 3% of Italy's energy needs could be obtained [26].

However, in the complex context of waste reuse in agriculture, the development and application of the use of livestock waste in biodigesters through anaerobic digestion has been crucial over the past ten years. Anaerobic digestion is a biological process in which, in the absence of oxygen, the organic substance is transformed into biogas. In order for biomass to become biogas, the action of various types of specialised microorganisms is necessary. A first group of bacteria starts the degradation process, transforming the organic substance into intermediate compounds, such as hydrogen, acetic acid and carbon dioxide. A second group of bacteria, formed by methanogenic microorganisms, completes the process by producing methane [27]. Widespread in many European countries, including Italy, anaerobic digestion aims to transform the waste produced by livestock farms into biogas, thus enabling the recovery and enhancement of animal manure. Biogas production therefore represents a virtuous model of circular economy that produces a form of renewable energy (biogas) and ends with the ‘return‘ to the soil of the organic substance (digestate[l]) not transformed into methane or CO_2. The use of digestate for agronomic purposes, authorised and

regulated in Italy as well [m], allows for the enhancement of the soil improving and fertilizing properties, which are made better compared to those of manure or other organic residues used as such. All this translates into a net saving of synthetic chemicals and a reduction in greenhouse gas emissions related to their production, transport and use.

In terms of environmental sustainability, it is a technology that does not pose a risk to the land or the health of its inhabitants, given that emissions are negligible and in any case lower than those that would occur from distributing or leaving manure or other organic residues on the fields [28]. What strongly emerges from all this is that farms, thanks to special and regulated systems for the reuse of animal slurry, have the opportunity to complement the consolidated feed and food market with the market for low-impact energy production. Through this virtuous mechanism, therefore, in addition to the obvious economic repercussions, there is also a positive environmental impact on which the agricultural and livestock sector is placing ever-increasing attention.

10.



10. Growth and sustainability: constraints and opportunities

One of the historical constraints of the contemporary economic system can be identified in the need to create value, or rather to grow. Added to this, with overwhelming urgency in recent years, is the need to do so in a sustainable manner, thanks to strategies and tools that allow us to rapidly advance on this path. Looking back over the last few months, we can cite some messages of primary importance that have highlighted all this, starting with that of Pope Francis who reminded us of the scarcity of time still available to improve the health of the Planet and correct those development models that lead to the destruction of nature and humanity (Apostolic Exhortation "Laudate Deum" - October 4, 2023). The UN Summit in New York too, dedicated in September 2023 to the sustainable development objectives, provided an alarming assessment of achievements with respect to the ambitious, but necessary, challenges set out in the 2030 Agenda. The New York Summit took place only five days after the worrying alarm launched by scientists from the Stockholm Resilience Centre, who released the updated results of the mapping of the nine parameters assessed as essential for the Planet's survival, i.e. the measurements reached by certain specific variables with respect to the "sentinel" thresholds of planetary risk. Six critical points were highlighted for crossing the alarming risk threshold: climate, biosphere, soil, freshwater, biogeochemical cycles, and the level of degradation-pollution of certain chemical substances.

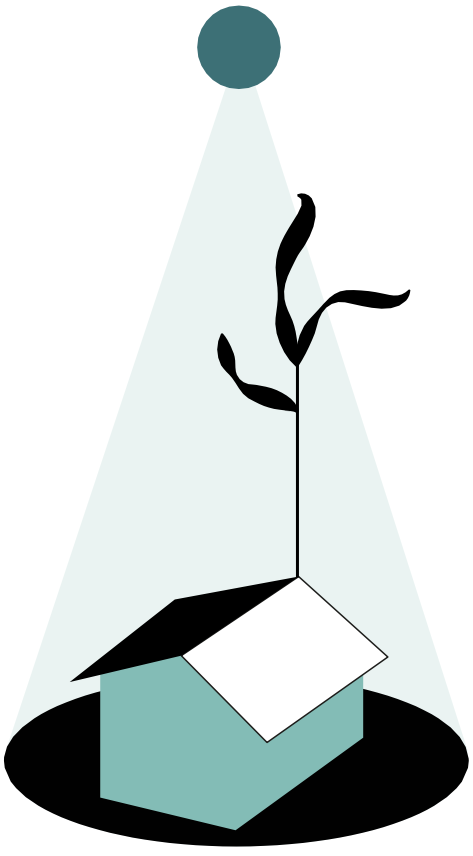
Exceeding these parameters alters the Earth's equilibrium and reduces the overall level of security. Today, the issue concerns the possibility of recovery, or rather the existence of a possible process for recovering the damage, and the time available for this clean-up/rescue operation with respect to the "no return" period. In essence, the direction indicated by the 2030 Agenda has been reaffirmed, while highlighting the importance of the time-frame for the process: with the objective unchanged, the time factor is becoming increasingly important. On the other hand, the 2030 Agenda is already eight years old and perhaps there is no need to remind people of the burden of this period. A financial crisis, a global pandemic, the crisis of globalization, from multilateralism to multi-regionalism, a war within Europe, intersections of trade wars and other wars that are historically difficult to resolve diplomatically, with the obvious reference to the events between Israel and the Palestinians in the Gaza Strip. Concern regarding climate change is therefore globally recognized, with the ever-increasing concentration of CO_2 in the atmosphere, having a clear impact on global warming. In order to avoid catastrophic consequences, the goal has been set of reducing net greenhouse gas emissions by 55% by 2030, as well as achieving their zero emissions by 2050. This objective obviously implies the need to redesign the way in which we consume, produce and live as a whole, given that emissions derive from the energy sources used. The choice of sources used to produce energy therefore becomes essential and can also reveal opportunities. It has long been known that the wisest and healthiest choice is to use renewable sources: to protect human health (the air we breathe); for the climate (reduction of emissions); for the costs to be incurred (they are certainly less onerous than fossil sources, especially considering the burdens of derived externalities); for intergenerational equity (resources and environmental balance). With respect to these objectives, however, the Russian invasion of Ukraine, and the resulting ongoing conflict, has induced additional considerations aimed at other urgent goals:

a) safeguarding economies from price volatility of fossil energy sources (oil and gas) which in fact can subject entire countries to the severe consequences of inflation, imbalances, and financial speculation typically associated with them;

b) seek energy independence (especially from autocracies and dictatorships) or at least minimise the risks of dependence through an intelligent assessment of the energy production mix to be achieved and the origins and sources of any necessary supplies of energy

products. In summary, it can be said that in the last fifteen years the foundations of a new path have been laid which, if carefully evaluated, even in national and internal contexts within companies and businesses, given the well-known constraints, can give rise to interesting opportunities, especially from a global perspective.

11.



1 1 . Energy transition and green path

The green path is developing along project trajectories that affect the "sustainability" of all key sectors of the economy, including, of course, the agri-food sector, which has gradually taken on an extreme and central importance. However, the most significant weight in the debate on emissions control is, as is obvious, not only the transportation sector, but also other highly emitting activities, such as the energy and other energy-intensive industries. A more specific and less ‘one-way’ focus, however, is on the agricultural sector, precisely because of the essential and specific role it plays in protecting the soil and ecological balance. On the other hand, it is precisely the agricultural sector that is bearing the most immediate and severe impacts of climate change, given the sudden and extreme adversities that we have been experiencing in recent years (drought, heat stress, water bombs and floods, etc.), with risks that have an impact on food security, on the supply of food and its quality, on the level of prices and therefore on consumption capacity. It should also be noted that our agricultural production has long been moving along the path of ecological transition: the use of water resources has certainly improved in terms of efficiency, as has the use of pesticides, herbicides, and fertilizers (all of which in turn contribute to global emissions). In essence, European agriculture, and Italian agriculture in particular, is already playing a primary role in protecting the soil by maintaining and improving its ability to

to absorb carbon. A general effort is already under way to protect the value of the land and to orient crops toward food production processes consistent with the climate challenge we are experiencing.

Many of these programmatic and intervention lines have been "governed" by strategic guidelines, while others, which more directly regard the "circular" efficiency of the entire supply chain, need to be implemented more decisively to accelerate the process. In this sense, we might consider the diffusion of biorefineries and green chemistry. It is necessary to accelerate the expansion of bioenergy, while naturally avoiding incentives for renewables that reduce the amount of land available for food production. Biomass is, for example, an extremely versatile source of bioenergy. Its uses, as seen in the previous pages, are in fact numerous: the production of biofuels (substitutes for diesel, petrol or methane); the use of waste that becomes raw material for certain intermediate chemical products; and the direct production of electrical or thermal energy. All the objectives set by various green projects, starting with the most general ones such as the UN 2030 Agenda, push to adopt development strategies aimed at the use of agricultural waste to encourage the introduction of new biodegradable and compostable materials, which will cover at least a third of plastics and chemicals (non-bio-based) over the next decade. The other fundamental destination is the production of biogas. As already mentioned, our country is well-positioned in this area, ranking fourth in the world and second in Europe, but in essence we're still seeing relatively modest absolute volumes (even though Italy already potentially has plants with five times the capacity, indicating strong development potential). The agricultural sector can therefore play an important role in the race to replace fossil fuels. The decarbonization process, therefore, requires the development of circular agriculture, the growth of bioenergy, and its integration with other renewables. A synergistic path that can no longer be postponed.

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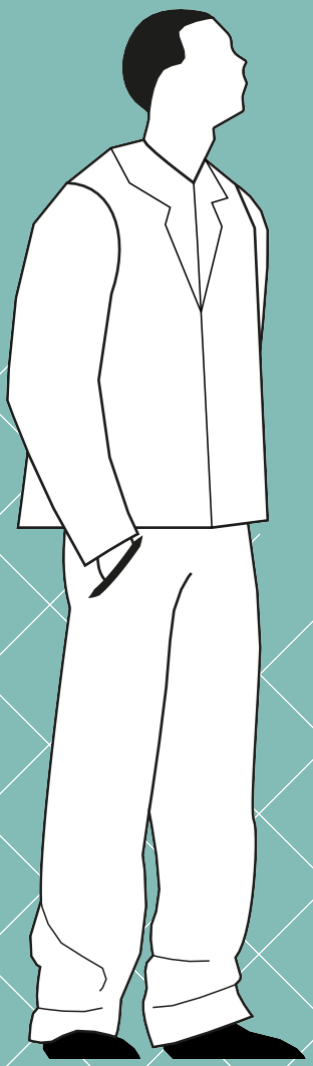


Notes

a. Wind power plants installed in flat areas far from the sea.
b. Wind power plants built in offshore areas in the oceans.
c. Crop rotation involves alternating crops on a plot of land, so as not to grow the same plant on the same plot for too long. This generally takes place on a two-year, three-year or four-year rotation basis, but can also be carried out seasonally depending on needs.
d. The 2003/30/EC Directive was then largely superseded by the subsequent 2009/30/EC Directive "amending Directive 98/70/EC as regards to the specifications for petrol, diesel fuel and gas oil while introducing a mechanism to monitor and reduce greenhouse gas emissions, amending Council Directive 1999/32/EC as regards to the specifications for fuel used for inland navigation, repealing Directive 93/12/EEC". This directive, in addition to introducing significant changes in the environmental specifications of petrol and diesel fuels, defines the sustainability criteria of the fuels used to achieve the greenhouse gas reduction targets. The directive was then implemented with Legislative Decree 55/2011 containing "Implementation of directive 2009/30/EC, which amends directive 98/70/EC, with regard to the specifications relating to petrol, diesel fuel and diesel oil, as well as the introduction of a mechanism to monitor and reduce greenhouse gas emissions, amending Directive 1999/32/ EC as regards to the specifications relating to the fuel used by inland waterway vessels, repealing Directive 93/12/EEC".
e. The 'Ready for 55%' package is a set of proposals aimed at reviewing and updating EU regulations

and implementing new initiatives in order to ensure that EU policies are in line with the climate objectives agreed by the Council and the European Parliament.

f. 4.6% of all renewables and 1.9% of total capacity. Installed capacity, not the number of plants, was taken into consideration.

g. Installed capacity, not the number of plants, was taken into consideration.

h. For the purposes of monitoring European targets for RES (Renewable Energy Sources), energy is calculated by applying a specific accounting procedure to normalize actual data. The weight was calculated on the actual consumption.

i. Other feedstocks of agricultural interest also include crops specifically for the production of bioliquids and which can be sustainably applied on fallow/rotational land or on exhausted soils unsuitable for food production.

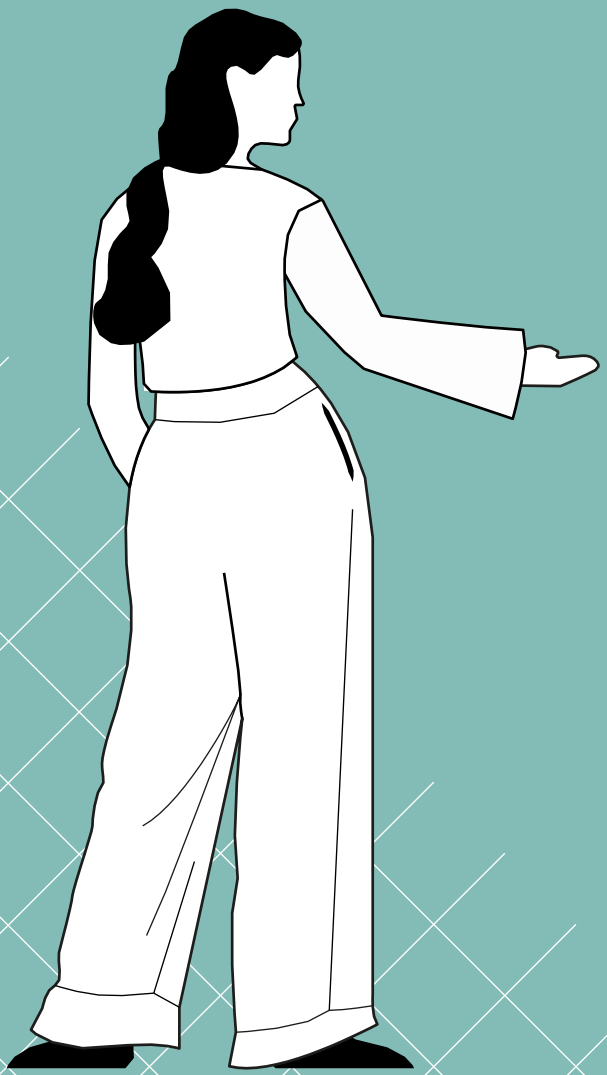
j. The process also makes it possible to enhance other agricultural waste, such as crop residues and residues from the food industry.

k. The composition and conditions of use of the digestate produced by the various agricultural and agro-industrial fermentation substrates are essential for its use in agriculture.

l. Digestate is the residue of the anaerobic digestion process; it can derive from the digestion of livestock effluents, plant biomass, animal and agro-industrial by-products.

m. Regulated by the Decree of the Ministry of Agricultural, Food and Forestry Policies of 25 February 2016: general technical criteria and standards for regional regulations on the agronomic use of livestock effluents and waste-water, as well as for the production and agricultural use of digestate. (16A02762) (GU General Series
no. 90 of 18-04-2016 -
Ordinary Suppl. No. 9)

b.



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