THE STATE OF RENEWABLE ENERGIES IN EUROPE

EDITION 2024

23rd EurObserv'ER Report

This barometer was prepared by the EurObserv'ER consortium, which groups together Observ'ER (FR), TNO (NL), Renewables Academy (RENAC) AG (DE), Fraunhofer ISI (DE), VITO (Flemish Institute for Technological Research) (BE) and Statistics Netherlands (NL).

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TOO FAR IN TO TURN BACK

Vincent Jacques le Seigneur, president of Observ'ER

Just a single figure is what it takes to realize how Europe's energy landscape has been transfigured. In the first half of 2024, renewable energies generated 50% of the EU's electricity. A quick glance in the rearview mirror will show you the extent of this transition, for in 2010, less than fifteen years ago, the renewable electricity output of the EU-27 was "only" 21%.

This achievement vindicates the Commission's introduction to its now traditional "State of the Energy Union" report, published last September with this epigraph: "A stronger, greener, and more secure Energy Union, putting Europe on the path to climate neutrality, energy independence, and a competitive and sustainable European economy".

The Member States' assessments clearly demonstrate that this is no pious vow. More to the point, this is a path they have fully embraced even though there are still a few delays as evidenced by gaps in the ten-year National Energy Climate Plans (NECPs) submitted to Brussels starting in 2021. Now other indicators show the incredible progress made by the various renewable energy sources, such as wind power, which for the first time overtook gas-fired electricity production in Europe in 2023 and so became the No. 2 source of electricity behind nuclear. Photovoltaic, whose electricity output outstripped that of coal, commissioned 56 GW of new installations in 2023, after the previous year's new high of 40 GW. Last but not least, the renewably sourced share of heat and cooling consumption in 2023 was 26.2%.

All in all, about a quarter (24.6%) of the European Union's final energy consumption was renewable in 2023.

The momentum could have been broken by the global economy upheavals in the wake of the COVID pandemic and the energy crisis triggered by Russia's aggression in Ukraine. Nothing of the sort happened and Europe proved how resilient it is. The Green Deal (2019), Fit for 55 Plans (2021) then REPowerEU (2022) through to the NetZero Industry Act (2024) are so many milestones that mark how steadfast European energy policies are despite occasional disagreements in one area, energy, that whether we like it or not, are a matter of Member State sovereignty.

Of course, the building of the "European Energy Community", as called for by Jacques Delors, must progress along this tightrope. Let's hope that the new incumbents at the helm of certain Member States do not jeopardize this profound and much-needed transformation. The bases of Europe's energy transition, which is unique in the world and must remain exemplary, must not be undermined by the discussions surrounding the "Competitiveness Compass" action plan for affordable energy recently presented by President Ursula von der Leyen. *"If there is one project today which carries a positive vision for Europe, it is definitely the energy transition"*, wrote the former Commission president in 2017. May his words still be heeded. ■

1. Preface to Report 114 of the Jacques Delors Institute, 2017

23RD EUROBSERV'ER REPORT MAIN HIGHLIGHTS

Energy indicators

- The renewable share of gross electricity consumption reached 45.3% in 2023. According to the specifications of Directive (EU) 2018/2001, 1 230.1 TWh of renewable electricity was produced in 2023, with wind power being the largest source (473.6 TWh , i.e., 38.5% of total renewable electricity production). This was followed by hydropower (346.4 TWh) and photovoltaics (252.1 TWh), while biomass ranked fourth with 151.2 TWh .
- 92% of all new electricity capacity connected in 2023 came from renewable sources (69.3 GW out of a total of 75.1 GW). The remaining 8% came from gas, nuclear, coal and other fossils fuels.
- In 2023, the renewable share of heat and cooling consumption was 26.2%. According to the specifications of Directive (EU) 2018/2001, 110.8 Mtoe was produced, 69.9% of which came from solid biofuels (77.4 Mtoe) in a context of prevailing low heating requirements and higher biomass fuel prices. Heat pumps ranked second with 19.8 Mtoe.
- Renewable energies covered 24.6% of gross final energy consumption in the EU-27 in 2023. The pace must greatly accelerate to reach the new 42.5% target set by RED III by the end of 2030.

Socio-economic indicators

- The total direct and indirect employment from the renewable sectors is estimated at 1.86 million full-time equivalents by 2023. This figure is 14% higher than in 2022. The leading sector was photovoltaics with 560 300 full-time equivalents.
- The economic activity related to renewable energies in 2023 is estimated at €232.6 billion (+ 13% compared to 2022). In terms of jobs, photovoltaics is the sector that has generated the highest turnover with €66.3 billion.

Investment indicators

- In 2023, EU MS invested $360 billion in energy transition. The top EU investing countries were Germany, France, Spain, and Italy, mainly investing in electrified transport and renewables.
- In the wind energy sector, investments in wind onshore and offshore projects have slowly recovered in the EU, bouncing back to €39 billion in 2023, associated with capacity added of 18 GW .
- Within the EU, the distribution of EU PV investments varies considerably, focusing on either distributed small-scale plants or utility-scale installations. Germany, Spain and the Netherlands remained as the top three investors in solar PV. Overall, investment costs of PV increased between 2021 and 2023.

Renewable energy costs and prices

Looking at a time horizon of one or two decades, the specific investment cost and energy yield for solar PV and wind power showed a relatively stable trend: costs were decreasing and yield was increasing over time. In some periods, such as during the uncertain macro-economic circumstances in the years 2021 and 2022, investment costs were increasing considerably. However, it seems that currently the longer-term trend of gradual cost decrease is leading again. We present updated investment cost for some renewable technologies for the year 2024 in line with the literature approach as used in previous years. These investment cost and updated estimates for the weighted average cost of capital (WACC) were used to find levelized costs of energy (LCoE). Some highlights as reported for the year 2024:

- For renewable electricity production, onshore wind has the lowest average LCoE in 2024 (65 €/MWh), ahead of hydropower (72 €/MWh) and offshore wind (74 €/MWh), followed by power from large commercial photovoltaic plants (82 €/MWh).
- For heat production, the lowest average LCoE observed is for heat from biomass (63 €/MWh).
- Prices for natural gas and electricity for households show an increase from 2022 to 2023, which in both energy carriers is most pronounced for natural gas. The non-household price level shows an opposite trend in that period: prices there seem to be unchanged (for electricity) or even going down (for natural gas).
- Prices for natural gas and electricity for households and non-households show an increase from 2021 to 2022, which for both energy carriers is most pronounced for non-households. The effect of higher energy and supply prices on the average household price level was mitigated by tax alleviation and other support measures against high energy prices, as introduced by many European Union Member States.

Avoided Fossil fuel and resulting avoided costs

- In 2023, the use of renewable energy substituted 206 Mtoe of fossil fuels compared to the level of renewable energy use in 2005. These figures correspond to an annual avoided cost of €117 billion for the EU-27.

Indicators on innovation and competitiveness

- €1 070 million of public investment in R&D was invested in 2022 in the EU-27 for renewable technologies. €2 032 million was committed by private actors in 2021 (latest year available).
- The EU filed 1 081 patents in renewable energy in 2021 with Germany being the most active country (294 patent families). China remains the world leader in number of patents filed in renewable energy with 16 541 patent families.
- The trade balance (difference between imports and exports) of the renewable energy sectors in the EU-27 as a whole shows a negative balance in 2023 of EUR €15 325 million. The main partner remains China, which exported €20 090 million of goods and services in renewable technologies to the EU-27.

ENERGY INDICATORS

EurObserv'ER has been compiling data on the European Union's renewable energy sources for over twenty years, to chronicle the state and dynamics of the sectors in thematic barometers. The first part of this opus condenses the barometers released in 2024 for the wind power, photovoltaic, solar thermal, CSP, heat pump, renewable energy in transport and solid biomass sectors. All the energy indicators have been consolidated in these summaries using the official Eurostat data published for 2022 and 2023. Analysis and detailed statistical monitoring incorporating the latest official data from Eurostat have also been conducted on the remaining sectors that were not subject to dedicated barometers last year, namely: biogas, hydropower, geothermal energy, ocean energy, and renewable municipal waste. Thus, this document offers a comprehensive overview of the energy dimension of every industrially developed renewable sector in the European Union.

Methodological note

The tables set out the latest available figures foreach sector. In view of the publication date of this edition, most of the indicators published in this opus were sourced from the 28 January 2025 revision of the Eurostat database (Complete energy balances), and the indicator specific figures of the Renewable Energy Directive (EU) 2018/2001 (RED II) provided by the Eurostat SHARES tool (Short Assessment of Renewable Energy Sources). The results presented in the section on the European RED II targets are quoted from the 14th February 2025 updated version of the Eurostat "Share of energy from renewable sources".

This data alignment takes in the indicators for primary energy production, domestic energy consumption, net maximum electrical capacity, electricity production from power-only plants or cogeneration plants, gross heat production from heat-only plants or cogeneration plants, final energy consumption (industry, transport and other sectors), biofuel consumption in transport and the total solar thermal collector area in service. Data concerning the proportion compliant and non-compliant with the requirements of RED II of biofuels energy (solid biofuels, liquid biofuels, pure biogas or biomethane injected into the fossil gas network), whether for the production of electricity, heat production from the transformation sector and final energy consumption, were compiled by EurObserv'ER from the detailed results sheets by country in Eurostat's Share tool. However, whenever there are no parallel indicators published by Eurostat, such as market data for the various categories of heat pump (number of units sold) or solar thermal collector area (in installed square meters), the indicators used are solely those of EurObserv'ER. We also present specific indicators for pilot projects and prototypes in the ocean energy and CSP sectors, to enhance our appraisal of the sectors' momentum and activity.

The energy indicators drawn from Eurostat sources are those defined in the joint "Annual Renewable Questionnaire" methodology used by Eurostat and the International Energy Agency.

Accordingly, electrical capacity data refers to the notion of net maximum capacity defined as the maximum active capacity that can be supplied, continuously, by all the installations in service at their exit point, recording the net maximum capacity on 31 December of the year in question, expressed in MW.

Eurostat is working on introducing new monitoring indicators for photovoltaic capacity. The first will represent the maximum net electrical capacity expressed in direct current (DC) and will cover the capacity of installed panels (peak capacity) that generate direct current electricity. The second will cover the maximum net electrical capacity expressed in alternating current (AC) and will represent electrical capacity as it leaves the inverter, namely, the maximum capacity that inverters can supply, which is a little less than the DC capacity because of the slight loss incurred by the inverters. While Eurostat aims to produce these two different indicators for all European countries, to compare them applying a common basis, which was not the case before, as some countries only communicated their figures in DC while others expressed their capacity in AC. At the beginning of 2025, work to make the presentation of these indicators uniform was well advanced with only a minority of countries communicating only one of the two electrical capacity indicators. To calculate the solar photovoltaic capacity that contributes to a country's total electricity generating capacity, Eurostat specifies in its metadata that the lower of the two indicators must be considered (logically the AC capacity). If only one of the two indicators is available, it is that one that contributes to the country's total electricity generating capacity. Consequently, this rule modifies the statistical series of countries once they adopt the AC capacity indicator.

As for the energy used for heating and cooling, gross heat production (from the processing sector) is distinguished from final energy consumption, in line with Eurostat definitions. Gross heat production corresponds to the total heat produced by heating plants and CHP plants (combined heat and power production). It includes the heat used by any auxiliary equipment in the installation that operates with hot fluids (space heating, liquid fuel heating, etc.) and heat exchange losses between the facility and the grid, in addition to chemical process heat used as a primary form of energy. In the case of auto-producing facilities, the heat used by the undertaking for its own processes is excluded from the data, only the part of the heat sold to third parties is included.

Final energy consumption represents all the energy for all uses delivered to end users such as households, industry and agriculture and thus excludes the energy used for processing processes and energy-producing industries' own use. As for the gross electricity and heat production data, a distinction is made between the plants that only generate either electricity or heat and cogeneration plants that combine the production of both energy types. The Overseas Departments are included in the indicators for France.

WIND ENERGY

The new renewable energy targets of the October 2023 European RED III Directive No. 2023/2413 will probably revive wind energy ambitions, in both the onshore and offshore segments. However, the European Union is unlikely to see any significant increase in its annual installed capacity prior to 2025. Eurostat reports that EU net installed wind power capacity, defined as the net maximum operational capacity that can be injected into the grid, rose to at least 218.9 GW by the end of 2023 (including 19 GW of offshore capacity), i.e., 15.2 GW of net additional capacity compared to 2022 (including 2.85 GW of offshore capacity). This installation figure is a little lower than that of the previous twelve-month period 2022–2021 (15.7 GW). EurObserv'ER puts the 2023 capacity installation figure a little higher – at just over 16 GW – by subtracting EU-wide decommissioned capacity, estimated at 850 MW for the year (551 MW for Germany, 110 MW for Belgium and 93 MW for France). Incidentally, annual decommissioned capacities are rising, and the decommissioning pace is set to increase sharply in the next few years. This is a blessing in disguise, as some of the wind farms in question will undergo repowering operations that will increase their capacity and output.

OFFSHORE WIND POWER SURGES IN THE EU

In 2023, the European Union hailed the completion of many offshore wind power projects off its coastlines. Eurostat claims that as much as 2 850 MW of offshore wind turbine capacity officially went on-grid compared to just over 1 GW in 2022 (1 005.5MW), making 2023 the best year ever for new EU offshore wind farm installations.

Once again, the Netherlands led the pack in 2023, consolidating its status with the second highest offshore wind capacity in the European Union, behind Germany but ahead of Denmark and Belgium. Statistics Netherlands reports that the Netherlands formally connected 1 408 MW of offshore wind power, stating that its statistics only include the capacity that was injected into the grid in 2023. This capacity figure applies to the Hollandse Kust Noord 5 farm (759 MW, comprising 69 Siemens Gamesa SG 11.0-200 DD turbines each with unit capacity of 11 MW). This unsubsidized wind farm went on stream on 20 December 2023. It is expected to generate 3.3 TWh per annum. It also covers the remaining turbines of the Hollandse Kust Zuid Wind Farm – currently the biggest offshore wind farm in the world – equipped with 139 Siemens Gamesa SG 11.0-200 DD turbines, for a total of 1 529 MW of capacity. The latter is split across two wind farms and four production sites, Hollandse Kust Zuid 1&2 and Hollandse Kust Zuid 3&4 of the same capacity. Although the last wind turbine was installed in June 2023, the farm will not be fully operational until 2024. It was originally designed to operate 140 turbines, but in January 2022, the bulk carrier, Julietta D, collided with one of the turbine foundations under construction during a storm causing it irreparable damage. The next stage, due at the end of 2026, will be the commissioning of Hollandse Kust West 1&2 whose call for tenders closed at the end of 2022.

In 2023, France was the second most active country for new offshore installations with two wind farms off Fécamp (497 MW) and Saint-Brieuc (496 MW). The Fécamp farm has 71 Siemens Gamesa SG 7.0-154, 7-MW turbines, while the Saint-Brieuc farm, whose last wind turbine was installed on 17 December 2023, is equipped with 62 Siemens Gamesa SG 8.0-167, 8-MW turbines. The Eurostat figure for net additional capacity is a little lower at 985.7 MW between 2022 and 2023.

Germany also added 257 MW... the capacity of the Arcadis Ost 1 Wind Farm which started up on 5 December 2023 northwest of Rügen Island in the Baltic. It has 27 Vestas V174/9.5 MW turbines (174 metres in diameter and 9.5 MW of capacity) with enhanced performance capability turbines. Denmark has also started the ball rolling again with the connection of 168 MW of capacity in 2023, according to the Danish Energy Agency, from the Vesterhav Syd Wind Farm which delivered its first electrons in November 2023. It is equipped with 20 Siemens Gamesa 8.0-167 DD turbines (uprated to 8.4 MW). Eurostat

1

Wind power capacity installed in the European Union at the end of 2023 (MW)*

	2022	*of which Offshore*	2023	*of which Offshore*
Germany	66 202.0	*8 216.0*	69 486.0	*8 473.0*
Spain	30 113.8	*0.0*	30 868.5	*5.0*
France	20 835.2	*500.8*	23 131.6	*1 486.5*
Sweden	14 279.0	*193.0*	16 224.0	*193.0*
Italy	11 820.5	*0.0*	12 307.3	*31.0*
Netherlands	8 700.1	*2 569.5*	10 734.1	*3 977.5*
Poland	8 150.2	*0.0*	9 343.3	*0.0*
Denmark	7 083.8	*2 305.7*	7 277.0	*2 469.1*
Finland	5 677.0	*73.0*	6 946.0	*73.0*
Portugal	5 538.1	*25.0*	5 538.1	*25.0*
Belgium	5 303.4	*2 261.8*	5 454.1	*2 261.8*
Greece	4 702.3	*0.0*	5 231.7	*0.0*
Ireland	4 536.1	*0.0*	4 739.3	*0.0*
Austria	3 633.1	*0.0*	3 896.3	*0.0*
Romania	3 015.2	*0.0*	3 026.8	*0.0*
Lithuania	946.0	*0.0*	1 284.0	*0.0*
Croatia	986.9	*0.0*	1 160.2	*0.0*
Bulgaria	704.3	*0.0*	704.3	*0.0*
Czechia	339.1	*0.0*	342.5	*0.0*
Estonia	316.0	*0.0*	340.0	*0.0*
Hungary	324.0	*0.0*	324.0	*0.0*
Luxembourg	165.3	*0.0*	207.3	*0.0*
Cyprus	157.5	*0.0*	157.5	*0.0*
Latvia	82.4	*0.0*	128.3	*0.0*
Slovakia	4.0	*0.0*	4.0	*0.0*
Slovenia	3.3	*0.0*	3.3	*0.0*
Malta	0.1	0.0	0.1	0.0
Total EU-27	**203 618.9**	*16 144.8*	**218 859.6**	*18 994.9*

** Net maximum electrical capacity. **Source: Eurostat***

quantifies 163.4 MW of net additional capacity between 2002 and 2023, factoring in the decommissioned capacity of two 2.3-MW wind turbines. The Vesterhav Nord Wind Farm (176 MW), equipped with 21 of the same turbines, has also been installed, but will not be connected to the grid until early 2024. Spain had two offshore prototypes operating in 2023, one of 5 MW (Elisa project) commissioned in 2019 off Gran Canaria and another of 2 MW (DemoSATH test platform) commissioned in August 2023, 3 km off its Basque coast. However, Eurostat has quantified just 5 MW of capacity beginning in 2023.

There will be a flurry of wind farms starting up. Germany had three wind farms under construction at the end of 2023: Baltic Eagle (476.3 MW) and God Wind 3 (241.8 MW), both of which started up at the end of 2024, while Borkum Riffgrund 3 (900 MW) installed its last wind turbine at the start of 2025. The commercial commissioning date of this wind farm was postponed until early 2026, because of delays in connecting the offshore grid to the onshore grid. The final investment decision was also taken on the EnBW He Dreiht (900 MW) Wind Farm in July 2023 for construction in 2024 and commissioning in 2025. The Netherlands will be adding the Hollandse Kust (West) VI (756 MW) and Hollandse Kust (West) VII (760 MW) Wind Farms slated for 2026. The three French floating offshore pilot wind farms in the Mediterranean have been slightly delayed but are nearly completed. The Provence Grand large (25.2 MW) project produced its very first electrons at the tail end of 2024 and will be fully operational in 2025. The turbines of the Golf du Lion (30 MW) Wind Farm are due to be installed during the summer of 2025 and commissioning is scheduled for the end of 2025, likewise for the Eolmed Wind Farm (30 MW). Difficulties in drilling the turbine foundations for the Normandy Courseulles-sur-Mer (448 MW) Wind Farm have also caused delays and may push back commissioning to 2026.

A GUST OF AIR FOR THE EUROPEAN UNION'S ELECTRICITY MIX

According to Eurostat, European Union wind power output, onshore and offshore taken together, increased by 13.3% (56.2 TWh) YoY and reached 478.1 TWh in 2023, a record level. Wind power output even overtook that of natural gas-fired power plants for the first time. The latter was in sharp decline between 2022 and 2023 (dropping from 538.3 to 458.6 TWh... i.e., 14.8%). Offshore wind power output in 2023 is put at 55.1 TWh, a 9.7% (4.9 TWh) increase, and thus amounted to 11.5% of total wind power output. This good performance can also be ascribed to better wind conditions enjoyed by the European Union generally in 2021 and 2022. The YoY increase was almost universal with the exception of Portugal whose output slipped (by 99 GWh, or 0.7% YoY), as well as Cyprus with 16 GWh (7% YoY) less output. The best increases were made in Germany (12.6%, 15.7 TWh), France (32.1%, 12.3 TWh), the Netherlands (36.9%, 8 TWh), Poland (22.2%, 4.4 TWh), Italy (15.4%, 3.1 TWh), Belgium (25%, 3.1 TWh) and Finland (25.1%, 3 TWh).

Eurostat claims that in 2023, wind power covered the largest share of Denmark's electricity mix (57.5%), ahead of Lithuania (42.4%), and Ireland (37.2%). In Germany, more than a quarter (27.5%) of the country's electricity was generated by wind power. The same goes for Portugal (26.8%). Wind power coverage rates topped 20% in the Netherlands (24.3%), Spain (22.5%), Greece (22.1%) and Sweden (20.6%).

NEW AMBITIONS FOR WIND POWER

Europe's wind power industry will at last have the means to face off China's industry players on the European continent. The European Commission has grasped the nettle following repeated warnings issued by the EU wind power sector. On 23 October 2023, it presented the European Wind Power Action Plan to ensure that the transition to clean energy goes hand in hand with the industrial competitiveness of Europe's players. The action plan aims to maintain a healthy and competitive wind power supply chain, backed by a string of long-term projects in the pipeline, to attract the necessary funding and compete globally on a level footing. The European Wind Power Action Plan also called on Member States to make specific concrete (but legally non-binding) commitments on wind power deployment volumes from at least 2024–2026, to provide a clear and credible preview of wind power deployment over the coming years, to be formalized at the end of 2024. As a result of the Commission's call, 21 Member States submitted their wind power commitments for a total of 55 GW of new wind energy capacity by the end of 2026.

2

Gross electricity production from wind power in the European Union in 2022 et 2023 (TW)

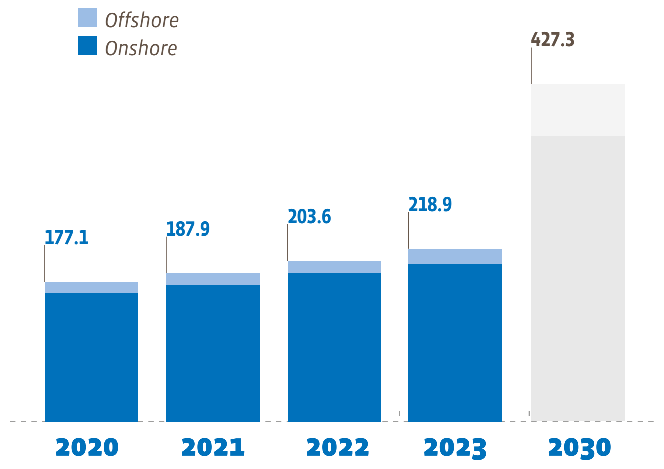
	2022	*of which Offshore*	2023	*of which Offshore*
Germany	124.816	*25.124*	140.538	*23.887*
Spain	62.784	*0.000*	64.275	*0.006*
France	38.199	*0.649*	50.479	*1.914*
Sweden	33.253	*0.550*	34.245	*0.549*
Netherlands	21.566	*8.126*	29.525	*11.712*
Poland	19.780	*0.000*	24.176	*0.000*
Italy	20.494	*0.000*	23.640	*0.054*
Denmark	19.022	*8.743*	19.393	*8.573*
Belgium	12.353	*6.652*	15.444	*8.040*
Finland	12.022	*0.273*	15.043	*0.243*
Portugal	13.244	*0.078*	13.145	*0.079*
Ireland	11.393	*0.000*	11.863	*0.000*
Greece	10.883	*0.000*	11.022	*0.000*
Austria	7.242	*0.000*	8.037	*0.000*
Romania	6.997	*0.000*	7.548	*0.000*
Croatia	2.138	*0.000*	2.587	*0.000*
Lithuania	1.512	*0.000*	2.536	*0.000*
Bulgaria	1.499	*0.000*	1.584	*0.000*
Czechia	0.641	*0.000*	0.702	*0.000*
Estonia	0.668	*0.000*	0.683	*0.000*
Hungary	0.610	*0.000*	0.646	*0.000*
Luxembourg	0.312	*0.000*	0.495	*0.000*
Latvia	0.190	*0.000*	0.271	*0.000*
Cyprus	0.224	*0.000*	0.208	*0.000*
Slovenia	0.006	*0.000*	0.006	*0.000*
Slovakia	0.004	*0.000*	0.004	*0.000*
Malta	0.000	*0.000*	0.000	*0.000*
Total EU-27	421.853	*50.193*	478.097	*55.056*

Source: Eurostat

This plan is accompanied by the communication, Delivering on the EU offshore renewable energy ambitions, which follows on from the Union's Offshore Renewable Strategy adopted three years ago, that aims to dramatically increase offshore wind energy development. The new overall ambition is to install about 111 GW of offshore renewable energy generating capacity by the end of 2030... 232 GW by the end of 2040, and to rise to about 317 GW by the middle of the century. ■

3

EurObserv'ER projection of the evolution of wind power net capacity in the EU-27 (in GW)



Source: EurObserv'ER

PHOTOVOLTAIC

THE EU'S UNITY IS STRENGTH... ANOTHER 51.1 GW WENT ON-GRID IN 2023

In 2023, the European Union set a new annual grid connection record and did so for the third year running. Total additional net maximum capacity (likely to be delivered to the grid) amounted to 51.1 GW, which equates to 26.5% of annual growth from the 2022 level, and takes the combined net maximum capacity of the 27 Member States to 243.8 GW at the end of 2023. This figure is more representative of the alternating current capacity with a few exceptions (see our methodology note).

Russia's 2022 invasion of Ukraine created geopolitical and energy shock waves that understandably boosted the installation level to record heights. The war on European soil led to drastic hikes in gas and electricity prices and put the spotlight on the EU's dependency on Russian hydrocarbons raising serious energy issues. This event has radically changed the EU countries' view of solar photovoltaic power. It has now been fully recognized by politicians (and economic players in particular), as a rapid, cost-effective way of reducing reliance on Russian fossil fuels and having an affordable electricity supply. The European Union, dictated by necessity, undertook to roll out its REPowerEU plan, that it launched in May 2022. The plan aims to halt EU reliance on Russian fossil fuels, by diversifying its supplies and by fast-tracking

Methodological note

Eurostat is working on introducing new monitoring indicators for photovoltaic capacity. The first will represent the maximum net electrical capacity expressed in direct current (DC) and will cover the capacity of installed panels (peak capacity) that generate direct current electricity. The second will cover the maximum net electrical capacity expressed in alternating current (AC) and will represent electrical capacity as it leaves the inverter, namely, the maximum capacity that inverters can supply, which is a little less than the DC capacity because of the slight loss incurred by the inverters. While Eurostat aims to produce these two different indicators for all European countries, to compare them applying a common basis, which was not the case before, as some countries only communicated their figures in DC while others expressed their capacity in AC. At the beginning of 2025, work to make the presentation of these indicators uniform was well advanced with only a minority of countries communicating only one of the two electrical capacity indicators. To calculate the solar photovoltaic capacity that contributes to a country's total electricity generating capacity (table 1), Eurostat specifies in its metadata that the lower of the two indicators must be considered (logically the AC capacity). If only one of the two indicators is available, it is that one that contributes to the country's total electricity generating capacity. Consequently, this rule modifies the statistical series of countries once they adopt the AC capacity indicator. Only three countries – Finland, Austria and Poland – did not provide AC indicators for 2023. Therefore, by default the DC photovoltaic capacity was used to express their respective electricity capacities. France, is a special case because it began publishing its photovoltaic capacity indicator in AC in 2023, as in previous years its photovoltaic capacity indicators were expressed in DC. The obvious result of this switch is that its net maximum photovoltaic capacity in 2023 is lower than that of 2022 in the Eurostat database (i.e., 17 341.3 MW in 2022 and 17 025.7 MW in 2023). To maintain a common basis for comparison in table 1, EurObserv'ER has estimated France's photovoltaic capacity in AC for 2022 applying the same 2023 ratio between capacity in AC and capacity in DC. Incidentally, the net maximum capacity officially acknowledged for France and the European Union for 2022 as mentioned in the Eurostat database (30 January 2025 update) is 17 241.3 MW for France and 195 221.2 MW for the European Union, pending the next update.

1

Installed solar photovoltaic capacity in the European Union at the end of 2023 (MW)*

	2022	2023
Germany	61 188.0	74 882.0
Spain	23 897.3	29 579.6
Italy	24 555.2	29 351.4
Netherlands	17 356.5	21 274.6
France	14 810.8	17 025.7
Poland	12 170.4	16 427.5
Belgium	6 781.2	8 351.9
Greece	5 430.1	6 688.7
Austria	3 791.7	6 394.8
Hungary	4 235.0	5 910.0
Sweden	2 388.0	3 993.0
Portugal	2 646.3	3 868.8
Denmark	3 069.9	3 529.0
Czechia	2 403.8	3 251.0
Romania	1 808.9	2 988.0
Bulgaria	1 736.5	2 908.1
Lithuania	567.5	1 153.0
Slovenia	626.2	1 031.2
Finland	664.0	1 009.0
Estonia	520.0	813.0
Ireland	209.3	752.9
Slovakia	549.0	594.0
Cyprus	424.1	580.7
Croatia	222.0	462.5
Luxembourg	316.6	403.7
Latvia	113.0	319.0
Malta	209.5	225.7
Total EU-27	192 690.7	243 769.0

** Net maximum electrical capacity.* ***Source: Eurostat (except France and Total EU 27 for the year 2022, see methodological note)***

renewable energy development. The solar photovoltaic part of this plan aims to double solar capacity by 2025, i.e., 320 GWac (equating to 400 GWdc) and to install 600 GWac of generating capacity by 2030.
Germany, one of the countries most exposed to Russian gas imports, struck a heavy blow by connecting as much as 13.7 GW to the grid during 2023, equating to over a quarter (26.8%) of the European Union's newly installed capacity. Spain, the second most active market, added 5.7 GW, followed by Italy (4.8 GW), Poland (4.3 GW) and the Netherlands (3.9 GW). Another nine EU countries each connected over one gigawatt of capacity to the grid, namely Austria (2.6 GW), France (2.2 GW), Hungary (1.7 GW), Sweden (1.6 GW), Belgium (1.6 GW), Romania (1.2 GW), Bulgaria (1.2 GW), Portugal (1.2 GW) and Greece (1 GW). Almost all the Member States are putting their shoulders to the wheel to build up the strength of the European Union's photovoltaic market.
Germany's capacity-to-date lead, with 74.9 GW at the end of 2023, is unassailable. Spain is creeping up with 29.6 GW, just ahead of Italy (29.4 GW). Per capita (PC) installed capacity is more representative of the "solarization" level of each Member State. This time, the Netherlands tops the rankings (1 194.4 W PC), Germany (887.7 W PC) and Belgium (711.2 W PC).

247 TWH PRODUCED IN THE EUROPEAN UNION

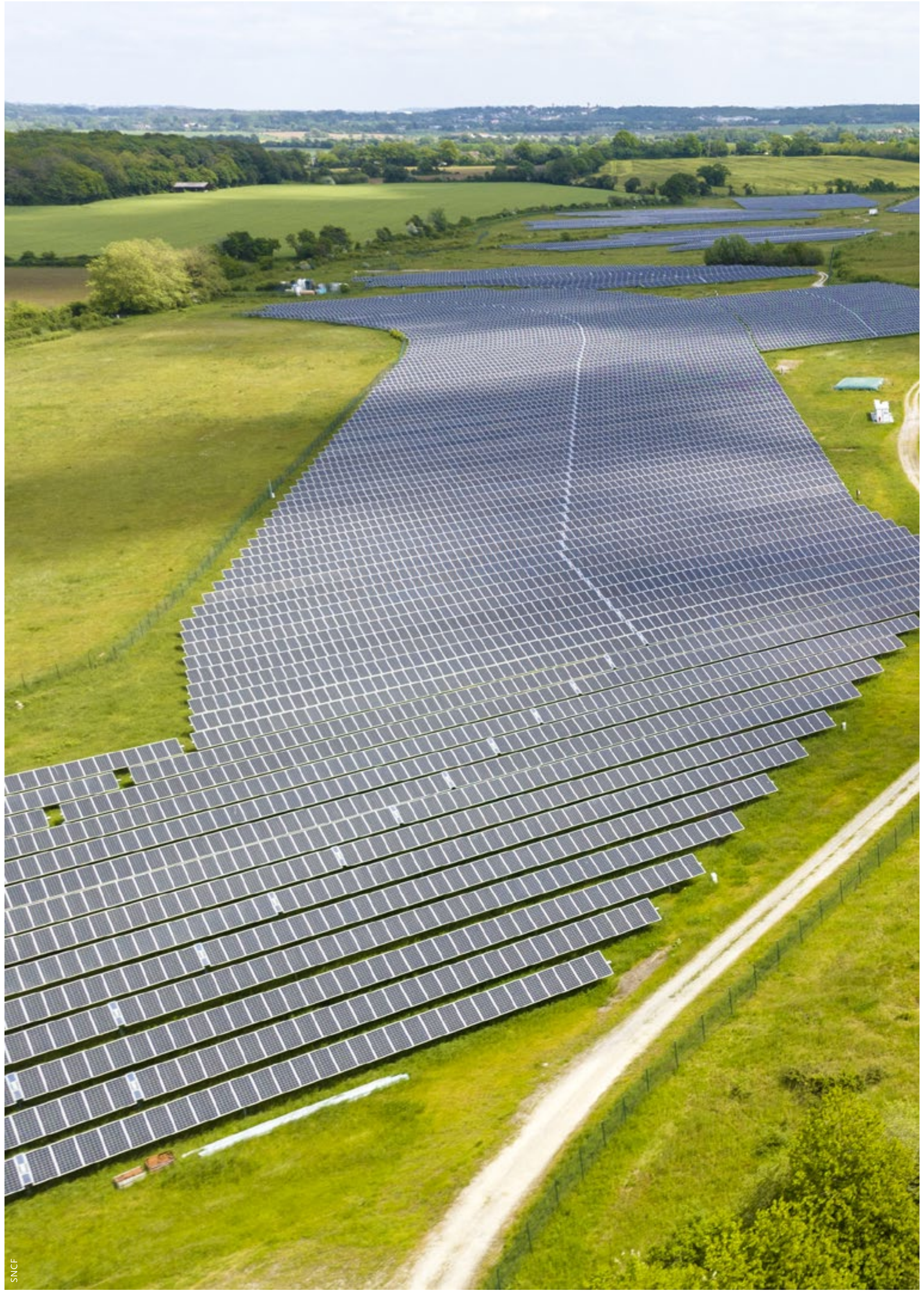
The 2023 sunshine levels in Europe were less exceptional and more varied than those of 2022. The latest European States of the Climate 2023- ESOTC 2023 report for 2023 as a whole, written by the Copernicus Climate Change Service, signalled lower than average solar photovoltaic production potential in the north-west and central Europe contrasting with above average potential in the south-west and south of Europe and Fennoscandia (Finland, Sweden and Norway). The impact of these climate variations on electricity production should be viewed in relation to the impressive installation efforts made over the past two years by the European Union's countries.
Eurostat reports that solar photovoltaic electricity output increased by 19.9% between 2022 and 2023 to 247 TWh, which is 40.9 TWh higher than in 2022. However, this increase is lower than the 29.5%, or 47 TWh increase of the previous twelve months. The slight increase in German solar power output, which only amounted to 4.2% (2.6 TWh) between 2022 and 2023, totalling 63.6 TWh is responsible for this poorer performance. AGEE-Stat, the Working Group on Renewable Energy Statistics on behalf of the Federal Ministry for Economic Affairs and Climate Action, singles out three main reasons for the difference between the sharp increase in installed capacity and the relatively low increase in solar power output. Firstly, solar irradiation was much weaker in 2023 compared to 2022; secondly, a significant number of power plants were already registered as installed, but were still awaiting grid access as the grid operators do not have enough employees to certify and connect them. The third reason mooted is the surge in self-consumption in

2

Gross electricity production from solar photovoltaic in the European Union in 2022 and 2023 (in TWh)

	2022	2023
Germany	61.022	63.576
Spain	31.187	43.421
Italy	28.121	30.711
France	19.628	21.823
Netherlands	16.657	19.578
Poland	8.310	11.107
Greece	7.140	8.894
Belgium	6.879	7.820
Hungary	4.732	6.925
Austria	3.783	6.395
Portugal	3.519	5.160
Bulgaria	2.094	3.521
Denmark	2.203	3.363
Sweden	1.980	3.114
Czechia	2.626	2.892
Romania	1.988	2.227
Slovenia	0.646	0.984
Cyprus	0.602	0.831
Estonia	0.596	0.721
Finland	0.392	0.716
Lithuania	0.342	0.688
Ireland	0.149	0.646
Slovakia	0.650	0.605
Croatia	0.152	0.413
Malta	0.289	0.309
Luxembourg	0.276	0.294
Latvia	0.075	0.239
Total EU-27	206.037	246.974

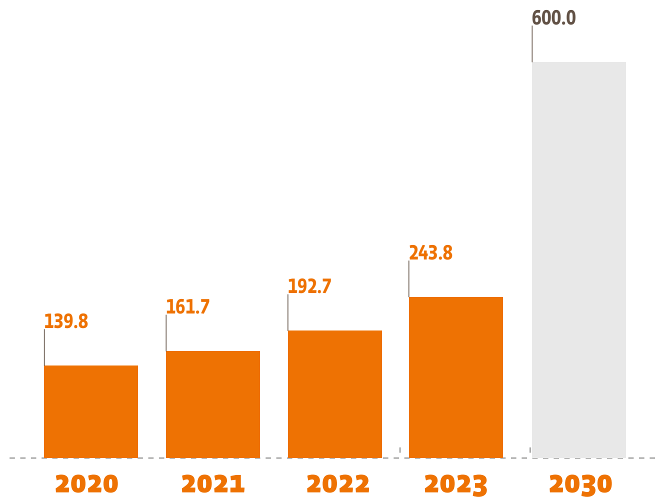
Source: Eurostat



Germany that affects both small and large installations. It is harder to quantify self-consumption as this electricity is not injected into the grid.
The increase in self-consumption across the European Union is a general trend that can be put down to the hike in the price of electricity and the growing battery storage system ownership level. This said, the vast majority of EU countries posted double-digit increases in solar photovoltaic electricity output. In 2023, Spain's output increase by 39.2% (12.2 TWh) to 43.4 TWh, the Netherlands by 17.5% (2.9 TWh) to 19.6 TWh, Poland by 33.7% (2.8 TWh) to 11.1 TWh, France by 11.2% (2.2 TWh) to 21.8 TWh and Portugal by 46.6% (1.6 TWh) to 5.2 TWh.

3

EurObserv'ER projection of the evolution of net photovoltaic capacity installed in the EU-27 (in GW)



Source: EurObserv'ER

TARGETS FOR 2030 DOUBLED

The publication in the Official Journal of the European Union of the Renewable Energy Directive (RED III) No. 2023/2413 dated 18 October 2023 opened up new possibilities for the photovoltaic sector. It stipulates that «The Member States will collectively endeavour to ensure that the energy share produced from renewable sources in the Union's final gross energy consumption in 2030 is at least 42.5%» and that «The Member States will collectively endeavour to achieve a 45% share of the Union's final gross energy consumption in 2030 produced from renewable sources.» This new target with an extremely short deadline will force the Member States to radically reassess solar photovoltaic energy's contribution for the next seven years when they revise their integrated National Energy and Climate Plans (NECP). The NECP update process has significantly raised the solar photovoltaic ambitions of Member States that have submitted a new project to the European Commission. Spain's updated NECP, for example, raises the total installed photovoltaic capacity target for 2030 from 39 to 76 GW, which is almost double the previous NECP target. Germany's new 2023 NECP proposes to roll out an average of 22 GW per annum, amounting to cumulative capacity of 215 GW in 2030 and 400 GW in 2040. France has raised its photovoltaic targets to 54–60 GW in 2030 from 35.1–44 GW by 2028 in its previous NECP, and from 75–100 GW by 2035. Another major solar player, Italy, has raised its photovoltaic target of 51 to 79 GW for 2030, while Portugal's target photovoltaic contribution has risen from 9 to 20.4 GW. Poland, which submitted its revised NECP on 5 March 2024, indicates a new solar contribution of 29.3 GW for 2030 up from its initial forecast figure of 7.3 GW. EurObserv'ER, which has examined the new photovoltaic targets for 2030 detailed in the draft NEPCs submitted to the Commission in 2023, along with those of Poland and Bulgaria submitted early in 2024, reckons that the overall EU-wide target has increased to 625.2 GW for 2030 (based on the high assumptions for France and Czechia), compared to a global target of 316 GW from the old NECPs submitted in 2019. The new European ambitions for solar amount to almost double the overall target. ■

SOLAR THERMAL

Although for two years the European Union's solar thermal market seemed to be faring better, it stalled in 2023. The newly installed collector surface area decreased sharply, by about 21.1% – just under 1.9 million m² year-on-year (tables 1 & 2). Germany's market bore the brunt of this decline, conceding its European solar thermal market leader status to Greece. Most major European solar thermal markets posted lower installed collector surface areas, including those that had recovered in 2022 (Germany, Italy, Poland and the Netherlands). The Greek market and the French market, propped up by its overseas territories (Guiana, Martinique, Reunion Island, Guadeloupe and Mayotte) were exceptions to this trend. What is more concerning is that some formerly prosperous markets (Spain, Portugal and Austria) have been unable to stem their haemorrhaging sales.

SOLAR THERMAL PLAGUED BY A CLIMATE OF UNCERTAINTY

The European market's decline primarily mirrors falling sales in the residential sector and has hit forced circulation solar thermal systems in particular, both those geared to hot water and to heating production (combined solar systems). Thermosyphon systems that are especially well suited to the Mediterranean or tropical climates (for instance, the French overseas departments) have been relatively spared. The trend in the major installation market (>1 000 m²), be it for multi-occupancy housing, the solar heating networks or industrial heat segments, still relies on the individual Member States' incentive programmes. The commissioning of these installations, that may have collector fields ranging from several thousand to tens of thousands of m², may boost national statistics.

As for the method applied, the market data given in tables 1 & 2 includes solar systems that use flat glazed collectors and vacuum tube collectors, both of which technologies are geared to domestic hot water production or space heating in the residential sector as well as heat and hot water production for heating networks or industrial processes. The data also includes non-glazed collectors, mainly used for heating pools, even though statistical bodies rarely monitor this technology. Solar systems using concentrating mirrors (Fresnel-type, parabolic or parabolic trough) for hot water or steam production, as well as PV-T water- or air-borne hybrid collectors and air solar collectors are not included in the statistics given in tables 1 & 2 in the glazed collectors category.

There are several reasons for the 2023 solar thermal market's decline, including country-specific factors such as regulatory developments, level of aid, and the tougher European economic context. The return of inflation, the rise in energy price and interest rate hikes have created a climate of uncertainty that is inconducive to investments in solar thermal. In many European countries, the new build construction segment, which is usually highly supportive of solar thermal, is in crisis. Some key EU markets may also have been rattled by uncertainty surrounding new legislative elections and changes to associated policies, for instance in Italy in 2022, and the Netherlands which held snap elections in 2023, or even by tensions in the incumbent governing coalitions (Germany) that curbed the rollout of energy efficiency policies and the promotion of renewable heating systems. Germany's (47% YoY) market contraction can be directly attributed to the underlying political uncertainty on the legislative obligations for heating appliance renewal initially sought by the law on heating and the promotion of renewable energy heating systems. The Italian solar thermal market suffered the double whammy of the end of the "Superbonus" and credit transfer mechanisms, thus contracting by 28.7% YoY. When specific aid schemes for solar thermal (communal programmes co-financed by the European Union) were wound up Poland's market was dealt a hard blow (it fell by 37.7% YoY).

On the bright side, the market in Greece, that is basically one of thermosyphon systems, kept its momentum going with a 10% annual increase in collector area installed (i.e., 461 000 m² in 2023). The French market, supported by its overseas component (which in 2023 accounted for 90 740 m² installed in Guiana, Martinique, Reunion Island, Guadeloupe and Mayotte), picked up pace in 2023 (expanding by 26%, or 205 624 m²). In the mainland market, the MaPrimRénov' and Coup de pouce chauffage incentive systems geared to the lowest income earners, benefitted the most from cheap combined solar systems and self-storing systems suitable for the climate in the south of France. The French market was also boosted by the March 2023 commissioning of the Lactosol solar thermal plant at Verdun (15 000 m² of collector area), that supplies a Lactalis dairy group factory. The plant, which received Heat Fund subsidies from Ademe (France's Environment and Energy Management Agency), is Europe's biggest industrial solar heat installation to use flat glazed collectors.

THE EU HAS 246 SOLAR HEATING NETWORKS UP AND RUNNING

Denmark has long pioneered solarizing district heating (SDH) and by the end of 2023, according to data released in the

1

Annual installed surfaces in 2022 per type of collectors (in m²) and capacity equivalent (in MWth)

	Glazed collectors		Unglazed collectors	Total (m²)	Equivalent capacity (MWth)
	Flat plate collectors	Vacuum collectors			
Germany	524 000	185 000		709 000	496.3
Greece	419 000			419 000	293.3
Italy	339 750			339 750	237.8
Poland	208 500	1 500		210 000	147.0
France**	163 300			163 300	114.3
Spain	125 587	8 665	2 000	136 252	95.4
Cyprus	73 924			73 924	51.7
Portugal	66 100			66 100	46.3
Austria	56 830	660	1 480	58 970	41.3
Bulgaria	45 863			45 863	32.1
Netherlands	24 516	14 960	2 621	42 097	29.5
Czechia	23 167	2 336		25 503	17.9
Belgium	15 000	3 500		18 500	13.0
Romania*	16 932			16 932	11.9
Slovakia	16 000			16 000	11.2
Hungary*	14 000			14 000	9.8
Croatia*	13 558			13 558	9.5
Finland+	8 000			8 000	5.6
Luxembourg	3 574			3 574	2.5
Denmark	2 664			2 664	1.9
Sweden*	2 014			2 014	1.4
Lithuania*	1 751			1 751	1.2
Latvia*	1 700			1 700	1.2
Slovenia*	1 479			1 479	1.0
Estonia*	1 425			1 425	1.0
Malta+	1 051	263		1 314	0.9
Ireland	1 116			1 116	0.8
Total EU-27	**2 170 801**	**216 884**	**6 101**	**2 393 786**	**1 675.7**

*+ EurObserv'ER estimation based on the market trend of recent years (these are not sufficiently accurate to be used for percentual change reference in these markets). * Estimation from Solar heat Europe «Decarbonising heat with solar thermal market, Market outlook 2022-2023). ** Including 96 500 m² in the overseas departments. Note: PVT hybrid systems, CSP systems (Fresnel, Parabolic, Parabolic trough) and air collector systems are not included. Breakdown for glazed collectors between flat plate collectors and vacuum collectors is not always available.* ***Source: EurObserv'ER***

2

Annual installed surfaces in 2023 per type of collectors (in m²) and capacity equivalent (in MWth)

	Glazed collectors		Unglazed collectors	Total (m²)	Equivalent capacity (MWth)
	Flat plate collectors	Vacuum collectors			
Greece	461 000			461 000	322.7
Germany	268 000	108 000		376 000	263.2
Italy	242 242			242 242	169.6
France**	205 724			205 724	144.0
Poland	130 800			130 800	91.6
Spain	99 487	6 536	1 840	107 863	75.5
Cyprus	66 740			66 740	46.7
Portugal	51 410	1 590		53 000	37.1
Austria	43 891	1 319	1 038	46 248	32.4
Hungary+	42 000			42 000	29.4
Netherlands	19 870	12 360	2 621	34 851	24.4
Bulgaria+	19 556			19 556	13.7
Czechia	15 333	3 473		18 806	13.2
Romania+	13 500			13 500	9.5
Denmark	13 000			13 000	9.1
Slovakia+	12 800			12 800	9.0
Croatia*	12 473			12 473	8.7
Belgium	9 300	2 500		11 800	8.3
Finland+	6 400			6 400	4.5
Sweden*	4 600			4 600	3.2
Luxembourg	2 755			2 755	1.9
Lithuania+	1 400			1 400	1.0
Latvia+	1 400			1 400	1.0
Slovenia*	1 269			1 269	0.9
Ireland+	1 116			1 116	0.8
Estonia+	1 100			1 100	0.8
Malta+	1 000			1 000	0.7
Total EU-27	**1 748 166**	**135 778**	**5 499**	**1 889 443**	**1 322.6**

*+ EurObserv'ER estimation based on the market trend of recent years (these are not sufficiently accurate to be used for percentual change reference in these markets). * According Solar heat Europe «Decarbonising heat with solar thermal market, Market outlook 2023-2024). ** Including 90740 m² in the overseas departments. Note: PVT hybrid systems, CSP systems (Fresnel, Parabolic, Parabolic trough) and air collector systems are not included. Breakdown for glazed collectors between flat plate collectors and vacuum collectors is not always available.* ***Source: EurObserv'ER***

3

Cumulated capacity of thermal solar collectors installed in the European Union in 2022 and 2023*** *(in m^2 and in MWth)*

	2022		2023	
	m^2	MWth	m^2	MWth
Germany	22 415 000	15 690.5	22 395 000	15 676.5
Greece	5 442 000	3 809.4	5 742 000	4 019.4
Italy	4 953 763	3 467.6	5 135 714	3 595.0
Austria	4 616 474	3 231.5	4 616 474	3 231.5
Spain	4 449 343	3 114.5	4 525 423	3 167.8
France	4 101 490	2 871.0	4 282 452	2 997.7
Poland	3 405 690	2 384.0	3 067 862	2 147.5
Denmark	2 059 096	1 441.4	2 072 096	1 450.5
Portugal	1 545 055	1 081.5	1 598 055	1 118.6
Cyprus	1 139 643	797.8	1 156 360	809.5
Belgium	756 400	529.5	760 100	532.1
Netherlands	662 000	463.4	668 000	467.6
Czechia	611 000	427.7	630 000	441.0
Bulgaria	515 697	361.0	535 253	374.7
Hungary	418 000	292.6	460 000	322.0
Sweden	435 000	304.5	377 000	263.9
Ireland	345 907	242.1	347 023	242.9
Croatia	312 600	218.8	322 000	225.4
Slovakia	265 000	185.5	279 000	195.3
Romania	249 109	174.4	249 109	174.4
Slovenia	212 854	149.0	204 168	142.9
Finland	88 000	61.6	88 000	61.6
Luxembourg	73 095	51.2	73 126	51.2
Malta	46 485	32.5	41 817	29.3
Latvia	21 672	15.2	21 672	15.2
Total EU-27	**59 140 373**	**41 398.3**	**59 647 704**	**41 753.4**

** All technologies included unglazed collectors. No official estimation is available for Estonia or Lithuania.* ***Source: Eurostat***

latest 2024 edition of "Solar heat worldwide" report, had as many as 124 heating networks spread across the country, amounting to 1 608 591 m^2 of collector area (the equivalent of 1 126 MWth). Yet, the drive to install has stuttered recently. Only one solar heating network was connected in 2023, at Blendstrup (2 000 m^2). According to the Danish PlanEnergi consultancy's data, two projects are being finalised at Bjerringbro (8 000 m^2) and Aeroskobing (1 910 m^2).

Germany has overtaken Denmark as the leading European proponent of SDH. The German Steinbeis Solites research institute states that in January 2024 the country had 55 solar urban heating plants up and running with total capacity of 112 MW (equivalent to 160 317 m^2), six new solar thermal systems for relatively small heating networks went on stream in 2023 with an aggregate collector area of 13 955 m^2. A further nine systems with combined capacity of 79 MW are being installed (equating to a solar thermal collector area of 112 424 m^2) and some are slated for commissioning in 2024, such as the Sonderhausen project that will be equipped with 6 086 m^2 of high-vacuum flat plate collectors and should be operating by the end of Q2. Construction work on the Leipzig district heating network (65 000 m^2, Ritter XL collectors), which will be Germany's largest, kicked off in March 2024 and should be delivering heat by the beginning of 2026. The April 2023 Ritter XL press release states that solar heat will cover about 20% of the daily heat demand in summer and 2% of the annual demand made on the Leipzig network.

Elsewhere in Europe, another major SDH project, that of Groningen in the Netherlands, whose construction started at the end of 2022, is nearing completion. It boasts 48 000 m^2 of collec-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4

Heat consumption from solar thermal in the countries of the European Union in 2022 and 2023 (in ktoe)*

	2022			2023		
	Total	*of which final energy consumption*	*of which derived heat***	Total	*of which final energy consumption*	*of which derived heat***
Germany	837.0	*834.9*	*2.1*	784.7	*781.7*	*3.0*
Spain	344.1	*344.1*	*0.0*	349.7	*349.7*	*0.0*
Greece	319.6	*319.6*	*0.0*	337.2	*337.2*	*0.0*
Italy	263.2	*263.0*	*0.2*	277.3	*277.0*	*0.3*
France	235.6	*235.6*	*0.0*	244.2	*244.2*	*0.0*
Austria	178.0	*175.1*	*2.9*	171.3	*168.2*	*3.1*
Portugal	110.5	*110.5*	*0.0*	114.9	*114.9*	*0.0*
Poland	90.8	*90.8*	*0.0*	81.8	*81.8*	*0.0*
Cyprus	76.9	*76.9*	*0.0*	78.0	*78.0*	*0.0*
Denmark	81.9	*15.3*	*66.6*	77.0	*14.4*	*62.6*
Bulgaria	32.0	*32.0*	*0.0*	33.2	*33.2*	*0.0*
Netherlands	27.9	*27.9*	*0.0*	28.1	*28.1*	*0.0*
Belgium	27.9	*27.9*	*0.0*	26.4	*26.4*	*0.0*
Czechia	20.0	*20.0*	*0.0*	20.7	*20.7*	*0.0*
Hungary	16.0	*16.0*	*0.0*	17.6	*17.6*	*0.0*
Croatia	16.1	*16.1*	*0.0*	16.4	*16.4*	*0.0*
Ireland	14.1	*14.1*	*0.0*	14.1	*14.1*	*0.0*
Slovakia	9.1	*9.1*	*0.0*	9.6	*9.6*	*0.0*
Sweden	9.8	*9.8*	*0.0*	9.5	*9.5*	*0.0*
Slovenia	7.2	*7.2*	*0.0*	6.0	*6.0*	*0.0*
Malta	3.2	*3.2*	*0.0*	2.9	*2.9*	*0.0*
Finland	2.6	*2.6*	*0.0*	2.6	*2.6*	*0.0*
Luxembourg	2.5	*2.5*	*0.0*	2.6	*2.6*	*0.0*
Romania	0.8	*0.8*	*0.0*	0.8	*0.8*	*0.0*
Latvia	0.9	*0.0*	*0.9*	0.7	*0.0*	*0.7*
Estonia	0.0	*0.0*	*0.0*	0.0	*0.0*	*0.0*
Lithuania	0.0	*0.0*	*0.0*	0.0	*0.0*	*0.0*
Total EU-27	**2 727.7**	**2 654.9**	**72.8**	**2 707.5**	**2 637.7**	**69.8**

** Gross heat production in the transformation sector and Final energy consumption in «Industry» and «other sectors» excluding «transport». ** Derived heat is equivalent to Gross heat production in the transformation sector.* ***Source: Eurostat***

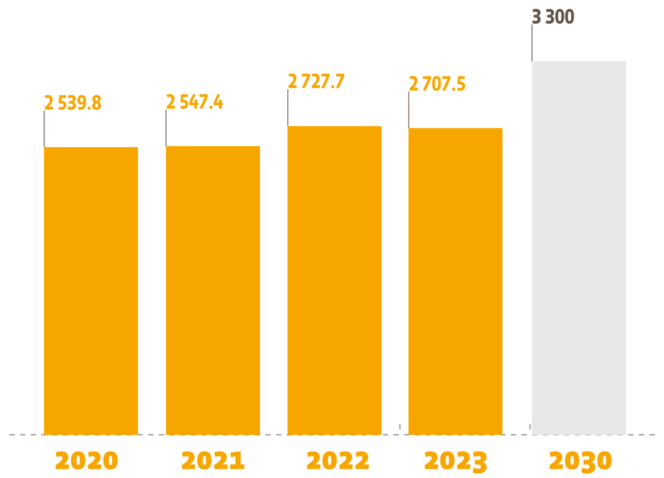
tor area (33.6 MWth of capacity). The plant will produce 25 GWh of solar heat, taking the solar energy share of the city's total energy consumption to 25%, while reducing annual emissions by 6 000 tCO2 p.a. The plant project was subsidized by an SDE+ government grant.

THE SPECTRE OF A DROP IN THE SOLAR THERMAL COLLECTOR AREA IN OPERATION

Eurostat claims that the total area of the European Union's solar thermal base stood at 59.6 million m² at the end of 2023, which is a 0.9% increase on the 2022 level, implying that its aggregate area increased by about 507 331 m². This assessment includes the three main solar thermal technologies (glazed flat collectors, vacuum tube collectors and non-glazed collectors) and factors in the decommissioning hypotheses submitted by each Member State. Some countries are struggling to increase their total collector areas in service, while the collector bases of others are starting to contract. The volumes decommissioned at the start of the millennium are close to the currently installed volumes, which may explain this trend (the EU market in 2003 stood at about 1.7 million m²). Decommissioning will be more widespread in coming years and stems from the particularly high installation rates of the second half of the noughties through to the start of the 2010s (which culminated at 4.5 million m² in 2008). If the market does not pick up significantly a few years down the line, this trend will raise the issue of whether solar heat contributions can meet European Union targets. In the meantime, the volume of solar thermal heat, be it directly consumed by the end user or delivered by heating networks, slipped slightly in the European Union (by 0.7% between 2022 and 2023) to 2 707.5 ktoe (including 69.8 ktoe of heat sold from heating networks). Lower sunshine levels in 2023 in many EU countries and particularly Germany also played a part in this decline.

5

EurObserv'ER projection of solar thermal heat consumption in the EU-27 (in ktoe)*



**Final energy consumption and gross heat production in the transformation sector .*
Source: EurObserv'ER

THE MAJOR CHALLENGE OF DECARBONIZING HEAT

Now, from the climate change combat perspective, the solar thermal market's set-back in 2023 is nothing to cheer about. As Solar Heat Europe acknowledged in an April 2024 press release, "The current growth rate of our sector falls short of the EU Solar Strategy's ambitions, which suggest our sector should at least triple by 2030—from 40.5 GWth to 140 GWth. Clearly, we need to scale up!"
The scale change, is what the European Union public decision-makers and institutions are trying to implement via European regulations. The revised Energy Performance of Buildings Directive that was finally adopted in April 2024 by the European Parliament and published in the Official Journal of the European Union on 5 May 2024 addresses this challenge. A future key to the success of the renewable heat market will also entail system hybridization, an element clearly touted by the European Commission in the RePowerEU plan: "Solar heat and solar power combined with heat pumps can replace natural gas boilers for heating in residential or commercial spaces. Solar energy in the form of electricity, heat or hydrogen can replace natural gas consumption in industrial processes". ■

HYDROPOWER

The water situation across the European Union improved in 2023, after suffering one of the worst recorded hydroelectric deficits in 2022. Eurostat puts gross hydropower output produced by natural water flow, i.e., excluding electricity produced by pumped storage, at 329.9 TWh in 2023 in the EU-27, at 19.4% above its 2002 level (276.2 TWh). However, this is below its 2020 (347.2 TWh) and 2021 (348.4 TWh) output levels. Pumped-storage output remained stable between 2022 and 2023. It slipped from 31.3 to 31.2 TWh and was at a high level compared to previous years.

Most EU countries registered double-digit growth rates for hydropower output in 2023. The largest rises were enjoyed by Italy (42.7%, 12.1 TWh), France (24.5%, 11.1 TWh), Spain (42.1%, 7.4 TWh), Austria (17.5%, 6 TWh) and Portugal (84.2%, 5.5 TWh). In the southern countries, such as Spain and Portugal, extreme output variations can be felt from one year to another depending on rainfall and drought events. Sweden is one of the few countries to have suffered a drop in hydropower output between 2022 and 2023 (5.3%, 3.7 TWh) along with Bulgaria (19%, 0.7 TWh).

It should be pointed out that for the purpose of calculating the countries' renewable energy targets, hydropower output is normalized over the last fifteen years to mitigate the effect of hydraulicity. The normalized hydropower output adopted for 2023 across the EU by Eurostat was 346.4 TWh, which is 0.4 % higher than in 2022 (345.1 TWh). Thus, the normalized hydropower output figure across the EU was higher than actual hydropower output (16.5 TWh difference).

As regards capacity, Eurostat distinguishes three categories of hydropower plants: "pure hydro plants" that only use direct inputs of natural water but have no pumped-storage capacity to raise water upstream of the dam. Thus, all their output is qualified as renewable. Mixed hydro plants have natural water input using all or part of the equipment to pump water upstream of the dam. These plants can also generate electricity with the natural flow in addition to the pumped water. The only part of the output qualified as renewable is produced using natural flow. Lastly, pumped hydroelectric energy storage (PHES) plants or pure pumped storage plants, are not linked to a water course and do not use natural water flow, thus the electricity they generate is not considered as renewable. A PHES plant comprises two reservoirs at different altitudes. They store the energy by pumping water from the lower reservoir to the upper reservoir when both electricity demand and the market price of electricity are low and restore it when both electricity demand and the price are high.

Eurostat quantified net maximum capacity of the EU-27 pure hydro plants at 106 648 MW in 2023 (105 769 MW in 2022), while the net maximum capacity of mixed hydro plants slipped to 23 857 MW in 2023 (from 24 231 MW in 2022). If we only consider pure hydro plants, the five best-endowed countries were France (19 225 MW), Sweden (16 307 MW), Italy (15 660 MW), Spain (13 738 MW) and Austria (9 392 MW).

1

Hydraulic capacity of pure hydro plants, mixed plants and pure pumped plants in the European Union countries in 2022 and in 2023 (in MW)*

	2022				2023			
	Pure hydro power	Mixed hydro power	Pure pumped hydro power	Total	Pure hydro power	Mixed hydro power	Pure pumped hydro power	Total
France	18 863.7	5 372.3	1 727.7	**25 963.7**	19 224.8	5 372.8	1 727.7	**26 325.2**
Italy	15 598.7	3 334.1	3 928.0	**22 860.8**	15 660.0	3 282.5	3 969.6	**22 912.0**
Spain	13 734.5	3 071.2	3 331.4	**20 137.1**	13 737.6	3 071.2	3 331.4	**20 140.2**
Sweden	16 300.0	99.0	0.0	**16 399.0**	16 307.0	99.0	0.0	**16 406.0**
Austria	9 127.8	5 796.3	0.0	**14 924.1**	9 391.6	5 561.5	0.0	**14 953.1**
Germany	4 436.0	1 134.0	5 353.0	**10 923.0**	4 566.0	1 040.0	5 345.0	**10 951.0**
Portugal	4 541.4	3 647.2	0.0	**8 188.6**	4 539.4	3 647.2	0.0	**8 186.6**
Romania	6 293.2	277.9	91.5	**6 662.6**	6 317.8	277.9	91.5	**6 687.2**
Greece	2 722.0	699.0	0.0	**3 421.0**	2 760.0	699.0	0.0	**3 459.0**
Bulgaria	2 335.2	149.0	864.0	**3 348.2**	2 337.3	149.0	864.0	**3 350.3**
Finland	3 171.0	0.0	0.0	**3 171.0**	3 169.0	0.0	0.0	**3 169.0**
Slovakia	1 616.0	0.0	916.0	**2 532.0**	1 615.0	0.0	916.0	**2 531.0**
Poland	607.9	376.0	1 423.0	**2 406.8**	611.5	376.0	1 423.0	**2 410.4**
Czechia	1 113.6	0.0	1 171.5	**2 285.1**	1 116.9	0.0	1 171.5	**2 288.4**
Croatia	1 930.4	275.3	0.0	**2 205.7**	1 908.9	281.0	0.0	**2 189.9**
Latvia	1 587.7	0.0	0.0	**1 587.7**	1 587.7	0.0	0.0	**1 587.7**
Belgium	123.3	0.0	1 307.0	**1 430.3**	124.3	0.0	1 307.0	**1 431.3**
Slovenia	1 166.1	0.0	180.0	**1 346.1**	1 170.8	0.0	180.0	**1 350.8**
Luxembourg	34.0	0.0	1 296.0	**1 330.0**	33.9	0.0	1 296.0	**1 329.9**
Lithuania	117.0	0.0	760.0	**877.0**	117.0	0.0	760.0	**877.0**
Ireland	237.0	0.0	292.0	**529.0**	237.0	0.0	292.0	**529.0**
Hungary	60.0	0.0	0.0	**60.0**	60.0	0.0	0.0	**60.0**
Netherlands	37.7	0.0	0.0	**37.7**	37.7	0.0	0.0	**37.7**
Estonia	8.0	0.0	0.0	**8.0**	10.0	0.0	0.0	**10.0**
Denmark	6.6	0.0	0.0	**6.6**	7.1	0.0	0.0	**7.1**
Total EU-27	**105 768.9**	**24 231.2**	**22 641.1**	**152 641.2**	**106 648.3**	**23 857.0**	**22 674.6**	**153 179.9**

** Net maximum electrical capacity.* ***Source: Eurostat***

THE EU REINVESTS IN HYDROELECTRIC STORAGE

With more frequent disturbances to the availability of water caused by climate change in the EU, increasing hydropower's contribution presents an ongoing challenge. One of the obvious implications of climate change is the heightened unpredictability of production, with a sharp increase in both drought and flooding episodes that affect the operation of dams and underline the justification for water storage.

The rapid development of "variable" renewable energies such as wind power and solar photovoltaic power has also increased the European electricity system's flexibility needs. These needs have opened up new prospects for pumped-storage hydropower production and the modernization of Europe's existing hydropower fleet.

Furthermore, the new (temporary) agreement on the electricity market reform passed in January 2024 between the European Council and the European Commission, obliges EU Member States to assess their flexibility solution needs and set targets to reduce their reliance on fossil fuels. To do so, they will be empowered to introduce new support mechanisms, in particular to meet demand and manage storage. The 2024 World Hydropower Outlook – Opportunities to advance net zero published by the IHA (International Hydropower Association) give a few examples of new projects announced in 2023 in the European Union countries. Worth noting are the Ebensee pumped storage power plant on Traunsee lake, Austria, developed by EnergieAG, whose preparatory site work kicked off in 2023.

2

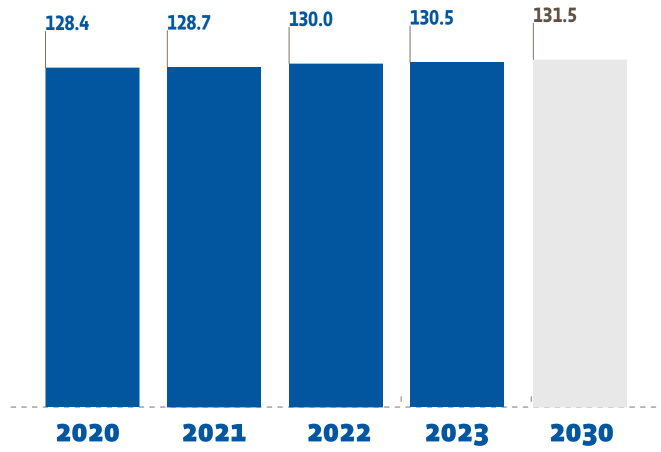
Hydraulic gross electricity production (pumping excluded) in the European Union (in TWh) in 2022 and 2023

	2022	2023	Normalised production 2023*
Sweden	69.871	66.187	67.494
France	45.521	56.657	60.258
Austria	34.625	40.673	43.009
Italy	28.398	40.517	47.813
Spain	17.590	24.996	30.167
Germany	17.624	19.894	20.057
Romania	13.977	18.137	15.849
Finland	13.492	15.200	14.502
Portugal	6.536	12.039	12.778
Croatia	5.460	8.161	6.858
Slovenia	3.149	5.021	4.607
Slovakia	3.678	4.686	4.302
Greece	3.855	3.815	5.130
Latvia	2.750	3.794	2.932
Bulgaria	3.803	3.080	4.043
Poland	1.968	2.410	2.332
Czechia	2.093	2.363	2.220
Ireland	0.701	0.943	0.761
Lithuania	0.464	0.450	0.439
Belgium	0.271	0.407	0.348
Hungary	0.178	0.222	0.237
Luxembourg	0.064	0.089	0.096
Netherlands	0.050	0.069	0.084
Estonia	0.023	0.024	0.041
Denmark	0.015	0.020	0.016
Total EU-27	**276.156**	**329.854**	**346.372**

Normalised production according to Directive 2018/2001 (EU). **Source: Eurostat*

3

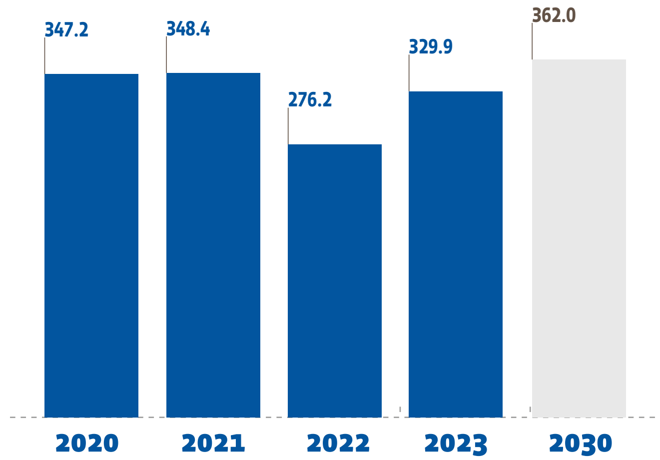
EurObserv'ER projection of the net hydraulic capacity (pure pumping excluded) in the EU-27 (in GW)



Source: EurObserv'ER

4

EurObserv'ER projection of hydroelectricity production (without pumped storage) in the EU-27 (in TWh)



Source: EurObserv'ER

Construction should take four years and the 170-MW variable-speed reversible pump turbine, supplied by ANDRITZ Hydro, should start operating towards the end of 2027. In Estonia, the Zero Terrain underground STEP project, at Paldiski, developed by Energislav, was granted its licence in January 2023 and is ready for the construction phase. This new 500-MW project is one of the EU's "projects of common interest" backed by the Connecting Europe Facility. At the end of 2023, the Finnish energy company Suomen Voima, announced its intention to develop a new energy storage project, Noste, in Northern Finland. It will construct one to three small-scale pumped-storage hydropower plants, for total capacity of over 100 MW and take up total investment of 300 million EUR. The European Commission has awarded a 26.3 million EUR grant to finance the project under the EU rules on state aid. Spain's Chiara STEP plant on Gran Canaria has been given a 90 million EUR European Regional Development Fund grant. Once completed, the hydropower plant will have 200 MW in turbine mode, 220 MW in pumping mode and 3.6 GWh of total storage capacity. In March 2023, the Spanish government gave Iberdrola the go-ahead for the Valdecañas PHES project. The power plant will have a total of 275 MW of capacity and is designed as a hybrid system that will include an integrated 15-MW chemical battery unit. ■

GEOTHERMAL ENERGY

Geothermal energy systems extract the heat contained in the subsoil and use it to heat buildings, cool them or produce electricity. Geothermal techniques and uses differ depending on the temperature of the soil or aquifers where water is drawn. When the temperature ranges from 30 to 150°C (from a depth of a few hundred metres to about 2 kilometres), geothermal heat can be used for collective urban heating (heating networks) or be directly drawn to heat individual homes, buildings or farming business activities. One or more very high capacity heat pumps (HPs) may be associated to enhance the performance of a geothermal heating network, by increasing the temperature that can be harnessed by the network and making the most use of the available geothermal energy.
Electricity can also be produced using binary cycle technology when the aquifer temperature ranges from 90 to 150°C. In that case, the abstracted water, be it liquid or gaseous when it reaches the surface, transfers its heat to another working fluid that vaporizes at below 100°C. The steam obtained in this way drives a turbine to produce electricity. These plants can operate in cogeneration mode and simultaneously produce electricity and heat to supply a network. Above 150°C (up to 250°C), water extracted from depths of more than 1 500 metres reaches the surface as steam and can be directly used to drive electricity generating turbines. This is known as high-energy geothermal, that is found in volcanic and plate boundary regions. Heat pump systems that extract surface heat from the ground and surface aquifers are examined apart, and by convention are not included in the official geothermal energy production data.

1

Capacity installed and net capacity of geothermal electricity plants in the EU in 2022 and 2023 (in MW)*

	2022		2023	
	Capacity installed	Net capacity	Capacity installed	Net capacity
Italy	915.5	771.8	915.5	771.8
Germany	59.0	52.0	57.0	52.0
Portugal	34.0	29.1	34.0	29.1
Croatia	16.5	10.0	16.5	10.0
France	17.2	16.2	17.2	16.2
Hungary	3.4	3.0	3.4	3.0
Austria	1.2	0.3	1.2	0.3
Total EU-27	1 046.8	882.3	1 044.8	882.3

** Net maximum electrical capacity.* ***Source: EurObserv'ER (capacity installed), Eurostat (Net capacity)***

EDF

2

Gross electricity generation from geothermal energy in the European Union countries in 2022 and 2023 (in GWh)

	2022	2023
Italy	5 836.9	5 692.2
Germany	206.0	195.0
Portugal	194.6	207.5
France	113.6	128.8
Croatia	72.7	20.6
Hungary	4.0	16.0
Austria	0.002	0.005
Total EU-27	6 427.8	6 260.1

Source: Eurostat

HEAT PRODUCTION

Geothermal heat production has many applications. The main outlet is space heating for homes and commercial premises, but there are other outlets including farming (heating greenhouses, drying agricultural produce, etc.), pisciculture, swimming pool heating and cooling. The official statistical bodies still do not monitor the thermal capacity of the installations accurately or regularly, because of this plethora of uses.

The EGEC (European Geothermal Energy Council) monitors the capacity of Europe's and the European Union's geothermal heating networks. It claims that 299 EU geothermal heating (and cooling) networks were in service in 2023, with 2 286.3 MWth of combined capacity (2 254.2 MWth in 2022), and that eight new urban geothermal heating and cooling systems went on stream in the EU (11 in 2022), amounting to an additional capacity of 32.1 MWth (compared to 90.7 MWth in 2022). Going into detail, Finland deployed three new geothermal plants (3.7 MWth), the first of which supplies a heating network, Romania added two (12.2 MWth), Germany added one (7.5 MWth), the Netherlands added one (7 MWth) and Slovakia added one (3.5 MWth). EGEC's "Geothermal market report 2023" that came out in July 2024, presents more information with a country-by-country breakdown of geothermal heating network capacities.

Turning to new installations, the geothermal heating plant constructed by QHeat in the Varisto district of Vantaa for Vantaan Energia is Finland's first geothermal plant to be linked to a heating network. The plant has three heating wells about 800 m deep, and will produce about 2 600 MWh per annum, which cover the annual heating demand of about 130 private homes. QHeat inaugurated two other plants – one at Finnoo that has a heating well 1000-m deep, that will deliver heat to six residential blocks (for a total of 14 000 m^2), in addition to a geothermal heat storage system on the Lounavoima waste-to-energy plant site at Salo. The system will be hooked up to the town's urban heating network from the winter of 2024–2025. In June 2024, it was decided to construct another three wells on the site, the last of which should be completed in the summer of 2025.

Germany commissioned its fortieth geothermal heating plant (7.5 MWth) that was inaugurated by Chancellor Olaf Scholz in Schwerin in April 2023. It will use geothermal water pumped from a depth of 1 300 m extracted at 56 ° Celsius. The heat will then be transferred to an intermediate circuit backed by a heat pump to raise the water's temperature. The plant will meet the heating needs of 2 000 households, i.e., about 15% of Schwerin's district heating customers.

The geothermal heat highlight of 2023 was the inauguration of the European Union's biggest geothermal heating network (235.8 MWth) by Elisa Ferreira, the European Commissioner for Cohesion and Reforms. This network located at Szeged, in Hungary, has been fully operational since 2024. The European Union invested 23 million euros to extend the existing network and supply geothermal heat to 28 000 inhabitants and over 400 public buildings. Szeged's heating network is Europe's biggest outside Iceland. It has 27 geothermal wells, 16 heating plants and a 250-km long distribution pipe network.

Eurostat estimates that the processing sector across the European Union produced 344.8 ktoe of heat in 2023 (353.1 ktoe in

2022), that is sold and distributed by heating networks. If we add geothermal heat directly used by end users, put at 604.8 ktoe in 2023 (601.2 ktoe in 2022), total geothermal heat consumption by the EU-27 amounts to 949.5 ktoe (954.3 ktoe in 2022). EurObserv'ER deems the YoY drop in geothermal heat sales to be insignificant and locally attributable to a temporary fall in heating and maintenance needs. The recent trend has been positive with a 7.8% gain between 2020 and 2023 for geothermal heat sales and an 8.4% gain for geothermal heat as a whole.

Geothermal heat's growth prospects look very promising through to 2030. The EGEC counted 333 urban heating and cooling plants under development in 2024 across the European Union. Germany (133), France (24), the Netherlands (39) and Italy (21) have the biggest project pipelines, with the potential for more than doubling the number of projects in service in upcoming years than at the end of 2023. The European geothermal heating and cooling networks market is primed for significant growth, driven by political support, technological progress and the need to roll out sustainable energy solutions. The EGEC feels that the emphasis put on low-temperature systems and innovative business models will clear the way for overcoming current challenges and achieving ambitious targets in the future.

ELECTRICITY PRODUCTION

The electricity generating capacity of the European Union's geothermal plants held steady in 2023 at 1 044.8 MW, as no new plants went on stream (Germany's capacity was 2 MW lower than in 2022, according to AGEE-Stat calculations). Eurostat puts net capacity for the EU, which is the maximum capacity deemed exploitable, at 882.3 MW in 2023... the same as in 2022. This capacity is spread across seven countries: Italy (771.8 MW), Germany (52 MW), Portugal (29.1 MW), France (16.5 MW), Croatia (10 MW), Hungary (3 MW) and Austria (0.25 MW). The EGEC identifies about sixty geothermal power plants operating in the European Union, mainly in Italy (36) and Germany (12), three in Portugal (in the Azores), three in France (in Guadeloupe and at Soultz), two each in Austria and Romania, and one each in Croatia and Hungary.

Eurostat reports a slight decline (2.6%) in gross geothermal electricity output over the 12 months to 2023 from 6.4 to 6.3 TWh, recording lower output in Italy, Germany, Croatia and higher output recorded in France, Portugal and Hungary. These annual variations can be attributed to downtime for maintenance operations.

The EGEC primarily blames the adverse context of the 2020–2023 period characterized by the lack of or uncertainty surrounding regulatory support,

3

Heat consumption from geothermal energy in the countries of the European Union in 2022 and 2023 (in ktoe)***

	2022			2023		
	Total	*of which final energy consumption*	*of which derived heat***	**Total**	*of which final energy consumption*	*of which derived heat***
France	190.7	40.2	150.5	193.0	40.2	152.9
Germany	165.3	93.2	72.2	162.6	95.8	66.9
Netherlands	162.4	162.4	0.0	162.4	162.4	0.0
Hungary	154.7	79.8	74.8	159.0	85.4	73.6
Italy	135.3	109.6	25.7	132.2	107.8	24.4
Bulgaria	36.6	36.6	0.0	37.1	37.1	0.0
Poland	31.5	31.5	0.0	32.8	32.8	0.0
Austria	25.0	8.6	16.4	21.6	7.7	13.9
Romania	17.6	11.3	6.4	14.3	8.0	6.3
Slovenia	13.2	12.7	0.5	13.5	13.0	0.4
Greece	7.9	7.9	0.0	7.6	7.6	0.0
Slovakia	4.9	0.7	4.2	4.8	0.8	4.0
Croatia	4.7	4.7	0.0	4.2	4.2	0.0
Portugal	1.8	1.8	0.0	1.9	1.9	0.0
Belgium	1.5	0.0	1.5	1.7	0.0	1.7
Denmark	1.0	0.0	1.0	0.8	0.0	0.8
Spain	0.2	0.2	0.0	0.2	0.2	0.0
Total EU-27	**954.3**	**601.2**	**353.1**	**949.5**	**604.8**	**344.8**

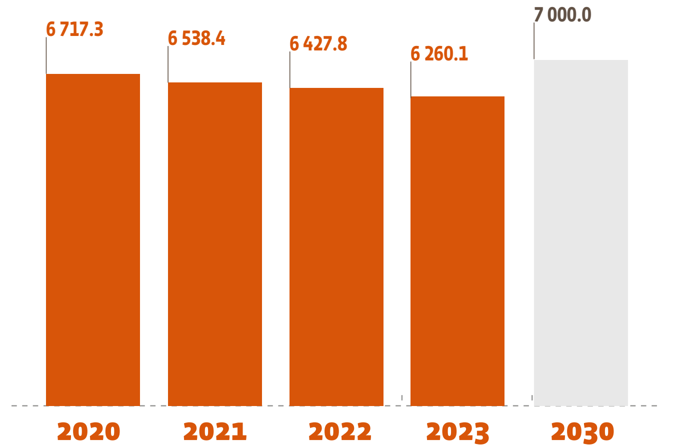
** Heat consumption is equivalent to Final energy consumption in «Industry» and «Others sectors» except transport and gross heat production in the transformation sector. ** Gross heat production in the transformation sector.* ***Source: Eurostat***

the slowdown effects of COVID-19 pandemic, the war in Ukraine, high interest rates and a stagnant electricity market for the absence of new plant commissionings. Hardly any projects will be completed in the short term, given the 5–7-year development time for geothermal power plants. Only one project was commissioned in 2024, that of the Centiba 50-kW pilot geothermal power plant, in the town of Lendava, Slovenia. Construction work kicked off early in 2023 by Petrol Geo on behalf of Dravske Elektrarne Maribor (DEM). The pilot project aims to test patented technology that enables unproductive gas boreholes to be reused to produce geothermal electricity. It uses a geothermal gravity heat pipe to produce sufficient heat flow to produce electricity at depths of over two kilometres. If the pilot project produces conclusive results, the technology will be harnessed for other abandoned gas wells in Slovenia and around the world. Larger-scale projects are under construction. In Germany, drilling started in July 2023 at Geretsried, Bavaria on a commercial project that uses Canada's Eavor Technologies' Eavor-Loop™ system. It is an innovative system that operates in a totally closed circuit with no fracking, GHG emissions, brine production or aquifer contamination. Four loops (eight wells) will be drilled to a depth of 4 500 m and use high-collapse tubular solutions produced by the French company Vallourec. The plant should be fully operational in 2025. During its initial thirty-year lifecycle, it will produce 64 MW of thermal energy and 8.2 MW of electricity and deliver 44 000 tonnes of CO2 emission savings per annum. The project has been backed by a 91.6 million euro European Investment Fund grant and a 45 million euro loan from the European Investment Bank (EIB).

The EGEC is optimistic about the future development of geothermal power plants in Europe. The association reckons that the geothermal electricity market has entered a new development phase with many plants scheduled to come on stream in the next five to seven years. It has identified 34 projects in development and 145 in the study phase in the European Union. Germany should remain the most active EU country for installations through to 2030, with according to the EGEC, 17 projects in the development phase. Countries such as Croatia, France and Italy should also increase their production capacity, while emerging markets like Spain and Greece should start harnessing their geothermal potential for electricity production. ■

4

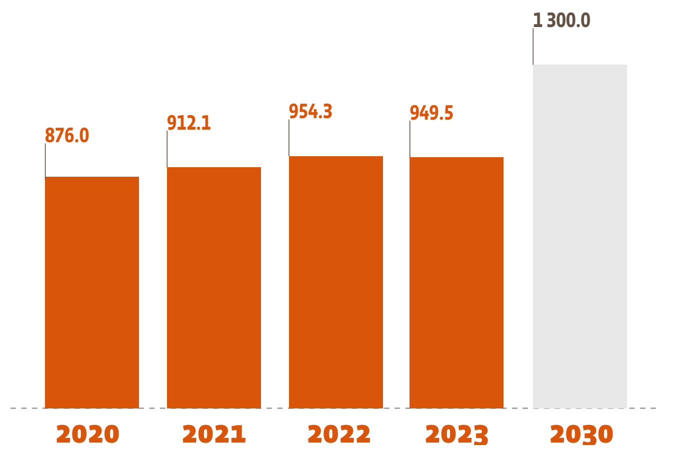
EurObserv'ER projection of geothermal electricity production in the EU-27 (in GWh)



Source: EurObserv'ER

5

EurObserv'ER projection of geothermal heat consumption in the EU-27 (in ktoe)*



** Heat consumption is equivalent to Final energy consumption in «Industry» and «Others sectors» except transport and gross heat production in the transformation sector.* ***Source: EurObserv'ER***

HEAT PUMPS

The heat pump (HP) is one of the key technology options for achieving carbon neutrality, particularly as the electricity used to operate it tends to be decarbonized. HP technology can be used in all types (new, old, residential, tertiary, industrial or agricultural) and sizes of buildings (from single-family houses to large service sector tower blocks). Heat pumps cover heating, domestic hot water production and cooling needs. They can also be used in industrial processes that require heat, primarily in the agrifood sector, greenhouse heating and to raise the temperature of heating networks.

A RANGE OF TECHNOLOGIES

The heat pump system differences need to be understood in order to grasp the significance of their market trends. There are three major families of HPs, distinguished by the particular thermal energy source that they harness. Air source HPs (ASHP) "capture" thermal energy in the ambient air. The second type, geothermal HPs (GSHP) group together the systems that "capture" the ground's thermal energy, and hydrothermal HPs harness the calories in the water (groundwater, lakes, etc.). EurObserv'ER processes the hydrothermal family of HPs' indicators together with those of the GSHP family in the interests of simplicity, and technological resemblance. HPs are also distinguished by their heat (or cooling) distribution method. They are water-borne when the heating method comprises hot water radiators or a hydraulic underfloor circuit and applies to air-to-water air-source HPs and almost all geothermal or ground-source HPs. When the HPs use a wall-mounted unit to blow warm or cold air in reversible mode, they are known as air-to-air HPs. Nowadays, almost all air-to-air HPs operate in reversible mode, and in hot climate countries and regions, the cooling function is often the main if not the only mode of use. Hence, some air-to-air HP markets in the European Union are not directly comparable. Furthermore, HP usages and power ranges differ across the climate zones. This phenomenon raises statistical comparison issues between the various European Union markets, not to mention the fact that in the Northern European countries, Sweden, Denmark and Finland, reversible air-to-air HPs are widely used for heating purposes. A final ASHP category uses the exhaust air of buildings as the heat source, described as exhaust air HPs (EAHP). The main heat distribution method is via the air but there are also water-borne EAHPs. These installations can be used for top-up heating depending on the building's needs.

EU HP SALES APPROACH 6 MILLION UNITS

The 2023 air-water HP market segment performed badly in relation to 2022. A number of factors conspired to bring this about, such as the sharp fall in the gas price on the wholesale market, an inflation shock, a rise in interest rates that hobbled the new build market, and still more worrying, the rollout by several European governments of much less friendly policies and less generous public aids for renewable heating appliances. Sales of reversible air-air HPs were more resilient in 2023 and still account for most HP

1

Market of aerothermal heat pumps in 2022 and 2023 in the European Union (number of units sold)

	2022				2023			
	Aerothermal HP	of which air-air HP	of which air-water HP	of which exhaust air HP	Aerothermal HP	of which air-air HP	of which air-water HP	of which exhaust air HP
Italy	2 200 957	1 911 912	289 045	0	1 947 309	1 835 290	112 019	0
France	1 163 679	808 206	355 473	0	1 216 954	910 420	306 534	0
Spain	414 396	357 796	56 600	0	527 905	465 713	62 192	0
Netherlands	398 011	304 031	93 980	0	451 385	305 086	133 799	12 500
Germany	242 059	0	205 702	36 357	412 788	0	330 358	82 430
Portugal	332 300	331 982	318	0	355 775	355 295	480	0
Sweden	187 213	150 000	19 162	18 051	160 623	113 500	21 289	25 834
Poland	208 574	20 374	188 160	40	110 840	0	110 800	40
Finland	184 587	161 920	19 035	3 632	105 258	90 866	11 715	2 677
Hungary	99 127	87 659	11 468	0	74 347	65 745	8 602	0
Malta	60 796	60 796	0	0	60 796	60 796	0	0
Denmark	83 720	48 472	34 975	273	53 395	32 456	20 803	136
Czechia	57 644	0	57 524	120	52 924	0	52 898	26
Slovenia	38 200	30 400	7 800	0	44 100	31 400	12 700	0
Belgium	23 754	0	23 754	0	40 527	0	40 527	0
Austria	44 645	1 201	43 444	0	39 613	2 047	37 566	0
Ireland	25 288	6 397	17 554	1 337	31 645	156	26 943	4 546
Lithuania	14 866	8 907	5 959	0	28 280	18 450	9 830	0
Greece	30 519	30 519	0	0	21 966	21 966	0	0
Estonia	19 575	13 902	5 636	37	17 500	12 000	5 500	0
Slovakia	12 774	1 219	11 555	0	11 383	1 602	9 771	10
Luxembourg	303	0	303	0	303	0	303	0
Total UE	5 842 987	4 335 693	1 447 447	59 847	5 765 616	4 322 788	1 314 629	128 199

Note: Market data for air-air heat pump for Italy, France, Spain, Portugal and Malta are not directly comparable to others, because they include animportant part of reversible heat pumps whose principal function is cooling. Only heat pumps that meet the efficiency criteria (seasonal performance factor) defined by Directive 2018/2001 (EU) are taken into account. Market data for Romania, Bulgaria, Latvia, Croatia and Cyprus was not available during our study. ***Source: EurObserv'ER***

2

Market of geothermal (ground source) heat pumps in 2022 and 2023 in the European Union (number of units sold)*

	2022	2023
Sweden	28 160	35 470
Netherlands	22 693	26 563
Germany	25 320	24 979
Finland	11 772	11 728
Poland	7 200	8 100
Belgium	5 922	7 331
Austria	5 748	5 911
Denmark	5 113	3 646
France	2 972	3 517
Czechia	2 419	2 696
Estonia	2 191	2 500
Slovenia	1 248	1 355
Italy	625	781
Lithuania	710	670
Spain	246	531
Greece	356	356
Slovakia	319	260
Ireland	190	243
Luxembourg	199	199
Portugal	82	78
Total UE	123 485	136 914

** Hydrothermal heat pumps included. Note: Market data for Romania, Bulgaria, Hungary, Croatia, Latvia, Cyprus and Malta was not available during our study.* ***Source: EurObserv'ER***

3

*Total number of heat pumps in operation in 2022 and 2023 in the European Union **

	2022			2023		
	Aerothermal HP	Geothermal HP	Total	Aerothermal HP	Geothermal HP	Total
Italy	20 831 000	17 723	20 848 723	20 900 000	18 300	20 918 300
France	9 548 000	169 800	9 717 800	10 500 000	166 000	10 666 000
Spain	5 410 730	4 062	5 414 792	5 938 635	4 593	5 943 228
Portugal	2 326 400	1 187	2 327 587	2 586 418	1 265	2 587 683
Sweden	1 767 110	560 997	2 328 107	1 897 595	564 903	2 462 498
Netherlands	1 760 665	125 374	1 886 039	2 196 295	147 837	2 344 132
Germany	1 216 249	449 742	1 665 991	1 611 551	471 103	2 082 654
Finland	1 234 715	157 896	1 392 611	1 339 973	169 624	1 509 597
Denmark	585 783	82 316	668 099	655 279	87 092	742 371
Belgium	631 035	28 524	659 559	671 562	35 855	707 417
Poland	466 032	78 989	545 021	576 872	87 089	663 961
Greece	607 017	4 234	611 251	628 983	4 590	633 573
Malta	535 000	0	535 000	595 796	0	595 796
Austria	232 575	118 070	350 644	271 077	120 419	391 496
Slovenia	308 600	16 014	324 614	337 000	17 370	354 370
Bulgarie	349 667	4 695	354 362	349 667	4 695	354 362
Czechia	266 808	31 812	298 620	319 732	34 508	354 240
Estonia	214 750	23 757	238 507	232 250	26 257	258 507
Slovakia	231 412	4 773	236 185	242 795	5 033	247 828
Hungary	124 251	4 419	128 670	198 598	4 419	203 017
Ireland	101 409	5 418	106 827	133 054	5 661	138 715
Lithuania	45 600	24 800	70 400	73 880	25 470	99 350
Luxembourg	3 095	1 596	4 691	3 398	1 795	5 193
Total UE	**48 797 903**	**1 916 198**	**50 714 100**	**52 260 410**	**2 003 878**	**54 264 288**

*Note: Market data for air-air heat pump for Italy, France, Spain, Portugal and Malta are not directly comparable to others, because they include an important part of reversible heat pumps whose principal function is cooling. Only heat pumps that meet the efficiency criteria (seasonal performance factor) defined by Directive 2018/2001 (EU) are taken into account. *Estimation.*
Source: EurObserv'ER

sales across the European Union, be they for space heating in winter or dealing with the increasingly suffocating heat waves affecting swathes of Europe.
EurObserv'ER estimates that some 5.9 million heat pumps were sold in the EU during 2023, all capacities and technologies taken together (ASHPs, GSHPs, hydrothermal, airborne and water-borne), compared to just under 6 million in 2022, which amounts to a 1.1% slip on the 2022 sales figure. This should be taken as a broad assessment as it includes all the thermodynamic technologies designed to produce heat for space heating, including reversible heat pumps (that produce heat or cooling to order), whose main use is for cooling. This caveat is important, as the market for HPs whose main function is heating, is smaller. The EHPA (European Heat Pump Association) puts European HP sales at 3 million in 2023 – a 6.5% YoY fall (3.2 million HPs sold in 2022). The methodology that EurObserv'ER uses differs from that of the EHPA, as its scope for the inclusion of reversible HPs primarily used to meet summer cooling needs is broader. The national statistics offices responsible for renewable energy accounting also apply this more generous inclusion. This interpretation is justified by the contribution that these appliances make towards EU's renewable energy production targets both for heating and cooling, provided that their performance criteria make them eligible. Incidentally, the accounting of renewable energy production used for cooling and cooling networks has considerably improved since the Commission defined a specific calculation method (delegated regulation 3022/759 of 14 December 2021). The figures published in tables 1 & 2 are particularly representative of the residential and tertiary markets (with power ranges starting at a few kW to several tens of kW), as the medium- and high-capacity HP market is much smaller.
It should be remembered that the various types of HPs produce different amounts of renewable energy. Their outputs depend on the thermal energy source tapped (ground, water, air), the application (heating or cooling), the usage period and installation climate zone. The unit power ratings of air-to-air HPs are generally much lower than those of water-borne HPs. A low power reversible air-to-air HP installed in a hot climate zone primarily used for cooling will produce much less renewable heat than a ground-source or air-to-water HP installed in Finland or Sweden.

AIRBORNE HPS DOMINATE THE EUROPEAN MARKET

Reversible air-to-air ASHPs still dominate HP sales in the European HP market, which EurObserv'ER puts at over 4.3 million units for 2023... a similar sales volume to 2022. Italy is the European Union's biggest market with upwards of 1.8 million air-to-air systems sold in 2023.
The water-borne ASHP market specifically caters for heating needs, even though most units provide a cooling mode. After the exceptional year of 2022, when the sales volume increased by 71.8% to almost 1.5 million units (1.45 million), the 2023 market stumbled by 9.2% to just over 1.3 million air-water HPs. Most of this fall can be attributed to the poorer performances of the markets that had surged in 2022 that recorded the following year-on year percentage falls: Italy (61.2%), France (13.8%), Poland (41.1%), Finland (38.5%) and Denmark (40.5%). This shortfall was not made up for by the positive thrust of the German (60.6%), Dutch (42.4%) and Belgian (70.6%) markets.
The geothermal HP segment also caters specifically for heating needs but is less popular. The growth of this market remained positive across the European Union. Between 2022 and 2023, the number of geothermal and hydrothermal heat pumps increased by about 10.9% to 136 914 units sold in 2023. Sweden, Germany, the Netherlands, Finland and Poland are the European Union's biggest markets for these HPs.
Taken together, the sales volume of water-borne HPs (air-to-water ASHPs, geothermal and hydrothermal) was about 1.5 million units (1 451 543 systems) amounting to a 7.6% year-on-year fall.

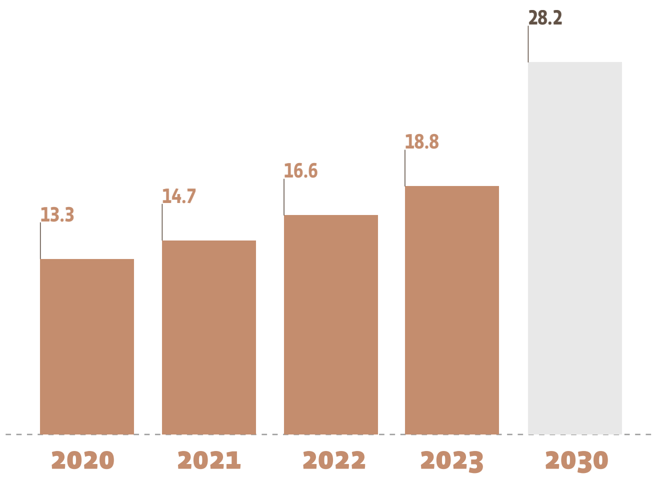
THE EUROPEAN HP BASE STANDS AT ABOUT 54.2 MILLION HPS

Estimating the number of HPs in service is a tricky task as the exercise must make allowance for the decommissioning assumptions factored in by each country and the availability of statistics supplied by the Member States or HP industry associations. EurObserv'ER puts the combined total of installed HPs in the European Union at roughly 54.3 million units (52.3 million ASHPs and 2 million GSHPs) at the end of 2023. This figure reflects not only

the heating uses, but the cooling and heating uses, provided that the system performance coefficients meet the Renewable Energy Directive criteria.
In its 2024 European Heat Pump Market and Statistics report, the EHPA, whose approach to heat pump is more restrictive, put the total base of HPs in service in Europe in 2023 mainly used for heating (space heating and domestic hot water production) at about 24 million (23.96 million including Norway, the UK and Switzerland). The HP equipment rate of Europe's building stock where HPs are the main heating mode, is about 20% on the basis of 115–120 million buildings.
HPs are not only identified as a promising key technology for decarbonising the building sector but are also accepted as harnessing one of the technologies that already makes the greatest contribution to the increase in renewable energy production. The Eurostat SHARES tool puts the total renewable heating contribution of HPs in the EU-27 at 18.8 Mtoe ... a YoY rise of 2.2 Mtoe. In 2023, air source and hydrothermal HPs produced 15.9 Mtoe of renewable energy compared to 2.8 Mtoe by geothermal HPs. By the way, since 2022, the renewable energy output of HPs for renewable heat and cooling has outstripped the renewable energy output of district heating networks (derived heat). In 2023, they accounted for over 16.9% of the renewable heat and cooling total. SHARES puts the renewable energy output of HPs for refrigeration and cooling at 859 ktoe in 2023 (852.7 ktoe in 2022).

4

EurObserv'ER projection of renewable energy from heat pumps for heating in the EU-27 (in Mtoe)



Results for 2020 take into account specific calculation provisions as in place in Directive 2009/28/EC, whereas results for 2021, 2022 and 2023 follow Directive (EU) 2018/2001.
Source: EurObserv'ER

FIRST NEGATIVE SIGNALS ABOUT EUROPEAN AMBITIONS

Unfortunately, the slowdown in sales observed since the second half of 2023 continued in 2024 and resulted in radical restructuring of the European HP sector (factory and production line closures). The fall can be blamed on the reconsideration of some aids as new political regimes came to power, divergences in national coalitions and also on the hike in Europe's electricity price and the slump of the gas price on the markets.
The stars seemed to be lined up for long-term, strong growth, driven by heat pump sales and a clear political vision by the European institutions on the priority role of this technology in efficiently decarbonizing buildings, industry and local heating networks and achieving the "Fit for 55" targets for 2030 and REPowerEU. The Net-Zero Industry Act (NZIA), that aims to stimulate European production of green technologies, also views HP technology as strategic. According to the Commission's impact analysis for its 2040 climate target (PRIMES energy modelling), about 60 million heat pumps whose prime application is space heating will be required by 2030 to achieve these goals. That means tripling the number of heat pumps in Europe within seven years. The European Commission, taking a leaf out of the Solar Energy and Wind Power Action Plans had imagined a Heat Pump Action Plan as early as 2023 to achieve this. It was depicted as a strategic plan that would set out the terms for accelerating the rollout of this technology over the European market. The action plan aimed to fast-track the deployment of heat pump installations, through financial support measures, decarbonization incentives and strengthening the supply chains. But above all, it was to provide the sector with regulatory security as well as a strong, renewed political signal in favour of this technology.
A public consultation was launched in April 2023 aiming for publication before the year was out. Sadly, when the end of the year came, publication of this action plan was removed from the agenda and postponed until after the European elections and the resumption of these topics by the new European Commission. The reason for this U-turn apparently stemmed from the failure to agree on the question of whether or not to make HP installation compulsory. On 14 May 2024, some fifteen EU countries including France, Spain, Denmark (Germany, the Netherlands and Italy being non-signatories) had asked the Commission, via an informal communication (joint non-paper) for the rapid publication of a Heat Pump Action Plan reminding it that the heating and cooling sector had an important role to play to achieve the European Union's 2040 climate goals and further reminding it of the essential role of the electrification of heating needs. It would appear that the process has been resuscitated. The European Commission is currently working on an Electrification Action Plan scheduled for Q1 2026 and on 30 January 2025, the Commission organized the first Heat Pump Accelerator Platform meeting to draw up a plan to revive the European market. ■

5

Primary production of ambient heat (heat pumps) for heating according the Renewable Energy Directive (EU) 2018/2001 (in ktoe)

	2022	2023
France	4 121.2	4 564.0
Italy	2 744.2	2 843.2
Germany	1 705.8	2 048.7
Sweden	1 620.5	1 625.8
Spain	1 211.2	1 345.7
Portugal	850.3	884.5
Finland	649.6	705.4
Poland	519.7	617.0
Netherlands	481.9	609.6
Austria	486.3	568.4
Greece	462.9	489.4
Czechia	386.3	462.7
Romania	0.0	449.6
Denmark	378.2	425.6
Belgium	245.3	285.2
Bulgaria	153.9	169.5
Estonia	113.5	142.3
Slovakia	86.3	113.6
Ireland	80.6	95.9
Lithuania	63.3	82.3
Hungary	53.1	69.5
Slovenia	60.0	64.5
Cyprus	48.6	49.1
Malta	18.7	20.7
Croatia	14.1	15.7
Luxembourg	5.4	6.3
Latvia	0.0	0.0
UE 27	16 560.9	18 754.2

2022 data for Romania not available. ***Source: Eurostat***

BIOGAS

Methanation is a natural biological process in which many micro-organisms break down organic matter in an oxygen-free environment. Biogas produced by anaerobic fermentation breaks down into three sub-sectors that are segmented by the origin and treatment of the waste. They include biogas from non-hazardous waste storage facilities (landfill biogas), anaerobic digestion of urban or process waste water treatment plant sludge (sludge digestion gas) and the anaerobic digestion of non-hazardous waste or raw plant matter ("other biogas" category). This "other biogas" category is very broad and covers various installation types. It includes small farming anaerobic digesters that basically ferment agricultural materials from farms, and larger territorial or industrial methanation plants. These co-digestion plants can treat a mixture of different feedstocks (agricultural waste, food processing industry waste, green waste and so on). It also includes household waste and biowaste anaerobic digestion units that treat selectively collected biowaste or the organic fraction of plant-sorted household waste. Landfill biogas is naturally produced in non-hazardous waste storage facilities by decomposition. The organic fraction of this waste is recovered by capture networks. So, this is not considered as methanation biogas, because it is not produced with the aid of a digester. A fourth biogas sector is also monitored in international nomenclature and results from heat treatment ("thermal process biogas") by thermal gasification of solid biomass (wood, forest residue, solid and fermentescible household waste) or by hydrothermal gasification of liquid biomass. These processes result in the production of a methane-rich syngas that is purified to biomethane. Biogas can be used unaltered in production plants that operate using low-methane gas (50–75%, depending on the production sources) or if previously "washed" to be converted into biomethane, a gas with >97% of methane content, similar to natural fossil gas. This biogas (or biomethane) can in turn be used directly locally as electricity (in cogeneration), heat, or vehicle fuel. Alternatively, when accessibility to the natural gas grid is economically viable, biomethane can be injected into the grid once it has been odorised with THT (tetrahydrothiophene). As a result, its use can be postponed and occur away from its production site. This solution offers better energy yield with 80% of the primary energy recovered compared to 40–55% for cogeneration). The biomethane will be used in the same way as grid gas, as electricity in gas-fired or CHP plants, as heat from the processing sector (e.g.: heat grid) or used directly by the final user in industry (process heat, cooling), households (heating, domestic hot water, cooking, etc.) and even as fuel for natural gas vehicles.

EU BIOGAS OUTPUT NEARING 16 MTOE

The three year-old conflict between Russia and Ukraine brought the need to accelerate the European Union's transition to energy self-sufficiency to a head and in doing so has given the European biogas sector a vital strategic role. Yet, the rollout of the May 2022 REPowerEU plan's biogas chapter by the European Union has yet to make its full impact felt. Europe's biogas sector producers and industry players are making headway but explain that they need time to significantly increase their output, time to obtain administrative authorizations and build their production units. We recall that this plan was implemented to protect EU citizens and businesses from energy shortages, accelerate the transition to clean energy and retrench European purchases of Russian hydrocarbons. Eurostat observes that European Union primary energy output from biogas between 2022 and 2023 remained stable to 15.8 Mtoe (0.1%, i.e., 23.6 ktoe less). The breakdown of the various biogas stocks has hardly changed. In 2023, the "Other methanation biogas" category accounted for 83.8% of total output, followed by sludge digestion biogas (7.9%), landfill biogas (7.4%) and thermal biogas (0.8%). This apparent stability masks rising and falling national production variations that cancel each other out at EU level.

Eurostat reports that the trend in recent years for France and Denmark to produce the most biogas energy was reaffirmed in 2023. French biogas output increased by 266.4 ktoe (16.4%) to 1 890 ktoe and Danish output by 66.6 ktoe (+9.6%) to 758.1 ktoe. Poland also produced more (a total of 376.2 ktoe by adding 6.7%, or 23.5 ktoe). This contrasts with the European Union's top two biogas producer countries whose output fell in 2023... Germany's fell by 4.3% (351.6 ktoe) to 7 743.1 ktoe

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Primary energy production from biogas in the European Union in 2022 and 2023 (in ktoe)

	2022					2023				
	Landfill gas	Sewage sludge gas	Other biogases from anaerobic fermentation	Thermal biogas	Total	Landfill gas	Sewage sludge gas	Other biogases from anaerobic fermentation	Thermal biogas	Total
Germany	100.7	466.7	7527.3	0.0	**8094.7**	94.5	463.2	7185.4	0.0	**7743.1**
Italy	252.9	47.1	1765.7	5.8	**2071.5**	239.1	76.4	1690.8	5.7	**2012.0**
France	395.2	57.7	1170.7	0.0	**1623.6**	408.8	71.2	1410.0	0.0	**1890.0**
Denmark	3.1	28.3	660.0	0.0	**691.4**	2.8	28.0	727.3	0.0	**758.1**
Czechia	19.0	43.7	535.7	0.0	**598.4**	18.2	45.0	534.3	0.0	**597.5**
Netherlands	10.3	63.1	360.6	0.0	**434.1**	9.9	69.1	369.0	0.0	**448.0**
Poland	52.1	129.4	171.2	0.0	**352.7**	43.3	132.3	200.6	0.0	**376.2**
Spain	154.5	98.9	78.8	1.1	**333.3**	154.1	100.2	82.0	5.5	**341.8**
Belgium	15.4	28.0	209.8	5.0	**258.1**	15.0	23.1	219.7	3.4	**261.2**
Austria	2.2	52.7	122.9	0.0	**177.8**	2.2	55.4	131.2	0.0	**188.9**
Finland	10.9	16.9	42.8	105.3	**175.8**	8.9	16.4	44.6	115.2	**185.2**
Sweden	5.1	71.8	99.9	0.0	**176.7**	4.5	70.1	103.3	0.0	**177.9**
Greece	45.2	18.3	81.8	0.0	**145.3**	49.0	19.4	94.4	0.0	**162.7**
Slovakia	6.0	6.8	90.1	0.0	**102.8**	5.3	8.0	93.2	0.0	**106.5**
Portugal	63.2	8.2	15.2	0.0	**86.6**	63.0	7.6	24.7	0.0	**95.3**
Hungary	6.9	32.8	57.1	0.0	**96.8**	6.9	31.7	55.9	0.0	**94.5**
Croatia	7.0	3.8	80.0	0.0	**90.7**	7.0	3.4	70.4	0.0	**80.7**
Ireland	25.8	9.5	17.7	0.0	**53.0**	24.5	8.9	18.2	0.0	**51.6**
Bulgaria	0.0	5.4	44.7	0.0	**50.1**	0.0	5.5	39.7	0.0	**45.2**
Latvia	6.9	1.5	47.1	0.0	**55.5**	6.4	1.9	34.7	0.0	**42.9**
Lithuania	5.5	8.2	28.1	0.0	**41.8**	3.3	8.1	27.8	0.0	**39.1**
Slovenia	1.3	1.2	21.9	0.0	**24.5**	1.0	1.1	20.8	0.0	**22.9**
Estonia	1.0	5.0	12.1	0.0	**18.2**	0.6	3.8	17.0	0.0	**21.4**
Romania	0.0	0.0	26.3	0.0	**26.3**	0.0	0.0	18.3	0.0	**18.3**
Luxembourg	0.0	1.8	17.3	0.0	**19.1**	0.0	1.2	12.3	0.0	**13.5**
Cyprus	0.3	0.9	11.2	0.0	**12.4**	0.0	1.1	11.0	0.0	**12.1**
Malta	0.0	0.0	2.0	0.0	**2.0**	0.4	1.1	1.2	0.0	**2.6**
UE 27	**1 190.4**	**1 207.7**	**13 297.7**	**117.1**	**15 813.0**	**1 168.5**	**1 253.5**	**13 237.6**	**129.8**	**15 789.4**

Source: Eurostat

while Italy's fell by 2.9% (59.5 ktoe) to 2 012 ktoe. In 2023, these two countries accounted for 49 and 12.7% respectively of total EU biogas output, followed by France (12%). The drop in German and Italian output can be primarily attributed to lower biogas electricity production.

DIFFERENT STATISTICAL PATHWAYS FOR FINAL BIOGAS ENERGY MONITORING

Since biomethane injection into the natural gas grid has stepped up, it has become harder to accurately monitor the final energy fraction of energy recovery in the biogas sector. As it stands, while primary biogas energy production includes all production, the quantity of renewable biomethane injected into the grid (and thus blended with fossil gas) is transferred to the statistical indicators of gas (accounted for in the Eurostat "Natural gas" questionnaire). Thus, the distinction is no longer made between fossil and renewable gas if the gas is used in the processing sector (power plants, cogeneration plants and heat plants) or in the final total energy consumption in transport, industry and other sectors. Unless otherwise indicated by the national statistics bodies, the standard final biogas energy monitoring indicators published by Eurostat only refer to biogas when used "pure", meaning not when mixed with fossil gas. An accommodation has been made to avoid losing track of the final " renewable" energy – the biomethane injected into the grid – and enable it to be included in the EU Member States' renewable energy targets. Through its SHARES ("SHort Assessment

2

Gross electricity production from pure biogas and from biogas blended in the grid in the European Union in 2022 and 2023 (in GWh)

	2022				2023			
	Electricity only plants	CHP plants	Total pure biogas	Electricity from biogas blended in the grid*	Electricity only plants	CHP plants	Total pure biogas	Electricity from biogas blended in the grid*
Germany	7 691.0	24 526.0	32 217.0	3 098.0	6 608.0	23 494.0	30 102.0	3 120.0
Italy	2 403.1	5 441.0	7 844.1	0.0	2 080.5	5 403.2	7 483.8	0.0
France	304.3	2 695.3	2 999.6	727.9	458.4	2 630.8	3 089.2	704.2
Czechia	37.2	2 579.3	2 616.5	0.7	43.9	2 557.9	2 601.8	1.5
Poland	0.0	1 394.2	1 394.2	0.0	0.0	1 482.4	1 482.4	0.0
Spain	718.0	272.0	990.0	69.6	680.0	329.0	1 009.0	93.6
Netherlands	13.9	826.2	840.0	302.9	16.2	683.3	699.5	398.5
Belgium	56.7	955.2	1 011.9	20.7	54.3	992.7	1 047.0	1.5
Denmark	1.6	572.7	574.3	269.1	1.2	520.4	521.6	302.6
Austria	542.1	121.4	663.4	16.7	545.4	128.4	673.7	13.2
Greece	68.6	448.2	516.8	0.0	66.9	533.2	600.1	0.0
Slovakia	74.0	317.0	391.0	0.0	58.0	348.0	406.0	0.0
Croatia	37.0	372.2	409.2	0.0	33.4	307.3	340.7	0.0
Hungary	37.0	278.0	315.0	5.0	55.0	265.0	320.0	8.3
Portugal	238.4	21.3	259.8	0.0	228.5	22.8	251.3	13.4
Finland	2.2	262.5	264.7	10.4	1.5	257.4	258.9	5.6
Latvia	0.0	249.6	249.6	0.0	0.0	181.4	181.4	0.0
Bulgaria	45.9	144.9	190.9	0.0	36.6	129.2	165.8	0.0
Ireland	100.5	58.6	159.1	2.2	95.7	53.9	149.6	11.1
Lithuania	0.0	158.7	158.7	0.0	0.0	116.3	116.3	0.0
Slovenia	1.1	99.1	100.2	0.0	0.4	93.1	93.5	0.0
Romania	24.1	66.1	90.2	0.0	16.4	49.2	65.7	0.0
Cyprus	0.0	57.8	57.8	0.0	0.0	53.9	53.9	0.0
Luxembourg	0.0	48.8	48.8	0.7	0.0	42.9	42.9	0.6
Sweden	0.0	12.0	12.0	6.6	0.0	14.0	14.0	6.9
Malta	0.0	7.4	7.4	0.0	0.0	9.6	9.6	0.0
Estonia	0.0	5.6	5.6	1.4	0.0	3.3	3.3	0.8
Total EU-27	**12 396.8**	**41 991.2**	**54 388.0**	**4 531.9**	**11 080.5**	**40 702.5**	**51 783.0**	**4 681.8**

*Note: The ranking in this table is based on the cumulative biogas electricity production from biogas used pure or mixed with the natural gas network. * Blended biogases and Biogases in the grid allocated based on sustainability certificates.* ***Source: Eurostat***

of Renewable Energy Sources") tool, Eurostat enables the Member States to distribute the biomethane blended into the grid between the various final energy recovery modes on a dedicated worksheet. They are obliged to use empirical and verifiable information, for instance, mass balance certificates, for the purpose of this monitoring and may also track the injected biogas using sustainability certificates. This breakdown results in estimates of the production relating to electricity, heat from the processing sector (heat sales) and heat directly consumed by end users, as well as the biomethane fuel used in transport. A further level of complexity is added to statistical monitoring by obliging the Member States to distinguish the share of these outputs deemed to comply with the renewable energy directive requirements.

LESS BIOGAS ELECTRICITY AND MORE BIOGAS HEAT IN 2023

In 2023, locally produced and used electricity output generated in pure biogas-fired plants (not injected into the grid), across the EU declined sharply. Eurostat quantified it at 51.8 TWh, which is 2.6 TWh (4.8%) less than in 2022. Most of this decline occurred in three countries, Germany (by 6.6%, equating to 2.1 TWh), Italy (by 4.6%, or 0.36 TWh) and the Netherlands (16.7%, or 0.14 TWh). Broadly speaking, stronger interest in injecting biomethane into the grid and the conversion of several biomethane plants are partly to blame for the falloff in electricity production and heat from specifically dedicated plants for locally produced

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Gross heat production in the transformation sector from pure biogas and from biogas blended in the grid in the European Union in 2022 and in 2023 (in ktoe)

	2022				2023			
	Heat only plants	CHP plants	Total pure biogas	Heat from biogas blended in the grid*	Heat only plants	CHP plants	Total pure biogas	Heat from biogas blended in the grid*
Germany	11.2	284.5	295.6	196.0	10.5	282.0	292.5	183.3
France	1.4	94.7	96.1	24.2	2.0	108.1	110.1	34.9
Denmark	2.0	42.3	44.3	56.3	2.5	37.3	39.9	75.5
Belgium	0.0	19.9	19.9	0.3	0.0	25.6	25.6	0.0
Finland	6.1	12.4	18.5	1.9	5.8	15.5	21.3	2.5
Italy	0.2	27.6	27.7	0.0	0.2	22.8	23.0	0.0
Poland	1.6	20.3	22.0	0.0	1.0	21.8	22.8	0.0
Czechia	0.1	18.7	18.7	0.1	0.1	17.7	17.8	0.3
Netherlands	0.0	7.0	7.0	7.4	0.0	6.3	6.3	9.8
Sweden	2.0	3.8	5.8	2.1	8.5	3.7	12.2	3.3
Slovakia	0.2	11.2	11.4	0.0	0.3	14.3	14.5	0.0
Croatia	0.0	14.5	14.5	0.0	0.0	11.4	11.4	0.0
Austria	1.0	5.7	6.6	1.0	1.2	7.6	8.9	1.0
Latvia	0.3	15.1	15.4	0.0	0.6	8.7	9.3	0.0
Hungary	0.0	2.7	2.7	0.4	0.0	3.5	3.5	0.8
Romania	1.3	3.4	4.6	0.0	1.0	2.3	3.4	0.0
Estonia	0.2	0.2	0.4	2.0	0.0	0.1	0.1	3.3
Slovenia	0.0	3.6	3.6	0.0	0.0	3.1	3.1	0.0
Luxembourg	0.0	2.5	2.5	0.2	0.0	2.4	2.4	0.2
Bulgaria	0.0	4.0	4.0	0.0	0.0	2.5	2.5	0.0
Lithuania	0.0	2.6	2.6	0.0	0.0	2.0	2.0	0.0
Cyprus	0.0	1.0	1.0	0.0	0.0	0.9	0.9	0.0
Portugal	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3
Ireland	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Greece	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Spain	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Malta	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total EU-27	27.4	597.6	625.0	292.0	33.8	599.6	633.4	315.1

Note: The ranking in this table is based on the cumulative gross heat production from biogas used pure or mixed with the natural gas network.
** Blended biogases and Biogases in the grid allocated based on sustainability certificates.* ***Source: Eurostat***

biogas (or biomethane) recovery units across the European Union. In contrast, electricity output generated from biogas mixed into the grid increased by 3.3% to just under 4.7 TWh in 2023. If we add the two together – pure biogas and biogas mixed into the grid – biogas output came to 56.5 TWh, which is a YoY drop of 4.2% (58.9 TWh in 2022).
Biogas heat output from plants specifically dedicated to locally produced biogas (or biomethane), excluding the biogas injected into the grid, increased slightly across the EU. Biogas heat output (from the processing sector) increased by 1.3% to 633.4 ktoe in 2023 while directly and locally used biogas heat in industries and the other sectors with the exception of transport, increased by 0.6% to 2 556.3 ktoe. Heat output from biogas mixed into the grid also increased… by 7.9% for heat sales (315.1 ktoe) and 22.3% for heat directly consumed by end users (1 316.1 ktoe).
Taken as a whole, namely pure biogas and biogas mixed into the grid, biogas heat sold or directly consumed at the point of production, increased by 6.3% to reach 4 820.8 ktoe in 2023, a rise of 286.4 ktoe. According to the data available from the Eurostat SHARES tool, almost all the output – electricity, derived heat and final energy consumption – is deemed to comply with RED II requirements and thus contributes to the Member States' renewable energy targets. If we add the pure biogas to the grid-injected biogas, the compliance percentage was 93.6% for electricity, 97.3% for derived heat and 96.6% for final energy consumption in industry and other sectors (excluding transport).

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Final energy consumption in industry and other sectors (except transport) from pure biogas and from biogas blended in the grid in the European Union in 2022 and in 2023 (in ktoe)

	2022		2023	
	Pure biogas	Biogas blended in the grid*	Pure biogas	Biogas blended in the grid*
Germany	1289.8	199.0	1237.0	227.3
France	256.7	387.8	333.7	525.1
Denmark	24.9	346.5	26.1	390.9
Netherlands	124.8	87.6	108.1	109.9
Czechia	152.7	0.8	153.4	1.7
Spain	103.9	5.2	109.5	9.1
Poland	105.7	0.0	106.5	0.0
Belgium	97.7	7.8	93.1	10.1
Finland	90.1	6.5	96.9	4.4
Sweden	51.3	17.3	55.1	13.4
Italy	64.4	0.0	56.4	0.0
Austria	30.8	6.6	33.1	6.8
Greece	35.1	0.0	30.5	0.0
Portugal	12.4	0.0	22.7	2.1
Slovakia	19.6	0.0	21.7	0.0
Hungary	22.7	2.9	16.2	5.1
Ireland	13.4	0.3	12.2	1.2
Lithuania	10.9	0.0	10.2	0.0
Bulgaria	9.9	0.0	10.0	0.0
Estonia	2.0	4.2	2.6	5.6
Latvia	7.3	0.0	6.9	0.0
Cyprus	4.8	0.0	5.1	0.0
Luxembourg	3.2	3.3	1.0	3.4
Slovenia	3.2	0.0	3.7	0.0
Romania	2.5	0.0	3.1	0.0
Malta	1.0	0.0	1.1	0.0
Croatia	0.6	0.0	0.5	0.0
Total EU-27	2541.7	1075.7	2556.3	1316.1

*Note: The ranking in this table is based on the cumulative final energy consumption from biogas used pure or mixed with the natural gas network. * Blended biogases and Biogases in the grid allocated based on sustainability certificates.* ***Source: Eurostat***

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Gross electricity production from biogas (pure and blended in the their grid) in the European Union in 2023 compliant with the Directive (EU) 2018/2001 (in GWh)*

	2023		
	Biogas (pure and blended in the grid)	of which compliant	% compliant
Germany	33 222.0	33 222.0	100.0%
Italy	7 483.8	5 156.2	68.9%
France	3 793.4	3 774.0	99.5%
Czechia	2 603.3	2 603.3	100.0%
Poland	1 482.4	1 451.3	97.9%
Spain	1 102.6	1 080.8	98.0%
Netherlands	1 098.0	368.2	33.5%
Belgium	1 048.5	1 048.5	100.0%
Denmark	824.2	824.2	100.0%
Austria	686.9	661.5	96.3%
Greece	600.1	600.1	100.0%
Slovakia	406.0	406.0	100.0%
Croatia	340.7	340.7	100.0%
Hungary	328.3	139.3	42.4%
Portugal	264.7	251.3	95.0%
Finland	264.5	264.2	99.9%
Latvia	181.4	52.4	28.9%
Bulgaria	165.8	113.6	68.5%
Ireland	160.7	115.8	72.1%
Lithuania	116.3	116.3	100.0%
Slovenia	93.5	93.5	100.0%
Romania	65.7	35.6	54.2%
Cyprus	53.9	53.9	100.0%
Luxembourg	43.5	43.5	100.0%
Sweden	20.9	20.8	99.5%
Malta	9.6	9.6	99.9%
Estonia	4.1	3.3	80.2%
Total EU-27	56 464.8	52 849.8	93.6%

** Compliant with the criteria of Article 29 of Directive (EU) 2018/2001.*
Source: From SHARES Eurostat

FRANCE CONTINUES TO INVEST

Of all the European Union countries, France currently invests more than any other in its biogas sector, and more specifically its biomethane sector. Eurostat reports that France increased its primary biogas energy output by 16.4% between 2022 and 2023 to 1 890 ktoe, i.e., 266.4 ktoe more in the space of 12 months. the Statistical Data and Studies Department (SDES) reports that on 31 December 2023, 652 installations injected biomethane into the natural gas grids after biogas production and cleaning, i.e., 139 more in 2022 (149). At the end of 2023, their maximum production capacity had risen 25% YoY to 11.8 TWh p.a.. Annual injected biomethane output as a whole had risen to 9.1 TWh GCV, which is a 31% increase on 2022. The growth rate was lower in 2024. On 30 September 2024, 710 installations had injected biomethane into the natural gas grids (58 more than at the end of 2023). Their capacity was 13.1 TWh p.a., which is 9% higher than at the end of 2023. The SDES points out that the biomethane share amounted to 4.7% of all gas grid injections in Q3 of 2024.

DENMARK AIMING FOR 100% OF GREEN GAS BY 2030

Biogas output in Denmark has increased rapidly over the past decade, from 105 to 758 ktoe in 2023. The reason for this success is the implementation of a fixed subsidy scheme back in 2012 devised to increase biogas output to generate electricity, produce heat and biomethane recovery. The scheme ended in 2018 and was replaced by a tendering

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Heat consumption biogas (pure and blended in the grid) of which compliant with the Directive (EU) 2018/2001** in the European Union in 2023 (in ktoe)*

	Gross heat production in the transformation sector			Final energy consumption in industry and other sectors (except Transport)			Total Heat		
	Biogas (pure and blended in the grid)	of which compliant	% compliant	Biogas (pure and blended in the grid)	of which compliant	% compliant	Biogas (pure and blended in the grid)	of which compliant	% compliant
Germany	475.8	475.8	100.0%	1 464.3	1 464.3	100.0%	1 940.1	1 940.1	100.0%
France	145.0	145.0	100.0%	858.8	858.8	100.0%	1 003.8	1 003.8	100.0%
Denmark	115.3	115.3	100.0%	417.0	417.0	100.0%	532.3	532.3	100.0%
Netherlands	16.1	7.9	49.0%	218.0	121.4	55.7%	234.2	129.3	55.2%
Czechia	18.1	18.1	100.0%	155.1	155.1	100.0%	173.2	173.2	100.0%
Poland	22.8	22.3	97.9%	106.5	104.2	97.9%	129.2	126.5	97.9%
Belgium	25.6	25.6	100.0%	103.3	103.3	100.0%	128.9	128.9	100.0%
Finland	23.8	23.8	100.0%	101.4	101.2	99.8%	125.2	125.0	99.9%
Spain	0.0	0.0	-	118.6	118.1	99.6%	118.6	118.1	99.6%
Sweden	15.4	15.3	99.2%	68.5	68.0	99.3%	83.9	83.3	99.3%
Italy	23.0	14.1	61.4%	56.4	49.7	88.1%	79.4	63.8	80.4%
Austria	9.8	8.7	88.3%	39.8	33.1	83.0%	49.7	41.8	84.1%
Slovakia	14.5	14.5	99.7%	21.7	21.7	100.0%	36.2	36.2	99.9%
Greece	0.0	0.0	-	30.5	30.5	100.0%	30.5	30.5	100.0%
Hungary	4.3	2.6	60.5%	21.3	19.0	89.0%	25.6	21.6	84.2%
Portugal	0.3	0.0	0.0%	24.7	22.7	91.7%	25.0	22.7	90.6%
Latvia	9.3	9.3	99.9%	6.9	6.9	100.0%	16.2	16.2	99.9%
Ireland	0.0	0.0	-	13.4	7.4	55.4%	13.4	7.4	55.4%
Bulgaria	2.5	1.1	44.4%	10.0	7.5	74.6%	12.5	8.6	68.6%
Lithuania	2.0	2.0	100.0%	10.2	10.2	100.0%	12.2	12.2	100.0%
Croatia	11.4	11.4	99.7%	0.5	0.5	100.0%	11.9	11.9	99.8%
Estonia	3.3	0.0	0.0%	8.3	2.6	31.8%	11.6	2.6	22.7%
Luxembourg	2.6	2.6	99.8%	4.3	4.3	100.0%	6.9	6.9	99.9%
Slovenia	3.1	3.1	100.0%	3.7	3.7	100.0%	6.8	6.8	100.0%
Romania	3.4	3.4	100.0%	3.1	3.1	100.0%	6.5	6.5	100.0%
Cyprus	0.9	0.9	100.0%	5.1	5.1	100.0%	6.0	6.0	100.0%
Malta	0.0	0.0	-	1.1	1.1	100.0%	1.1	1.1	100.0%
Total EU-27	948.5	922.8	97.3%	3 872.3	3 740.3	96.6%	4 820.8	4 663.1	96.7%

** Gross heat production in the transformation sector and final energy consumption in industry and other sectors (except transport).*
*** Compliant with the criteria of Article 29 of Directive (EU) 2018/2001.* ***Source: From SHARES Eurostat***

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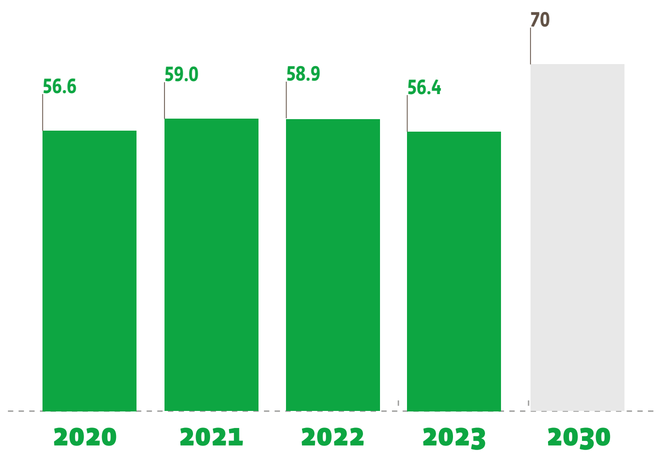
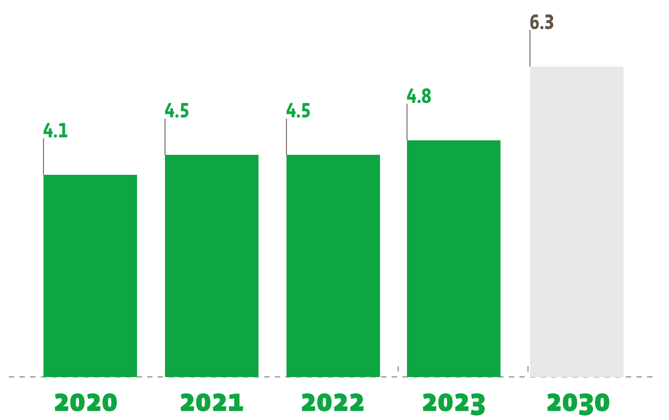
EurObserv'ER projection of electricity production from biogas in the EU-27 (in TWh)*



** Pure biogas and biogas blended in the grid compliant and not compliant.*
Source: EurObserv'ER

8

EurObserv'ER projection of heat consumption from biogas** in the EU-27 (in Mtoe)*



** Final energy consumption in industry and other sectors (except transport)and gross heat production in the transformation sector. ** Pure biogas and biogas blended in the grid compliant and not compliant.* ***Source: EurObserv'ER***

system. Most of the biogas currently being produced in Denmark is subsidized, as the subsidies were awarded for 20 years. Previously, most of the biogas was used for generating electricity, but nowadays, about 80% of the country's biogas output is injected into the natural gas grid. In 2023, according to the Danish Energy Agency (ENS), the biomethane share of its gas system skirted 40% and the country's target is to achieve 100% of green biogas consumption by 2030. The ENS claims that about 75% of the biomass used in the country's agricultural biogas units is sourced from farm animal waste. The remaining 25% includes different types of organic waste from households and industry (16%), energy crops (5%), glycerine (2%) and straw (2%).

CRUNCH TIME FOR GERMAN BIOGAS

Germany's primary biogas energy output has fallen for the second year running (8.2 Mtoe in 2021, 8.1 Mtoe in 2022 and 7.7 Mtoe in 2023). It now accounts for just under half (49%) of the European Union's output. The reason behind this drop may be that Germany is no longer striving to produce but trying to regulate the electricity grid's requirements, while prioritizing grid injection. According to the German Biogas Association (Fachverband Biogas), the biogas and biomethane share of the country's natural gas consumption was about 10.9% in 2023. It also claims that Germany had about 9 900 biogas installations, 248 of which inject biomethane into the gas grid. However, the new installation numbers are much lower than they were at the end of the noughties and the beginning of the 2010s when over a thousand biogas units were commissioned every year (1 314 new installations in 2009, 1 107 in 2010 and 1 526 in 2011). In 2022, only 77 small agricultural installations were commissioned and 38 in 2023. The government's aim, since the 2014 and 2017 reforms of the German renewable energy law (EEG), is to increase the biogas electricity output of existing units rather than to significantly increase the number of methanizers. Its goal is to expand the sites being operated to boost their installed capacity for this flexibility drive, in order to synchronize production with peak demand periods. This policy is behind the sharp increase in the electrical capacity of Germany's biogas installations since 2016, which according to Fachverband Biogas, rose from 4 018 MW in 2015 to 5 905 MW in 2023, although the installed capacity used only increased by 106 MW over the same period. Its president, Horst Seide, believes that current production capacity could be doubled from 6 to 12 GW by 2030. He adds that this does not mean producing more biogas and/or using more biomass but constructing additional cogeneration plants to produce electricity when there is no sunshine, and no wind is blowing. Existing biogas installations could thus obviate the need for constructing new gas-fired power plants. EurObserv'ER believes that this also raises the issue of inputs, because while the country is reducing its use of energy crops, their use remains significant. According to the German biomass research centre (DBFZ-Deutsches Biomasseforschungszentrum), energy crops (basically silage maize) still amounted to about 45% of the bulk of inputs used in biogas production compared to about 49% for slurry, 3% for food-processing waste and 3% for biowaste. Yet, given their methanogenic power, energy crops provide 73% of biogas energy (18% for slurry, 5% for food-processing waste and 4% for biowaste).

PROGRESS TOWARDS DOUBLING BIOMETHANE OUTPUT BY 2030

The investments already made in European biogas production, on environmental grounds or because of the Member States' will to reduce their energy dependency on gas, have been given real meaning since Russia invaded Ukraine. The European Union's over-reliance on Russian gas had disastrous consequences raising the energy bills of households, local authorities and businesses alike. The European Union responsiveness was exemplary, when as early as May 2020 it rolled out its REPowerEU plan. The European Commission's main measures were to set up a Biomethane Action Plan that defines tools such as a Biomethane Industrial Partnership and financial incentives to increase output to 35 billion m3 by 2030, included in the Common Agricultural Policy, to replace 20% of its Russian natural gas imports. Today's momentum is positive. According to the European Biogas Association (EBA), at least 25 billion euros will be invested in European biomethane by 2030 and the number of jobs in the sector could rise to 500 000 and generate an additional 12 billion euros' worth of profit per annum for Europe's bioeconomy.

The EBA emphasizes that biogas deployment is essential for boosting the resilience of the EU's energy system. As Harmen Dekker, CEO of the EBA explains: "Europe's greatest resource for reducing reliance on outside energy providers is a combination of all renewable energy sources including biogas. Biogases are a key contributor to renewable energy provision, and not only in volume terms. Thanks to their flexibility, energy storage capacity and ability to generate dispatchable power, biogases support and facilitate growth in other renewables." ■

RENEWABLE MUNICIPAL WASTE

According to Eurostat, in 2023, 8.8 Mtoe of primary energy (8 772.5 ktoe to be precise) was generated from renewable municipal waste treated in waste-to-energy (WtE) plants in the EU-27. The output figure dropped for the second year running, (by 411.4 ktoe, i.e., 4.5%) and is more marked than that of the 12 months to December 2022 (121.8 ktoe).

The figure does not include all the energy recovered in WtE plants but is restricted to the energy recovered from biodegradable waste feedstock (cartons, paper, kitchen waste, etc.). The non-biodegradable fraction of urban waste (miscellaneous plastic packaging, mineral water bottles, etc.) produced an equivalent amount of energy (8 580.2 ktoe in 2023, a year-on-year drop of 4.7%). Convention has it that the waste accounted for as renewably sourced is put at 50% of all incinerated urban waste, as it is hard to distinguish biodegradable waste from other waste, unless a Member State conducts specific studies.

Incidentally, non-renewable industrial waste is separately quantified and generated an estimated 4 746.5 ktoe of primary energy in 2023 (a 1.5% YoY decline). The renewable (biodegradable) fraction of industrial waste is conventionally assimilated with solid biofuels, which is covered in its own fact file in this opus. For information, it generated 1 513.1 ktoe of primary energy in 2023 (1.4% less than in 2022).

The CEWEP (Confederation of European Waste-to-Energy plants) put the number of WtE incineration plants at 498 in 2022 (including 57 plants in the UK, 29 in Switzerland and 18 in Norway), leaving 394 units in the European Union. Across Europe, they heat treat about 103 million tonnes of waste (79 million tonnes in the EU countries).

DALKIA WASTENERGY

THE WEST AND EAST OF THE EU DISPLAY OPPOSING TRENDS-

Not every EU country suffered a fall in primary energy output from renewable municipal waste. The bloc-wide fall in 2023 can be put down to significant declines in output in France (159.6 ktoe), Sweden (108.5 ktoe), the Netherlands (90.5 ktoe), Germany (80.8 ktoe) and Finland (41.7 ktoe). This contrasts with many Eastern European countries whose energy output from renewable municipal waste posted double-digit growth, cases in point are Lithuania (46.8 ktoe, with 88.4% growth), Czechia (13.1 ktoe, 13.8%), Hungary (6.2 ktoe, 10.9%) and Latvia (4.5 ktoe, 80.3%).

EurObserv'ER takes the view that this European Union-wide fall in energy output is not only cyclical and directly linked to the economic crisis, the decline in purchasing power and consumption (and thus the tonnage of waste to be processed) but is also structural in the countries most actively recycling and collecting waste (biowaste, cartons, etc.), that structurally reduces the volume of

1

Primary energy production of renewable municipal waste in the European Union in 2022 and 2023 (in ktoe)*

	2022	2023
Germany	3 052.5	2 971.6
France	1 318.3	1 158.6
Italy	848.2	847.6
Netherlands	865.4	774.9
Sweden	743.9	635.4
Denmark	454.2	442.4
Belgium	361.5	366.6
Finland	341.3	299.6
Spain	284.2	278.4
Austria	200.2	216.3
Ireland	151.7	154.3
Poland	114.0	113.5
Portugal	121.4	111.2
Czechia	95.2	108.3
Lithuania	52.9	99.6
Hungary	57.0	63.3
Bulgaria	42.4	43.3
Slovakia	34.0	38.5
Estonia	22.0	22.1
Luxembourg	12.5	10.2
Latvia	5.6	10.1
Romania	1.6	3.5
Cyprus	4.0	3.0
Total EU-27	**9 183.9**	**8 772.5**

Source: Eurostat

2

Gross electricity production from renewable municipal waste in the European Union in 2022 and 2023 (in GWh)

	2022			2023		
	Electricity only plants	CHP plants	Total	Electricity only plants	CHP plants	Total
Germany	3 295.0	2 332.0	5 627.0	3 478.0	2 226.0	5 704.0
Italy	1 004.6	1 321.1	2 325.7	1 005.6	1 330.6	2 336.2
France	863.3	1 244.8	2 108.1	710.8	1 371.7	2 082.5
Netherlands	0.0	2 225.1	2 225.1	0.0	1 981.5	1 981.5
Sweden	0.0	1 761.0	1 761.0	0.0	1 381.0	1 381.0
Belgium	376.9	623.2	1 000.1	339.3	626.9	966.2
Denmark	0.0	1 020.3	1 020.3	0.0	923.7	923.7
Spain	765.5	98.0	863.5	735.0	106.0	841.0
Finland	0.0	587.9	587.9	0.0	441.2	441.2
Austria	205.7	148.3	354.0	222.6	146.7	369.4
Ireland	346.8	0.0	346.8	333.8	0.0	333.8
Poland	0.0	301.6	301.6	0.0	303.8	303.8
Portugal	309.2	0.0	309.2	298.7	0.0	298.7
Lithuania	0.0	155.7	155.7	0.0	229.8	229.8
Czechia	0.0	129.7	129.7	0.0	150.2	150.2
Hungary	9.0	121.0	130.0	4.0	114.0	118.0
Estonia	20.5	20.0	40.5	21.8	31.1	53.0
Slovakia	0.0	50.0	50.0	0.0	45.0	45.0
Luxembourg	0.0	41.6	41.6	0.0	34.1	34.1
Total EU-27	**7 196.4**	**12 181.3**	**19 377.7**	**7 149.7**	**11 443.4**	**18 593.1**

Source: Eurostat

3

Gross heat production in the transformation sector from renewable municipal waste in the European Union in 2022 and in 2023 (in ktoe)

	2022			2023		
	Heat only plants	CHP plants	Total	Heat only plants	CHP plants	Total
Germany	249.6	616.7	866.3	231.4	621.0	852.4
Sweden	79.2	542.0	621.2	198.2	389.8	588.0
Denmark	26.6	332.8	359.4	24.9	341.3	366.2
France	117.2	290.3	407.5	39.2	286.1	325.3
Netherlands	0.0	203.8	203.8	0.0	189.5	189.5
Finland	60.1	123.5	183.7	82.9	104.3	187.2
Italy	0.0	102.5	102.5	0.0	111.9	111.9
Austria	12.7	69.9	82.6	12.9	76.0	88.8
Lithuania	0.0	34.4	34.4	0.0	55.2	55.2
Czechia	0.0	36.0	36.0	0.0	40.6	40.6
Poland	0.6	37.0	37.6	0.5	39.7	40.1
Belgium	0.4	33.4	33.8	0.4	28.4	28.8
Hungary	0.0	20.2	20.2	0.0	20.1	20.1
Estonia	0.0	13.9	13.9	0.2	14.2	14.3
Slovakia	0.0	2.4	2.4	0.0	2.6	2.6
Luxembourg	0.0	0.9	0.9	0.0	0.8	0.8
Total EU-27	**546.5**	**2 459.6**	**3 006.1**	**590.6**	**2 321.3**	**2 912.0**

Source: Eurostat

waste destined for incineration.
This renewables sector has an asset in that WtE incineration plants are usually sited close to major urban centres which provide the waste feedstock and consume a lot of energy. This proximity fosters optimum, local use of the energy as heat, electricity, or more commonly both, through cogeneration. Thus, heat can be easily exported to supply an urban heating network or as process heat to industrial sites.
If only the renewable fraction of household waste is considered eligible for quantification, then WtE plants generated 18.6 TWh in 2023, a little less (4%) than in 2022. Cogeneration is the main energy recovery method used by these plants and electricity accounted for 61.5 % of their output in 2023. The four countries whose electricity output from urban waste declined the most in 2024 in value terms were Sweden (by 380 GWh), the Netherlands (by 243.6 GWh), Finland (by 146.6 GWh) and Denmark (by 96.6 GWh). These falls contrast with modest rises registered in Germany (77 GWh), Lithuania (74.1 GWh) and Czechia (20.5 GWh).
Eurostat reports that the net maximum electrical capacity of plants treating municipal waste in the EU-27 stood at 7 630.4 MW at the end of 2023 (7 583 MW at the end of 2022).
Heat sales from the processing sector constitute the other major outlet for these incineration plants. Between 2022 and 2023, sales of renewable heat sourced from urban waste declined, partly because milder climate conditions weakened the demand for heating. These sales stood at 2 912 ktoe in 2023 (3 006.1 ktoe in 2022), including 79.7% from CHP plants. In value terms, the sharpest drops occurred in France (82.2 ktoe), Sweden (33.2 ktoe), the Netherlands (14.3 ktoe) and Germany (13.9 ktoe). Directly used heat also contracted and fell below the one Mtoe threshold in 2023 (from 1 064.8 to 911.2 ktoe).

4

Final energy consumption of renewable municipal waste in the European Union in 2022 and 2023 (in ktoe)

	2022	2023
Germany	530.3	414.8
France	153.5	121.5
Ireland	53.9	58.6
Bulgaria	42.4	43.3
Denmark	41.5	39.9
Latvia	43.6	39.6
Netherlands	43.1	36.1
Finland	36.6	31.1
Cyprus	26.8	27.0
Czechia	21.4	16.8
Slovakia	10.3	15.8
Poland	14.2	15.1
Hungary	18.3	12.8
Lithuania	0.0	10.0
Spain	8.7	7.4
Italy	6.5	6.6
Sweden	6.2	6.2
Belgium	5.9	5.0
Romania	1.6	3.5
Total EU-27	**1 064.8**	**911.2**

Source: Eurostat

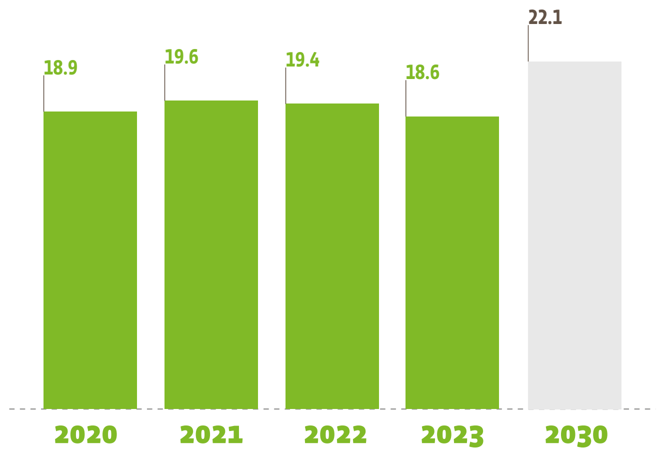
THE WRITING IS ON THE WALL FOR RENEWABLE MUNICIPAL WASTE

In those countries that still dispose of a large fraction of their household waste in landfills, the energy potential of energy recovery through waste incineration remains high. All Member States are obliged to comply with the targets set in the recast directive (EU) 2018/850 (modifying directive 1999/31/EC) for waste disposal in landfills. The (EU) 2018/850 directive introduces restrictions from 2030 onwards, on the disposal of waste in landfills whose materials or energy lend themselves to recycling or recovery, to support the EU's transition to a circular economy but most importantly, it limits the fraction of municipal waste landfilled to 10% by 2035. In 2022 (the latest year for available data), nine Member States had already met the target (Belgium, Finland, Sweden, Denmark, the Netherlands, Germany, Austria, Luxembourg and Slovenia), although several of them still incinerated a considerable amount of municipal waste – about 30% in Germany and up to 60% in Sweden and Finland.

At the same time, the European Union's resolve is clear and directed towards the drastic reduction in the production of household and food waste. The outcome will negatively impact the WtE industry's future. European waste management legislation is governed by the (EU) 2018/851 directive that amended the 2008/98/EC directive on waste that originally established a waste hierarchy, prioritising prevention, preparation for re-use, the other recovery modes (such as energy recovery) and disposal. The recast directive 2018/851 toughens the waste prevention and circular economy rules. Accordingly, all Member States must take measures to support sustainable production and consumption models with measures to reduce food waste, throughout the production chain through to the consumer. It also sets new municipal waste recycling targets: by 2025, at least 55% by weight of municipal waste must be recycled. This target will rise to 60% by 2030 and to 65% by 2035. The Member States must also set up separate collection for textiles (and hazardous waste produced by households) at the latest by 1 January 2025 and ensure that biowaste is collected separately or recycled at source (for example, by composting) at the latest by 31 December 2023. These measures should significantly reduce the tonnage of renewable municipal waste sent for incineration. This waste will either be diverted to composting or methanation. ■

5

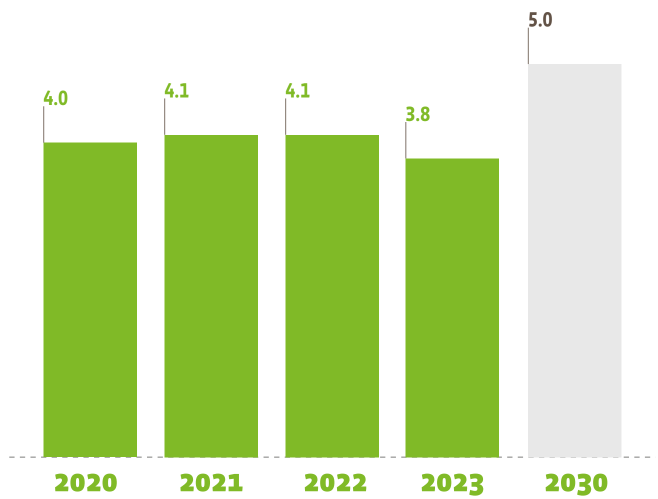
EurObserv'ER projection of electricity production from renewable municipal waste in the EU-27 (in TWh)



Source: EurObserv'ER

6

EurObserv'ER projection of heat consumption from renewable municipal waste in the EU-27 (in Mtoe)



*Final energy consumption in «Industry» and «Others sectors» except transport and gross heat production in the transformation sector. **Source: EurObserv'ER***

SOLID BIOFUELS

Solid biofuels, more commonly known as solid biomass, cover all solid organic matter of biological origin that can be used as fuel to produce heat or electricity. In energy statistics, solid biofuels are an aggregate of products equal to the sum of heating wood, wood residues and by-products (including wood pellets), black liquor (a by-product of the paper pulp industry), bagasse (a by-product of the sugar cane industry), animal waste, other plant matter and residue and the renewable fraction of industrial waste. Charcoal is also considered as solid biofuel, but as special statistical treatment is applied to it by convention, it is not included in the indicators presented. Renewable municipal waste is also subject to special statistical monitoring and is excluded from the category of solid biofuel. European Union solid biofuel consumption declined in 2023 for the second year running, having peaked in 2021. Eurostat quantified EU primary energy consumption at 95.8 Mtoe in 2023 compared to 100.4 Mtoe in 2022 and 104.5 Mtoe in 2021. The 2023 downturn has to be viewed against the backdrop of high energy prices and appeals for restraint following the energy crisis weathered by the European Union since February 2022. It is partly due to solid biomass electricity production's lower competitiveness and falling heating needs caused by two particularly mild winters across Europe.

UNHEARD-OF ECONOMIC AND CLIMATE DISRUPTIONS

There are several factors behind the European Union's declining solid biomass energy consumption. Compared to 2021, solid biofuels (wood pellets, wood chips, reclaimed wood, etc.) became less competitive as they bore the full brunt of the 2022 energy crisis with serious consequences for solid biomass electricity production. The 2022 hike in the price of wood pellets, as a corollary to the soaring price of gas and European demand constrained by the embargo on Russian and Belarusian imports, had already disturbed production at biomass-fuelled power plants. Although wood pellet prices tumbled in 2023 from their 2022 level (when they more than doubled), they were still above the previous years' average prices. The climate is also largely behind the drop in consumption, leading to lower heating needs across the European Union in 2022 and 2023. This trend, which is directly linked to climate change, is not about to go into reverse. The Copernicus Climate Change Service (C3S) of the European Union's Earth Observation Programme confirmed, "2024 is now certain to be the hottest year on record and will exceed the 1900 pre-industrial level by more than 1.5 °C", the limit set by the Paris agreement. However, this agreement refers to a long-term trend, the 1.5 °C average warming should be observed over several years to be considered as exceeded.

IMPORTS FROM OUTSIDE THE EU PLUMMET

Eurostat puts European Union solid biofuel production, i.e., the solid biomass taken from EU soil, at 94 Mtoe in 2023. This amounts to a 4% year-on-year drop, equating to a 4-Mtoe drop in output. The difference between the primary energy production data

1

Primary energy production and gross inland consumption of solid biofuels in the European Union in 2022 and 2023 (in Mtoe)*

	2022		2023	
	Production	Consumption	Production	Consumption
Germany	14.154	14.313	12.577	12.671
France	10.460	10.618	10.547	10.765
Sweden	10.095	10.065	9.729	9.761
Finland	8.462	8.704	8.346	8.601
Poland	8.478	8.548	8.333	8.317
Italy	7.265	8.403	6.760	7.914
Spain	5.297	5.297	5.466	5.466
Austria	5.042	4.967	4.935	4.833
Czechia	3.727	3.512	3.371	3.217
Romania	3.471	3.419	3.165	3.183
Denmark	1.545	3.111	1.570	3.089
Portugal	2.971	2.800	2.895	2.734
Netherlands	1.649	2.479	1.554	2.008
Hungary	2.091	2.117	1.878	1.901
Belgium	1.301	1.880	1.341	1.667
Latvia	2.515	1.535	2.730	1.509
Croatia	1.593	1.377	1.485	1.330
Bulgaria	1.589	1.605	1.311	1.303
Lithuania	1.297	1.292	1.284	1.286
Estonia	1.766	1.143	1.743	1.211
Slovakia	1.383	1.362	1.167	1.157
Greece	0.797	0.824	0.868	0.879
Slovenia	0.546	0.546	0.528	0.528
Ireland	0.242	0.263	0.188	0.221
Luxembourg	0.179	0.170	0.194	0.206
Cyprus	0.031	0.035	0.025	0.027
Malta	0.000	0.001	0.000	0.001
Total EU-27	97.945	100.387	93.987	95.785

*Excluding charcoal. **Source: Eurostat**

and gross domestic consumption represents the balance of imports and exports, and stock variations. Across the European Union, net imports of solid biomass remain fairly low and have fallen considerably since 2021 (3.7 Mtoe in 2021, 2.4 Mtoe in 2022 and 1.8 Mtoe in 2023). The drop in imports recorded since 2021 can be attributed to both the effects of the Russian and Belarusian wood pellet embargo and the gradual implementation of European legislation on the use of biomass in major industrial sites, particularly biomass-fuelled power plants. The distribution of European Union countries' domestic solid biomass production between the various biomass fuels is clearly dominated by the "wood, wood residue and by-products" category, which includes wood pellet production. According to Eurostat data, the distribution in 2022 by order of importance was 78.6% for "wood, wood residue and by-products" (incl. 6% of wood pellets), 14% for black liquor, 5% for other plant matters and residues, 1.6% for industrial renewable waste, 0.6% for bagasse and 0.2% for animal waste.

SOLID BIOMASS ELECTRICITY OUTPUT FALLS

Primary energy is the energy contained in natural resources prior to any processing. Final energy is the energy used by the consumer, after being transformed and transported, used and invoiced at the point of use. Final energy can be used either as electricity or heat. Solid biofuel heat is differentiated according to whether it comes from the processing sector, i.e., is distributed via heating networks (table 3) or used directly by the end users in the residential, industrial and agricultural sectors (excluding the transport sector), for example in heating appliances (boilers, stoves, fireplace inserts, etc.). In the EU-27, solid biofuel electricity output continued to stall in 2023. Eurostat quantified it at 78.4 TWh – i.e. 11.3% (10 TWh) less than in 2022. The 2023 output level is very similar to that of 2018 (76.2 TWh). Over the past two years, the drop in output rose to as much as 15.4%, namely a loss of 14.3 TWh (from 92.7 TWh in 2021 to 78.4 TWh in 2023). Electricity production from solid biofuels fell to 76.6 TWh in 2023, if we only include in our calculations the part that complies with the RED II 2018/2001 Directive requirements for inclusion in European targets. So, 97.7% of the electricity output from solid biofuel in 2023 was certified as compliant with the RED II requirements. Hence, negligible amounts of solid biofuels that in principle are non-compliant are being used in the European Union's power plants – which was one of the RED II targets.

There is no change to the rankings of the top three EU solid biomass electricity producer countries. The two major forest countries, Finland and Sweden monopolise the top two ranks with respective solid biomass electricity outputs of 10.6 TWh (10.6% less YoY) and 10.3 TWh (8.8% less YoY), all of which was produced in CHP plants. Germany remains in third place with 10 TWh despite its 6.2% drop in output. The sharpest drops felt can be ascribed to the European Union's two largest wood pellet importers, namely Denmark, whose output fell by 12.1% to 5 TWh (0.7 TWh less YoY) and the Netherlands whose output fell by 27.1% to 4.9 TWh (1.8 TWh less YoY). Only France and Poland of the main producer countries' club increased their outputs between 2022 and 2023 (Poland by 7.4% and France by 3.7%) with respective gains of 440 GWh (for a total of 6.4 TWh) and 170 GWh (for a total of 4.7 TWh).

Heat consumption, including final energy consumption (directly used by end consumers) and heat from the processing sector (heat sold), continued to decline in 2023 (by 3.3% YoY), albeit it not as sharply as in 2022 (3.9% down from its 2021 level), falling from 81.2 Mtoe in 2022 to 78.5 Mtoe in 2023. Almost 99% (98.6% in 2023) of this consumption was certified compliant by the European Union's Member States and is thus eligible for inclusion in the RES directive target calculations. Going into detail, solid biomass heat consumption directly used by end consumers slipped by 3.4% YoY to 66.6 Mtoe, i.e. 2.3 Mtoe less YoY. In 2023, Germany recorded the sharpest drop in final solid biomass energy consumption after having increased it sharply in 2022, which declined by 1.5 Mtoe (13.8%) for a total of 9.6 Mtoe. The YoY (5%) drop in Poland's consumption was 342 ktoe for a total of 6.5 Mtoe.

Gross solid biomass heat output (from the processing sector) sold to heating networks declined by 0.4 Mtoe to 11.9 Mtoe (a 3% YoY drop). Most of this decline can be put down to lower demand made of Sweden's CHP plants). Sweden actually witnessed a drop of about 14.9% (0.4 Mtoe) in heat sales to heating networks between 2022 and 2023, with a total

2

Gross electricity production from solid biofuels in the European Union in 2022 and 2023 (in TWh)*

	2022			2023				
	Electricity only plants	CHP plants	Total	Electricity only plants	CHP plants	Total	Compliant**	Compliant (%)
Finland	0.000	11.908	11.908	0.000	10.642	10.642	10.543	99.1%
Sweden	0.000	11.284	11.284	0.000	10.291	10.291	10.243	99.5%
Germany	4.931	5.732	10.663	4.367	5.630	9.997	9.997	100.0%
Poland	1.222	4.712	5.934	1.600	4.774	6.374	5.705	89.5%
Denmark	0.000	5.679	5.679	0.000	4.992	4.992	4.992	100.0%
Netherlands	1.905	4.849	6.755	1.385	3.541	4.926	4.805	97.5%
France	0.889	3.658	4.547	1.260	3.458	4.717	4.717	100.0%
Spain	4.125	0.807	4.932	3.288	0.759	4.047	3.887	96.0%
Austria	0.764	2.975	3.739	0.769	2.746	3.515	3.451	98.2%
Italy	2.266	2.092	4.358	1.629	1.811	3.439	2.922	85.0%
Portugal	1.473	2.071	3.544	1.354	1.896	3.250	3.250	100.0%
Czechia	0.001	2.658	2.659	0.001	2.438	2.439	2.439	100.0%
Belgium	1.464	1.379	2.843	0.481	1.304	1.785	1.785	100.0%
Bulgaria	0.409	1.644	2.053	0.186	1.523	1.708	1.708	100.0%
Estonia	0.553	0.970	1.523	0.492	0.828	1.321	1.321	100.0%
Hungary	0.620	1.073	1.693	0.300	0.826	1.126	1.016	90.2%
Slovakia	0.006	1.043	1.049	0.063	0.900	0.963	0.963	100.0%
Croatia	0.000	0.720	0.720	0.000	0.706	0.706	0.706	100.0%
Latvia	0.000	0.552	0.552	0.000	0.478	0.478	0.448	93.9%
Lithuania	0.000	0.394	0.394	0.000	0.416	0.416	0.416	100.0%
Romania	0.062	0.494	0.557	0.003	0.376	0.379	0.379	100.0%
Ireland	0.482	0.026	0.508	0.322	0.026	0.347	0.343	98.8%
Luxembourg	0.000	0.288	0.288	0.000	0.289	0.289	0.289	100.0%
Slovenia	0.000	0.162	0.162	0.000	0.196	0.196	0.196	100.0%
Greece	0.009	0.043	0.052	0.023	0.031	0.055	0.055	99.9%
Total EU-27	**21.182**	**67.213**	**88.394**	**17.521**	**60.876**	**78.398**	**76.576**	**97.7%**

Excluding charcoal. **Compliant with the criteria of Article 29 of Directive (EU) 2018/2001.* ***Source: Eurostat and SHARES for compliant part*

3

Gross heat production in the transformation sector from solid biofuels in the European Union in 2022 and in 2023 (in Mtoe)*

	2022			2023				
	Heat only plants	CHP plants	Total	Heat only plants	CHP plants	Total	Compliant**	Compliant %
Sweden	0.709	1.910	2.619	1.036	1.194	2.230	2.220	99.5%
Finland	0.961	1.013	1.975	1.083	1.036	2.119	2.100	99.1%
Denmark	0.505	1.032	1.537	0.550	1.035	1.585	1.585	100.0%
France	0.659	0.622	1.281	0.671	0.516	1.187	1.187	100.0%
Austria	0.615	0.355	0.971	0.590	0.353	0.943	0.926	98.2%
Germany	0.159	0.473	0.632	0.171	0.480	0.652	0.652	100.0%
Poland	0.145	0.353	0.498	0.150	0.378	0.528	0.473	89.5%
Lithuania	0.393	0.149	0.543	0.374	0.153	0.526	0.526	100.0%
Latvia	0.244	0.165	0.408	0.243	0.148	0.391	0.390	100.0%
Estonia	0.140	0.224	0.364	0.143	0.225	0.368	0.369	100.0%
Netherlands	0.115	0.222	0.337	0.090	0.192	0.282	0.233	82.7%
Czechia	0.044	0.178	0.222	0.042	0.188	0.230	0.230	100.0%
Italy	0.087	0.121	0.208	0.085	0.139	0.224	0.209	93.5%
Bulgaria	0.015	0.133	0.147	0.017	0.115	0.132	0.132	100.0%
Slovakia	0.052	0.087	0.139	0.054	0.076	0.130	0.130	100.0%
Luxembourg	0.005	0.089	0.094	0.006	0.087	0.093	0.093	100.0%
Hungary	0.033	0.060	0.093	0.039	0.047	0.086	0.074	86.2%
Croatia	0.000	0.091	0.091	0.000	0.085	0.085	0.077	90.8%
Romania	0.011	0.060	0.071	0.010	0.051	0.061	0.061	100.0%
Slovenia	0.015	0.031	0.046	0.015	0.024	0.039	0.039	100.0%
Belgium	0.000	0.024	0.024	0.000	0.037	0.037	0.037	100.0%
Total EU-27	4.908	7.393	12.300	5.369	6.560	11.929	11.743	98.4%

*Excluding charcoal. **Compliant with the criteria of Article 29 of Directive (EU) 2018/2001. **Source: Eurostat and SHARES for compliant part**

4

Final energy consumption from solid biofuels** in the European Union in 2022 and in 2023 (in Mtoe)*

	2022	2023	Compliant*** 2023	Compliant 2023%
Germany	11.148	9.614	9.614	100.0%
France	8.002	8.108	8.108	100.0%
Italy	6.708	6.564	6.562	100.0%
Poland	6.886	6.544	5.857	89.5%
Sweden	5.533	5.836	5.809	99.5%
Finland	4.815	4.801	4.769	99.3%
Spain	3.816	4.124	4.035	97.8%
Austria	3.296	3.223	3.223	100.0%
Romania	3.367	3.162	3.162	100.0%
Czechia	2.663	2.402	2.402	100.0%
Portugal	1.821	1.799	1.799	100.0%
Hungary	1.570	1.508	1.508	100.0%
Belgium	1.266	1.270	1.270	100.0%
Croatia	1.040	1.002	1.002	100.0%
Latvia	0.954	0.962	0.962	100.0%
Denmark	0.834	0.879	0.879	100.0%
Greece	0.804	0.857	0.857	100.0%
Bulgaria	1.007	0.852	0.836	98.1%
Slovakia	0.940	0.760	0.760	100.0%
Netherlands	0.669	0.612	0.582	95.1%
Lithuania	0.610	0.594	0.594	100.0%
Slovenia	0.471	0.454	0.454	100.0%
Estonia	0.445	0.422	0.422	100.0%
Ireland	0.164	0.149	0.144	96.4%
Luxembourg	0.034	0.033	0.033	100.0%
Cyprus	0.031	0.025	0.025	100.0%
Malta	0.001	0.001	0.001	100.0%
Total EU-27	**68.896**	**66.558**	**65.669**	**98.7%**

Final energy consumption in «Industry» and «other sectors», excluding «transport» **Excluding charcoal. ***Compliant with the criteria of Article 29 of Directive (EU) 2018/2001.* ***Source: Eurostat and SHARES for compliant part*

5

Heat consumption from solid biofuels** in the countries of the European Union in 2022 and 2023 (in Mtoe)*

	2022	2023	Compliant*** 2023	Compliant 2023 %
Germany	11.781	10.266	10.266	100.0%
France	9.283	9.295	9.295	100.0%
Sweden	8.152	8.066	8.028	99.5%
Poland	7.384	7.072	6.330	89.5%
Finland	6.790	6.920	6.868	99.3%
Italy	6.916	6.788	6.771	99.8%
Austria	4.267	4.166	4.148	99.6%
Spain	3.816	4.124	4.035	97.8%
Romania	3.438	3.223	3.223	100.0%
Czechia	2.885	2.632	2.632	100.0%
Denmark	2.372	2.464	2.464	100.0%
Portugal	1.821	1.799	1.799	100.0%
Hungary	1.663	1.594	1.582	99.2%
Latvia	1.362	1.352	1.352	100.0%
Belgium	1.289	1.308	1.308	100.0%
Lithuania	1.153	1.121	1.121	100.0%
Croatia	1.131	1.087	1.079	99.3%
Bulgaria	1.154	0.984	0.968	98.4%
Netherlands	1.005	0.893	0.815	91.2%
Slovakia	1.080	0.890	0.890	100.0%
Greece	0.804	0.857	0.857	100.0%
Estonia	0.809	0.791	0.791	100.0%
Slovenia	0.517	0.493	0.493	100.0%
Ireland	0.164	0.149	0.144	96.4%
Luxembourg	0.128	0.126	0.126	100.0%
Cyprus	0.031	0.025	0.025	100.0%
Malta	0.001	0.001	0.001	100.0%
Total EU-27	**81.196**	**78.487**	**77.412**	**98.6%**

Gross heat production in the transformation sector and final energy consumption in «Industry» and «other sectors», excluding «transport». **Excluding charcoal. ***Compliant with the criteria of Article 29 of Directive (EU) 2018/2001.* ***Source: Eurostat*

of 2.2 Mtoe in 2023. Further north, Finland made greater demand of its heat production plants, increasing output by 7.3% (145 ktoe YoY) for a total of 2.1 Mtoe in 2023. The cogeneration sector's difficulties in Sweden can be attributed to rising biofuel prices (wood pellets in particular), which came after Russia invaded Ukraine in February 2022, triggering an embargo on biomass imports from Russia and Belarus.

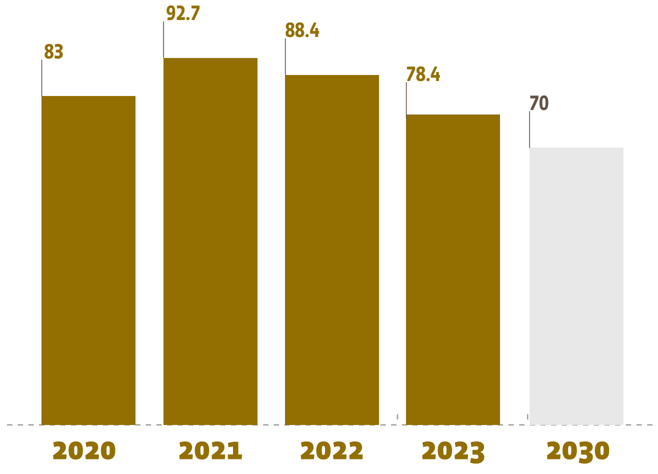
RED III GIVES SUSTAINABILITY CRITERIA A BROADER SCOPE

For the European Commission, greater use of biomass in the EU may contribute to diversifying Europe's energy supply both in the heat production and electricity production segments, creating growth and jobs and reducing GHG emissions. However, if energy recovery from biomass is to be efficient in reducing GHG emissions and if it is to continue maintaining ecosystem services (such as oxygen and air production) and preserving biodiversity, the biomass must be sustainably produced and used. Biomass production involves a chain of activities, ranging from growing the raw materials to final energy conversion. Each stage of the process may pose various sustainability challenges that must be managed. To this end, the European Union has laid down tougher sustainability criteria firstly within the framework of the Renewable Energy Directive 2018/2001 (known as RED II), and subsequently "broadened" them within the framework of the recast Renewable Energy Directive 2023/2413 (known as RED III) on 18 October 2023. RED III aims to extend the scope of the sustainability criteria further so that they apply to an even higher number of installations. It also aims to discourage the use of sawlogs, industrial quality timber for energy purposes, and similarly the use of biofuels exclusively for producing electricity. It also ensures that the Member States respect the cascading principle of using waste according to its hierarchy, the biomass energy must be produced so as to minimise the distortive effects on the raw materials market

EurObserv'ER reckons that the European Union's political determination to reduce the "industrial" uses of solid biofuels could significantly affect their contribution to renewable targets, because during the 2010s much of the increase in solid biofuel consumption was borne by the commissioning of major power plants via the conversion of coal-fired plants to biomass fuels or by the construction of large biomass-fired cogeneration plants. While the current difficulties of major industrial production plants using solid biofuels are more cyclical and stem from solid biomass electricity's lack of competitiveness due to high fossil fuel prices, the curtailment of grants for production could result in new plant closures in the coming years through lack of profitability. A situation of this nature will not be anodyne for the balance of electrical systems because biomass plants can operate in base load mode and respond to demand peaks in very cold weather. The long-term trend is that solid biofuels will be primarily used to meet heating needs, in direct use or via heat sales from biomass heating plants or cogeneration plants. ■

6

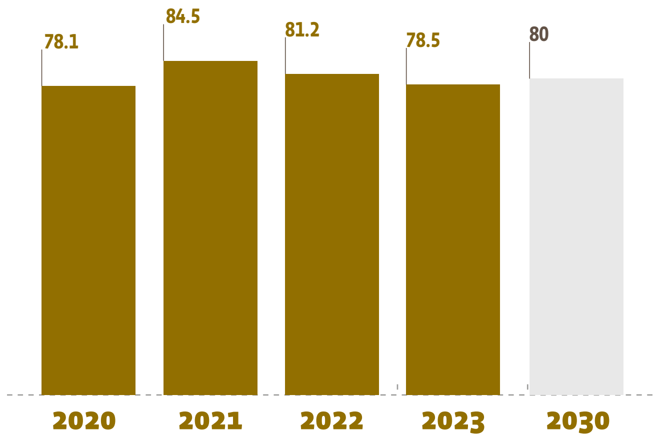
EurObserv'ER projection of electricity production from solid biofuels in the EU-27 (in TWh)



Source: EurObserv'ER

7

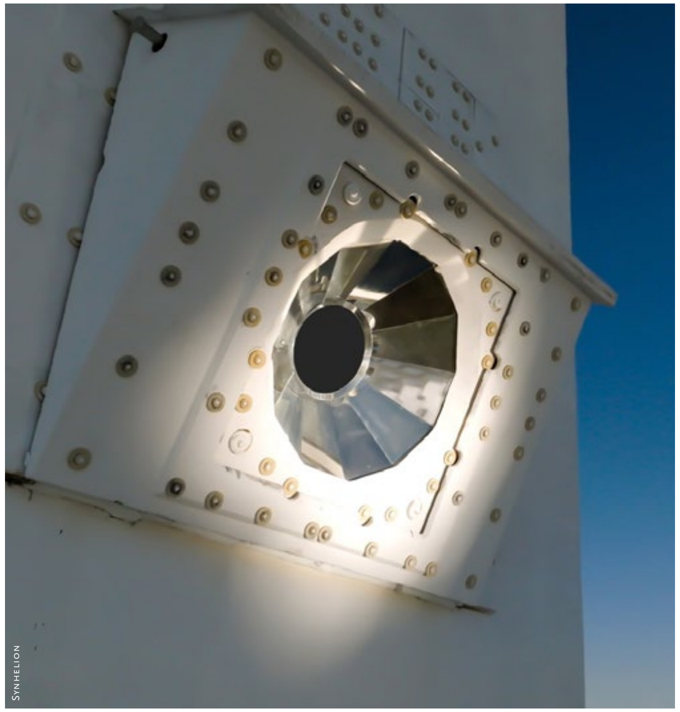
EurObserv'ER projection of heat consumption from solid biofuels in the EU-27 (in Mtoe)*



** Gross heat production in the transformation sector and Final energy consumption in «Industry» and «other sectors» excluding «transport». **Source: EurObserv'ER***

CONCENTRATED SOLAR POWER

The terms "solar thermodynamic" or "concentrated solar thermal" (abbreviated to CSP) cover the technologies that aim to transform the sun's radiant energy into very high temperature heat. The three main plant types are tower plants, whose heliostat fields (devices equipped with mirrors that track the sun's path) concentrate radiation onto a receiver at the top of a tower; parabolic trough plants, that comprise parallel rows of long semicylindrical mirrors that rotate around a horizontal axis to track the sun's path and concentrate the rays on a horizontal tube and lastly, Fresnel plants, whose rows of flat mirrors pivot to track the sun's path and permanently redirect and concentrate the sun's rays on an absorber tube. CSP plants were initially geared to electricity production. Now, new projects have been developed in the European Union that serve industrial heat needs. New CSP electricity generating projects are few and far between and of low capacity in the EU. Two 4-MW Fresnel power plants are currently under construction in Sicily.



Synhelion

AT THE END OF 2023, THE EU HAD 2 333.1 MW OF CSP ELECTRICAL CAPACITY

EurObserv'ER reports that at the end of 2023, five European Union countries had a total of 2 333.1 MW of CSP electricity generating capacity between them (unchanged from the 2022 level), namely one third of global CSP capacity. Most of this EU CSP capacity is based in Spain (2 304 MW), followed by Italy (12.4 MW), France (9.8 MW), Denmark (5.5 MW) and Germany (1.5 MW). The Eurostat database only measures Spain's installed capacity, whose gross output it quantified at 5 165 GWh in 2023, a 13.9% year-on-year increase (from 4 536 GWh).

As construction is underway on only two Fresnel CSP plants In Sicily – both by the Italian industrial group, Fata – growth prospects are restricted. Work began on the 4-MW SOLINPAR Stromboli project in Trapani (Trapani province) in 2020 and on the 4-MW BILANCIA project in Mezzo Juso, Palermo in 2022. The BILANCIA project, which is being built for Bilancia PV SRL, will use a blend of molten salts both as the heat transfer fluid and for thermal energy storage. Its design capacity equates to 16 hours of continuous operation at full load. The plant will cover a total area of about 145 000 m² with some 84 000 m² of mirror surface. This is the Italian Fata group's third Fresnel CSP plant, following the 4.26-MW Partanna project (Trapani province) that went on stream in 2022 and the SOLINPAR Stromboli project, that is nearing completion. Once the SOLINPAR Stromboli and BILANCIA are commissioned, Italy's CSP electricity generating capacity will rise to 20.4 MW and take that of the EU to 2 341.1 MW.

MEGA CSP PROJECTS OUTSIDE EUROPE

IRENA puts global concentrated solar power capacity at the end of 2023 at 6 876 MW (6 576 MW at the end of 2022), including 300 MW of additional capacity in the United Arab Emirates, resulting from the 2023 commissioning of two new plants constructed as part of the fourth phase of the Mohammed Bin Rashid Al Maktoum Solar Park, a Dubai Electricity and Water Authority (DEWA) development. It comprises the Noor Energy 1/DEWA IV (100 MW) tower plant and the second of three 200-MW parabolic trough plants in the Noor Energy 1/DEWA IV (3X200-MW) parabolic trough complex. The solar park's fourth phase will comprise three 200-MW parabolic trough plants, one 100-MW tower plant, and 250 MW of photovoltaic panels, for a total of 950 MW of solar technologies. As 2023 came to a close, commissioning of only the third and last remaining parabolic trough plant remained outstanding for 2024, while the photovoltaic plant was almost ready. At 262 metres, the Noor1/DEWA IV tower plant ("noor" in Arabic means light) enjoys the distinction of being the world's tallest tower plant. It has 15 hours' worth of (molten salts) storage capacity, hence it can operate 24 hours round the clock. The storage capacity of the three parabolic trough plants will be limited to 11 hours. Major projects were completed in 2024 such as South Africa's Redstone tower plant constructed by SEPCOIII Electric Power Construction Corporation, a POWERCHINA subsidiary. The 100-MW plant should generate 480 GWh of electricity per annum, which is enough to cover the electricity needs of 200 000 South African households. China's Three Gorges project, with its novel dual 50-MW tower plant configuration, produced its first MWh in July 2024.

INDUSTRIAL HEAT PUTS CSP THROUGH ITS PACES

Industrial solar heat projects can call on a vast array of temperature requirement-

1

Concentrated solar power plants in operation in the European Union at the end of 2023*

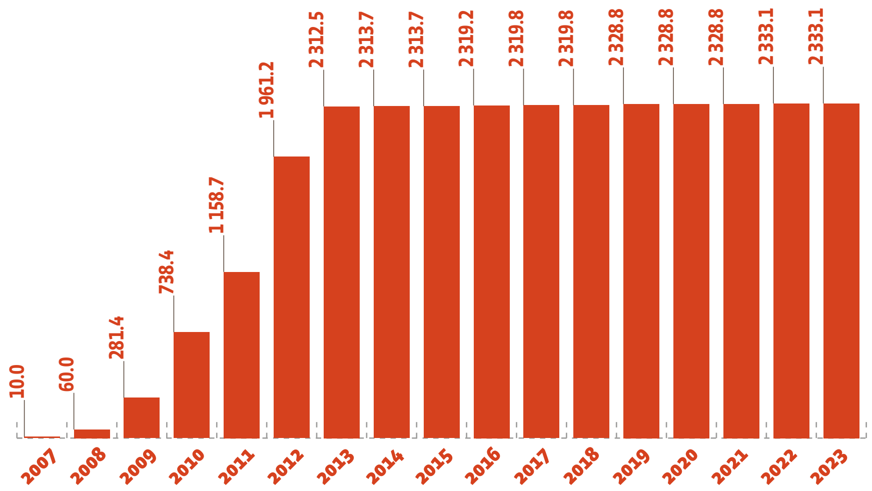
Project	Technology	Capacity (MWe)	Commisionning date
Spain			
Planta Solar 10	Central receiver	10	2007
Andasol-1	Parabolic trough	50	2008
Planta Solar 20	Central receiver	20	2009
Ibersol Ciudad Real (Puertollano)	Parabolic trough	50	2009
Puerto Errado 1 (prototype)	Linear Fresnel	1.4	2009
Alvarado I La Risca	Parabolic trough	50	2009
Andasol-2	Parabolic trough	50	2009
Extresol-1	Parabolic trough	50	2009
Extresol-2	Parabolic trough	50	2010
Solnova 1	Parabolic trough	50	2010
Solnova 3	Parabolic trough	50	2010
Solnova 4	Parabolic trough	50	2010
La Florida	Parabolic trough	50	2010
Majadas	Parabolic trough	50	2010
La Dehesa	Parabolic trough	50	2010
Palma del Río II	Parabolic trough	50	2010
Manchasol 1	Parabolic trough	50	2010
Manchasol 2	Parabolic trough	50	2011
Gemasolar	Central receiver	20	2011
Palma del Río I	Parabolic trough	50	2011
Lebrija 1	Parabolic trough	50	2011
Andasol-3	Parabolic trough	50	2011
Helioenergy 1	Parabolic trough	50	2011
Astexol II	Parabolic trough	50	2011
Arcosol-50	Parabolic trough	50	2011
Termesol-50	Parabolic trough	50	2011
Aste 1A	Parabolic trough	50	2012
Aste 1B	Parabolic trough	50	2012
Helioenergy 2	Parabolic trough	50	2012
Puerto Errado II	Linear Fresnel	30	2012
Solacor 1	Parabolic trough	50	2012
Solacor 2	Parabolic trough	50	2012
Helios 1	Parabolic trough	50	2012
Moron	Parabolic trough	50	2012
Solaben 3	Parabolic trough	50	2012
Guzman	Parabolic trough	50	2012
La Africana	Parabolic trough	50	2012
Olivenza 1	Parabolic trough	50	2012
Helios 2	Parabolic trough	50	2012
Orellana	Parabolic trough	50	2012
Extresol-3	Parabolic trough	50	2012
Solaben 2	Parabolic trough	50	2012
Termosolar Borges	Parabolic trough + HB	22.5	2012
Termosol 1	Parabolic trough	50	2013
Termosol 2	Parabolic trough	50	2013
Solaben 1	Parabolic trough	50	2013
Casablanca	Parabolic trough	50	2013
Enerstar	Parabolic trough	50	2013
Solaben 6	Parabolic trough	50	2013
Arenales	Parabolic trough	50	2013
Total Spain		**2303.9**	
France			
La Seyne sur mer (prototype)	Linear Fresnel	0.5	2010
Augustin Fresnel 1 (prototype)	Linear Fresnel	0.25	2011
SUN CNIM (Ello project)	Linear Fresnel	9	2019
Total France		**9.75**	
Italy			
Archimede (prototype)	Parabolic trough	5	2010
Archimede-Chiyoda Molten Salt Test Loop	Parabolic trough	0.35	2013
Freesun	Linear Fresnel	1	2013
Zasoli	Linear Fresnel + HB	0.2	2014
Rende	Linear Fresnel + HB	1	2014
Ottana	Linear Fresnel	0.6	2017
Solinpare CSP- Partanna	Linear Fresnel	4.26	2022
Total Italy		**12.41**	
Denmark			
Aalborg-Brønderslev CSP project	Hybrid. Parabolic Trough	5.5	2016
Total Denmark		**5.5**	
Germany			
Jülich	Central receiver	1.5	2010
Total Germany		**1.5**	
Total European Union		**2333.1**	

*HB (Hybrid Biomass). *Pilots and prototypes included.* ***Source: EurObserv'ER***

Continues overleaf

2

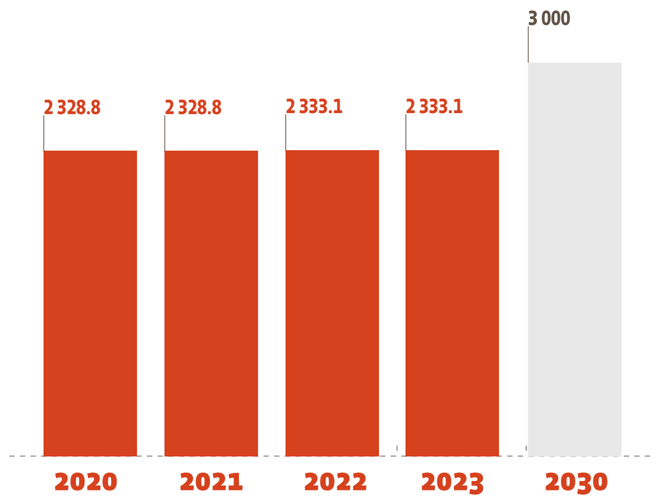
European Union concentrated solar power capacity trend (MW)



Source: EurObserv'ER

3

EurObserv'ER projection of the evolution of CSP capacity installed in the EU-27 (in GW)



Source: EurObserv'ER

dependent technologies, that offer new prospects to CSP technology development, alongside conventional flat solar thermal collectors and vacuum collectors. Increasingly high-powered industrial solar heat projects have emerged in recent years combined with several thousands, if not tens of thousands of m² of concentrating collector fields. This trend is not unique to Europe, in fact the largest solar heat CSP installation went on stream in China in 2024. It is a 114 000-m² (77 MWth) parabolic-trough CSP installation that supplies a tourist and leisure complex with space heating and artificial snow production. Several large-scale industrial heat production installations were commissioned in the European Union in 2023. They include Europe's biggest solar thermal platform commissioned in September 2023 at Turnhout, Belgium, operated by Avery Dennison, one of the world's leading packaging and materials manufacturers. The renewable energy project comprises a parabolic-trough system with 2 240 surface mirrors and a 5 540-m² collector field, with a solar field peak yield of 2.7 GWh of thermal power and six thermal storage modules with 5 MWh of capacity. The plant will supply heat required in the adhesive product coating process to the drying ovens. Spain's industrial solar heat market performed well in 2023, thanks to the major incentive programme that Feder funded to the tune of 108 million euros in 2022. One such large project commissioned in 2023 was the parabolic trough concentrating solar heat (CSH) plant that supplies heat to Seville's Heineken brewery. The 8-hectare plant has 43 414 m² of collectors offering 30 MW of thermal capacity coupled with 68 MWh of storage capacity. The investment will enable the brewery to slash its gas consumption by more than 60%. More recently, in March 2024, Heineken and CSIN (Solatom Indertec Company) started up the world's largest Fresnel CSH plant for industrial use (6 000 m² flat mirrors) at Quart de Poblet (4.2 MWth), near Valencia. This CSH plant, constructed in a record eight months should reduce annual CO_2 emissions by about 1 300 tonnes. By the end of 2024, Heineken's Valencia brewery aims to be 42% renewably supplied (electricity and heat). The positive feedback from these innovative projects should encourage expansion of CSH throughout the European Union.

SPAIN MAINTAINS AMBITIOUS GOALS FOR 2030

The coming years' European Union CSP development potential should be centred on Spain, which updated its 2023-2030 NECP in September 2024. It is aiming for 4 804 MW of CSP electrical capacity by 2030, which is higher than its current installed base. This expansion could contribute to Spain's storage goals, which have been increased from the previous 20 GW to 22 GW under the plan's frame of reference. The potential revamp of Spain's CSP sector, will require very swift and more to the point conclusive implementation of new tenders, so that it can restructure and construct new high-capacity projects over time, similar to the Chinese and Middle Eastern projects. This contrasts with Italy, Portugal and Greece, whose current NEPC plans do not formulate any specific CSP sector goals. ■

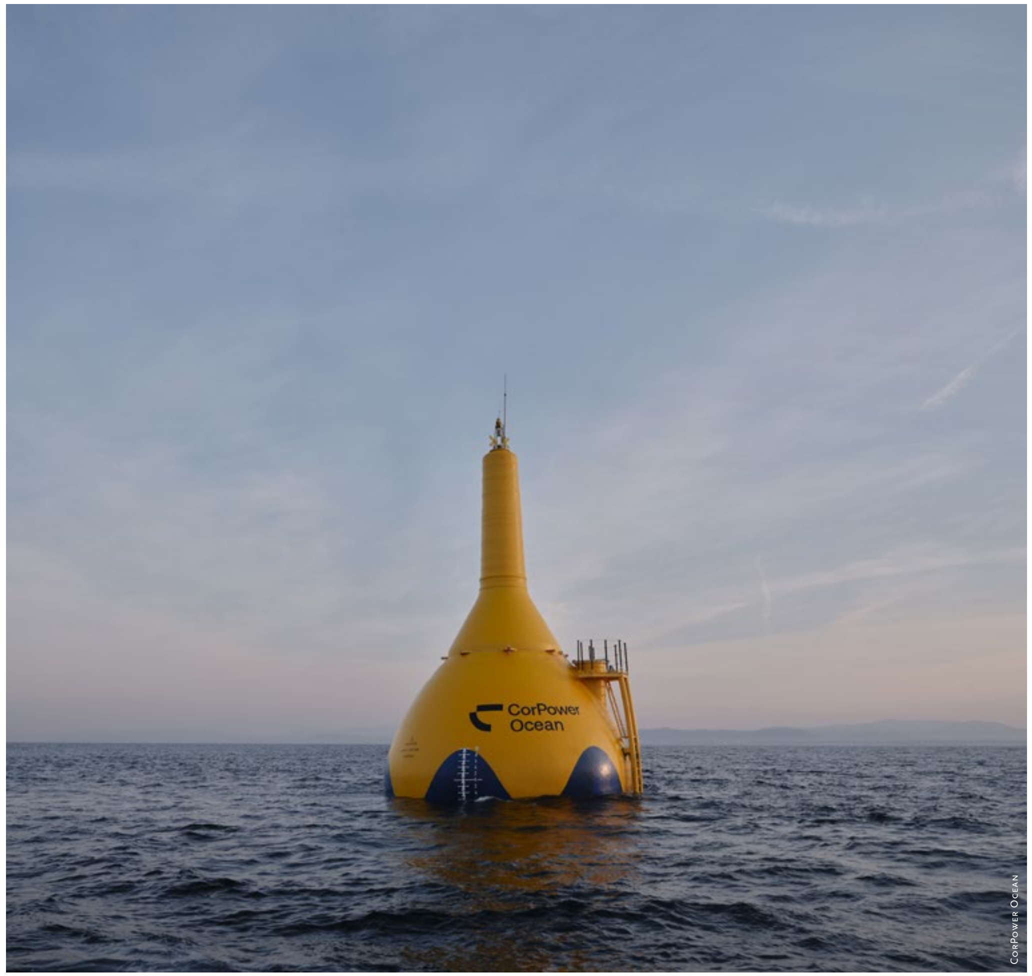
OCEAN ENERGY

Marine energy, also known as ocean energy, offers coastal countries significant diversification potential for their electricity mixes. Competition is rife in the European sector with companies trying to outdo each other and impose their marine turbine or wave energy converter (WEC) concepts for mass production. The tidal stream sector, which uses ocean current energy, has opened up a slight lead by launching its first commercial projects to benefit from power purchase agreements. It is currently collecting feedback on its full-scale prototypes, i.e., one-MW "commercial" size turbines. The wave energy converter sector is hard on its heels, testing prototypes dimensioned at several hundred kW adapted to deal with differing European coastal wave conditions. Marine energy breaks down into five distinct families each with its own technologies that are at different stages of development – tidal range energy (or tidal power), tidal stream energy (or hydrokinetic energy), wave energy (wave energy converter energy), ocean thermal energy conversion (OTEC – that exploits the temperature difference between the seabed and the surface water) and osmotic energy that exploits the difference in salinity between freshwater and seawater. The two most active sectors at industrial scale use the energy of tidal currents and wave energy.

LULL BEFORE THE STORM OF PROJECTS

Eurostat carries out the official statistical monitoring of net capacity of projects that use tide, wave and ocean energy, as defined by the international energy products classification. As it stands, only two EU-27 countries – France and Spain – monitor net marine energy capacity. The SDES (Monitoring and Statistics Directorate) of the French ministries of the environment, energy, construction, housing and transport releases data on the capacity and electricity output of the La Rance tidal range power plant and of the Sabella tidal turbines off the coast of Ushant Island, Brittany. The net maximum capacity measured in France came to 211.8 MW in 2023 with 449.3 GWh of output (490.5 GWh in 2022). Spain's Ministry for Ecological Transition only quantifies the capacity and output of the Enagas ocean thermal plant and the 296 kW capacity of the Mitriku wave energy plant, which at the end of 2023 amounted to total capacity of 4.8 MW and 12 GWh of output (23 GWh in 2022). The other EU countries with demonstrators and prototypes that were approached for the purpose of this barometer, have so far decided against monitoring, because of the low output levels and statistical confidentiality rules.

The number of projects in test phase hinders the task of drawing up a capacity inventory of marine energy projects in service. Regardless of whether or not the prototypes are connected to the grid, the official bodies do not methodically monitor their statistics, while the constant changing states of prototypes (immersion, improvement, maintenance and decommissioning phases), resulting in relatively short test periods, further compound efforts to arrive at accurate project accounting. Nonetheless, the European association, Ocean Energy Europe, has a monitoring service that publishes



CorPower Ocean

EUROBSERV'ER – THE STATE OF RENEWABLE ENERGIES IN EUROPE – 2024 EDITION

1

List of projects using ocean energy having been active during the year 2023 in the European Union*

Summary	Device Developper	Device Name	Technology	Location	Date	Total capacity (MW)
France						
Rance tidal power plant (EDF)	Alstom	Bulb Turbine (La Rance)	Tidal range	Brittany - La Rance	1966	240.00
DIKWE Project	Groupe Legendre & GEPS techno		Wave Energy	Brest	2022	0.01
Ushant Island	Sabella	D10	Tidal current	Ushant Island	2021	1.00
Bordeaux	Hydrokinetic	Evo25	Tidal current	Bordeaux	2022	0.025
Brest	EEL Energy	EEL	Tidal current	Brest	2022	0.03
Rhône river	EEL Energy	EEL	Tidal current	Lyon	2023	0.03
H2020 ELEMENT project	Nova Innovation	RE50	Tidal current	Etel	2023	0.05
Nantes (SEM-REV)	GEPS Techno	Wavegem	Wave Energy	Nantes	2023	0.01
Total France						241.16
Spain						
Enagas Huelva plant**	Enagas	Enagas Huelva plant	OTEC***	Huelva. Andalousia	2013	4.5
Ente Vasco de la Energia (EVE)	Voith Hydro	Mutriku	Wave energy	Pais Vasco	2011	0.296
Valencia Project	Rotary Wave	Rotary Wave	Wave energy	Valencia	2023	0.02
Total Spain						4.82
Netherlands	Tocardo	T2	Tidal_Stream	Oosterscheldedam	2015	1.25
100 kW VAWT for Vlissingen	Water2Energy	VAWT	Tidal current	Vlissingen	2021	0.1
Total Netherlands						0.1
Portugal						
HiWave-5 project	CorPower Ocean	C4	Wave energy	Aguçadoura	2023	0.3
Total Portugal						0.3
Denmark						
Pilot plant at the Afsluitdijk	Redstack	TRL7	Salinity Gradient	Breezanddijk on the Afsluitdijk	2014	0.05
First commercial project SEV	Minesto	DG100	Tidal current	Vestmannasund (Faroe Islands)	2020	0.1
Second commercial project SEV	Minesto	DG100	Tidal current	Vestmannasund (Faroe Islands)	2021	0.1
Total Denmark						0.25

Continues overleaf

Italy						
Messina Strait test project	ADAG	Kobold	Tidal current	Strait of Messina	2000	0.05
Civittavecchia test project	Wavenergy	REWEC3	Wave energy	Civittavecchia	2016	0.02
ISWEC project	Eni	ISWEC	Wave energy	Pantelleria island - Mediteranean Sea	2023	0.26
Total Italy						0.33
Slovenia						
Adriatic	Sigma Energy	Sigma WEC	Wave energy	Adriatic Sea	2022	0.03
Total Slovenia						0.03
Total UE 27						**247.0**

** including demonstrators and prototypes during the test phase. ** The Huelva project exploits the temperature difference between the ocean and liquefied natural gas. *** Ocean Thermal Energy Conversion.* ***Source: Ocean Energy Europe 2025***

Minesto

statistics on the installed machine and fleet capacity in service in European waters during the year. Table 1 displays another indicator monitoring installed marine energy capacity, that includes the capacity of prototypes, pre-commercial and commercial demonstrators that were operating (immersed) in European Union waters in 2023.
Accordingly, EU-27 ocean energy capacity increased to 247 MW in 2023, including the 240 MW of capacity at the La Rance tidal power plant and the 4.5 MW of Spain's Enagas LNG terminal's ocean thermal plant. A further 1.5 MW of tidal stream energy capacity and 0.9 MW of WEC capacity (rounded figures) off the Faroe Islands have been added. The UK, whose test centres accommodate many projects funded by European programmes, contribute an additional 10.33 MW of tidal stream energy and two small WEC prototypes.
Tidal stream energy harnesses the kinetic energy of both tide and ocean currents. It is generally captured by marine turbines, placed or anchored on the seabed or, in the case of floating marine turbines, moored under a barge or platform, usually in pairs. Technologies capable of developing tidal currents' potential abound, such as axial flow turbines, cross-flow turbines and oscillating profiles such as underwater wings. Marine turbines are much smaller than wind turbines at equivalent capacity, because the density of water is 833 times higher than that of air. Another advantage is the low visual impact of completely submerged or low height models, while turbines placed or anchored on the seabed that are not exposed above the sea's surface level present fewer navigational constraints.
According to Ocean Energy Europe, in its "Ocean Energy, Key trends and statistics 2023" publication that came out in April 2024, Europe has amassed 30.5 MW of marine turbine capacity since 2010 using tidal streams, 11.75 MW of which were still immersed in European waters (European Union, UK and Norway) in 2023. Ocean Energy Europe claims that only 4 units were deployed in Europe (2 in Scotland and 2 in France) with combined capacity of 280 kW (200 kW for Scotland and 80 kW for France) and that this figure is slightly below the average European deployment level of recent years, because the developers are currently seeking funding for their upcoming pre-commercial farms. No significant capacity increases from these pre-commercial projects are expected before 2026/2027.
As regards French projects in 2023, the biggest is led by the Scottish startup Nova Innovation, which tested its RE50 marine

2

Capacity and electricity production from ocean energy in European Union in 2022 et 2023 (in MW and in GWh)*

	2022		2023	
	MW	GWh	MW	GWh
France**	212.1	490.5	211.8	449.3
Espagne	4.8	23.0	4.8	12.0
Total EU-27	216.9	513.5	216.6	461.3

Net maximum electrical capacity. ** Electricity production excluding pumped storage. Note: Most countries with marine energy demonstrators or prototypes do not officially include them in the capacity and production data communicated to Eurostat.* ***Source: Eurostat.*

turbine (50-kW capacity horizontal-axis tidal stream turbine) in the Etel Estuary (Morbihan) this year. The turbine was developed as part of the European ELEMENT project, [abbreviation for Effective Lifetime Extension in the Marine Environment for Tidal Energy], a € 50M EU-funded project. The project aims to show how artificial intelligence can reduce the cost of tidal power by about 17% using marine turbines ideally located in estuaries or rivers. The second marine turbine installed in France in 2023 is a 30-50 kW river-going floating machine launched on the Rhône near Lyon, developed by EEL Energy. It is a bio-mimetic marine turbine (inspired by the propulsion method of some fish that can reach speeds of up to 110 km/hour), that harnesses the undulation of a membrane created by river or marine currents of 1.2 to 3.5 m/s. EEL Energy points out that it is the first grid-connected river marine turbine farm in France. The project may expand to 4 units under a concession agreed with Voies Navigables de France.
Furthermore, Nova Innovation was behind the scenes of the launching of two new units on its tidal farm off the Shetland Islands in 2023, taking the number of machines in service on the site to six. They are NOVA M100 D horizontal-axis tidal stream turbines, called Grace and Hali Hope. The project has funds from the European Union's EU Horizon 2020 programme.
As for WEC projects between 2010 and 2023, Ocean Energy Europe reports the installation of 13.3 MW of capacity in Europe (the EU, the UK and Norway) 12.3 MW of which was taken out of service on completion of the test and demonstration programmes. The combined capacity of the WEC projects in service in 2023 is 1 MW, mainly sited in the European Union's waters (Spain, Portugal, Italy, France and Slovenia).Currently, Southern Europe is the focal point of the wave energy converter development drive with four new projects totalling 590 kW of capacity that started up in 2023. The most powerful WEC was launched by CorPower Ocean north of Portugal. The 300-kW CorPower C4 point absorber energy converter was launched in Viana do Castelo port, prior to being towed out 4 km off shore to the Aguçadoura site. The unit was connected to Portugal's national power grid via a submarine power export cable after its connection to an anchor pre-installed on the seabed. CorPower Ocean now aims to start mass production and develop a profitable commercial offer. The Hiwave-5 WEC project was made possible through funding from the Swedish Energy Agency and Portugal 2020 via AICEP Global (Norte2020) and CCDR-N. CorPower Ocean has received a lot of financial support from the European Commission, EIT InnoEnergy, Wave Energy Scotland, CoreSpring New Technology, ALMI Invest Greentech, SEB Greentech VC and other private investors. In March 2023, Italy's ENI completed the installation of its ISWEC wave energy converter off the Pantelleria Island coasts in the strait of Sicily in the Mediterranean Sea. The WEC, lying 800 metres off the coast can deliver up to 260 kW of power. It was connected via a submarine electricity cable to the island's grid. ISWEC was developed by ENI in conjunction with Turin's Polytechnic (Politecnico di Torino) and Wave for Energy, a spinoff company of the polytechnic. The device comprises an 8 x 15 m steel hull, that houses the energy conversion system consisting of two gyroscopic units each over 2 m in diameter. It is anchored to the 35-m deep seabed by a special mooring system. Spain's Rotary Wave put its 20-kW point absorber WEC on its Pobla de Farnals test site near Valencia. In France, the French company GEPS Techno successfully tested its WaveGem (10 kW) laboratory buoy in 2023 for offshore hydrogen production. The buoy was connected to the SEM-REV test site grid off the coast of Croisic (France). It was launched in June 2023 and tested for several months. The now completed project has proven the feasibility of producing hydrogen in a totally isolated environment.

DAWN OF THE INDUSTRIALIZATION ERA

The marine energy sector is set to enter a new phase, that of industrialization and mass production. According to Ocean Energy Europe, Europe has 137 MW of projects in the pipeline backed by both European Union programmes and national support schemes, that form a solid base for financiers and industrial investors. Tidal stream energy alone lays claim to about a hundred MW of pre-commercial farms in development, admittedly mainly around the UK, but also France with the FloWatt project's HydroQuest (17.5 MW). The French project, based in English Channel's Alderney Race, one of the globe's most energetic tidal streams, will be the biggest ever marine turbine farm to be deployed in the European Union. In 2023, HydroQuest developed by Qair, and their leading shareholder CMN (industrial partner) received backing from the French state in the form of a 75 million euro investment and a preferential tariff for the electricity generated as part of the Plan France 2030. The pilot farm will have a total capacity of 17.5 MW delivered by seven HQ 2.5 marine turbines to be manufactured by CMN in Cherbourg, with annual output enough to meet the electricity demand of 20 000 inhabitants. The turbines will be immersed 3 km off the coast at a depth of 30-35 metres and thus be completely invisible. Work on the FloWatt project site will kick off in 2025 with commissioning due in 2027. Wave energy converter projects are expected to pick up speed in the next five years, primarily in Spain, Portugal and Ireland. The Saoirse pre-commercial farm project is a 50:50 joint venture led by Simply Blue and Ireland's national energy company ESB that is set to be one of the biggest. The project should be completed by the middle or end of the 2020s, provided that it obtains the necessary permits and is connected to the grid. The 5-MW WEC, that will be equipped with 14 CorPower Ocean C4 converters will be located in the offshore waters of County Clare. In the shorter term, CorPower Ocean's HiWave-5 (1.2 MW) project will provide Portugal with its first commercial size WEC connected to the grid as early as this year (2025). ■

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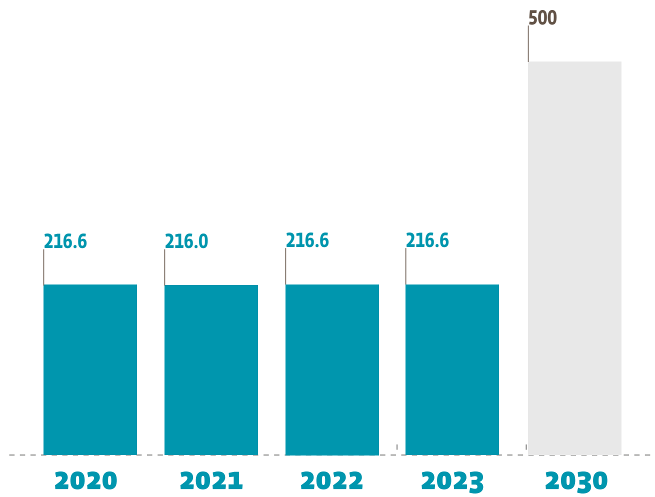
EurObserv'ER projection of the evolution of ocean energy net capacity in the EU-27 (in MW)*



Net maximum electrical capacity. Note: Most countries with marine energy demonstrators or prototypes do not officially include them in the capacity and production data communicated to Eurostat.* ***Source: EurObserv'ER*

RENEWABLE ENERGY IN TRANSPORT

Transport decarbonisation is one of the key climate change challenges, which when all elements are taken together – road, air, rail or maritime – amounts to about a quarter of all the European Union's GHG CO_2 equivalent emissions (including CO_2, CH_4, N_2O and HFC). Given the technological choices to be implemented over the long term and the implications for the European transport industry and economy facing extremely aggressive international, and especially Chinese competition, this challenge is also a strategic European Union policy topic. The renewable energies used in transport essentially originate from biofuels blended with petrol and diesel fuels, as well as biogas used in vehicles that run on natural gas and biokerosene used in aviation. Renewable electricity is also used, albeit to a lesser extent, mainly in rail transport and increasingly in road transport, with an uptake in the ownership of 100% rechargeable electric and hybrid vehicles.

THE RES SHARE IN TRANSPORT ASSESSED AT 10.8% IN 2023

Eurostat claims that sustainable renewable energy consumption in European Union transport (compliant with the requirements of the 2018/2001 Directive, known as RED II), be it road, rail, maritime or air, powered by combustion or electric engines, increased by about 5.3% between 2022 and 2023, to almost 20.5 Mtoe. Renewable energy consumption included in the RES directive transport targets is higher because it takes into account the incentives for using the more virtuous non-food biofuels in road and rail transport and using renewable electricity in road and rail transport. However, the incentives factored in for transport target monitoring were lower in the RED II directive than they were in RED I. In particular, the renewable electricity used by electric vehicles (EVs) is multiplied by 4 instead of 5, and the renewable electricity used in rail transport is multiplied by 1.5 instead of 2.5. RED II also introduced incentives for aviation biofuels: their consumption is multiplied by 1.2. The same incentive dictated in RED I is applied to consumption of biofuels produced from waste, residues or non-food cellulose matter (including those used in aviation) that are still multiplied by 2.

With the inclusion of these incentives, the eligible renewable energy consumption was measured at 29.5 Mtoe in 2023 up from 26.2 Mtoe in 2022 compared to total energy consumption in transport (with multipliers) from 272.2 Mtoe in 2023 up from 272.0 Mtoe in 2022. The renewable energy share used in EU's transport sector thus rose from 9.6% in 2022 to 10.8% in 2023, namely by 1.2 of a percentage point. The symbolic threshold of 10% which was the 2020 target of the first renewable energy directive 2009/28/EC (known as RED I) has thus been passed for the second time (it was measured at 10.3% in 2020) despite the application of the less favourable (but more sustainable) calculation rules of RED II. We should point out that while European renewable energy legislation changed again in 2023, the new calculation rules and targets of the 2023/2413 directive (known as RED III) will not apply until 2025 (see below). The 2018/2001 directive (RED II) calculation rules have applied since 2021 and will remain in force through 2024 for calculating the renewable energy share in transport.

NO UNIFORM EFFORT FOR RES INCLUSION IN TRANSPORT ACROSS THE EUROPEAN UNION

The Member States present wildly varying renewable energy shares in their transport. The 2023 shares range from 33.6% in Sweden and 20.6% in Finland to 1.4% in Lithuania and 0.9% in Croatia. Sweden shows the way with its high use of advanced biofuels and very strong market share of EVs. In addition to Sweden and Finland, 11 other EU countries had renewable energy shares of 10% or more, namely, Slovenia (10%), France (10%), Italy (10.3%), Malta (10.7%), Denmark (10.8%), Portugal (11.2%), Germany (11.9%), Spain (12%), Belgium (12.1%), Austria (13.2%) and the Netherlands (13.4%).

While the EU-wide renewable energy share of transport increased by 1.2 of a percentage point, the individual country picture tells another story. The RES shares of six Member States contracted yet rose in 21 countries. The sharpest falls were felt in Lithuania (1.8 pp) and Croatia (1.5 pp) and can be attributed to a drop in biofuel consumption. The sharpest rises were achieved by Sweden (4.8 pp), Austria (2.5 pp), Portugal (2.5 pp) and the Netherlands (2.4 pp). The 2023 rise in Sweden can be explained by the sharp (x4) rise in renewable electricity consumption in road transport combined with a drop in total energy consumption in transport, rather than by increased biofuel consumption, or even a rise in sustainable biofuel consumption that is eligible for double counting (x2), that actually plummeted. The country, which is a major advanced biofuel producer from tall oil, decided to prioritize exports in 2023.Nonetheless, the EU-wide increase in the renewable electricity share of consumption in transport can be put down to increases in both liquid and gaseous biofuel and renewable electricity consumption in transport.

INCREASINGLY VIRTUOUS EUROPEAN BIOFUEL CONSUMPTION

Eurostat data shows that sustainable biofuel consumption (that complies with RED II specifications), in liquid or gaseous form, increased by 4.9% between 2022 and 2023, rising from 17.2 to 18.1 Mtoe (by 843 ktoe). As happened in 2022, almost all the biofuel used in transport in 2023 was certified as sustainable (98.8% in 2022 and 99% in 2023), meaning that only 185.8 ktoe of the biofuel used was uncertified.

This rise in sustainable biofuel consumption can only be ascribed to an increase in the consumption of non-food crop biofuel, whose contribution – which rose 12.9% from 6.7 Mtoe in 2022 to 7.6 Mtoe in 2023 (by 865.2 ktoe) – can be deemed to equate to double its energy content for target calculations. Double counting applies to "advanced biofuels" produced from the non-food feedstocks listed in Annex IX, part A of RED II and the biofuels produced from the feedstocks listed in Annex IX, part B (namely used cooking oils and some animal

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Biofuels consumption for transport in the European Union in 2022 (in ktoe)

	Biodiesel	Biogasoline	Others liquid biofuels	Total liquid biofuels	Biogas*	Total biofuels	Sustainable biofuels**	Sustainable biofuels %
France	2 211.1	849.5	33.6	3 094.3	3.6	3 097.9	3 097.9	100.0%
Germany	2 207.7	748.0	1.9	2 957.6	91.3	3 048.9	2 937.5	96.3%
Sweden	1 405.1	150.8	0.0	1 555.9	120.3	1 676.2	1 676.2	100.0%
Italy	1 354.1	35.0	0.0	1 389.1	184.9	1 573.9	1 573.0	99.9%
Spain	1 327.6	118.6	0.0	1 446.2	0.0	1 446.2	1 445.5	100.0%
Poland	971.5	231.9	0.0	1 203.4	0.0	1 203.4	1 203.4	100.0%
Belgium	603.7	159.3	0.0	763.0	0.1	763.0	763.0	100.0%
Netherlands	299.9	251.1	20.0	571.0	40.7	611.7	611.7	100.0%
Romania	441.0	143.9	0.0	584.9	0.0	584.9	584.9	100.0%
Finland	426.3	118.6	0.0	545.0	26.5	571.5	545.8	95.5%
Austria	351.8	51.6	0.1	403.5	0.4	403.9	403.9	100.0%
Portugal	315.4	25.7	0.0	341.1	0.0	341.1	341.1	100.0%
Czechia	259.8	63.2	0.0	323.0	0.0	323.0	323.0	100.0%
Hungary	212.7	90.2	0.0	302.9	0.0	302.9	302.9	100.0%
Denmark	164.9	79.9	0.0	244.8	8.8	253.6	242.7	95.7%
Ireland	204.3	23.3	2.0	229.6	0.9	230.6	230.6	100.0%
Greece	148.7	67.9	0.0	216.5	0.0	216.5	160.8	74.2%
Bulgaria	165.2	20.9	0.0	186.1	0.0	186.1	183.1	98.4%
Slovakia	140.6	28.1	0.0	168.7	0.0	168.7	168.7	100.0%
Luxembourg	107.8	19.9	0.0	127.7	0.0	127.7	127.7	100.0%
Lithuania	99.9	19.7	0.0	119.6	0.0	119.6	119.6	100.0%
Slovenia	73.3	6.5	0.0	79.7	0.0	79.7	78.6	98.6%
Estonia	26.0	2.0	0.0	28.0	12.9	40.9	40.9	100.0%
Cyprus	24.9	0.0	0.0	24.9	0.0	24.9	24.9	100.0%
Croatia	20.8	0.2	0.0	21.0	0.0	21.0	21.0	100.0%
Latvia	5.6	10.1	0.0	15.8	0.0	15.8	15.8	100.0%
Malta	12.6	0.0	0.0	12.6	0.0	12.6	12.6	100.0%
Total EU-27	**13 582.2**	**3 315.8**	**57.7**	**16 955.8**	**490.4**	**17 446.2**	**17 236.5**	**98.8%**

** Possibility to allocate domestically produced biomethane blended in the natural gas grid to the transport sector with appropriate tracking requirements. ** Compliant biofuels (articles 29 and 30 of Directive 2018/2001 EU). Note: Breakdown between types of biofuel has been estimated by EurObserv'ER.* ***Source: SHARES Eurostat (Total and compliants biofuels)***

fats). Incidentally, RED II caps the latter's contribution to the calculations of the EU biofuel targets to 1.7% of the energy content of fuels and electricity supplied to the transport sector with the exception of Cyprus and Malta. The import and use of these fuels are not limited by this ceiling that only applies to their contribution to the European Union targets. The co-legislators of RED II took this decision to prioritize the use of advanced and innovative renewable fuels. Specifically, EU advanced biofuel consumption according to the detailed data of the Eurostat SHARES tool for each country, increased from 2.8 Mtoe in 2022 to 4.3 Mtoe in 2023 (by 50.9%) and biofuel consumption produced from used cooking oils and animal fats fell from 3.9 Mtoe in 2022 to 3.3 Mtoe in 2023 (by 14.6%). EurObserv'ER believes that the considerable growth in advanced biofuel consumption can be explained by the major investments made by several energy groups, generally from the oil sector (Neste, Preem, Eni, Shell, UPM, St1, etc.), and also the technical feasibility of some HVO (Hydrotreated Vegetable Oil) also known as HDRD (hydrogenation-derived renewable diesel) biodiesel production refineries to change their supply sources to process eligible feedstocks. The challenge for these industrial concerns is to find these highly sought-after feedstocks in the global market and safeguard their supply. These investments are also being made in sustainable aviation fuels (SAF) such as biokerosene whose consumption is tending to increase significantly. The EurObserv'ER

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Biofuels consumption for transport in the European Union in 2023 (in ktoe)

	Biodiesel	Biogasoline	Others liquid biofuels	Total liquid biofuels	Biogas*	Total biofuels	Sustainable biofuels**	Sustainable biofuels %
France	2 352.6	844.7	54.8	3 252.1	5.4	3 257.4	3 249.5	99.8%
Germany	2 210.8	786.7	2.4	3 000.0	124.3	3 124.2	3 041.9	97.4%
Spain	1 792.2	151.9	0.2	1 944.3	0.0	1 944.3	1 941.6	99.9%
Italy	1 414.7	85.1	14.0	1 513.8	225.2	1 739.0	1 738.8	100.0%
Sweden	1 248.6	188.1	12.6	1 449.4	125.9	1 575.3	1 575.3	100.0%
Poland	865.3	243.6	0.0	1 108.9	0.0	1 108.9	1 109.0	100.0%
Belgium	597.3	174.0	0.0	771.3	0.1	771.3	771.3	100.0%
Netherlands	289.1	257.5	63.1	609.6	37.1	646.8	646.8	100.0%
Finland	421.4	136.6	4.2	562.3	31.3	593.6	563.0	94.8%
Romania	379.1	154.8	0.0	533.9	0.0	533.9	533.9	100.0%
Austria	395.1	99.8	0.1	495.0	0.6	495.6	495.6	100.0%
Portugal	340.3	25.4	0.9	366.7	0.0	366.7	366.6	100.0%
Hungary	224.0	87.0	0.0	311.0	0.0	311.0	311.0	100.0%
Czechia	241.3	62.6	0.0	303.8	0.1	303.9	303.9	100.0%
Ireland	249.3	32.8	0.3	282.3	2.0	284.4	283.8	99.8%
Denmark	134.0	84.0	0.0	218.0	10.8	228.8	224.6	98.1%
Greece	148.7	67.9	0.0	216.5	0.0	216.5	160.8	74.2%
Bulgaria	152.7	21.1	0.0	173.7	0.0	173.7	173.7	100.0%
Slovakia	126.4	38.7	0.0	165.1	0.0	165.1	165.1	100.0%
Luxembourg	99.8	23.3	0.6	123.8	0.0	123.8	123.8	100.0%
Lithuania	97.5	20.4	0.0	117.9	0.0	117.9	117.9	100.0%
Slovenia	85.5	8.6	0.0	94.2	0.0	94.2	94.2	100.0%
Estonia	20.1	2.3	0.0	22.4	16.0	38.4	38.4	100.0%
Cyprus	25.3	0.0	0.0	25.3	0.0	25.3	25.3	100.0%
Malta	13.3	0.0	0.0	13.3	0.0	13.3	13.3	100.0%
Latvia	3.2	8.7	0.0	11.9	0.0	11.9	1.1	9.0%
Croatia	0.3	0.0	0.0	0.3	0.0	0.3	0.3	100.0%
Total EU-27	**13 927.6**	**3 605.6**	**153.3**	**17 686.5**	**578.9**	**18 265.4**	**18 070.1**	**99.0%**

** Including biomethane blended in the natural gas grid allocated to the transport sector with appropriate tracking requirements.*
*** Compliant biofuels (articles 29 and 30 of Directive 2018/2001 EU). Note: Breakdown between types of biofuel has been estimated by EurObserv'ER.* ***Source: SHARES Eurostat (Total and compliants biofuels).***

view is that SAFs account for most of the "Other liquid biofuels" used in transport (tables 1 & 2) whose consumption rose from 57.7 ktoe in 2022 to 153.3 ktoe in 2023.

RENEWABLE ELECTRICITY CONSUMPTION IN TRANSPORT STEADILY INCREASING

The increased renewable energy share in transport can also be put down to the rise in renewable electricity consumption. In 2023, this rise stemmed primarily from the increase in electricity consumption in road transport and over 2.3 million new EV registrations in the EU (just over 1.5 million 100% EVs and just over 0.8 million plug-in hybrid vehicles). At the end of 2023, the EV fleet stood at about 8.2 million (4.7 million 100% electric and 3.5 million plug-in hybrid vehicles). The 10 million threshold was passed in 2024.
The increase in the renewable electricity consumption in transport can also be explained, for the relevant countries, by an increase in the renewable energy share of gross national electricity output. This is because, according to RED II calculation methodology for each country, the consumption of renewable electricity used in transport must be calculated from the national electricity production mix. Thus, the greater the renewable electricity share of the national electricity mix, the greater the renewable electricity consumption of an EV. Now, individual Member States must refer to the previous two-year period prior to the current year when the electricity was supplied on their territory (normalized elec-

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Biofuel consumption whose raw materials used are considered to be equivalent to twice their energy content in 2022 and 2023 (in ktoe)

	2022			2023		
	Advanced biofuel[1]	Used cooking oil and animal fats[2]	Total	Advanced biofuel[1]	Used cooking oil and animal fats [2]	Total
Germany	476.9	642.4	1 119.3	1 330.7	336.3	1 667.1
Italy	612.9	857.6	1 470.5	833.2	570.5	1 403.7
Spain	767.7	401.3	1 168.9	805.1	501.3	1 306.3
Sweden	231.6	565.6	797.2	240.7	329.8	570.6
Netherlands	167.7	298.0	465.7	235.0	253.7	488.7
France	139.1	200.4	339.4	204.8	268.8	473.6
Portugal	96.3	172.0	268.3	182.6	123.1	305.7
Ireland	30.4	187.6	218.0	58.0	203.6	261.6
Hungary	36.8	127.3	164.1	14.7	143.6	158.2
Belgium	28.4	55.3	83.7	88.5	51.9	140.5
Austria	0.0	18.0	18.0	0.0	122.2	122.2
Finland	77.9	5.7	83.6	78.9	7.4	86.3
Poland	1.9	28.0	30.0	6.4	79.9	86.3
Slovenia	27.0	41.8	68.8	36.5	45.6	82.2
Bulgaria	9.6	57.3	66.9	18.5	61.6	80.1
Luxembourg	3.3	49.8	53.0	9.4	58.1	67.5
Slovakia	8.6	41.2	49.8	14.2	43.7	57.9
Czechia	17.0	45.9	62.9	8.4	41.1	49.5
Estonia	30.1	0.9	31.0	35.1	1.9	37.0
Greece	0.0	34.9	34.9	0.0	34.9	34.9
Denmark	12.7	18.2	30.8	15.0	13.8	28.8
Cyprus	3.6	19.6	23.1	6.5	18.8	25.3
Lithuania	5.6	2.9	8.5	13.8	9.7	23.5
Malta	0.8	11.8	12.6	10.9	2.4	13.3
Romania	26.2	0.0	26.2	3.5	0.0	3.5
Latvia	4.7	0.0	4.7	0.5	0.0	0.5
Croatia	0.0	9.4	9.4	0.0	0.0	0.0
Total EU-27	2 816.6	3 892.9	6 709.5	4 251.0	3 323.7	7 574.7

** Within the authorised limits for biofuels produced from feedstocks listed in Part B of Annex IX. 1. Advanced biofuels means biofuels that are produced from the feedstock listed in Part A of Annex IX of the Directive (EU) 2018/2001 2.Biofuels that are produced from the feedstocks listed in Part B of Annex IX of the Directive (EU) 2018/2001.* ***Source: SHARES Eurostat***

tricity output for wind power and hydropower. However, this effect was relatively low in 2023 compared to previous years, as across the European Union, the renewable electricity share of gross national electricity consumption rose marginally between 2020 and 2021 (from 37.4 to 37.8%), with positive and negative variations for individual countries. As the renewable electricity share increased across the EU in 2022 (by 41.2%) and 2023 (by 45.3%), the effect will be much greater for the 2024 and 2025 annual calculations.

The Eurostat SHARES tool data on renewable electricity consumption in transport (road, rail and other modes) recorded an EU-wide increase from 2.2 Mtoe in 2022 to 2.4 Mtoe in 2023 (8.4%). Going into detail, renewable electricity consumption in road transport rose from 378.9 ktoe in 2022 to 578.5 ktoe in 2023 (by 52.7%), that of rail transport from 1 530.8 to 1 549.8 ktoe (by 1.2%), while that of other transport modes fell from 304 to 270.9 ktoe (by 10.9%). We should also point out that in some countries (such as Italy), a considerable proportion of renewable electricity consumption in transport is not distinctly monitored and by default is assigned to the "other transport modes" category, which is excluded from the incentive scheme. Better administrative monitoring of electricity consumption in transport is the reason for this indicator's reduction.

RULES AND TWO TARGETS HAVE BEEN ADJUSTED FROM 2025 ONWARDS

Following long legislative work initiated by the " Fit for 55" package, many texts aimed at setting up instruments to reduce GHG emissions in transport were published in the OJEU during 2023. These pieces of legislation relate to the implementation of a separate emissions trading scheme (ETS) for road transport, buildings and other sectors (not covered by the existing ETS), infrastructure targets for EVs and substitution fuel, emissions reduction targets for light-duty and heavy-duty vehicles in road transport, targets for the use of renewable and low carbon fuels in maritime (FuelEU maritime) and air (ReFuelEU aviation) transport. The high point was the eagerly awaited recast Renewable Energy Directive, RED III, which was finally adopted and published in the OJEU on 31 October 2023. RED III clearly raised the European Union's renewable energy targets to bring them in line with the European Union Green Deal that set 2050 as the EU's climate-neutral target date. It sets an interim target of reducing net GHG emissions of at least 55% from 1990 levels by 2030 and also aligns the targets with the RePowerEU Plan outlined in the Commission's communication of 18 May 2022 that aims to end the EU's dependence on Russian fossil fuels long before 2030. Broadly speaking, the new directive raises its renewable energy share targets of the EU's gross final electricity consumption in 2030 from 32 to at least 42.5% and encourages the Member States to aim for 45%.

As for the transport chapter, it offers the Member States more flexibility by allowing them to choose between two goals – either a binding goal of reducing GHG intensity in transport by 14.5% resulting from the use of renewable energies by 2030, or a binding renewable energy share of at least 29% in the transport sector's final renewable energy consumption by 2030 based on the EF(t) f reference value or fuel or fossil fuel set at 94 gCO_2eq/MJ, in compliance with an indicative trajectory set out by the Member State. This second target is much more ambitious than its predecessor, RED II, that

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Renewable electricity used in transport (road, rail, other transport modes) in 2022 and 2023 (in ktoe)

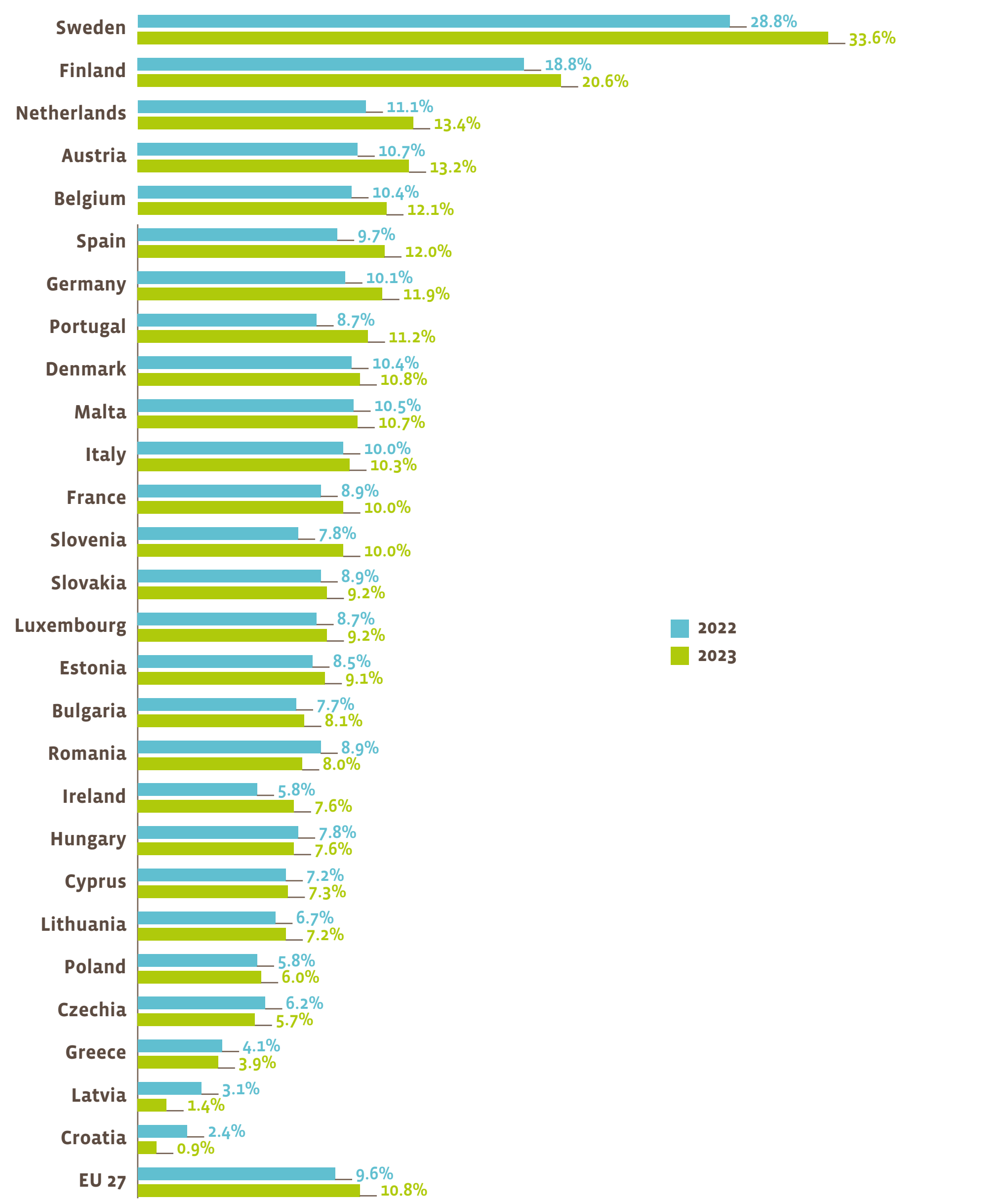
	2022				2023			
	Ren. electricity in road transport	Ren. electricity in rail transport	Ren. electricity in all other transport modes	Total	Ren. electricity in road transport	Ren. electricity in rail transport	Ren. electricity in all other transport modes	Total
Germany	93.3	445.0	50.5	588.8	147.2	433.9	47.5	628.6
Sweden	64.2	170.3	20.0	254.5	103.2	168.5	20.7	292.3
France	33.5	176.1	26.8	236.4	51.6	198.1	26.4	276.1
Italy	19.1	182.6	92.8	294.4	25.7	191.2	57.2	274.2
Austria	28.7	125.1	92.7	246.5	28.1	116.1	97.4	241.6
Spain	20.3	120.8	8.5	149.6	32.1	131.1	9.1	172.3
Netherlands	42.5	39.2	0.0	81.7	69.2	47.9	0.0	117.1
Denmark	23.2	28.0	0.0	51.2	31.6	30.8	0.0	62.3
Belgium	12.7	31.7	5.0	49.4	24.1	32.8	2.6	59.5
Poland	2.4	46.4	0.2	49.0	3.8	49.0	2.6	55.4
Finland	13.6	23.4	0.0	37.1	25.1	22.8	0.0	47.9
Romania	8.1	37.6	0.9	46.6	10.0	22.1	0.7	32.8
Portugal	2.0	22.6	0.3	24.9	4.6	24.4	0.4	29.5
Czechia	1.3	20.6	1.0	22.9	1.6	20.1	0.8	22.5
Hungary	1.3	12.0	0.1	13.5	2.0	13.3	0.1	15.5
Slovakia	0.5	9.9	2.8	13.2	0.5	10.2	2.9	13.6
Croatia	0.6	11.2	1.6	13.4	0.9	11.0	1.7	13.5
Ireland	5.7	1.7	0.0	7.4	8.9	1.7	0.0	10.6
Slovenia	0.8	7.3	0.2	8.3	1.2	7.1	0.2	8.5
Bulgaria	0.8	8.3	0.3	9.4	0.8	6.8	0.2	7.8
Greece	0.6	5.7	0.0	6.3	0.7	5.5	0.0	6.1
Latvia	1.5	3.0	0.1	4.6	1.9	2.8	0.1	4.8
Luxembourg	0.6	1.7	0.0	2.3	1.1	1.8	0.0	2.8
Lithuania	1.0	0.2	0.4	1.6	1.4	0.2	0.4	2.1
Estonia	0.5	0.3	0.0	0.8	0.9	0.6	0.0	1.5
Malta	0.1	0.0	0.0	0.1	0.2	0.0	0.0	0.2
Cyprus	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.1
Total EU-27	**378.9**	**1530.8**	**304.0**	**2213.7**	**578.5**	**1549.8**	**270.9**	**2399.2**

Note: In some countries a significant share of renewable electricity consumption in transport is not clearly traced and is allocated, by default, to the category «other transport modes. ***Source: SHARES Eurostat***

aimed at a binding renewable energy share of at least 14% in the transport sector's final renewable energy consumption in 2030. The binding target for reducing GHG intensity resulting from renewable energies appears to be much more accessible and should logically be given preference in many Member States. Sweden and Finland, which have the highest RES shares in their transport, believe that they should have no difficulty achieving their renewable energy share targets.
Furthermore, the new RED III rules establish a combined binding sub-target of 5.5% in 2030 (and an interim target of 1% in 2025) for advanced biofuels and biogas (produced from the non-food feedstocks listed in Annex IX, part A) and renewable fuels of non-biological origin (mainly renewable hydrogen and hydrogen-based synthetic fuels) in the share of renewable energies supplied to the transport sector. The target for 2030 has a minimum requirement of 1% of RFNBOs. The recast directive also retains the limit on the use of fuels produced from human and animal food crops. Their use must not exceed more than one percentage point of the share of these fuels in a Member States' transport sector's final energy consumption in 2020, with a maximum 7% share of final energy consumption in that Member State's transport sector. It also retains the provision limiting the share of biofuels and biogas produced from the feedstocks listed in Annex IX, part B (namely used cooking oils and animal fats) to 1.7% in the energy content of fuels and electricity supplied to the transport sector, with the exception of Cyprus and Malta. Nonetheless, the Member States may increase this limit, when justified by the availability of the feedstocks in question, providing they submit any increase for approval by the European Commission. A minor accounting nuance has been added to deter countries from agrofuel consumption. When the share of biofuels produced from human and animal food crops in a Member State is capped at less than 7% or a Member State decides to limit this share even further, it can reduce the minimum share of renewable energy or the GHG intensity reduction target, on the basis of the contribution that these fuels would have had on the minimum share of renewable energy or GHG emissions reductions.
The main target numerator calculation rules remain unchanged. Recycled carbon-based fuels can be included as well as a certain number of incentives. The share of biofuel and biogas produced from the feedstocks listed in Annex IX and the share of renewable fuels of non-biological origin are considered to equate to twice their energy content; the renewable electricity share is considered to equate to four times its energy content when intended for road transport and can be considered to equate to 1.5 times its energy content when intended for rail transport. The share of advanced biofuel and biogas produced from the feedstocks listed in Annex IX, part A, supplied in air and maritime transport modes is considered to equate to 1.2 times their energy content, and the share of renewable fuels of non-biological origin is considered to equate to 1.5 times their energy content supplied in air and maritime transport modes. ■

5

Share of energy from renewable sources in transport according Directive (EU) 2018/2001



Source: Eurostat (updated 14 February 2025)

RENEWABLE ENERGIES' WINNING STRATEGY

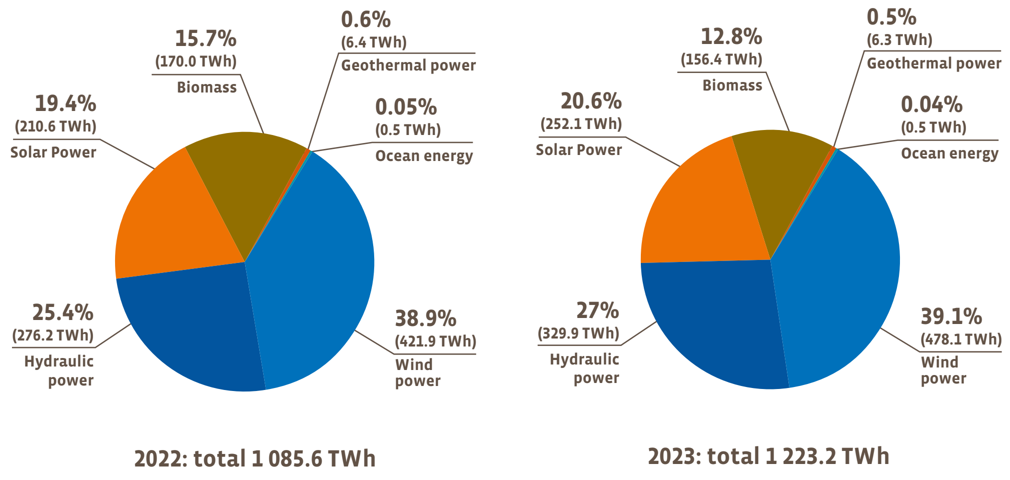
We should bear in mind in our foreword to this conclusion, that Europe's strategy for combatting climate change was rolled out over twenty years ago and then followed by the Green Deal launched at the end of 2019. It is now paying off. The transition to clean, renewable energy is crucial in the combat and provides an opportunity for enhancing energy independence, while at the same time it establishes energy efficiency/consumption reduction measures. Energy fuels, wherever they are in the European Union or the rest of the world, are by far the main source of greenhouse gas (GHG) emissions. The European Environment Agency's (EEA) ETC CM Report released in October 2024 drew up an inventory of EU greenhouse gas emissions for 2023. Energy was responsible for 76.2% of the European Union's total emissions, including fugitive emissions from fuels (1.8%), disregarding the carbon emissions and sequestrations by forest or agricultural ecosystems, relating to land use, land-use change, and forestry (LULUCF). The remaining emissions are released by agriculture (11.5%), industrial processes (manufacturing of cement, chemicals and metals) (8.8%) and even waste (3.5%). If we factor in the beneficial role of LULUCF that enabled the EU to sequester almost 257 million tonnes of GHG (CO2eq) net in 2023, the energy share of the EU's annual GHG emissions rises to 83.1% of total emissions, which is a similar level to that of 2022.

In October 2024, the European Commission published the Climate Action Progress Report 2024 that determined that in 2023 the EU's greenhouse gas (GHG) emissions had fallen by an annual 8.3% from the 2022 level, which amounts to about 3 billion tonnes of GHG (CO2 equivalent). Unfortunately, while the EU is succeeding in reducing its GHG emissions, that cannot be said for the rest of the world. Interim data from the JRC (the European Commission's Joint Research Centre) reports that global GHG emissions, with the exclusion of net emissions relating to LULUCF, reached 53 billion tonnes of CO2 equivalent in 2023, which is 1.9% more than the 2022 level and 3.3% more than the pre-pandemic emissions level (2019). China and India were singled out as the biggest emitters with the highest emission increases of (5.2%) and (6.1%) respectively.
The Climate Action Progress Report 2024 points out that the EU's GHG emissions compared to 1990 levels have fallen more that those of all the other emitting economies. They now amount to 6.1% of global emissions compared to 14.9% in 1990 (if LULUCF is factored in, they accounted for 5.6% in 2023 and 14.5% in 1990). The emissions fall registered in 2023 across the EU is the biggest for decades with the exception of 2020, when the COVID-19 pandemic led to a 9.8% reduction. Net greenhouse gas emissions are now 37% below 1990 levels, while at the same time GDP has increased by 68%, which demonstrates the continuing disconnection between emissions and economic growth. The Progress Report further claims, that the EU is still on track to honour its undertaking to reduce emissions by at least 55% by 2030, even though considerable efforts still need to be made. As things stand, the European Environment Agency (EEA) is more cautious. It expects a 43% fall in 2030, compared to 1990 levels, a reduction that could be as much as 49% if the Member States introduce the promised measures that have yet to be rolled out.
The Commission reports that power plants and energy-intensive industrial installations covered by the European Union Emissions Trading System (EU ETS) registered a record 16.5% drop in emissions in 2023. Electricity and heating production emissions fell by 24% from their 2022 level under the stewardship of the EU, driven by the growth of renewable energy sources, especially wind and solar power, and the switch away from coal. Positive developments for emissions have also been identified in the building, domestic transport, small industry and waste sectors. Likewise, the EU's natural carbon sinks increased by 8.5% in 2023, reversing the last decade's downward trend in the land use, land-use change, and forestry (LULUCF) sector.
While the Climate Action Progress Report 2024 offers encouraging news on the European Union's GHG emissions, the Member States, like the rest of the world, have not been left unscathed by large-scale disasters exacerbated by climate change. For example, Central Europe was hit by deadly floods at the end of May and early June 2024 followed by Southeast Spain at the end of October. On both occasions, the economic losses run into the billions. The reinsurer Munich RE quantified the damage at 5 billion dollars including 2.2 billion dollars in insured losses for the June floods in Germany, Poland, Italy, Austria and Czechia (which caused 8 fatalities) and 11 billion dollars including 4.2 billion dollars in insured losses for the Valencia floods (which caused 229 fatalities). On a global level, the figures are even more eye-watering. A Munich RE press release dated 9 January 2025 entitled "Climate change is showing its claws: The world is getting hotter, resulting in severe hurricanes, thunderstorms and floods", put its annual estimate of global natural disaster costs for 2023 at 320 billion dollars of damage including 140 billion dollars in insured losses. Sadly, the intensity and recurrence of these phenomena stemming from the rise in global temperatures and climate inertia are expected to worsen. The Copernicus Climate Change Service (C3S) claims, "it is now virtually certain that 2024 (after 2023) will be the warmest year on record and the first year of more than 1.5°C above pre-industrial levels"... the limit set by the Paris Agreement. Nonetheless, this agreement refers to a long-term trend, the 1.5 °C warming average must be observed over several years to consider the threshold as crossed.
Therefore, it is absolutely vital for the European Union to persevere with implementing its resolute policy to combat climate change and meet its 2030 targets (55% emissions reduction compared with 1990) and its 2050 "net zero emissions" target. One of the new Commission's first briefs will be to negotiate the 2040 target, for which its predecessor, in its February 2024 communication (Communication on the EU's climate target for 2040), recommended a 90% reduction in net greenhouse gas emissions compared to 1990. It will have to work with a new more conservative European Parliament, that has also seen the emergence of a far-right populist faction grow from within. The latter considers climate issues as secondary, ignores them or is in denial.
At European level, having second thoughts about

EUROBSERV'ER – THE STATE OF RENEWABLE ENERGIES IN EUROPE – 2024 EDITION

1

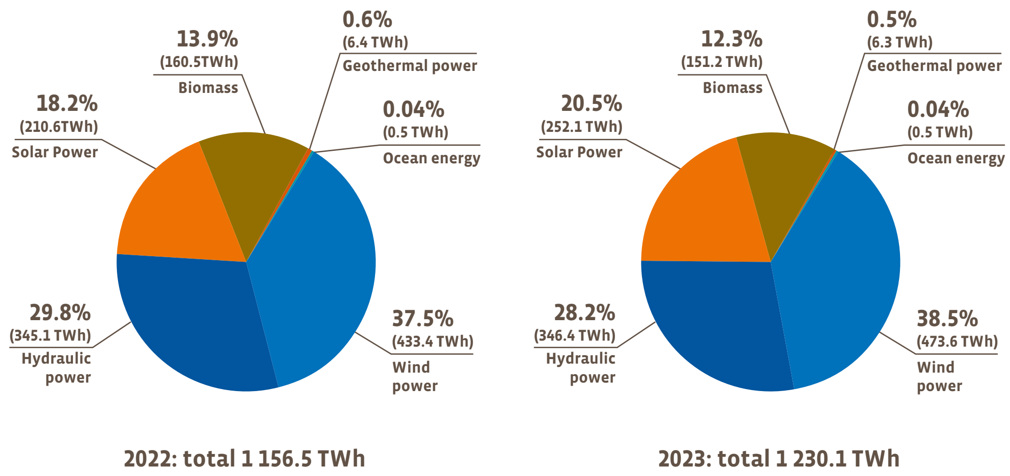
Share of each energy source in renewable electricity generation in the EU-27 in 2022 and 2023 (in %)



Notes for calculation: Hydro is actual (not normalised) and excluding pumping. Wind is actual (not normalised). All electricity production, compliant or not with renewable Directives, from solid biofuels, biogas (pure and blended in the gas natural grid) and bioliquids is included.
Source : EurObserv'ER from Eurostat database (updated 28 january 2025)

2

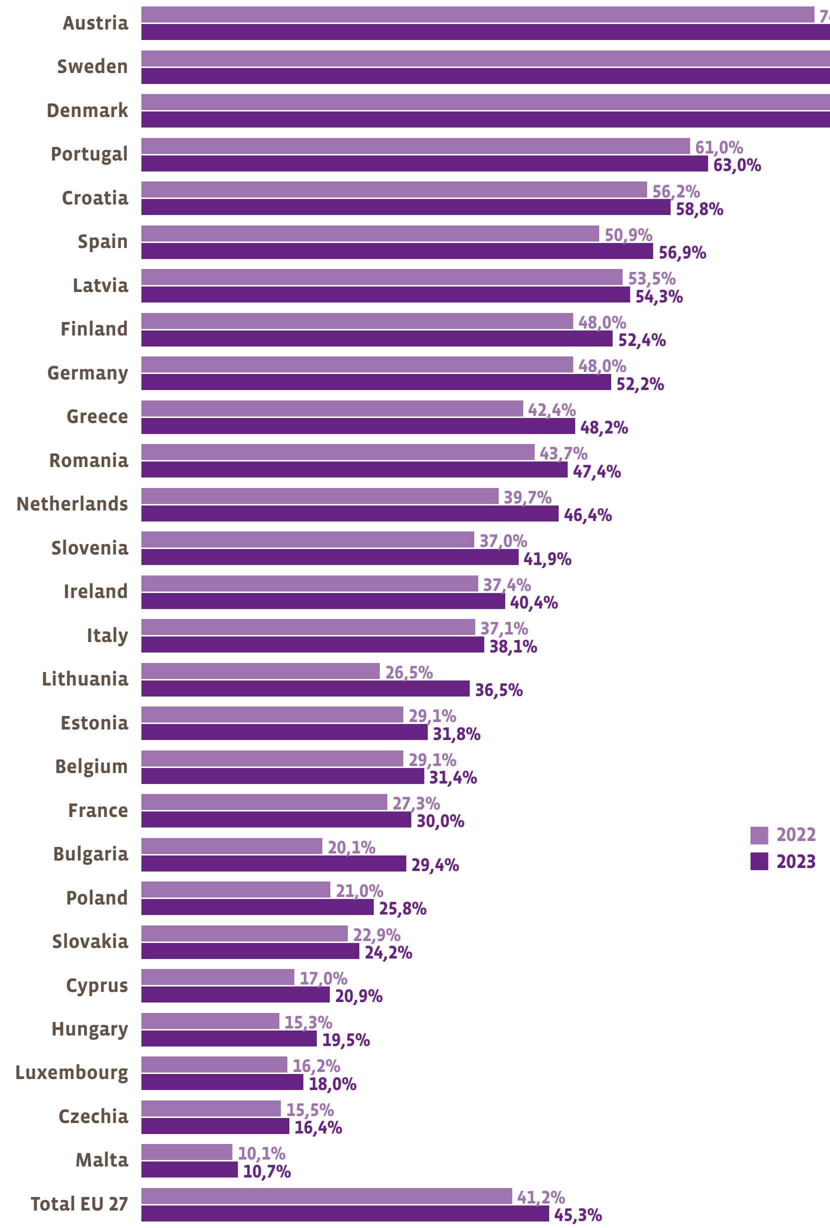
Share of each energy source in renewable electricity generation in 2022 and in 2023 in the EU-27 (in %) according the Directive (EU) 2018/2001 specifications.



Notes for calculation: Hydro is normalised and excluding pumping. Wind is normalised. Solar includes solar photovoltaics and concentrated solar power generation. Biomass includes electricity generation from solid biofuels, liquid biofuels and biogas (pure and blended in the natural gas grid) calculated according to their compliance with the criteria of Directive (EU) 2018/2001 and also renewable municipal waste..
Source : EurObserv'ER from Eurostat database (updated 28 january 2025) and SHARES

3

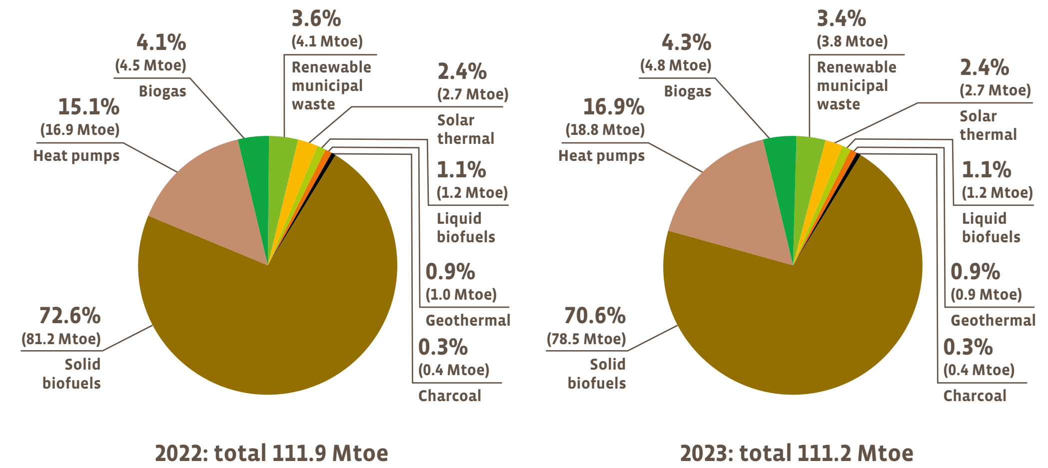
Share of energy from renewable sources in gross electricity consumption (%) - According the Directive (EU) 2018/2001



Notes for calculation: Hydro is normalised and excluding pumping. Wind is normalised. Solar includes solar photovoltaics and concentrated solar power generation. Biomass includes electricity generation from solid biofuels, liquid biofuels and biogas (pure and blended in the natural gas grid) calculated according to their compliance with the criteria of Directive (EU) 2018/2001 and also renewable municipal waste..
Source: Eurostat (updated 14th February 2025)

4

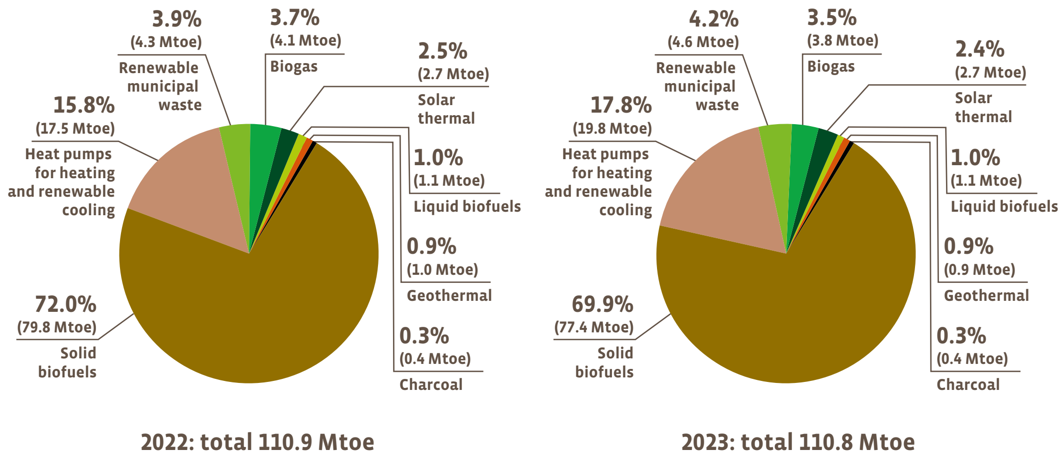
Share of each energy source in renewable heat and cooling consumption in the EU-27 (in %)



Note for calculation: Renewable sources for heating and cooling correspond to the sum of final energy consumption of renewables fuels in Industry and Others Sectors, of production of derived heat from renewable fuels and heat pumps (final energy consumption and derived heat). Final energy consumpion and derived heat from biogas blended in the grid is included. All final energy consumption and derived heat from solid biofuels, liquid biofuels and biogas (pure and blended in the grid) is including, complying or not with the requirements of renewable Directives.. ***Source : EurObserv'ER from Eurostat database (updated 28 january 2025)***

5

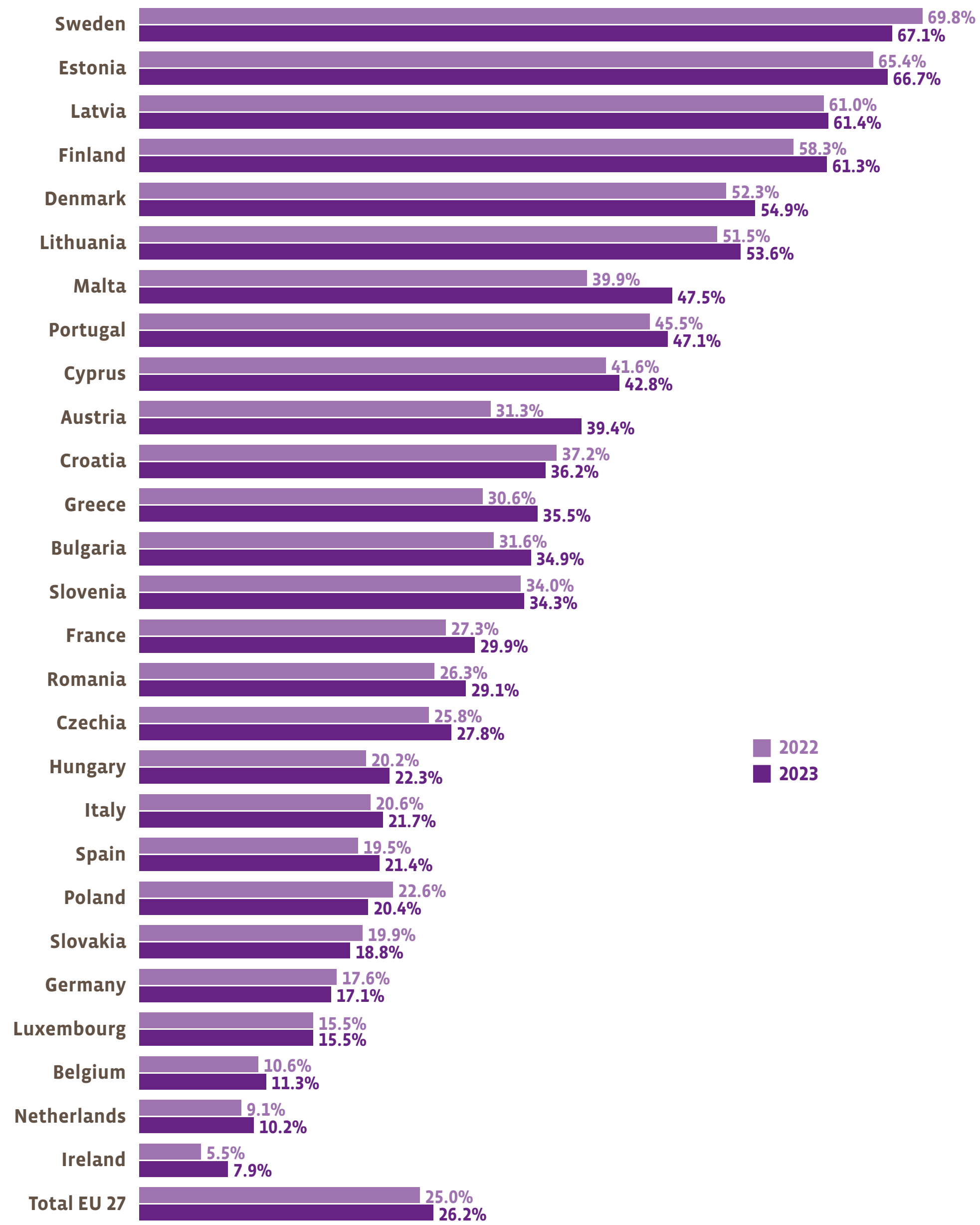
Share of each energy source in renewable heat and cooling consumption in the EU-27 (in %) according the Directive (EU) 2018/2001 specifications.



Note for calculation: Renewable sources for heating and cooling correspond to the sum of final energy consumption of renewables fuels in Industry and Others Sectors, of production of derived heat from renewable fuels, heat pumps for heating and renewable cooling. For final energy consumption and derived heat from solid biofuels, liquid biofuels and biogas (pure and blended in the grid), only the part complying with the requirements Directive (EU) 2018/2001 is included. ***Source : EurObserv'ER from Eurostat database (updated 28 january 2025) and SHARES***

6

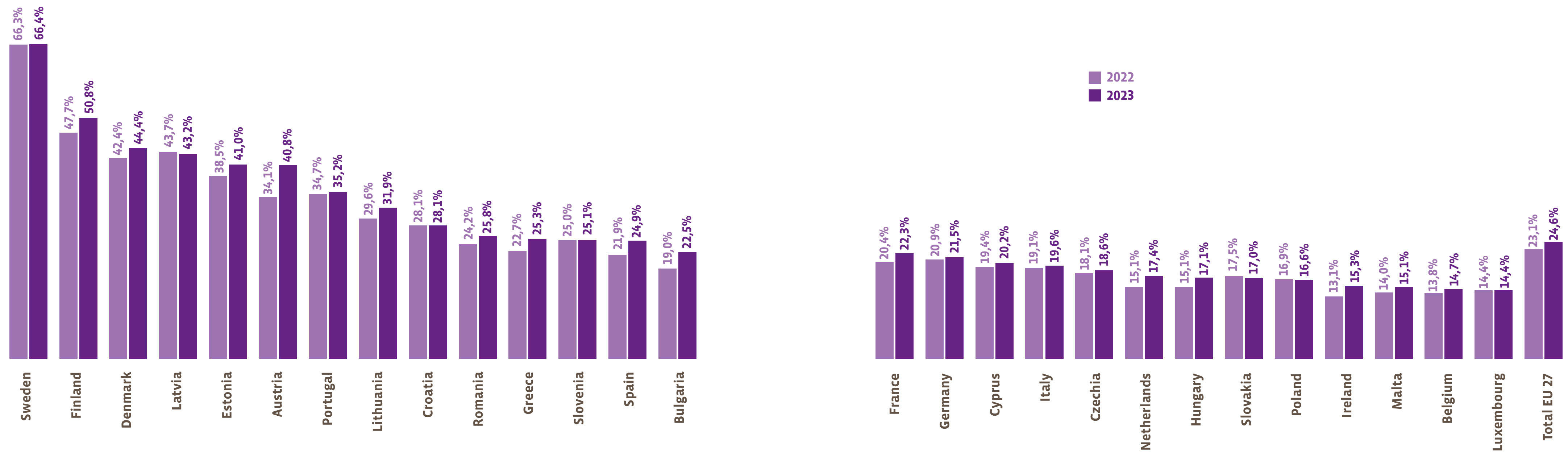
Share of energy from renewable sources for heating and cooling (%) - According the Directive (EU) 2018/2001



Note for calculation: Renewable sources for heating and cooling correspond to the sum of final energy consumption of renewables fuels in Industry and Others Sectors, of production of derived heat from renewable fuels, heat pumps for heating and renewable cooling. For final energy consumption and derived heat from solid biofuels, liquid biofuels and biogas (pure and blended in the grid), only the part complying with the requirements of Directive (EU) 2018/2001 is included. ***Source: Eurostat (updated 6th February 2024)***

7

Overall share of energy from renewable sources (%) - According the Directive (EU) 2018/2001



Source: Eurostat (updated 14th February 2025)

the progress of the Green Deal made on climate undertakings would be extremely harmful for the common welfare and that of generations to come. The danger is real if we observe what is happening in the United States where the new administration responding to the orders of a clearly climate-sceptic administration has withdrawn from the Paris Climate Agreement for the second time and has gone further by deleting all references to climate change on its Federal websites.
Before we draw up an in-depth inventory of the initial monitoring indicators of RED II, this conclusion will submit an initial assessment of the state of actual renewable electricity production in 2023, namely non-normalized, for hydropower and including all the biomass electricity output (solid, liquid and gaseous biofuels), RED II-compliant and non-compliant. The same applies to the presentation of the various renewable energy shares used for heating and cooling in the EU-27, that includes all RED II-compliant and non-compliant biomass energy production. These "standard" indicators were obtained from the Eurostat database referring to the complete energy balance of the Member States, updated on 28 January 2025. They are valuable in highlighting divergences from the "eligible" energy indicators that meet the legal specifications of RED II.

A BREATH OF FRESH AIR FOR RENEWABLY SOURCED ELECTRICITY

On the basis of actual renewable electricity production, i.e., non-normalized for wind and hydropower, and excluding pumped-storage output, EU renewable electricity output enjoyed double-digit growth between 2022 and 2023 (12.7%). It increased by 137.6 TWh to 1 223.2 TWh. This sudden rebound can be attributed to more conducive climate conditions for hydropower and wind power, and also to significant investments made over the last two years in the wind energy and solar photovoltaic sectors and comes after the very mediocre performance of 2022 when renewable electricity production stagnated (with 0.3% YoY growth). This contrasts with declining biomass electricity output between 2022 and 2023, blighted by solid biofuel price rises and a shift in European policy on the use of biomass in large power plants.
To elaborate, wind energy confirmed its top renewable energy sector status for electricity production in 2023. Eurostat reports that wind power output, be it onshore or offshore, reached 478.1 TWh, setting an output record on the basis of its 13.3% increase on the 2022 level (56.2 TWh). For the first time, this output overtook that of natural gas-fired power plants, that contracted sharply (from 538.3 to 458.6 TWh – a 14.8% YoY drop). As for offshore wind energy output, it was put at 55.1 TWh, thanks to 9.7% growth (4.9 TWh) and thus added up to 11.5% of total wind energy output. The EU enjoyed better wind conditions all round, resulting in slightly higher actual output than normalized wind energy output assessed at 473.6 TWh (see below).
The European Union's No. 2 renewable sector for electricity production, hydropower, improved its contribution in 2023 after suffering one of the worst deficits in its history in 2022. Eurostat quantified gross hydropower production from natural water flow, i.e., that excludes the 329.9 TWh of pumped-storage output produced in the EU-27, a YoY rise of 19.4% (276.2 TWh). However, it is lower than its 2020 (347.2 TWh) and 2021 (348.4 TWh) output levels. We should point out that for the purpose of calculating the Member States' renewable energy targets, hydroelectricity production is normalized over the last 15 years to mitigate the effect of hydraulicity variations. Eurostat quantified normalized hydroelectricity output across the European Union at 346.4 TWh in 2023, which is 0.4 % higher than in 2022. Thus, in 2023, the normalized hydropower output figure across the EU was 16.5 TWh higher than its actual output.
As for solar power, it continued its inexorable rise, growing by 19.7%. Output increased by 41.6 TWh in the space of 12 months to reach 252.1 TWh (just a little less than 247 TWh for photovoltaic and 5.2 TWh for concentrated solar power). However, in Europe, the year 2023 was less exceptional and sunshine irradiation fluctuated more than in 2022. The latest

8

Statistical transfers reported by countries for reference year 2023 (ktoe)

		Amount added to the share of renewables		
		Belgium	Germany	Luxembourg
Amount deduced from the share of renewables	Denmark	50,3	4,2	77,4

Source: Eurostat

European States of the Climate 2023 – ESOTC 2023 report from the Copernicus Climate Change Service states that for the year taken as a whole, the solar photovoltaic energy production potential was lower than average in the north-west and central Europe contrasting with above-average potential in the south-west and south of Europe and Fennoscandia (Finland, Sweden and Norway). Germany, for example suffered a solar irradiation deficit that curbed its solar power output. This output only increased by 4.2% (2.6 TWh) between 2022 and 2023, for a total of 63.6 TWh, despite the fact that the country connected at least 13.7 GW of capacity in 2023. The impact of these climate variations on electricity production should be viewed in relation to the impressive installation efforts made over the past two years by the European Union's countries. The EU's on-grid solar PV capacity increased by 82 GW between 2021 and 2023 to 243.8 GW (adding 30.9 GW in 2022 and 51.1 GW in 2023).

Biomass electricity output, across all its RED II-compliant and non-compliant components (solid biomass, biogas, renewable municipal waste and liquid biomass), declined. It fell by 8.1% (13.7 TWh) to 156.4 TWh. The solid biofuel component is mainly responsible for the decline. Eurostat quantified EU solid biofuel electricity output at 78.4 TWh, i.e. an 11.3% YoY fall (10 TWh). The 2023 output level was very similar to that of 2018 (76.2 TWh). Over the past two years, output has dropped by a further 15.4%, namely 14.3 TWh (from 92.7 TWh in 2021 to 78.4 TWh in 2023). The fall can be attributed to both the decline in profitability of the major biomass power plants and to changes in support mechanisms. As for the breakdown of EU biomass electricity output in 2023, half of it (50.1%) was generated from solid biofuels, 33.1% from biogas (including electricity produced from biomethane mixed into the natural gas grid, the amount of which was confirmed by sustainability certificates), 11.9% recovered from renewable municipal waste in incineration plants and 1.9 % from liquid biomass. The European Union's geothermal (essentially Italian) and marine energy (essentially French) electricity generating sectors made little progress over the 12 months, with respective 2023 outputs of 6.3 TWh (0.2 TWh less) and 0.5 TWh (0.05 TWh less). Thus in 2023, renewable energies accounted for 44.5% of total gross electricity output in the EU-27, (that Eurostat measured at 2 748.6 TWh). That is 6 percentage points more than in 2022, when the RES share was measured at 38.5 % (with electricity output totalling 2 822.9 TWh).

RENEWABLE HEAT HOLDS STEADY IN 2023 NOTWITHSTANDING DECLINING NEEDS

Eurostat data from the 28 January 2025 update of the Member States' complete energy balance, signals that all in all, renewable energy consumption for heating and cooling remained stable between 2022 and 2023 (it slipped by 0.6%) falling from 111.9 Mtoe in 2022 to 111.2 Mtoe in 2023). Broadly speaking, as the contribution of solar heat has hardly changed, the decline in biomass energy consumption for heating and cooling was largely offset by the increase in the heat pump take-up of ambient heat.

For the purpose of calculating the renewable energy share of heating and cooling, final energy consumption from renewable sources is defined as the final renewable energy consumption in industry, households, services, agriculture, forestry and fishing for heating and cooling purposes, in addition to the heat output from renewable sources in the processing sector (heat sales). Final total consumption for heating and cooling equates to that of all energy products, with the exception of electricity, for purposes other than transport, revised upwards by heat consumption for own use in power and heat plants and district heating network heat losses. EurObserv'ER has opted to add estimates of final energy consumption (from "industry" and "other sectors", for non-transport purposes) and of heat derived from biomethane injected and mixed into the natural gas grid (as well as the fraction confirmed by sustainability certificates). This consumption, which can be considerable in certain countries (Denmark, Germany, France), is not included in the biogas indicators of the full energy balance that correspond to the energy use of "pure" biogas that is not mixed into the grid. The final energy consumption estimate (excluding transport) and derived heat consumption of biomethane injected into the natural gas grid and the fraction accounted for using sustainability certificates are presented in the country files of the Eurostat SHARES tool, that distinguishes the share that is RED II-compliant.

An important point to remember is that the Member States' energy balance data cannot be directly used for the RED II target calculations, as the directive has its own calculation specifications and terms. It has, for example, specific biomass indicators subject to certification that factor in the compliance criteria, as well as specific indicators that measure the renewable energy production of HPs dedicated solely to heating and renewable cooling. EurObserv'ER holds that for 2023, about 1.3 Mtoe of renewable biomass heat (across all biomass components) was not deemed compliant and was thus excluded from the RED II target calculations. That is relatively little compared to total biomass heat consumption. Most of the European Union's solid biomass feedstock is sourced on EU soil where the forestry operation and energy recovery conditions comply with the RED II criteria. Furthermore, energy and heat suppliers avoid using non-compliant biomass feedstock as doing so makes them ineligible for support for production.

Heat pumps should take much of the credit for the recent renewable heat and cooling growth. The sector's momentum is such that ambient heat's contribution remains positive from one year to another, even in years with lower heating requirements. A case in point is 2023 when HPs contributed an additional 2 Mtoe (11.7 %) year-on-year, for a total of 18.8 Mtoe. The opposite applies to solid biofuels. For two years running their consumption for heat production purposes has declined from 84.5 Mtoe in 2021 to 81.2 Mtoe in 2022 and to 78.5 Mtoe in 2023. This falloff can be put down to the prevailing low heating requirements and higher biomass fuel prices.

Solar thermal heat's contribution, primarily used for domestic hot water production and also as a top-up in combined solar heating installations and solar district heating networks stabilized at 2.7 Mtoe, and this despite the approximately 1% increase in the EU's solar thermal area (just over 59.6 million m2 in service in 2023). Despite the dearth of solar irradiation in the sector's key producer countries, such as Germany, this stability is understandable. Geothermal energy's contribution to heat and cooling consumption was also stable in 2023, and close to the one-Mtoe threshold.

As for the respective shares of the different renewable sectors, the underlying trend has followed that of recent years, namely a decline in the still dominant share of solid biofuels (70.6% in 2023, 2 pp less than in 2022) in renewable heat and cooling and the heat pump sector has grown a little year after year to command a 16.9% share in 2023 (1.4 pp more than in 2022). The other contributors to heat consumption in order of importance are biogas (4.3% in 2023), including biomethane mixed into the grid, renewable municipal waste (3.4%), solar thermal (2.4%), liquid biomass (1.1%), geothermal energy (0.9%) and charcoal (0.3%).

SPECIFIC TARGETS OF THE RED II DIRECTIVE

THE 50% RENEWABLE ELECTRICITY TARGET IS WITHIN REACH

The monitoring indicator used for calculating the (EU) 2018/2001 renewable energy directive's target for renewable electricity production is specific, because it factors in normalized production for hydro- and wind power (separating onshore from offshore wind power) to mitigate the vagaries of climate and be more representative of each Member State's efforts. Moreover, it only includes the electricity production from liquid, solid and gaseous biofuel that complies with the RED II criteria. The Directive also devised specific ↘

accounting rules for heat pumps' renewable energy contribution for renewable heat and cooling.

In 2023, the normalized output for hydropower adopted for the EU-27 was 346.4 TWh (345.1 TWh in 2022), and that of wind power was 473.6 TWh (433.4 TWh in 2022). As it happens, normalized hydroelectricity output in 2023 exceeded actual hydropower output (329.9 TWh), while normalized wind power output was a little lower than the actual wind power output of 478.1 TWh.

The co-legislators felt no need to normalize solar electricity production, therefore, actual electricity output is taken into account, i.e., 252.1 TWh in 2023. Electricity production from solid, liquid biomass and biogas (pure and mixed into the natural gas grid) compliant with RED II requirements is provided in the detailed country files of the Eurostat SHARES tool. EurObserv'ER, having compiled all the sub-indicators, quantifies biomass electricity output at 151.2 TWh in 2023, thus 5.1 TWh of biomass electricity has been disregarded as the feedstock in question was non-compliant.

As regards distribution, wind energy keeps its top renewable sector status for renewable electricity production with a 38.5% share (1 pp increase), ahead of hydropower with 28.2% (1.7 pp decline). Solar energy, primarily photovoltaic, is in third place with 20.5% (2.3 pp increase) and enjoyed the most positive thrust (19.7% growth between 2002 and 2023) – a 41.6 TWh gain. Wind powered electricity production grew less rapidly (by 9.3%) but its gain was similar to that of solar (40.2 TWh). Electricity production from biomass, deemed compliant, lies in fourth place with a 12.3% share (1.6 pp decline), having reported a negative 9.3 TWh contribution between 2022 and 2023. The contributions of geothermal energy and marine energies remain negligible in renewable electricity production with respective shares of 0.5% and 0.04%.

Total renewable electricity production, i.e., the numerator used for calculating the renewable energy share of gross electricity consumption, is thus put at 1 230.1 TWh for 2023, while the total electricity production figure adopted (the denominator) is 2 715.3 TWh. If we apply the RED II calculation specifications and terms, the renewable share of gross electricity consumption is put at 45.3% in 2023 compared to 41.2% in 2022 (4.1 pp increase).

Graph 3 shows that the Member States' renewable electricity share can vary wildly and is contingent on the renewable energy potential, especially that of hydroelectricity and wind energy, and the support policies in place. In 2023, Austria had the highest renewable electricity share (87.8%) just ahead of Sweden (87.5%), which was ahead of Denmark (79.4%). The renewable electricity share is over 50% in Portugal (63.0%), Croatia (58.8%), Spain (56.9%), Latvia (54.3%), Finland (52.4%) and the latest country to join the club, Germany (52.2%). Three other countries are about to produce the majority of their electricity renewably, Greece (48.2%), Romania (47.4%) and the Netherlands (46.4%). In 2023, only four countries produced less than 20% of their electricity renewably, namely: Hungary (19.5%), Luxembourg (18.0%), Czechia (16.4%) and Malta (10.7%).

RENEWABLE HEATING AND COOLING PASS THE 25% MARK

The hardest challenge facing the European Union Member States is undoubtedly that of decarbonizing their heating and cooling requirements, in other words shutting down or hybridizing their fossil fuel-burning plants, boilers and heating appliances with renewables. Decarbonation calls for developing thermal renewable energies, industrial and collective boilers and biomass heating appliances, individual solar water heaters (ISWH) or combined water heaters (solar hot water and heating), the development of renewable heating networks (biomass and waste, solar and geothermal). It also calls for the electrification of heating requirements using thermodynamic systems such as heat pumps. Furthermore, the ambient and geothermal energy harnessed for heating and cooling using heat pumps and district cooling systems is eligible for inclusion in the RED II renewable energy calculations, provided that the final energy yield of the HPs significantly exceeds the primary energy input required to operate them. The amount of heat or cooling must be considered as energy produced from renewable sources and is calculated by applying the method set out in Annex VII of the Directive. Quantification of the renewable energy produced for cooling and district cooling has improved greatly since the European Commission defined a specific calculation method (delegated regulation 3022/759 dated 14 December 2021), amending Annex VII of the (2018/2001) renewable energy directive (RED II). Initially, Annex VII only provided a renewable energy calculation method for heat pumps dedicated solely to heating. The introduction of a specific calculation for renewable cooling since 2021 enables us to distinguish between

the renewable energy produced by heat pumps for heating and that of the systems that provide a cooling function, such as reversible HPs in cooling mode and district cooling systems. The latter often harness renewable energy sources via heat pumps but also through refrigeration units that are cooled by seawater or rivers, or by the direct use of a naturally cold source of water, such as pumped deep seawater or river water in winter to cool down the network.
In 2023, renewable sources accounted for a little over a quarter (26.2%) of the EU's total final energy consumption for heating and cooling, i.e., 1.2 of a percentage point more than in 2022. While the rise in the renewable share of heat and cooling is slower than that of electricity, it has nonetheless practically doubled since 2006 (when the share was 12.4%). The Eurostat SHARES tool quantified the total renewable energy used for renewable heating and cooling at 110.8 Mtoe in 2023 compared to 111.4 Mtoe in 2022 (a 0.5% YoY loss) and 111.6 Mtoe in 2021. At the same time, Eurostat could consolidate downwards the 2022 renewable total slightly in its next update, because of an accounting overstatement of the compliant to total solid biofuel usage figure in the SHARES files of three countries. The EurObserv'ER calculations of the 2022 eligible renewable heat and cooling total should be closer to its 2023 level. Renewable heat and cooling consumption has held up against the backdrop of declining heating and cooling needs across the European Union that have fallen from 484.7 Mtoe in 2021, to 445.2 Mtoe in 2022 and to 422.3 Mtoe in 2023. Heat pump technologies have contributed the most to the increase in renewable energy consumption to meet heating and cooling needs. The contribution of renewable energy from heat pumps solely for heating purposes rose by 2.2 Mtoe from 16.6 Mtoe in 2022 to 18.8 Mtoe in 2023. Renewable energies used for cooling, essentially via thermodynamic systems, were quantified at 975 ktoe in 2022 and at 998.1 ktoe in 2023. If we add the heat pump input for heating and renewable cooling into the equation, their share of the renewable total rose from 15.7% in 2022 to 17.8% in 2023... namely a 2.1 pp gain.
The above contrasts with the solid biofuel input, which shed a further YoY 2.4 Mtoe from 79.8 Mtoe to 77.4 Mtoe in 2023. Its share of the renewable total fell from 72 to 69.9%. Biomass across all its components is by far and away the most popular renewable energy used for heating. If we add RED II-compliant biogas (4.2% in 2023) to the solid biofuel input, including the biogas injected into the natural gas grid, renewable municipal waste (3.5%), compliant liquid biomass (1.0%) and charcoal (0.3%), the year's total comes to 78.9% (80.9% in 2022). Solar thermal and geothermal energy round off the list with respective shares of 2.4% and 0.9% in 2023 (2.5% and 0.9% in 2022).
At Member State level, as to be expected the forested countries, with their readily available supplies of biomass, mostly rely on renewable energy for heating and cooling as biomass is by far the main source of renewable heating. In 2023, Sweden topped the rankings with a 67.1% share (a 2.7 pp YoY fall). The country fully exploits its forestry potential (industries and district heating) and has universalized the use of heat pumps in the home. Biomass use is also over 50% in Estonia (66.7%, 1.2 pp rise), Latvia (61.4%, 0.4 pp rise), Finland (61.3%, 3 pp rise), Denmark (54.9%, 2.6 pp rise) and Lithuania (53.6%, 2.1 pp rise). Biomass as a resource for heating and cooling plays a decidedly minority role in Germany (17.1%, 0.5 pp fall), Luxembourg (15.5%, 0.1 pp fall), Belgium (11.3%, 9.7 pp rise), the Netherlands (10.2%, 1.1 pp rise) and Ireland (7.9%, 2.3 pp rise).

THE RENEWABLE TARGET IS TO RISE FROM 24.6 TO 42.5% IN 7 YEARS

The renewable energy share continues to increase relentlessly percentage point by percentage point. Eurostat reports that 24.6% of the EU's 2023 final gross energy consumption was renewably sourced, which equates to about 1.5 of a percentage point more than in 2022 and 2.7 pp more than in 2021. The European directive 2023/2413 (known as RED III), raised the EU's 2030 renewable energy target from 32 to 42.5% (and harbours an ambition to raise the target to 45%). As a result, EU countries must redouble their efforts to collectively meet the new EU target for 2030. This will require the share of renewable energy sources in their final gross energy consumption to increase by at least 18 percentage points within a seven-year timeline.
Some countries such as Sweden (66.4% share), Finland (50.8%), and Latvia (43.3%), have already sailed past this target. These countries, and we could include Estonia (38.5%), have the advantage of being able to count on their sizeable forest resources that they exploit commercially. They also have abundant hydroelectricity resources, and moreover have popularized heat pump use for heating, invested in mainly renewable heating networks, a high-growth wind energy sector, and more recently in solar photovoltaic. Denmark (at 44.4%), whose forest and hydraulic resources are less generous, has managed to green its energy mix, both the electricity and heating applications, by developing its own top-flight wind energy industry and production sector (onshore and offshore). At the same time, it has pioneered the use of codigestion biogas, heat pumps and also massively integrated renewable energies into its heating networks, with solid biomass, solar thermal, geothermal energy and more recently high-capacity heat pumps. Denmark is an example of choice because of all the European Union countries, its renewable energy share increased most of all between 2004 and 2023, starting from a relatively low share in 2004 (14.8%) to achieve a 44.4% share in 2023 (a 29.6 pp rise). This share would have been as high as 45.3% (30.5 pp rise) had it not decided to transfer part of its output (via the statistical transfer mechanisms) to help Belgium and Luxembourg meet their commitments. Denmark exemplifies very fast energy transition and shows the way to countries whose renewable energy levels are still low, such as Poland (16.6%), Ireland (15.3%), Malta (15.1%), Belgium (14.7%) and Luxembourg (14.4%). In their defence, it should be said that the latter have not been standing idle, as they had negligible shares of renewable energy in 2004.
The Netherlands also deserves to be put into the limelight for making fast headway since 2018. In the space of 5 years, it has increased its renewable share by 10 percentage points from 7.4 to 17.4% and achieved this by rapidly greening its electricity system, inter alia by installing offshore wind farms and onshore and roof-mounted photovoltaic plants. The Netherlands has become the top EU country for per capita photovoltaic capacity in just a few years. This pace of growth can also be credited to its proactive work in the field of transport (biofuel and electrification of road transport) and the promotion of heat pump systems. By and large and without sidelining the direct contributions of biomass, solar and geothermal heat for domestic hot water production and heating, the electrification of transport and heating and cooling needs along with increasing the renewable share of electricity production, are no doubt the surest way to ensure that the European Union collectively succeeds in achieving the 2030 targets. ■

Énergie Partagée

FOCUS: INTEGRATION OF RES IN THE BUILDING STOCK AND URBAN INFRASTRUCTURE

The share of RES in the building stock in Europe has grown strongly in recent years. In general, RES have been particularly successful in electricity generation. However, the use of RES in the heating and cooling sector still lags somewhat behind. In 2022, RES reached around 41% of electricity generation, almost 4 percentage points higher than in the previous year (Eurostat). In heating and cooling, the share of RES reached only around 25%, 2 percentage points higher than in the previous year (Eurostat). At the same time, energy for heating and cooling is the largest energy demand in buildings. In residential buildings, space heating and cooling account for up to 70%, while electricity consumption for lighting and appliances amounts only to about 14% (EU building factsheets). In the following, the first chapter focuses on the integration of RES heating and cooling in the building stock and urban infrastructure. The second chapter looks into the integration of RES electricity, with a focus on self-consumption of electricity from photovoltaics.

EUROBSERV'ER – THE STATE OF RENEWABLE ENERGIES IN EUROPE – 2024 EDITION

INTEGRATION OF RES HEATING AND COOLING

Heating and cooling demand is met by a variety of decentralised technologies integrated into the building or by centralised heating infrastructures. Decentralised renewable heating technologies in buildings include for example heat pumps, electric boilers, biomass boilers and solar thermal collectors. Centralised heating infrastructures are collective heating systems based on underground pipes that transport heat to multiple consumers. A distinction can be made between gas and district heating networks. District heating is based on large-scale plants such as biomass combined heat and power plants (CHP), deep geothermal plants, solar thermal fields and large-scale heat pumps. Heat pumps can thereby use a wide variety of sources, including for example air, water from rivers, lakes and seas or wastewater from sewage treatment plants.
The consumption and market indicators on renewable heating integration in the building stock and urban structure are designed to depict the status quo of RES use and the development of RES deployment in this respect. Due to the large and heterogeneous building stock and the long lifecycle of heating systems and buildings, the consumption shares change slowly over time while the market shares reflect changes at the margin.

METHODOLOGICAL APPROACH TO ASSESS THE INTEGRATION OF RES HEATING AND COOLING

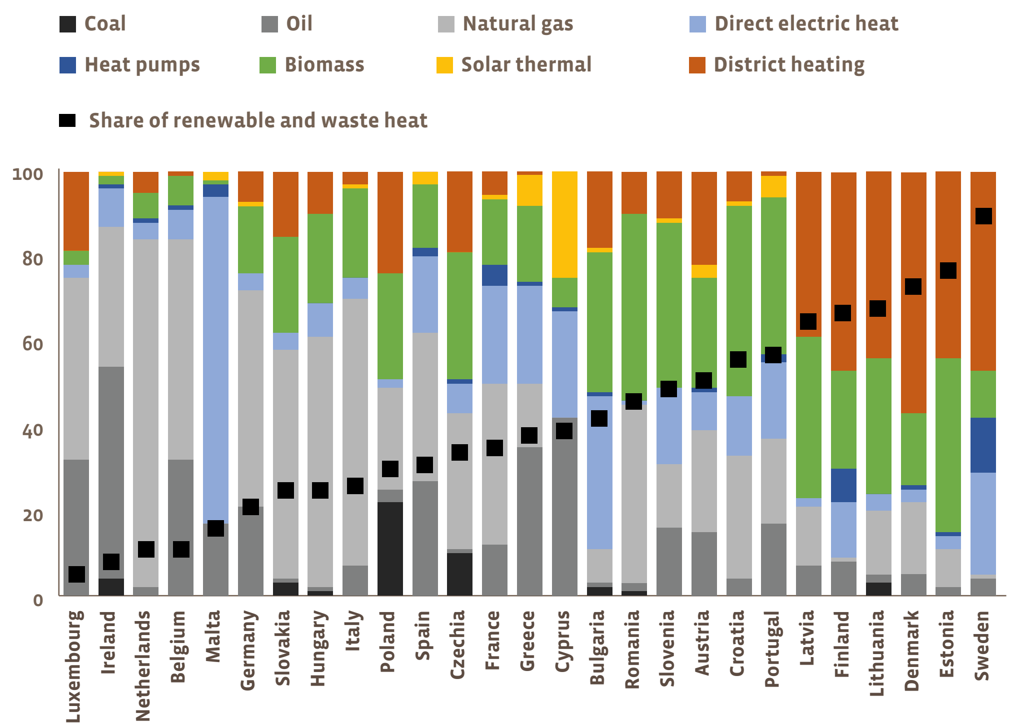
The **consumption shares of RES** heating and cooling in the building stock indicate the degree to which the respective RES is used in the building sector. It is the quotient of the final renewable energy demand for heating and cooling in buildings and the total final energy demand in buildings, including electricity for heating and hot water preparation. The total share of RES and waste heat is derived from the shares of biomass, solar thermal, district heating (considering the share of RES and waste heat in district heating), heat pumps and direct electrification (considering the share of RES in electricity generation). While the shares of the different energy carriers reflect final energy, the total share of renewables and waste heat is based on useful energy to adequately account for the contribution of heat pumps.
The **share of RES in district heating** displays the type of energy carrier used in district heating networks. It is calculated from the amount of energy generated from RES technologies in district heating divided by the total energy generation in district heating, including fossil fuel-based generation. Therefore, this indicator provides an overview to what extent district heating networks operate sustainably. The total share of RES and industrial waste heat in district heating is based on useful energy from biomass, biofuels, geothermal energy, industrial waste heat, electric boilers and heat pumps (considering the share of RES in electricity generation).
In addition, the **market stock shares of RES in heating** are depicted. They show the installed heating units in a dwelling as a percentage of all dwellings. As solar power is mainly applied in combination with other technologies, it is not counted as an alone-standing system. In contrast, electric heating is included in the market stock share as an alone-standing system. It is an important technology for heating and hot water preparation in some countries.
In contrast to consumption shares or **market stock shares of RES**, market sales shares of RES heating technologies depict the dynamics and development of RES at the edge. Market sales shares show the shares of specific heating technologies sold in relation to the total sold heating units. They may vary from year to year in each country. As sales data were unavailable for several technologies or countries, the number of exchanged systems is assessed based on the change in market stock shares. Although solar thermal energy is mainly used in combination with other systems, it is separately listed here to show its significance and dynamics.

The **shares of RES electricity for heating** in the building stock are shown to display the increasing importance of electricity in the heating sector. By dividing the electricity consumption from RES for direct electric heating as well as for heat pumps by the final heat demand in buildings, this indicator can be used to track developments in the RES electricity for heating deployment.
The **market stock share of sector integration technologies** shows the degree of coupling of the heating and electricity sector through decentralized technologies in buildings. For this purpose, the total market stock share of decentral heat pumps and direct electric boilers in buildings is depicted.

RESULTS ON THE INTEGRATION OF RES HEATING AND COOLING

1

Consumption shares in heating in 2022



***Source:** Own assessment based on diverse sources: Eurostat, EHPA Market and Statistic Report and Heat Roadmap Europe project.*
Notes: District heating contains derived heat obtained by burning combustible fuels like coal, natural gas, oil, renewables (biofuels) and waste, or also by transforming electricity to heat in electric boilers or heat pumps. The shares of energy carriers are based on final energy, while the total share of renewable and waste heat is based on useful energy (COP heat pumps = 3).

CONSUMPTION SHARES OF RES IN HEATING AND COOLING

Figure 1 presents the consumption shares of RES heating and cooling in 2022 for residential buildings and services. This share is a combined indicator for the integration of RES in buildings and urban infrastructure. It depicts the share of RES in the total final energy demand for heating and cooling (i.e. decentralised heating and centralised district heating system). Due to low exchange rates and long lifetimes of heating and cooling systems, the consumption share shows only small changes from one year to the other.

Gas remains a crucial source of heating for most countries. Especially in the Netherlands, Italy, Slovakia, Belgium, Germany and Luxembourg, gas is dominating the heating market. Although oil boilers are in steady decline in the heating market, they are still an important source of heating in Ireland, Cyprus, Greece, Luxembourg and Belgium. In Poland, more than 20% of heating still relies on coal. Direct electric heating plays a very dominant role in Malta. Bulgaria,

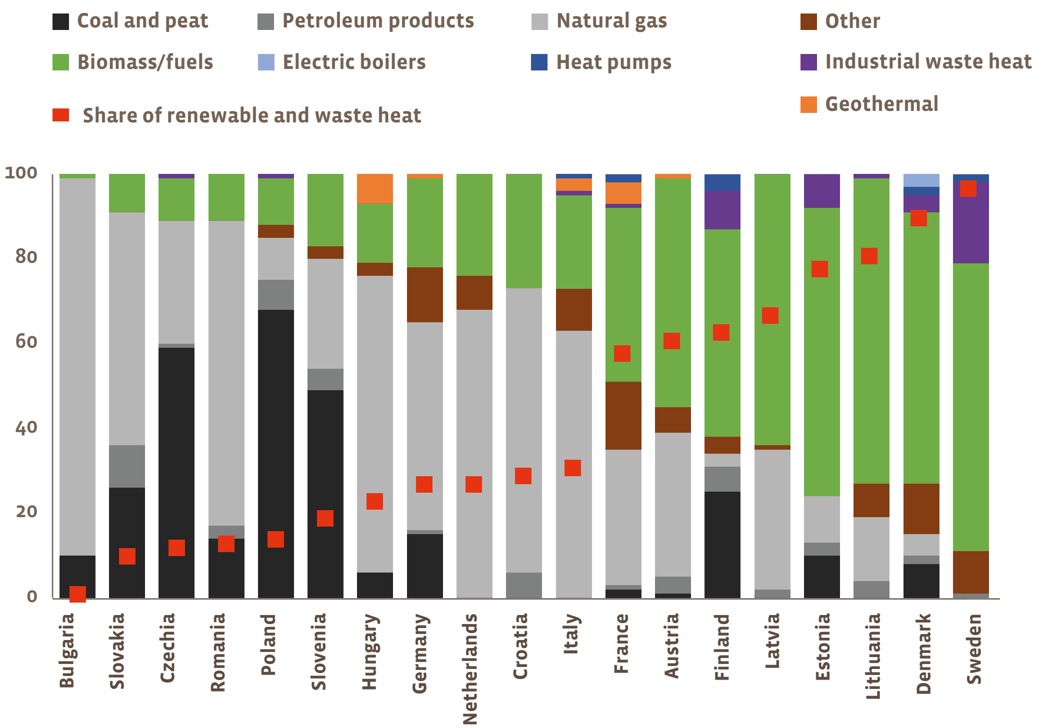
Cyprus, Sweden, Greece and France also exhibit shares above 20% for direct electric heating. District heating prevails particularly in the Scandinavian and Baltic countries, with leading shares. Eastern European countries, with established networks and a long history of district heating, also rely prominently on these systems.

The share of renewable and industrial waste heat in Figure 1 depicts the total of RES shares in decentralised heating and centralised district heating, including RES shares in electricity used to generate heat. RES and waste heat dominate in Sweden (90%), Estonia (77%), Denmark (73%), Lithuania (68%), Finland (67%) and Latvia (65%). In addition, these countries have the highest shares of district heating in Europe, highlighting the advantage of district heating to integrate large shares of RES and waste heat that cannot be used in individual heating systems.

In contrast, Croatia (56%), Slovenia (49%) and Romania (46%) reach high RES shares due

2

District heating supply mix in 2022



Source: Own assessment based on diverse sources: Eurostat, Euroheat & Power DHC Market Outlook Insights & Trends 2023 and data from national statistic institutes of the MS. *Notes: Based on 2021 data for: BG, DE, AT, FI, SE, HR, RO, PO, CZ, SI, HU, IT, EE, FR, DK, LT; 2018 data for: NL, SK. Other includes renewable and non-renewable forms of energy such as non-renewable waste, solar thermal, etc.. The shares of energy carriers are based on final energy, while the total share of renewable and waste heat is based on useful energy (COP heat pumps = 3).*

to the highly decentralised use of biomass, which represents a rather cheap fuel for heating in these countries. Decentral use of biomass has also a high share in Estonia, Portugal, Latvia and Bulgaria. Decentral heat pumps are growing in importance every year. However, higher shares are mainly reached in Scandinavian countries such as Sweden (13%) and Finland (8%). Solar thermal displays the smallest shares in most countries. It is mainly used in southern Europe countries with high solar radiation potential, such as Cyprus (25%) or Greece (8%).

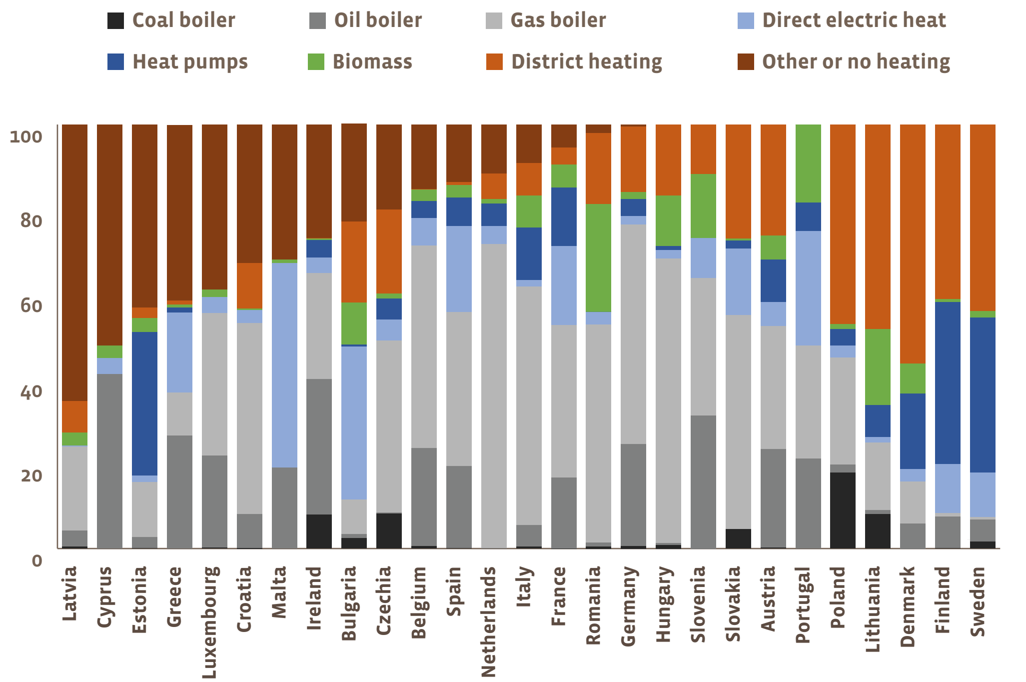
SHARE OF RES IN DISTRICT HEATING

Figure 2 shows the district heating supply mix in the countries where district heating covers at least 2% or more of the heating demand in 2022. In most countries, the existing district heating networks still rely on fossil fuels, with natural gas and coal as the dominant sources. Coal and peat are mostly used in Poland (68%), Czechia (59%) and Slovenia (49%). Petroleum products as a source for district heating still play a relevant role in the supply mix of Slovakia (10%). In contrast, Sweden (97%), Denmark (90%), Lithuania (81%) and Estonia (78%) have very high shares of RES and industrial waste heat in district heating.

The most dominant RES in district heating are biofuels such as biomass, biogas and renewable waste. Especially in Lithuania (72%), Sweden (68%), Estonia (68%), Denmark (64%), Latvia (64%), Austria (54%),

3

Market stock shares of RES in heating in 2022



Source: Own assessment based on diverse sources: Eurostat, EHPA Market and Statistic Report, Bioenergy Europe Statistical Report, Euroheat & Power DHC Market Outlook Insights & Trends 2023 and Solar Heat Europe Market Statistics. *Notes: Solar is not counted as an alone standing system as it is used mainly in combination with other systems. Market stock data of coal, oil and gas boilers are based on data from 2020 adjusted with change in consumption (adjusted with HDD).*

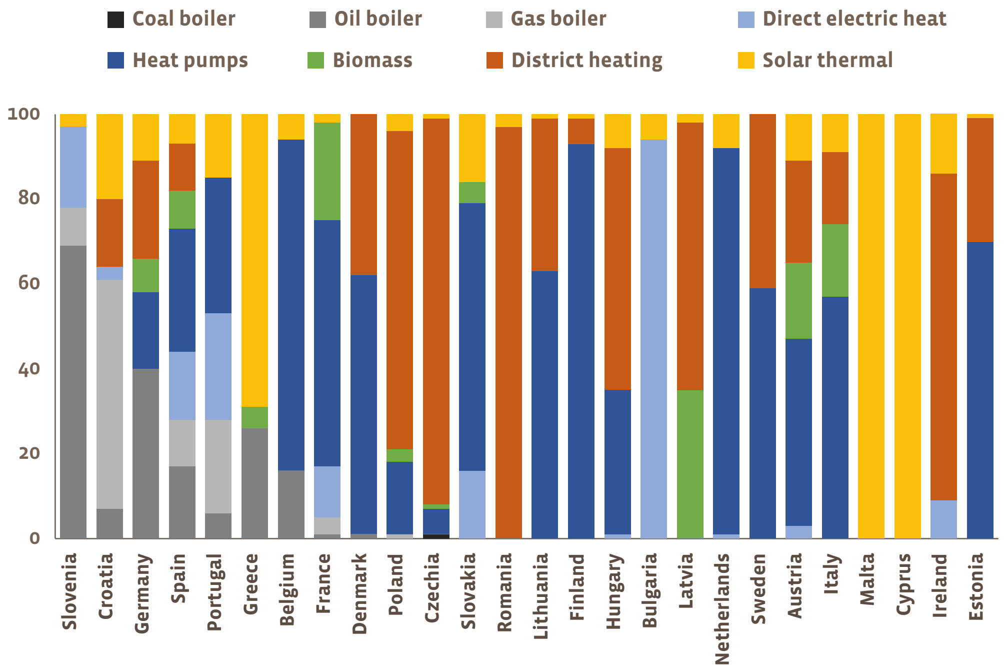
Finland (49%) and France (41%) biofuels are the most important source in district heating. Large-scale heat pumps are mostly used in Finland (7%), Sweden (2%) and Denmark (2%). Waste heat from industrial processes reached high shares in Sweden (19%). Finland (9%) and Estonia (8%). Geothermal energy reaches only low shares in a few countries, such as Hungary (7%) and France (5%). Solar thermal plays an almost negligible role in the EU-wide district heating mix and is therefore included in "Other". Denmark is the only exception, having a relatively high share of solar thermal energy of up to 2%.

MARKET STOCK AND MARKET SALES SHARES OF RES IN HEATING

Figure 3 depicts the technology shares in the building stock. In contrast to Figure 1 above, it shows the share of dwellings with the respective heating technologies and bundles unknown heating systems or no heating system in a further category called "Other or no heating". This share is high for Latvia, Cyprus, Estonia and Greece. Due to climatic conditions, some dwellings might have only a small heater or stove, which is not accounted for in the statistics. Further, the high share of unknown heating reflects data problems in this group. As solar thermal is not included here as a separate system, dwellings which use only solar thermal energy for heating are part of this group as well. However, the share of "Other or no heating"

4

Market sales shares of RES in heating in 2022



Source: Own assessment based on diverse sources: Eurostat, EHPA Market and Statistic Report, Bioenergy Europe Statistical Report and Solar Heat Europe Market Statistics. *Notes: Fossil fuel boilers, electric boilers and district heating are calculated based on the change in market stock share. One unit of solar thermal contains 4 m2 per household. Luxembourg is excluded due to a lack of data. According to a German association (BDH), there were also sales of gas boilers in Germany in 2022, but no net sales were observed (due to the methodology used, i.e. change in market stock). The high share of solar thermal in Malta and Cyprus is also due to the methodology used. To a lesser extent, sales of other heating systems (e.g. electric boilers and heat pumps) may also have occurred in these countries*

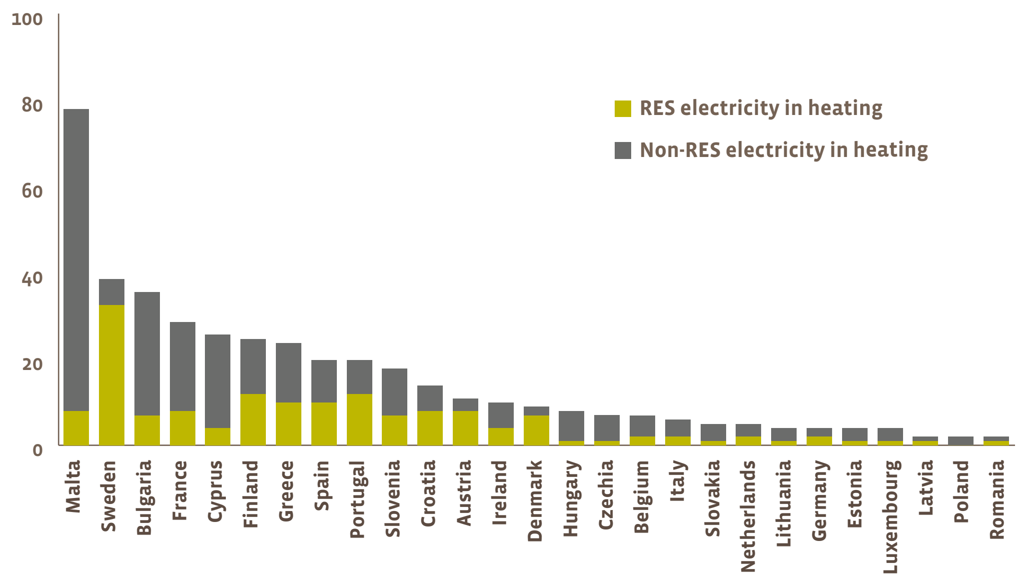
is decreasing in most countries compared to the previous year, indicating that data availability is increasing.

Figure 4 shows the (net) market sales share of heating technologies for the heating of buildings. In contrast to Figure 3 above, Figure 4 highlights the dynamics in the heating market by illustrating the sales shares of RES heating technologies in the respective year. For fossil fuel boilers, electric boilers and district heating, sales are calculated on the basis of changes in market stocks due to a lack of data. Therefore, the sales shown for these technologies are net stock changes.

Heat pumps show very high dynamics in most countries, especially in Finland, Netherlands, Belgium, Estonia, Lithuania, Slovakia, Denmark and Sweden. Direct electric heating technologies are pushed out by heat pumps and only have a high share of sales in a few countries like Bulgaria and Portugal. Solar thermal energy shows very high sales rates in countries where it has already a high share, such as Malta, Cyprus and Greece. Biomass boilers display a high dynamic in Latvia, France and Austria. Sales of fossil fuel-based heating systems are still at a high level in countries like Slovenia, Croatia and Germany. Overall, the RES market sales share shows a higher dynamic compared to the previous year in most MS, and thus, RES technologies in heating are taking off and increasingly contributing to the GHG emission targets.

5

Share of RES and fossil-based electricity used in heating in 2022



Source: Own assessment based on other indicators and Eurostat.

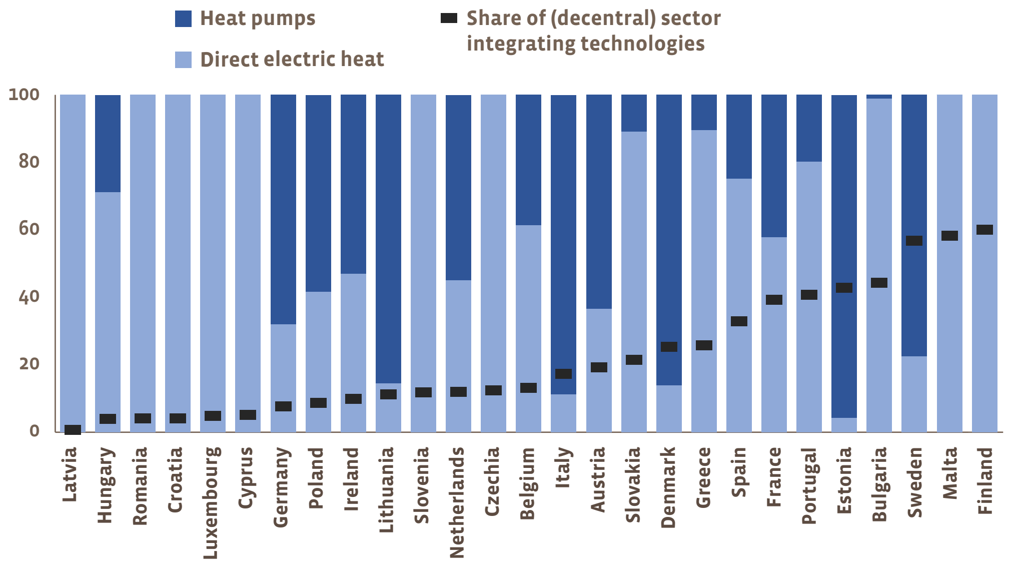
SHARES OF RES ELECTRICITY FOR HEATING

As the share of RES in the electricity sector increases, electric heating becomes more important. Figure 5 shows the share of RES electricity used for heating of buildings, including the share of electricity in district heating. This indicator thus shows the share of RES electricity used in small and large direct electric heaters and in small and large heat pumps.

Figure 5 shows that even though electricity as a source of heating is gaining importance, the EU average of RES electricity for heating purposes is still below 6%. Malta and Sweden are leading countries using high shares of RES electricity in their heating mix. Bulgaria, France, Cyprus, Finland and Greece also have a higher share of electricity in their heating mix (above 20%). In Malta, Bulgaria, Cyprus and France, electricity is largely generated from non-RES sources (including nuclear).

6

Market stock share of (decentral) sector-integrating technologies in 2022



Source: Based on the market stock indicator.

MARKET STOCK SHARE OF SECTOR INTEGRATING TECHNOLOGIES

Sector integration of the electricity and heating sector can make an important contribution to the integration of RES, mainly by increasing the share of RES electricity used for heating. Figure 6 shows the market stock share of (decentral) sector-integrating technologies in buildings, such as (decentral) direct electric heaters and heat pumps. In Malta, Sweden and Finland, market stock shares are above 40% and in Bulgaria, Estonia, Portugal and France, market stock shares of more than 30% can be observed. ■

CONCLUSION RES HEATING AND COOLING INTEGRATION IN BUILDINGS

In conclusion, fossil fuel boilers are still a widely used heating technology, followed by district heating. The consumption and market share of coal and oil boilers are slowly declining. However, due to their long lifecycle and ongoing sales, these boilers are expected to continue playing a role in the next years. Despite the relatively high dynamics of heat pumps in some countries, consumption shares remain low compared to fossil fuel heating. Nevertheless, RES electricity, used in direct electric heaters and heat pumps, has the potential to become a dominant option for heating and cooling supply in the residential and service sectors. Similarly, solar thermal plants have quite some potential and their dynamics are quite high in some countries.

Some countries have shown high consumption and sales dynamics of RES. Heat pumps are increasingly used in Scandinavian countries, while biomass still plays a significant role in several Eastern European countries. Overall, there is more momentum in the heating and cooling sector and RES technologies are becoming more important compared to previous years, but further action is needed to meet energy and climate goals.

INTEGRATION OF RES ELECTRICITY (SELF-CONSUMPTION)

Harnessing the potential of renewable electricity from solar photovoltaic (PV) systems plays a crucial role in advancing as well as «democratising» the European Union's (EU) energy transition and getting citizens involved. Apart from large-scale installations, a shift towards decentralisation has introduced independent actors such as households, businesses, or cooperatives, who have entered the scene as self-producers and consumers. Depending on the nature of ownership over the power generation assets we distinguish two distinct forms of self-consumption: individual and collective. Individual self-consumption is generally onsite generation and consumption while collective self-consumption, e.g. energy communities, can either be on-site (e.g. multi-family houses) or off-site (from larger-scale power plants). This evolution enables diverse actors to actively participate in and shape the energy transition taking into account their different capabilities.

The present chapter investigates the onsite integration of electricity from renewable energy sources (RES). Focus is put on the self-production and self-consumption of solar photovoltaics (PV) as the most mature, affordable and therefore widespread technology available, specifically looking at building-applied photovoltaics (BAPV) as opposed to building-integrated photovoltaics (BIPV).

In the past years, there has been a substantial rise in the cumulative installed capacity of solar PV systems within EU Member States (MS). This development also goes along with the further development of incentive mechanisms provided by MS to overcome potential financing gaps of solar PV systems and incentivise their uptake. Regulatory schemes for self-consumption vary considerably among MS with countries providing different incentives and remuneration mechanisms. Recent years have witnessed the emergence of new trends, including the gradual phasing out of Feed-in-tariffs (FITs), replacing them with net-metering and net-billing schemes. The key differences between FITs and net-metering and net-billing lie in how surplus electricity is accounted for, i.e. priced, bought, and sold, in each mechanism. While FITs provide a fixed price for excess electricity sold to the grid, net-metering and net-billing involve crediting or compensating households for the excess electricity they inject into the public grid, with variations in how the net is compensated.

Before deciding on installing a PV-based electricity system at building level, one will evaluate how long it will take for the installation to "break even" and whether the investment is likely to be profitable in the foreseeable future or not. Once up and running, building owners or owners of PV-based electricity generation systems are then faced with the decision on how to best allocate the self-generated electricity. The choice between consuming the electricity entirely or partially for personal use, versus injecting it into the grid for compensation, hinges on a complex interplay of economic factors, personal preferences, and motives. In addition to the expected revenues from feeding in self-generated electricity, the levelised cost of electricity (LCOE) and remuneration for grid-injected energy, also the retail electricity price has a major impact on the profitability of the investment and thus ultimately the self-consumption decision. Combining PV self-consumption with complementary technologies including storage for electricity and heat, most notably batteries, heat pumps, electric vehicles or thermal heat storage, can be crucial to increase self-consumption shares and enable optimised coordination of supply and demand.

METHODOLOGICAL APPROACH TO ASSESS RES ELECTRICITY SELF-CONSUMPTION

Despite being an important and growing phenomenon in the EU energy landscape, self-consumption is still not systematically monitored and evaluated across the different MS and there is a lack of uniform indicators. It is therefore difficult to grasp it in its entirety and draw comparisons over time and countries. Aiming to minimize this gap, the present analysis assesses the self-consumption of PV-based electricity within the EU from various angles. This is done by combining empirical data collection and techno-economic approaches. One of the main indicators to assess the development of self-consumption in a specific country is the self-consumption share. In essence, the PV self-consumption share can be defined as the share of the total PV production directly consumed by the PV system owner.

To assess RES self-consumption in buildings, three different approaches are combined to obtain a holistic picture.

First, an **empirical assessment** is conducted, using survey data. Questionnaires were sent to national contact points, e.g. national statistical offices, Ministries, energy agencies, etc. and compiled and assessed. In some cases, the information was complemented by reports and studies as well as websites. The empirical data delivers information about the self-consumption shares in different countries, but without a particular focus on small-scale residential PV systems. Countries were asked for the cumulative and annual PV capacity installed as well as the gross electricity from PV produced and the share of self-consumption.

Second, the **technical assessment** calculates the technical self-consumption share per country, defined as the overlap of generation profile (solar PV energy production) and load profile (home energy use). As the most likely investment object, a residential PV system without battery storage (neither stationary nor mobile) or power-to-heat appliances is considered. This choice is motivated by limited data availability or granularity regarding storage and balancing for home energy use as well as the fact that these are not yet very commonly used. Residential PV systems are also not further distinguished by their deployment location. This means that BIPV installations inside the roof or facade as well as BAPV installations on top of the roof or ground-mounted located directly next to the building are added up. Furthermore, only grid-connected systems are considered. The calculation relies on residential PV installations with an estimated capacity of up to 10 kWp.

Input of the calculation are hourly amounts of consumed electricity of a household in kWh («load») and the hourly amounts of produced electricity by the PV system in kWh. The «load» means the hourly load, equal to the terms demand and consumption, of a household in the respective country. It is calculated as the product of the average yearly electricity consumption of a household in the respective country and the hourly load, derived from standard load profiles. For the calculation, climate-corrected unit consumption data of electricity per dwelling (Odyssee indicators database) were used to adjust the average load to the year of consideration.

Production is defined as the hourly produced electricity and calculated as the product of the specific hourly production in kWh per kWp and the capacity of a residential PV system. The values of the hourly production are also used as the denominator to calculate the self-consumption shares per hour. The specific hourly production is based on data provided by the ENTSO-E transparency platform and Eurostat for the production of installed PV systems in a country.

Third, as for the **economic assessment**, it is assumed that households are rational economic actors seeking to minimise their electricity spending. Their decision for or against installing and using a PV-based electricity generation for self-consumption is based on three major factors:

- The specific generation costs of self-produced electricity (LCOE),
- the revenues from feeding in self-generated electricity: for example feed-in tariffs (FiT) or the (wholesale) price of electricity with or without feed-in premium, and
- the retail electricity price (PGrid) that a household pays for drawing electricity from the grid, including potential network fees, taxes or levies.

Given these factors and their levels, six potential combinations (cases) are possible, resulting in the options presented in Table 1.

For the calculation, all support schemes that accompany the average FiT in each country for each year are considered. If the compensation amount changes during a given year, the average of the prices is calculated and considered as the FiT. If there is no policy support in place, the FiT is considered to be equal to zero. ■

1

Potential constellation of costs, prices and tariffs and resulting scenarios of self-consumption

Case	Combinations	Scenario
1	PGrid > FiT > LCOE	Self-consumption
2	PGrid > LCOE > FiT	Self-consumption
3	FiT > LCOE > PGrid	Feed-In, no self-consumption
4	FiT > PGrid > LCOE	Feed-In, no self-consumption
5	LCOE > FiT > PGrid	No investment
6	FiT > LCOE > PGrid	No investment

Self-consumption (Cases 1 and 2): The household invests into a PV system and self-consumes all electricity produced. As the production of the PV system is volatile and batteries are excluded in this case, a self-consumption and self-sufficiency share of 100% is not feasible. Thus, for cases 1 and 2, the objective function is to maximize the share of self-consumed electricity as LCOE are lower than PGrid. Electricity costs of the consumer are: LCOE + PGrid (for the remaining electricity drawn from the grid).

Feed-in (Cases 3 and 4): The household invests into a PV system, feeds the total amount of electricity produced by the PV system into the grid and receives a remuneration in form of a FiT while he/she draws electricity for final consumption from the grid. In cases 3 and 4, the objective is to maximize revenues, i.e. maximize the amount of electricity fed into the grid and no self-consumption as the FiT is higher than PGrid. The profit (FiT - LCOE) from feeding-in reduces the electricity expenditures. Electricity costs of the consumer are: PGrid.+ share of (LCOE – FiT).

No invest (Cases 5 and 6): In these cases, it is most profitable for the consumer not to invest into the installation of a PV system at all and instead draw electricity from the grid as LCOE are higher than the FiT or PGrid. Electricity costs of the consumer are equal to PGrid.

RESULTS OF PV BASED SELF-CONSUMPTION OF ELECTRICITY IN BUILDINGS

RESULTS OF THE EMPIRICAL APPROACH

In a first step, the deployment of PV on buildings as well as the share of self-consumed PV is assessed empirically, using a compilation of survey data sources.
For presentation reasons, PV-based electricity production and self-consumption are illustrated in two figures, Figure 1 and Figure 2. They depict the development of total electricity production from PV per country and year as well as the share of self-consumed PV electricity in total PV electricity production in selected MS. The first figure depicts the situation in bigger and more populous MS with total electricity production from PV above 10,000 GWh annually (Italy, France, Germany, Spain), while the second figure compares countries where total electricity production from PV is below 6,000 GWh per year (Austria, Portugal, Czechia, Sweden, Lithuania, Malta).

As can be seen from the graphs, self-consumption shares vary considerably among the investigated MS, ranging from close to 0% to almost 45%. In all countries that provided data in reply to the survey, self-consumption shares either increased or remai-

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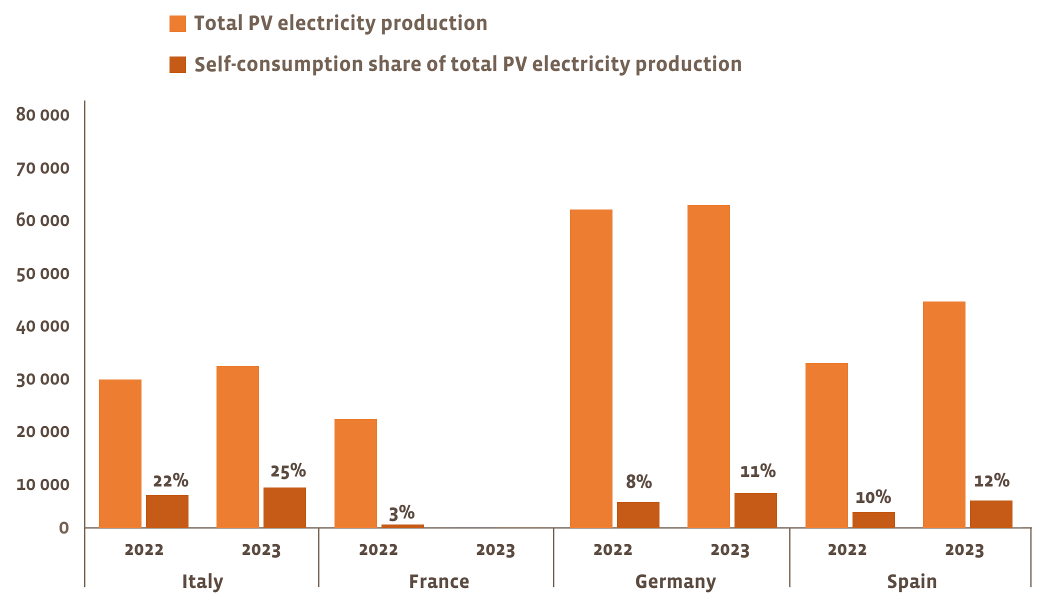
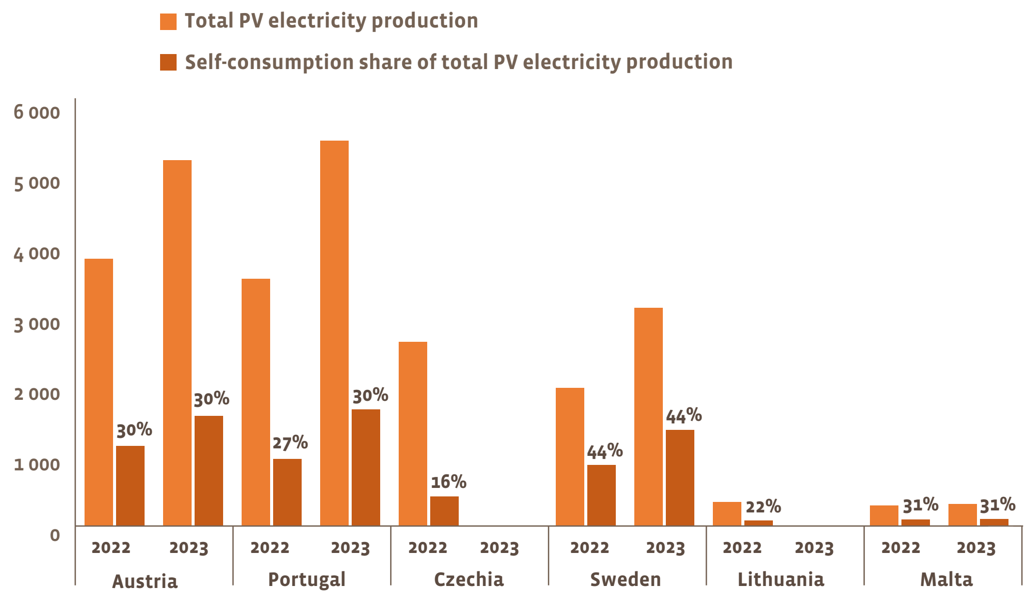
Electricity production from photovoltaics in 2022 and 2023 in larger EU MS



Sources: Ministry of Ecological Transition - Directorate General for Infrastructure and Security (Italy); Ministry of Ecological Transition and Territorial Cohesion, General Commission for Sustainable Development, Service for statistical data and studies (France); Working Group on Renewable Energy Statistics (AGEE-Stat) (Germany); Ministry for the Ecological Transition and the Demographic Challenge and Institute for Diversification and Saving of Energy (IDAE) (Spain), own calculations. Note: data is not reported for France in 2023.

8

Electricity production from photovoltaics in 2022 and 2023 in smaller EU MS



Sources: Statistics Austria (Austria); Directorate-General for Energy and Geology (DGEG) (Portugal); Ministry of Industry and Trade (Czechia); Statistics Sweden (Sweden), Statistics Lithuania (Lithuania); National contact point (Malta), own calculations Note: data is not reported for Czechia and Lithuania in 2023.

ned at least constant between 2022 and 2023. In the sub-set of countries analysed, self-consumption shares are highest in Sweden, remaining constant at a high level of 44% in 2022 and 2023. In Portugal, the share of self-consumption has been increasing since 2021 from 19% to 30% in 2023, along with rising overall electricity production from solar PV. The other two MS with high self-consumption shares of at least 30% are Malta and Austria, where the self-consumption shares remain stable along with increasing overall PV electricity production. Shares of around 20% can also be observed in Italy and Lithuania. Specifically, the self-consumption shares in Italy increased between 2022 and 2023, while no data is reported for Lithuania in 2023. Czechia reported a self-consumption share of 16% in 2022, while no data is reported for 2023. Germany and Spain both exhibit rising self-consumption shares and reach slightly above 10% in 2023. Among the investigated MS, the lowest self-consumption share can be seen in France, where only roughly 3% of the total PV electricity production was self-consumed in 2022. However, no data were provided for 2023.

It has to be noted that some respondents indicated that the provided numbers include estimates. The low number of survey respondents might also be explained by the fact that not all MS have a consistent approach to collecting and tracking self-consumption indicators. While the depicted shares do indicate the situation in different countries, the lack of uniform definition and standards on how to meter and calculate self-consumption, makes it difficult to do cross-country comparisons. Over the coming years improvements in data availability, accessibility and quality of data on self-consumption are to be expected.

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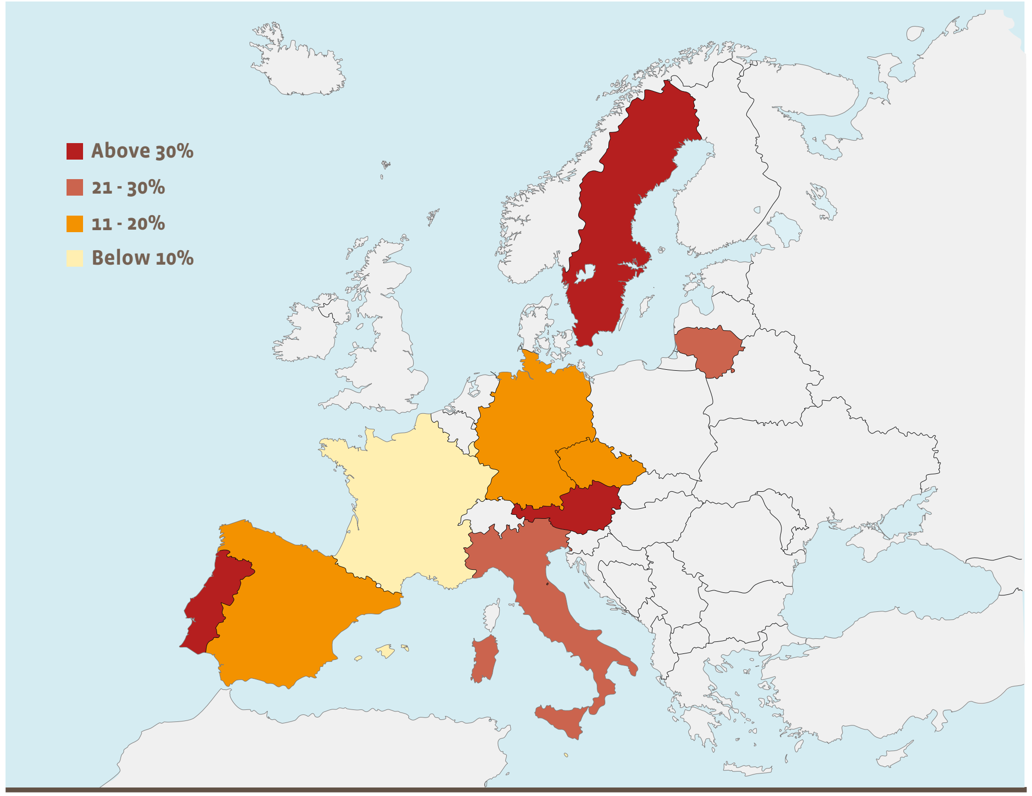
Self-consumption shares in 2023



Sources: Own assessment and calculation based on survey data

RESULTS OF THE TECHNICAL APPROACH

The technical assessment takes into account technical aspects via the generation and load profiles of households. It assesses the theoretical self-consumption share of PV-based electricity, without taking into account any other factors. It is defined as the overlap of the generation profile (PV energy production) and load profile (home energy use) of a hypothetical household, using synthetic load profiles. Thus, it represents a theoretical, maximum self-consumption potential. In times when the production exceeds the load, i.e. the required electricity, self-consumption is equal to the load because the total electricity demand can be covered by the PV production. In that case, the excess electricity can be fed into the grid. If production is zero, self-consumption is zero as well and all the electricity has to be taken from the grid. When the PV system produces less electricity than needed, for example in periods with very little sunshine, all of the produced electricity is self-consumed and the remaining demand is withdrawn from the grid. Figure 4 represents the results for these technical maximum shares per country for 2022, covering all EU MS.

The highest technical self-consumption shares of above 45% are possible in Spain, Portugal and Greece. Most countries are within the low to middle of the distribution and have technical self-consumption shares between 30 and 45%. The lowest technical self-consumption shares are observed in Romania and

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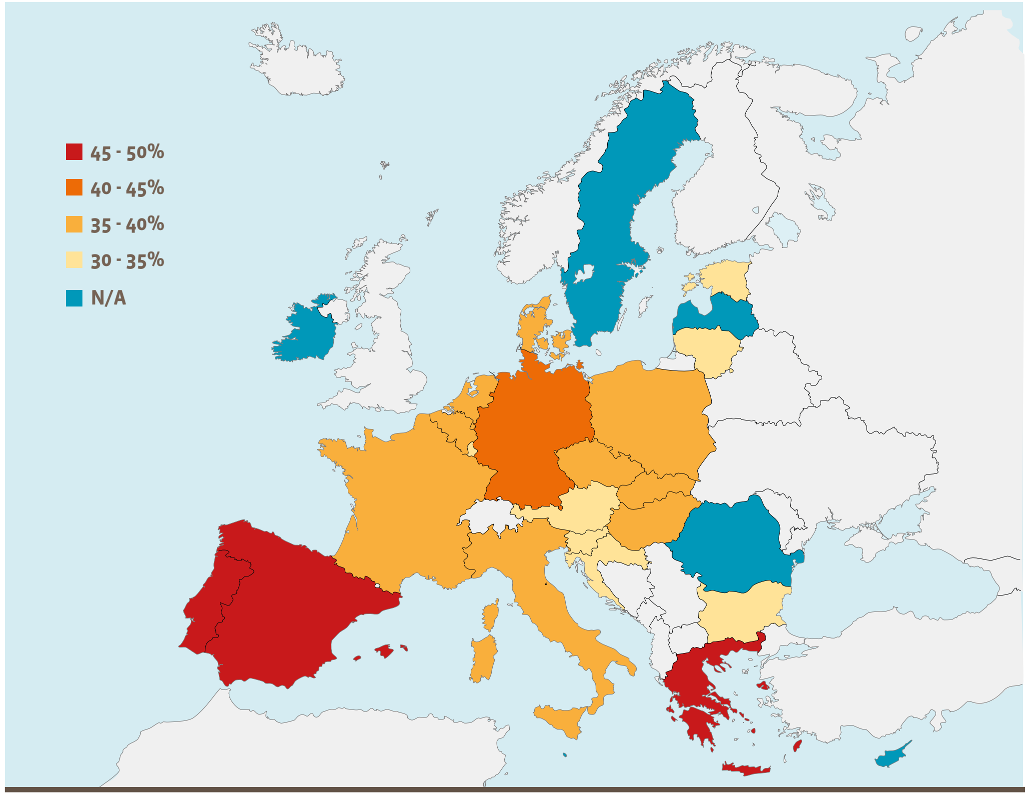
Technical maximum self-consumption shares



Sources: Own assessment and calculation based ENTSO-E Transparency Database, Eurostat, Odyssee indicators database

Croatia at around 33%. The calculated optimal shares are broadly in line with the literature which suggests technically optimal self-consumption shares around 30 to 40%. The EU average is at about 38%. It is, however, possible that the technical self-consumption shares are over- or underestimated for certain countries due to the use of generic synthetic load profiles that might not adequately represent energy use patterns across Europe. The results might be improved by assuming country-specific load profiles, taking into account the different climatic conditions and electricity consumption patterns. So far, only two synthetic load profiles are used for all countries, one for Southern European countries and one for the rest. Also, due to the lack of data, the approach does not consider the option of shifting consumption via storage or demand-side management. It can be assumed that the presence of battery systems can considerably boost demand coverage.
As the technical self-consumption share is based on different assumptions and approaches, the calculations deviate from the empirically grounded self-consumption shares described above. Overall, the considerable gap between empirical self-consumption and technical maximum shares suggests that self-consumption is not yet fully exploited from a technical perspective which means that there is potential for growth and optimisation.

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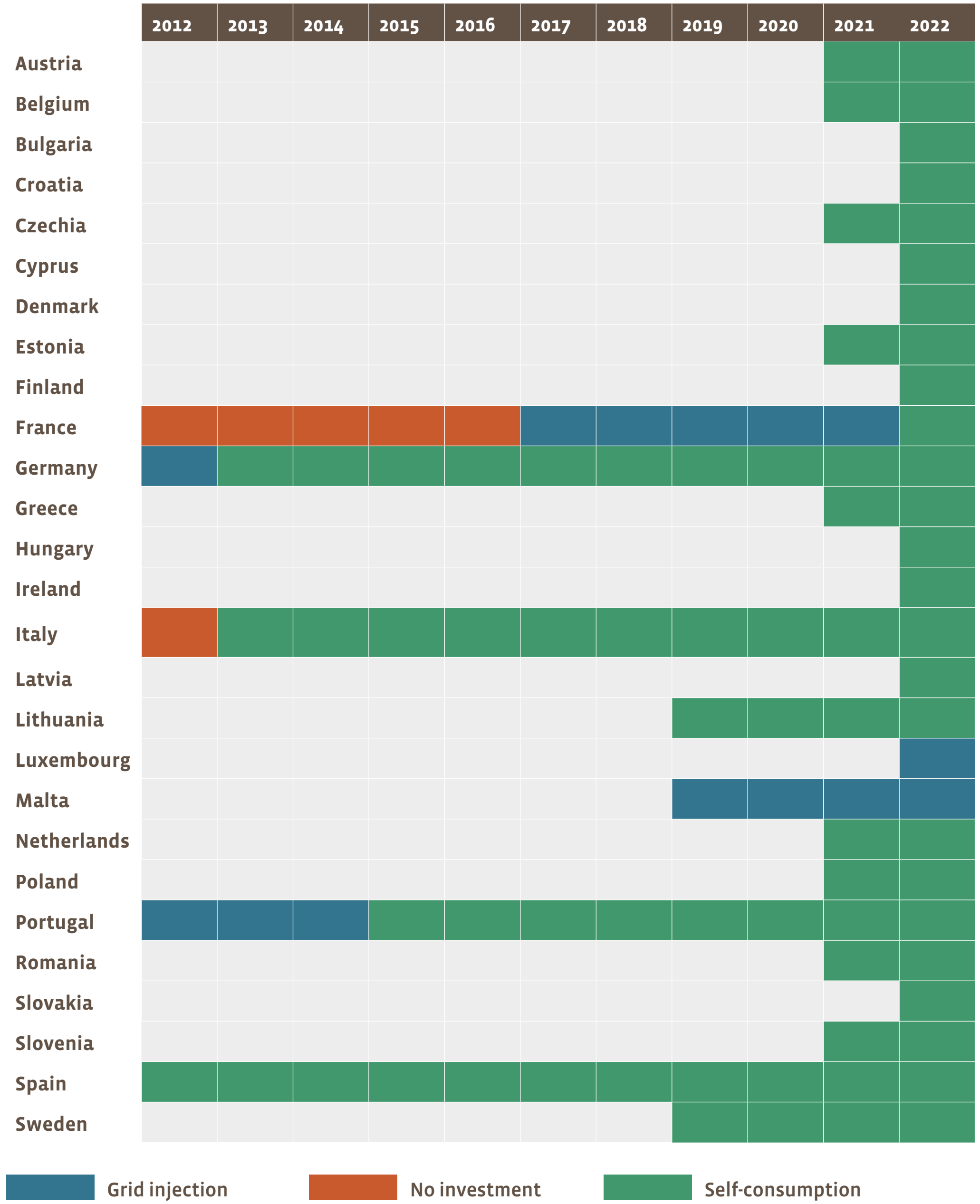
Economically optimal decision on self-consumption option per country per year



Source: Own assessment and calculation based on Eurostat, ENTSO-E and other sources

RESULTS OF THE ECONOMIC APPROACH

As outlined above, from a technical perspective the self-consumption potential is still expandable. Reasons for the gap between technically feasible and observed self-consumption shares might also be of an economic nature. Thus, also economic considerations are taken into account in the analysis. The assumption is that economic agents such as households or final energy consumers strive to minimise their energy expenditure. When making investment decisions related to electricity in the context of self-consumption, they choose among the following options:

- Investing and self-consumption,
- Investing and no self-consumption but feeding into the grid,
- No investment and drawing electricity from the grid.

The economic evaluation showcases for each country which is the most lucrative «self-consumption scenario», thus revealing the most probable choice for investment decisions. Table 2 depicts the results for all EU MS.

The expected trend is that with decreasing PV FiTs and PV system prices as well as increasing electricity retail prices, the self-consumption of PV electricity will become increasingly attractive, rather than feeding into the grid.

This is exactly what can be seen in the results. Overall, self-consumption seems to become the more and more dominant scenario and also was the most profitable decision in almost all EU MS in 2022, except for Luxembourg and Malta. This suggests that in many countries effective incentives are put in place to stimulate self-consumption and that investing in solar PV systems is generally profitable. Among all EU MS, FiTs are still in place in only nine of them and only three MS, namely Luxembourg, Malta and France, provide remuneration above 10 €ct per kWh. On the other hand, the high electricity prices in 2022 have also indirectly improved the economic feasibility of self-consumption of PV electricity. In Luxembourg and Malta, grid consumption and feeding into the grid was more attractive than self-consuming according to the scenario analysis which can be explained by the relatively high FiTs that made grid injection more attractive. Interestingly in France, self-consumption of PV electricity was less economical in 2021 and became more an attractive option due to the high electricity prices and lowered FiTs in 2022.

What the scenario analysis cannot adequately depict, is that the decision to self-consume or not will vary from consumer to consumer and that also «mixed strategies» are possible. This means that under temporal differing price structures «hybrid» consumption models, i.e. self-consuming and feeding the electricity into the grid present another financially profitable solution. Hence, the results should be understood in light of the particular conditions and circumstances existing in each individual case.

The results are, of course, also influenced by non-economic factors such as individual preferences, e.g. a preference for sufficiency, the specific reference electricity price, or the presence of additional support mechanisms. Nevertheless, the findings presented above can give some indication as to which decisions households are likely to make in a particular country during a specific time period and assess whether self-consumption is advantageous or not from a general perspective. ■

Naturstrom AG Mieterstrom Möckernkiez

CONCLUSION RES ELECTRICITY INTEGRATION IN BUILDINGS

In conclusion, the analysis of RES electricity integration in buildings presented in this chapter sheds light on both economic and technical aspects of self-consumption, comparing it against actual self-consumption shares which we can observe empirically. The economic approach underscores the viability of self-consumption in a large set of analysed countries. To complete this picture, the technical approach provides a theoretical framework for self-consumption, depicting what would be the optimal level from a purely technical point of view, albeit without factoring in storage options. Comparing the technically optimal self-consumption shares with the empirical results we collected, we show that there still is a large potential for more self-consumption in the European Union and that no single country seems to have exploited its potential for self-consumption. Nonetheless, it is worth noting that the self-consumption share in Austria is only 5% below the technical optimal.

The findings thus affirm a substantial technical potential for self-consumption of electricity, indicating a significant opportunity for harnessing renewable energy sources within buildings. This potential aligns with economic feasibility, particularly in countries where self-consumption emerges as the predominant scenario. However, the empirical analysis exposes notable gaps between the actual level of self-consumption and the technical optimum, particularly evident in France and Spain.

Solarimo

The economic analysis suggests that self-consumption stands as an attractive option across most countries. It also implies that the barriers to widespread adoption may not be primarily rooted in direct support policies for remuneration but are likely influenced by other factors. These barriers could encompass challenges related to grid access, additional fees or taxes, and administrative processes. Particularly, if the procedures and regulatory framework for installing, connecting, or managing PV systems are perceived as cumbersome or unclear, households may be deterred from making investments in self-consumption. It might also be the case that the level of awareness regarding self-consumption profitability is generally low and that more information and supports need to be provided to different stakeholder groups.

In moving forward, addressing these non-financial barriers becomes crucial for unlocking the full potential of self-consumption. Policy efforts should therefore be closely looked at but also extend beyond economic incentives. Streamlining administrative processes, reducing additional fees, and ensuring clarity in regulations can all be important additional steps. By doing so, countries can pave the way for a more efficient and widespread integration of renewable energy sources in buildings and onsite self-consumption. ■

FOCUS: RENEWABLE ENERGY COMMUNITIES

Alongside traditional projects led by private developers, renewable energy operations initiated by communities or groups of citizens are increasingly numerous within the European Union. This new approach, commonly referred to as 'citizen energy', is both a way of financing new production sites differently and a way of proposing new forms of governance in which local players are more involved.

HANDS-ON POWER

Citizens not only participate hands on the financing of renewable energy operations by taking an equity stake in the projects but are also involved in their governance. The European Union has taken up this citizens' approach through the Clean Energy Package, that officially considers European citizens as important actors of energy transition for the first time. Now, Directives 2018/2001 of December 2018 and 2019/944 of June 2019 introduced the concepts of «Renewable Energy Community (REC)» and «Citizen Energy Community (CEC)» respectively. Although defined by slightly different criteria and by different Directives, these two concepts intend to create a regulatory framework conducive to citizen-led renewable energy projects.

The first distinction that should be made between renewable energy and citizen energy communities, which are relatively comparable in terms of governance modes and aims, is the remit of their operations. RECs intervene in the energy sector in the broad sense, but their projects must be renewable energy based. So, they can supply renewable heat and even biofuels in addition to electricity. In contrast, CECs work exclusively with the electricity sector. Another important difference lies in the catchment area of their actions. REC members exercising effective control of a REC community must be based geographically close to their project. This proximity criterion does not apply to CECs.

> ***Renewable Energy Communities*** *(RECs) are defined in Article 22(2) of Directive 2018/2001: Member States shall in particular ensure the following. RECs are entitled to:*
> *- produce, consume, store and sell renewable energy,including through renewables power purchase agreements;*
> *- share the renewable energy within the community;*
> *- access all relevant energy markets, both directly and through aggregation, in a non-discriminatory manner.*
> *EU Member States are obliged to transpose the texts of the Directive into their own legislation in order to provide a framework that promotes and facilitates the development of these renewable energy communities.*

While the European Commission has addressed the issue of citizen projects for several years, these initiatives have been flourishing for much longer. Several countries have witnessed the emergence of citizen collectives since the early 2000s, implementing projects within their own territories. However, these projects may take different forms or modalities from one country to another. Citizen energy is not only a key lever for the success and acceleration of energy transition and the essential deployment of renewable energies, but also a vector for the democratisation of energy and its appropriation by the citizens. It makes energy production more identifiable and helps to overcome, in many cases, opposition in principle by showing all the benefits that these projects can have for the territories and their inhabitants. The cultural and, above all, legal specificities of the different Member States obviously have an impact on the dynamics of citizen energy on their territory.

Consequently, this section not only focusses on a single specific concept but will endeavour to report on the various national approaches to developing RECs, from the different Member States' standpoints as they transpose the EU directives into their own legislation, and on how they mobilise the various European funds to contribute to financing these communities.

RESCOOP.EU – AN INFORMED OBSERVER

The REScoop.eu federation is a network of European actors that actively promotes citizen energy. REScoop.eu has developed a tool for the purpose of its activities, to track and assess the process of transposing the EU directive texts relating to citizen energy projects in the Member States. It is used to analyse the existence of a definition for energy communities in national law, and the detail into which the definitions go. Furthermore, this tool can assess whether or not the national framework for energy communities is constructive.

The REScoop.eu observation tracking tool shows how progress in introducing legislative frameworks to promote the establishment of energy communities differs between the Member States. Ireland and Italy, for instance, have already enshrined a clear, functional definition for energy communities in their legislative corpus and rolled out support actions (development aims, energy community observation body, etc.) to support their growth. Other Member States have set up only minimal regulations, that may be too flimsy to really develop projects of this type. The REScoop tool also includes an energy community funding component, which indicates which European funds have been requested and reports on the country-specific eligibility criteria to obtain funding within the support framework for energy community initiatives. The funding comes from different programmes (Recovery & Resilience Fund, Cohesion & Regional Development Funds, Modernisation Fund and REPowerEU) that the Member States manage in their own ways. Some, such as Spain, have introduced specific mentions of energy communities into the management of these funds and gear them to projects whose form or approach is along the lines of the concepts described in the 2018 directive. Others use vaguer criteria or limit the scope of aid allocation thus reducing the extent of this funding available to energy communities.

The European Union has tried to foster the development of renewable energy communities. In its EU Solar Strategy roadmap presentation of May 2022, the European Commission declared

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Assessment of the legislative landscape and financial support awarded to energy communities

Transposition	Energy communities definition; Existence of an enabling framework and supporting schemes	Optimal regulatory framework	Satisfactory regulatory framework	Basic regulatory framework	Incomplete regulatory framework	Absence of regulatory framework	No information
Financing	Recovery and Resilience Fund; Cohesion and Regional Development funds; Modernisation Fund		Specific provisions for energy communities (full scope of actors and activities)	Specific mentions of energy communities (limited to a specific type of actors and activities)	Mentions of energy communities but in a limited capacity	No mentions of energy communities or related concepts	
	REPowerEU*			Strong support for energy communities	Some positive energy reforms	No support to energy communities	

**Note: RESCoop's REPowerEU assessment applies three criteria (transparency and inclusivity during the drafting process of the REPowerEU chapter by the governments, potential support for fossil fuels and conducive reforms and investments towards collective self-consumption and energy communities). Source: REScoop, 2024*

that it would like every community of over 10,000 inhabitants to have at least one renewable energy based energy community by 2025. To achieve this, the European Commission is stepping up its initiatives. The Energy Communities Repository and the Rural Energy Community Advisory Hub, both launched in 2022 and concluded in early 2024, aimed to support energy communities across Europe by sharing best practices and providing technical assistance. The former focused on training and policy analysis, while the latter specialized in rural project development, offering networking opportunities and support to local stakeholders, businesses, and farmers. More recently, in September 2024, the Commission launched the European Energy Communities Facility, building on the experience of previous initiatives. This program plans to allocate €7 million in lump-sum grants to at least 140 energy communities, provide targeted training, and help them structure their business models. It will run until February 2028, with calls for applications scheduled for June 2025 and September 2026.

RENEWABLE ENERGY COMMUNITIES TAKE THEIR FIRST STEPS IN CZECHIA

On December 1, 2023, the Czech Chamber of Deputies passed an amendment to the Energy Act, known as the Energy Communities Act. This reform, which came into effect in January 2024, marks a key milestone in the transposition of the European Renewable Energy Directive into national law. The legislation defines two types of structures: Renewable Energy Communities and Citizen Energy Communities. Another major advancement is the introduction of a temporary electricity-sharing system, operational since July 1, 2024. This system relies on a static distribution method managed by the Electricity Data Center. It enables members of an energy community to locally produce, exchange, and consume energy. However, the static model does not allow for flexible electricity distribution, which would have let community members benefit from unused energy within the group. Instead, any surplus energy must be reinjected into the grid. To address this limitation, a transition to dynamic and hybrid sharing models could be implemented by July 2026, alongside the full deployment of the Electricity Data Center. Other restrictions remain in place until 2026: sharing groups cannot exceed 1,000 members and must be located within three neighboring municipalities with extended competence or within Prague. Nevertheless, enthusiasm for energy sharing is strong. Since the system launched in July 2024, over 12,000 people have signed up, according to the Electricity Data Center. In just 100 days, participants shared a total of 750 MWh of electricity—equivalent to the consumption of approximately 2,300 Czech households. Regarding financial support, Czechia has allocated 2.8% of its Modernization Fund resources to the KOMUENERG program, which focuses on developing local energy communities. These communities can also seek funding through other Modernization Fund programs, such as HEAT and RES+, broadening their financial opportunities. Additionally, the Czech National Recovery and Resilience Plan has set aside €4 million to establish 40 energy communities nationwide. This pilot initiative could serve as a model for future projects. However, the lack of a comprehensive regulatory framework hinders the full use of available funds. Despite the introduction of the Energy Communities Act in 2024, the specific rules governing their operation are still being developed, leaving many potential projects in a state of uncertainty. Even so, the adoption of the Energy Communities Act has spurred the emergence of new projects across the country. The nation's first energy cooperative was founded in December 2023 with 47 founding members and managed to attract 200 new members and raise approximately €125,000 within just two months. This energy community's project involves installing photovoltaic panels on the roof of an organic farm in Velké Hosterádky, south of Brno. The 50 kW installation, set to be operational in 2025, will cover 30% of the farm's energy needs, with any surplus shared among cooperative members or fed back into the grid.

TOWARDS A MORE DEFINED LEGAL FRAMEWORK IN GREECE

In 2018, Greece established its first institutional framework for energy communities under Law 4513 "Energy Communities and other provisions", creating a structure for citizen and community involvement in energy projects. This law, though not fully aligned with the EU's Clean Energy Package introduced that same year, launched the concept of "energy communities" as civil cooperatives, incorporating elements like democratic governance and local benefit. While also providing support for energy poverty and municipal involvement, its broad definitions allowed private investors to dominate the sector, leveraging incentives initially aimed at citizen-led initiatives. The introduction of Law 5037/2023 in March 2023 marked a significant shift in Greece's approach to energy communities by establishing the category of Renewable Energy Communities (RECs), in line with EU Directive 2019/944. This new law replaced the previous framework under Law 4513/2018, which prohibited the formation of new energy communities under the old framework from 1 April 2023 and restricted existing communities from submitting new applications for producer certificates or connections offers for excluded stations starting 1 November 2023. The updated legislation encourages local community participation in renewable energy projects by offering incentives such as enhanced tariffs and simplified licensing and supports collaboration with private investors and local authorities. As of September 2024, data from Greece's General Commercial Register (GEMI) highlights the growing presence of energy communities in the country, with 1,742 active communities. Of these, 1,685 were formed under the previous Law 4513/2018, while 40 RECs were established under the new framework of Law 5037/2023.

In Athens, the first democratic renewable energy community, Hyperion, serves as a model inspired by Germany's innovative energy cooperatives. Hyperion, with around 120 members, meets its electricity needs through a collectively owned 500 kW solar park located in Corinthia. Most Hyperion's members are based in Athens. In addition to providing sustainable energy for its members, the community contributes approximately 5% of the park's annual energy production to local causes, including the Mano Aperta social kitchen, the Anassa intercultural space, and households facing energy poverty. These donations are made in partnership with the municipalities of Halandri and Keratsini. Modeled after German Genossenschaften and other global cooperatives, the organization operates on a one-member, one-vote principle, regardless of the number of shares held. Each share is priced at €100. Hyperion secured €40,000 for its initial project via Greenpeace's peer-to-peer investment platform, Genervest. The funds were raised in less than three months through micro-credits with a 6% interest rate, attracting a diverse range of individual and organizational investors. A significant contribution came from Coopérnico, Portugal's largest energy cooperative, which covered one-eighth of the total amount. In addition to the initial capital, which ranged from €2,000 to €3,000 per stakeholder to secure equity in the collective solar park, members are required to pay an annual maintenance fee of approximately €60 for the next 25 years—the expected lifespan of a solar panel—making it a cost-effective long-term investment.

GERMANY... EUROPE'S TESTING GROUND

Germany's legal framework for RECs is primarily guided by two key EU directives: The Electricity Market Directive (EU Directive 2019/944), which emphasises consumer empowerment and encourages the establishment of energy communities, and the Renewable Energy Directive (RED II) (EU Directive 2018/2001), which promotes joint production and consumption of renewable energy, encouraging collective citizen involvement in energy projects. While Germany has made progress in incorporating these directives into national law, implementation gaps still exist. One significant area is energy sharing, a core component of RED II, which enables community members to collectively generate, consume, and trade renewable energy. Recent amendments made in April 2024, such as the introduction of the shared building supply model (Gemeinschaftliche Gebäudeversorgung) under Section 42b of the amended Energy Industry Act (EnWG), aim to close this gap. This model transposes the EU concept of «jointly acting renewables self-consumers,» enabling tenants and property owners in multi-apartment buildings to utilise electricity generated from on-site solar systems. Unlike the existing tenant electricity model, this approach focuses on partial electricity supply and exempts operators from many regulatory obligations typically applied to energy suppliers. While there is no dedicated financial support, this simplified framework is expected to impact up to 80,000 buildings, highlighting Germany's efforts to promote decentralised energy solutions and collective renewable energy consumption.

The legal frameworks that govern renewable energy communities in Germany vary based on project size and sector. The most common organisational structures include:

- Cooperatives (Genossenschaften) have a long history in rural electricity supply, thus benefitting from well-developed legislation and a strong tradition of social acceptance.
- Limited Liability Companies (GmbH/UG & Co. KG) are suitable for larger, more capital-intensive projects, and provide financial security by limiting the liability of members.
- Private Corporations (Gesellschaft bürgerlichen Rechts) are smaller, more informal partnerships that allow flexible arrangements but may carry higher risks compared to cooperatives or GmbHs.

Germany has one of the most developed REC landscapes in Europe, with an estimated 914 energy communities and over 220,000 members as of 2021. The country's REC models have evolved from a long tradition of cooperatives, with the first renewable energy cooperatives emerging in 2006, focusing on solar PV projects. However, financial barriers remain, particularly in the case of wind farms, which require high capital investment, limiting participation to wealthier areas. The 2023 amendment to the Renewable Energy Sources Act (EEG) aims to mitigate this by offering financial support through feed-in tariffs, making REC investments more predictable and profitable. In addition, the 2024 amendments to the EnWG and EEG introduce energy sharing and energy communities as new models to improve economic viability. By allowing participants to collectively manage energy-related obligations and outsource specific tasks to existing service providers, the changes aim to reduce administrative burdens and encourage broader participation. However, large companies are excluded from these provisions, and balancing requirements for energy inputs and withdrawals remain a challenge, potentially limiting immediate growth. These reforms, alongside the 2023 EEG amendment, enhance predictability and profitability, supporting investment in renewable energy projects. The Bürger Energie Genossenschaft Freisinger Land eG (BEG-FS) is a cooperative with a vision of driving the decentralised energy transition in the Freisinger Land region and the Munich area. The cooperative aims to create a full supply of renewable energy for the region, covering electricity, heat, and mobility. Additionally, BEG-FS contributes significantly to Munich's renewable energy supply, helping the city transition to cleaner energy. As of June 2024, BEG-FS boasts 1,755 members, including a diverse mix of stakeholders such as the Freising district, 21 municipalities, 6 associations, over

6 companies, and Catholic and Protestant parishes. This broad membership base reflects the cooperative's commitment to community involvement and collective action in the energy transition. By allowing citizens, businesses, and local institutions to invest in renewable energy projects, BEG-FS ensures that the benefits of clean energy are shared locally. Membership in BEG-FS is acquired through the purchase of a business share, which costs €250. Each member must hold at least one share to participate in cooperative projects, but there is no limit on the number of shares an individual can purchase. This structure fosters broad participation, with members collectively holding 8,509 shares as of June 2024. Members receive profit distributions based on their investments, with a return of 3.5% in 2023 (versus 2.5% in 2022 and 2.0% in 2021). Membership requires a minimum commitment of three years, and each member has an equal vote in decision-making, regardless of their number of shares. In addition to share ownership, members can participate in renewable energy projects through subordinated loans, with investments starting from €1,000. These loans offer a fixed annual interest rate and are available for terms of 5, 10, or 20 years, making them an attractive option for individuals looking to invest in long-term sustainable projects.


WPD

A STRENGTHENED SUPPORT IN IRELAND

Long before the adoption of the Clean Energy Package at the European level, Ireland had already laid the foundations for a model centered around citizen energy, known as Sustainable Energy Communities. Initiated by the Sustainable Energy Authority of Ireland (SEAI), this framework aimed to encourage the development of local projects focused on renewable energy. In line with this, the Renewable Electricity Support Scheme (RESS) introduced a specific definition for renewable energy communities. To be recognized as such, a structure must have at least one member registered as a Sustainable Energy Community with the SEAI. This definition of renewable energy communities encompasses the main criteria of the European RED II directive. The auction process of the Renewable Electricity Support Scheme (RESS) in Ireland marked an important step in supporting renewable energy communities. At the heart of the scheme, a preferential category was created specifically for projects led by communities, targeting installations between 5 MW and 4 MW. This approach aimed to offer a competitive advantage to renewable energy communities, allowing them to compete only among themselves, shielding them from competition with larger developer-led projects. Despite the creation of this specific category, the competitive nature of the RESS auctions posed challenges for some community projects. In response, the government developed the Small-Scale Renewable Electricity Support Scheme (SRESS), a non-competitive scheme better suited to small-scale initiatives. The first phase of SRESS was launched in July 2023. The second phase, announced in May 2024 and launched in January 2025, expanded its scope to include projects ranging from 50 kW to 6 MW in capacity. Additionally, SRESS offers regulated tariff support over 15 years through a Contract for Difference (CFD) mechanism, ensuring stable revenues for projects. The program provides higher rates for renewable energy communities than for other winners, recognizing the additional challenges these projects face in terms of planning, grid connection, and financing. For solar projects, renewable energy communities can receive up to €150/MWh for installations under 1 MW and €140/MWh for those between 1 MW and 6 MW. To date, Ireland has more than 900 sustainable energy communities, according to the SEAI. However, the exact number of renewable energy communities is not specified in this count but is likely lower, as their scope is more restricted. The Templederry Wind Farm, located in County Tipperary, is the first wind farm in Ireland owned by local citizens, including farmers, students, retirees, and homemakers. Commissioned in November 2012, it consists of two 2.3 MW turbines, with a total capacity of 4.6 MW, generating around 15 GWh of electricity annually to power 3,500 homes each year. The success of the Templederry wind farm paved the way for other initiatives, including the establishment of Community Power, Ireland's first community electricity supplier. Its model involves purchasing electricity from small renewable installations owned by energy communities, then redistributing it to consumers across the country.

WHAT PROSPECTS FOR RENEWABLE ENERGY COMMUNITIES?

While an increasing number of European Union member states have started transposing the European provisions regarding renewable energy communities, establishing a national legal framework conducive to their development is an iterative process. There can be several months or even years between different legislative texts, which can hinder the deployment of these projects generating energy at the local level and benefiting communities.

This is a bottom-up approach that has so far developed mainly thanks to the motivation of particularly committed groups of citizens who have acted, most of the time, without any financial incentive or particular facilitating arrangement. However, many tools have been developed by federations of associations or cooperatives to support citizens' initiatives. If progress is to be made, policies must now be inspired by these actions to set up the legal frameworks that will support the development of citizen energy in Europe on a larger scale in the future, and on the basis of greater resources. ■

FOCUS: MARKET SHARES OF THE POWER GENERATING CAPACITIES INSTALLED IN 2023 BY TECHNOLOGY

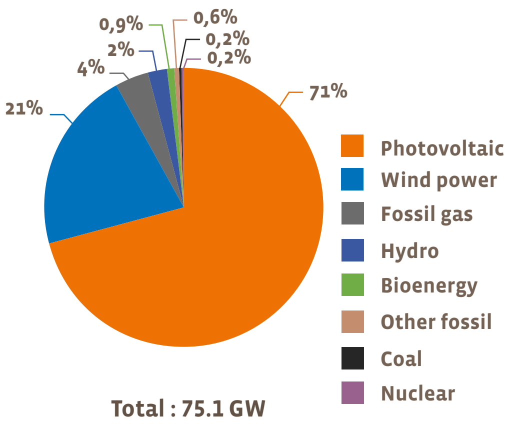
In 2023, 92% of newly connected electricity capacity within the European Union was related to renewable technologies. Photovoltaics remains by far the leading technology ahead of wind power.

Graph 1 shows that in 2023, 92% of newly connected electricity capacity in European Union countries came from renewable technologies (compared to 94% in 2022), i.e. 69 345 MW out of a total of 75 105 MW. Photovoltaic is still the most representative sector with 53 124 MW installed, accounting for 71% of the additional electrical capacity in 2023 clearly ahead from its performance in 2022 (61%). Wind power remains around 21%. As for fossil fuels, gas represented 8%. It has to be noted that 1,6 GW from nuclear sector has been connected in Finland.

Graph n°2 presents the details of each of the Member States in descending order of the additional electrical power connected in 2023. That year, eight countries commissioned fossil power plants, mostly for gas. The largest additional gas plant, totaling 1550 MW, is in Germany, accounting for 7% of the total additional electrical capacity connected in the country. This proportion is a little bit higher in Italy and France where two gas plants were also implemented for respectively 14% and 13% of their new electrical capacities in 2023. In Finland, the Olkiluoto 3 nuclear reactor has entered services in April. It is the largest European nuclear reactor and Finland expects that 14 percent of its own electricity consumption will be provided by it. ■

1

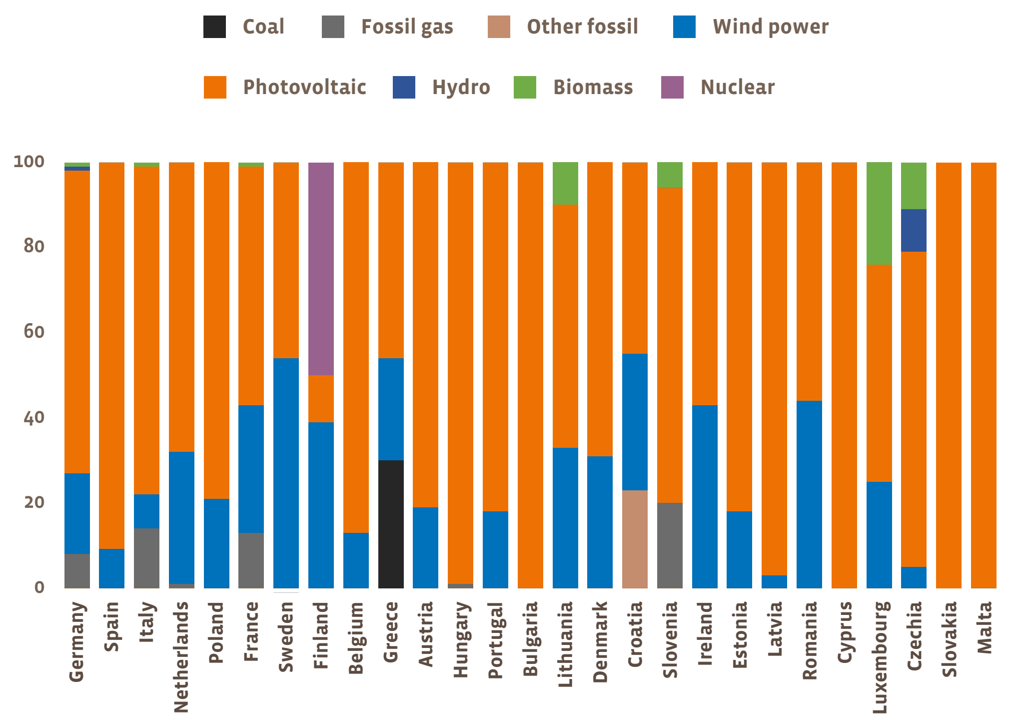
Distribution of additional electrical capacities connected to EU-27 grids in 2023 by technology



Source: EurObserv'ER - Ember

2

Distribution of additional electrical capacities connected to EU-27 gridsinstalled in 2023 by country and technology (in percentage)



Source: EurObserv'ER - Ember

FOCUS: ELECTRICITY STORAGE CAPACITIES

THE IMPORTANT ISSUE OF ENERGY STORAGE

In terms of electricity production and consumption, the European Union's energy landscape has been undergoing profound change for several years. Efforts to combat climate change are leading to a decline in the use of fossil fuels, driven by more sober consumption patterns combined with an increase in the use of renewable technologies. The environmental transition that has begun is also illustrated by a move to convert a growing proportion of the various needs (mobility, heating) from fossil fuels to electricity. The result is a major planned increase in the production and consumption of electricity from renewable sources in the energy balances of European countries. Wind power and photovoltaics are the sectors that best illustrate this trend, with respectively 16 and 53 GW of additional capacity connected in 2022 alone for all EU-27 countries. However, these latest technologies are characterized by variability in their energy production, heavily linked to weather conditions.

Applications for energy storage are growing fast in Europe because the amount of balancing power that can be delivered by fossil fuel power generation is declining and is increasingly being replaced by variable renewable energy sources. Energy storage systems nowadays produce Frequency Containment Reserve (FCR), automatic Frequency Containment Reserve (aFCR), and manual Frequency Containment Reserve (mFCR) and are playing a pivotal role in grid management and stability (see highlight).

STORAGE FACILITIES MAINTAIN GRID FREQUENCY

To ensure the required grid frequency of 50 or 60 Hz (depending on the country) the Transmission System Operators (TSO) of each country need instruments to maintain these reference values. These instruments are the balancing services: reactive short-term means to level out frequency deviations in the power grid. When frequency deviations occur, e.g. in consequence of a power plant outage, the Frequency Containment Reserve (FCR) intervenes automatically within seconds in the entire synchronous area to restore the balance between supply and demand. The FCR, also known as primary control reserve, is the first response to frequency disturbances. If the deviation persists, the Automatic Frequency Restoration Reserves (aFRR) subsequently replaces the primary control reserve. Large-scale battery storage systems have been playing an important role in the various energy markets for several years.

Energy storage can guarantee a consistent power supply for industrial applications, mitigating downtime and ensuring reliable production. Energy storage systems engage in multi-use operations, like arbitrage trading. They can purchase electricity when prices are low and sell it when prices are high, optimizing revenue generation. Energy storage can provide additional power during peak demand periods with high prices, alleviate grid congestion, and boost overall grid capacity to reduce curtailment of variable renewable energy projects. Storage related to cross-border exchange platformscan enable coordinated responses to frequency deviations across regions.

Storage facilities maintain grid frequency

To ensure the required grid frequency of 50 or 60 Hz (depending on the country) the Transmission System Operators (TSO) of each country need instruments to maintain these reference values. These instruments are the balancing services: reactive short-term means to level out frequency deviations in the power grid. When frequency deviations occur, e.g. in consequence of a power plant outage, the Frequency Containment Reserve (FCR) intervenes automatically within seconds in the entire synchronous area to restore the balance between supply and demand. The FCR, also known as primary control reserve, is the first response to frequency disturbances. If the deviation persists, the Automatic Frequency Restoration Reserves (aFRR) subsequently replaces the primary control reserve. Large-scale battery storage systems have been playing an important role in the various energy markets for several years.

Automatic Frequency Containment Reserve (aFCR): aFCR is an automated reserve that responds within short time to grid frequency deviations, injecting or withdrawing power to maintain grid stability, and it is crucial for ensuring the grid operates within acceptable frequency limits.

Automatic Frequency Restoration Reserve (aFRR): aFRR is a mechanism that provides rapid automated response as fast as possible to large frequency deviations in the power grid, helping restore grid frequency to its nominal value following significant disturbances or events.

Manual Frequency Containment Reserve (mFCR): mFCR requires manual intervention and control by grid operators to address frequency deviations, providing an additional layer of response when needed to ensure grid stability and reliability.

The specific response time requirements for each balancing power product may vary based on regional grid regulations and specific grid operator guidelines. It's essential for energy storage systems providing balancing services to meet the response time requirements outlined by the relevant grid operator or regulatory authority to ensure effective grid frequency management and compliance with grid stability standards. Response time can be in the range of seconds to several minutes.

These systems can also bridge the gap between fluctuating energy supply and demand, allowing for a more resilient and responsive grid over larger regions.

A DIFFERENT TECHNOLOGIES PORTFOLIO

There are many different technologies and types of electricity storage facility. These range from pumped-storage hydroelectric plants to individual batteries installed on private homes to complement photovoltaic roofs. This chapter covers only part of the existing storage infrastructure, focusing on large-capacity electricity storage facilities located close to production sites. These facilities are referred to as "front-of-meter" facilities, as opposed to facilities located at the point of consumption (typically an individual battery at a private home), which are referred to as "behind-the-meter" facilities. The available storage equipment technologies are listed on Table 1, grouped by family. Currently, the most commonly used electricity storage solution in Europe in terms of capacity is mechanical, specifically in the form of Pumped Hydro Storage (PHS). During low-electricity price periods, the plant pumps water from the lower to the upper reservoir to ensure that when the plant is faced with peak electricity demand and high prices, the water can be released through the turbines to the lower reservoir. Pumped hydro storage offers flexibility in conjunction with other hydroelectric infrastructures. The limiting factor for PHS is that not all countries have the natural geographical reliefs needed to develop this type of hydropower facility. The next most common form of electricity storage solution is electrochemical in the form of batteries. The most common technology uses a lithium-ion solution and usually cobalt (positive terminal) and graphite (negative terminal) electrodes. Thermal electricity storage technologies exist as well. These technologies use stored heat, which raise the temperature of a fluid or solid, change the physical state of a material, or produce endothermic (heat-absorbing) chemical reactions, exploiting the thermal capacities of the different materials. Steam turbines use this restored heat by reversing the state change to generate electricity. The main thermal development in Europe has been in molten salts sub-technology, but in the fairly restricted context of electricity storage on concentrated solar power sites.

The last form of technology relates to a chemical process and is essentially illustrated by "power-to-gas" (P2G). Electricity is converted into hydrogen (H_2) via the electrolysis of water. At present, the hydrogen produced in this way is most often used for purposes other than storage. Most hydrogen is used in the chemical industry (such as the production of fertilizers and chemical products) or as fuel for heavy transport over long distances, for aviation and replacement for coal in steel production. However, the process of storing renewable electricity in the form of hydrogen and then powering a turbine to produce electricity (known as power-to-gas-to-power) is a promising avenue to deliver large amount of energy. This is for when wind and sun is not available for a longer period of time as well as to provide power during peak consumption with high prices. It is not always easy to identify P2G projects that are singularly geared towards storage rather than other applications. The data collected for the purpose of this chapter is an endeavour to make this distinction, and the capacity data shown in the P2G columns of the following tables are storage projects.

THE EUROPEAN COMMISSION IS INVOLVED

In March 2023, the Commission adopted a list of recommendations to ensure greater deployment of energy storage, accompanied by a staff working document which provided an outlook of the EU's current regulatory, market, and financing framework for storage. The document also identified barriers, opportunities and best practices for its development and deployment. System flexibility is particularly needed in the EU's electricity system, where the share of renewable energy is estimated to reach around 69% by 2030 and 80% by 2050 (from 37% in 2021). Different analytical studies have tried to estimate the future of energy storage deployment in the EU. These studies indicate that between 200 GW and 600 GW of energy storage capacity will be needed by 2030 and 2050 respectively (from roughly 45 GW in 2022, mainly in the form of PHS). The EU needs a strong, sustainable, and resilient industrial value chain for energy-storage technologies. There is an increasing demand for data transparency and availability, and greater data granularity, including network congestion, renewable energy curtailment, market prices, renewable energy, greenhouse gas emissions content and installed energy-storage facilities. This need becomes more important for decisions about investing in, choosing a location for, and evaluating new energy-storage facilities.

1

Electricity storage technologies and sub technologies

Technologies	Sub technologies
Mechanical	Pumped Hydro Storage (PHS)
	Pumped Heat Electrical Storage (PHES)
	Adiabatic Compressed Air Energy Storage (ACAES)
	Compressed Air Energy Storage (CAES)
	Liquid Air Energy Storage (LAES)
	Flywheel/FES
Electro-chemical	Sodium Sulphur batteries
	Lead Acid batteries
	Sodium Nickel Chloride batteries
	Lithium-ion batteries
	Lithium-S batteries R&D
	Lithium-Metal-Polymer batteries
	Metal Air batteries R&D
	Ni-Cd batteries
	Ni-MH batteries
	Na-ion batteries R&D
	Redox flow batteries Zn Fe
	Redox flow batteries Vanadium
	Redox flow batteries Zn Br
Electrical	Superconducting Magnetic Energy Storage (SMES)
	Supercapacitor
Chemical	Power to Gas, hydrogen (H_2)
	Power to Ammonia - Gasoline
	Power to Methane
	Power to Methanol + Gasoline
Thermal	Molten salts
	Sensible Thermal Energy Storage (STES)
	Phase Change Material (PCM)
	Thermo - Chemical Storage (TCS)

Source: EurObserv'ER.

2

Electricity storage capacities installed in the EU-27 at the end of 2024 (in MW)

	Mechanical		Thermal		Electro-Chemical		P2G	
	Pumped Hydro	Other technologies	Molten Salt	Other technologies	Li-ion	Other technologies	P2G	Total
Germany	6 853.2	0	1.5	0	1 586.4	101.1	16.4	8 558.6
Italy	8 036.1	0	5.1	0	436.9	36.3	0	8 514.4
Spain	5 540.6	0.5	1 069.3	62.4	123.6	867.2	0	7 663.6
France	4 897.3	240.0	21.0	0	917.0	3.6	6.6	6 085.5
Austria	5 701.3	0	0	0	22.4	1.3	0	5 725.0
Portugal	3 067.8	0	0	0	12.5	0	0	3 080.3
Poland	2 443.6	0	0	0	11.3	11.0	0	2 465.9
Bugaria	2 263.0	0	0	0	0	0	0	2 263.0
Belgium	1 304.0	0	0	0	142.1	1.4	0	1 447.5
Luxembourg	1 294.0	0	0	0	0	0	0	1 294.0
Czechia	1 149.8	0	0	0	66.0	0	0	1 215.8
Lithuania	900.0	0	0	0	200.0	0	0	1 100.0
Slovakia	882.3	0	0	0	159.8	0	0	1 042.1
Croatia	1 020.9	0	0	0	0	0	0	1 020.9
Ireland	292.0	0	0	4.6	511.4	0	0	808.0
Greece	705.9	0	0	0	0	0	0	705.9
Sweden	425.0	0	0	10.0	265.4	0	0	700.4
Slovenia	605.0	0	0	-	42.6	0	0	647.6
Netherlands	2.8	0	0	-	165.7	28.0	0	196.5
Romania	154.5	0	0	0	0	7.0	0	161.5
Finland	0	0	0	0	37.9	2.0	0	39.9
Estonia	0	0	0	0	25.0	0	0	25.0
Denmark	0	0	5.3	0	2.3	0.0	1.2	8.8
Hungary	0	0	0	0	8.2	0.3	0	8.5
Cyprus	0	0	0	0	0	0	0	0
Latvia	0	0	0	0	0	0	0	0
Malta	0	0	0	0	0	0	0	0
Total EU-27	47 538.9	240.5	1 102.2	77.0	4 736.5	1 059.2	24.2	54 778.4

Source: EurObserv'ER.

EUROBSERV'ER – THE STATE OF RENEWABLE ENERGIES IN EUROPE – 2024 EDITION

3

Planned capacities by country at the end of 2024 (in MW)

	Mechanical		Thermal		Electro-Chemical		P2G	
	Pumped Hydro	Other technologies	Molten Salt	Other technologies	Li-ion	Other technologies	P2G	Total
Spain	7 212.9	0	100.0	0	1 086.8		0	8 399.7
Germany	4 156.0	960.0	0	0	1 214.4	3.2	200.0	6 533.6
Greece	2 715.1	0	52.0	0	784.6	0	0	3 551.7
Ireland	530.0	27.5	0	0	2 065.4	0	0	2 622.9
Belgium	550.0	0	0	0	1 255.0	0	0	1 805.0
Bulgaria	1 600.0	0	0	0	0	0	0	1 600.0
Austria	1 539.5	0	0	0	0	0	0	1 539.5
Romania	1 448.8	0	0	0	6.0	0	0	1 454.8
France	0	0	0	0	1 200.0	0	3.0	1 203.0
Slovakia	0	0	0	0	943.8	0	0	943.8
Netherlands	0	640.0	0	3.0	231.0	7.5	1.0	882.5
Estonia	600.0	0	0	0	0	0	0	600.0
Portugal	550.0	0	0	0	0	0	1.0	551.0
Croatia	490.0	0	0	0	50.0	0	0	540.0
Denmark	0	320.0	5.0	0	3.0	0	0	328.0
Poland	0	0	0	0	266.7	0	0	266.7
Lithuania	225.0	0	0	0	12.0	0	0	237.0
Finland	0	0	0	0	224.6	0	0	224.6
Sweden	0	0	0	0	182.5	0	0	182.5
Slovenia	0	0	0	0	60.0	0	0	60.0
Cyprus	0	0	0	0	46.0	0	0	46.0
Italy	0	0	0	0	24.0	0	0	24.0
Hungary	0	0	7	0	8.3	0	0	15.3
Czechia	0	0	0	0	8.0	0	0	8.0
Latvia	0	0	0	0	0	0	0	0
Luxembourg	0	0	0	0	0	0	0	0
Malta	0	0	0	0	0	0	0	0
Total	21 617.3	1 947.5	164.0	3.0	9 672.1	10.7	205.0	33 619.6

Source: EurObserv'ER.

NEARLY 55 GW IMPLEMENTED IN THE EU-27

Operational storage increased from around 48.7 GW to 54.8 GW from 2023 to 2024. The majority of storage in Europe is from Pumped Hydro Storage (47,6 GW), with the majority of facilities in Germany, Italy, France, Spain, Austria and Portugal, their aggregate being 34 GW. It is worth noting that the growing capacity of electrochemical projects is significant, having almost increased fivefold since 2022, going from 1 GW to nearly 5 GW by the end of 2024. Table 3 gives details of the planned projects in the European Union (licensed, under construction, in the pipeline, etc.). The total capacity identified amounts to 33.6 GW. While mechanical storage dominates this capacity (21.6 GW), an additional 9.7 GW is expected from electrochemical storage in the next few years. EurObserv'ER collected energy storage project data from 2022, 2023 and 2024 and updated the European Commission's 2020 Database of the European Energy Storage Technologies. Verification of projects was completed by extensive research using publicly available grid data, press releases, news coverage, energy storage association data and interviews. So far there is no centralised database and data collection is hampered by the multitude of technologies or operators active in this sector.

GERMANY, EUROPEAN STORAGE STRONGHOLD

In Germany, as the share of renewable energy (RE) in gross electricity consumption should be increased to at least 80 % by 2030, energy storage systems play a fundamental role in Energy Transition. The most important catalyst to achieve these targets is the Renewable Energy sources Act (EEG 2023). Apart from measures taken to lay the foundation for Germany to become climate neutral, EEG 2023 specifies actions for storage facilities. This act will also enable the government to provide funding for concepts combining renewable energy sources with local hydrogen-based electricity storage in the future. The Federal Ministry for Economic Affairs and Climate Action is also considering extending the grid fee cancellation of large-scale storage facilities under section 118(6) Energy Industry Act (Energiewirtschaftsgesetz, "EnWG") that applies until 2029. The number of electricity storage facilities, their installed power and storage capacities are recorded in the Core Energy Market Data Register by the Bundesnetzagentur. As of now, the country has about 30 pumped storage plants with a combined capacity of approximately 24 GWh and total power of approximately 7 GW. These figures align with current estimates and emphasize the importance of pumped storage in stabilizing the electricity grid. On the other hand, battery storage facilities in Germany are growing but are behind pumped storage in terms of capacity. The total installed capacity for battery storage was approximately 16 GWh by mid-2024, significantly higher than previous capacities reported. The total power output of battery systems is also expanding, reflecting investments in both residential and large-scale commercial systems.

Uniper has invested approximately 250 million euros to recommission a pumped storage plant in Happurg, Bavaria and will be in operation in 2028. This plant is one of the largest in Germany and biggest in Bavaria. At 160 MW, it has a drop height of 209 meters and can store around 850 MWh of electricity. By storing energy, the pumped storage power plant will contribute to higher security of supply in southern Germany. Another example is batteries with a total capacity of 140 MW lithium-ion battery energy storage project installed in Hamm-Uentrop commissioned in 2024 by the firm RWE. The battery storage facility aims to supply balancing energy from the second half of 2024. In 2023, Germany emerged as the leading market for energy storage in Europe. According to data from the European Energy Storage Association (EASE), total installations soared to 13.5GWh, marking a staggering 93% increase compared to the previous year. Particularly noteworthy was the surge in residential battery storage, which reached 9.5GWh, a remarkable 109% year-on-year rise, constituting 70% of the total capacity. While in many European markets attention is focused on upcoming tenders and auctions for energy storage systems, market participants in Germany are focusing on trade gains and the unpredictability of electricity prices due to the high share of renewable energies. The political support, such as the recently published energy storage strategy, and the increasing significance of large storage systems on the political agenda, has created incentives and has strengthened Germany's position as an attractive location for energy storage.

POLAND WANTS TO SPEED UP

Poland aims to increase energy storage capacity to support integration of variable generation and increase system flexibility. With the state-owned power company Polska Grupa Energetyczna (PGE) aim to build 0.8 GW of energy storage by 2030 and the Energy Policy of Poland until 2040 (EPP2040) setting a goal for around 1.0 GW of energy storage (excluding pumped storage) by 2040, emphasis on energy storage solutions has never been more crucial. In October 2024, the European Commission approved €1.2 billion in funding for Poland to invest in electricity storage facilities, supporting the transition to a net-zero economy. The scheme was approved under the State Aid Temporary Crisis and Transition Framework (TCTF) and is set to support the installation of at least 5.4 GW of new electricity storage capacity. Moreover, the goal of the scheme is to minimize Poland's dependence on fossil fuels for electricity and to integrate renewable energy sources into the grid.

To support the implementation of the investments in energy storage, the Polish state-owned company PGE recently announced a tender for 263 MW/900 MWh battery storage system in Zarnowiec, which is likely to become the nation's largest once completed. By 2030, PGE aims to develop at least 800 MW of new energy storage capacity. The company has also obtained connections for a battery storage facility of a capacity of 400 MW in Gryfino, Northwestern Poland. On 4 December 2024, EDF Renewables' Polish branch had acquired its second battery energy storage project in Poland, a 120 MW facility. Construction is set to begin in 2025, with commissioning scheduled for early 2028. The company had previously purchased its first battery energy storage project in Poland, a 50 MW facility, slated for commissioning in early 2026. This earlier project secured a 17-year capacity contract in mid-December last year during auctions conducted by Poland's transmission grid operator.

According to the Energy Law Act of 2021, electricity system operators must maintain electronic records of electricity storage facilities that are either connected to their network, integrated into their network, or part of a generating unit or end-user installation linked to their network. In Poland, transmission and distribution network operators have registered 12 power storage facilities with a capacity of at least 50 kW. Poland's energy storage market is experiencing significant growth. Energy storage accounted for 15% of the contracted capacity in the main auction for 2028, up from less than 7% in previous years. Following the main auctions for capacity covering 2021–2028 and supplementary auctions for 2021–2025, contracts have been secured for a total energy storage capacity of 9.5 GW. Of this, 7.1 GW is allocated to existing units, 0.5 GW to retrofitted units, and 1.9 GW to new units planned because of agreements with the market operator.

A NEW 2030 TARGET FOR SPAIN

In 2023, Spain's council of Ministers approved a Royal Decree which updated the National Integrated Energy and Climate Plan (PNIEC 2023-2030). This plan focused more of promoting renewables, storage, and demand management to improve integration. As of 2024, the Spanish government has set a new target of 22.5 GW for energy storage by 2030. By 2030, the country also expects to install battery energy storage projects, pumped hydropower, and solar thermal plants. As part of the PNIEC 2023-2030 plan, the country also aims for 76 GW of solar power, 62 GW of wind power, which includes 3 GW of offshore wind, along with 1.4 GW of biomass projects. To achieve these targets, the Spanish government launched 150 million euros in grants for standalone energy storage projects, 150 million euros for hybrid storage projects and 30 million euros for thermal energy storage projects.

There are several projects that depict the active landscape of energy storage in Spain. Out of the top five projects, the top two are worth mentioning. The first is a thermal energy storage system project, Sun2Store, developed by the firm Malta in 2024 promotes the storage of electrical energy through heat pumps in molten salt tanks, and then the generated energy is delivered to the grid for over 10 hours at an output of 100 MWe. The other example is of Erasmo Solar PV Park in Saceruela, Castile-La Mancha, Spain owned by the firm Soto Solo. The facility will be linked to energy storage and green hydrogen production. The battery energy storage system has a capacity of 80 MW, relying on lithium nickel manganese cobalt (NMC) batteries. Additionally, the energy storage market of Spain is gaining momentum especially with the battery energy storage systems. This is driven by the rising need to integrate renewable energy sources into the electricity grid, improve supply stability and optimize energy use. There are several policies and regulations that also act as a catalyst to this growth. The Energy Storage Strategy 2030, promoted by the Ministry for the Ecological Transition and the Demographic Challenge is one such catalyst. The strategy includes financial incentives and research and development for new technologies.

Moreover, The Solarplaza Summit Energy Storage Spain marks a significant step forward in Spain's energy storage market. The conference delves in key topics of grid integration, business models, revenue streams markets (capacity, flexibility), legislation, investment strategies, technological advancement, and project building. On 24 October 2024, the conference took place in Madrid.

ITALY BETS ON LI-ION BATTERIES

Italy has committed to reaching 65% of electricity from renewables by 2030 as part of its National Integrated Energy and Climate Plan (PNIEC). To achieve this, the country plans to have energy storage capacity totaling 8 GW of hydropower, 4 GW of distributed (residential) storage and 11 GW of large-scale storage, requiring a significant development of large-capacity battery energy storage systems. The large-scale electricity storage sector is still in its infancy and suffers from regulatory uncertainties, supply difficulties and increasing costs. However, strong growth is expected in the coming years due to the country's ambitious targets. Currently, the country's energy storage infrastructure is mainly based on pumped hydroelectric storage facilities and around 470 MW of Li-ion batteries. To develop large-scale electricity storage facilities, the Italian government has set up a programme that was approved by the European Commission at the end of 2023. Italy will promote investments in large-scale electricity storage to reach at least 70 GWh of capacity, and a value of over €17 billion, over the next ten years. The new storage capacity will be acquired through calls for tenders published by Terna, the Italian high-voltage grid operator. A call for tenders was launched in 2024 focusing on storage solutions based on lithium-ion batteries and hydroelectric pumping. However, Terna will update its analysis of the reference technologies at least every two years in order to evolve their respective share in future national calls for tenders. One of the main actors of the sector is Enel Green Power which currently has 26 energy storage plants in Italy. 15 of them are in operation, with a total capacity of about 800 MW, while 11 are under construction, and their completion will bring the total capacity to about 1.8 GW. In 2024, seven plants have become operative: Assemini, Carpi, La Spezia, Porto Corsini, Serre Tavazzano, Trino 2 (208 MW capacity) and Udine Sud. In addition to these, seven others are in the testing phase, while all the others are at an advanced stage of construction. In most of these cases, the main used technology on an industrial scale involves lithium-ion batteries. However, alternatives are also being studied: flow batteries (based on vanadium and iron chemistry), zinc, and evolutions of lithium batteries in which, however, the electrolyte is in a solid rather than a liquid state. For non-electrochemical technologies, on the other hand, solutions with thermal storage facilities or gravity-type storage are being studied. It has to be noted that a special attention, particularly in the case of BESS, is being paid to the end-of-life phase, with a view to circularity: in this way, the disposal of components and materials is transformed into an opportunity. For instance, a project known as «Second Life» has been developed by the Enel Group in Melilla, a Spanish city on the North African coast. The project, which is in collaboration with Nissan, involves repurposing used batteries from electric cars for reuse in a stationary BESS to support the local Grid.

A €100 MILLION PROGRAM IN PORTUGAL

Portugal has been actively engaged in the development of large-capacity stationary batteries to store electricity generated by renewables, with the aim of increasing the flexibility and stability of its electricity grid. The Portuguese government aims to increase the share of renewables in electricity consumption to 93% by 2030, surpassing the previous target of 85%. To achieve this ambition, energy storage is essential to manage the intermittency of renewable sources and ensure a stable energy supply. By the end of 2024, more than 3 GW of capacity has been identified for the country, with relatively few installations other than hydroelectric pumping stations. This situation is expected to change rapidly. To support these objectives, Portugal has implemented several policies. In July 2024, the Portuguese Ministry of Energy allocated nearly €100 million to grid flexibility and energy storage projects, with a total planned capacity of 500 MW. Eligible projects can receive up to €30 million and must be operational by the end of 2025. In addition, a recovery and resilience plan has been put in place. It aims to modernize the electricity infrastructure and promote storage solutions for more efficient management of energy resources. In terms of financing, Portugal is banking on the development of public-private partnerships. Collaborations between the public sector and private companies have been established to develop innovative storage solutions and strengthen national production capacity. The years 2023 and 2024 have seen a significant progress. This is particularly

the case for the battery storage plant in the Algarve. In February 2024, site developer Galp, in partnership with US company Powin, announced the installation of a 5 MW/20 MWh energy storage system at one of its photovoltaic plants in Alcoutim. This project will store excess solar energy for use during peak demand, optimising the value of the energy produced. By 2024, Portugal has reduced the share of electricity generated from fossil fuels to just 10%, due to a significant increase in clean energy production, particularly from hydropower, wind and solar. This transition has been supported by major projects such as the Tâmega dam (1,158 MW) and the Cerca solar farm (202 MW).

FRANCE, 6 900 MW WAITING IN LINE

By the end of 2024, France had an energy storage capacity of 6085 MW. A large part of this capacity was based on hydroelectric facilities, but the importance of stationary batteries continues to grow. With a fleet estimated at around 920 MW (the power of a nuclear

reactor), France is one of the European countries that has developed this type of installation the most in recent years. This is just the beginning as the country expects to quickly reach the threshold of 2 000 MW, according to an announcement by the Energy Regulatory Commission (CRE). In the long term, the Commission is talking about 6 900 MW of projects at varying degrees of development. These levels are a long way from those of 2019, since only 7 MW were connected at the time, and 100 MW were awaiting connection. In terms of energy storage, France's ambitions are to strengthen the country's energy sovereignty by developing a national battery production sector. By 2030, France plans to achieve a battery production capacity of between 100 and 120 GWh, thereby creating around 10,000 direct jobs. It should be noted that these figures also concern batteries for individuals.
Among the country's most important projects, that of the port of Nantes Saint-Nazaire (44) is distinct. British storage specialist Harmony Energy is currently building a battery energy storage system (BESS) located on a site previously occupied by the Cheviré power plant, which operated from 1954 to 1986 and was powered by coal, gas and oil. The future battery, with a power of 100 MW and a capacity of 200 MWh, will provide two hours of storage to the equivalent of 170,000 homes. This is therefore one of the largest projects of its kind in France. It will use Tesla Megapack technologies, each unit of which can store more than 3.9 MWh of energy, and Autobidder, an asset trading and control platform. Once in service, the facility will provide compensation services to the electricity grid and allow the increasing integration of renewable energies. Commissioning is scheduled for winter 2025. A variation of this project is being carried out in Oise, north of Paris, by the Swiss company Alpiq. Once again in partnership with Harmony Energy, the future site will also include a 100 MW battery to improve grid stability and contribute to the security of supply of renewable electrical energy.In this case, commissioning is expected for autumn 2026. However, the development of energy storage facilities is accompanied by debates. The professional organization France Renouvelables highlights the risks of supply tensions in lithium, a raw material for stationary batteries but also for those intended for electric vehicles. The organization also stresses the importance of developing a European battery industrybecause more than 80% of all batteries produced in 2022 were concentrated between six Chinese or Korean companies. ■

SOCIO-ECONOMIC INDICATORS

The following chapter sheds a light on the European renewable energy sectors in terms of socio-economic impacts, primarily industrial turnover and renewable energy employment. All 27 EU Member States are covered for 2022 and 2023. As of the 2021 Edition of 'The State of Renewable Energy in Europe' the U.K. is no longer included in the results.

Methodological note

Since the 2017 Edition of 'The State of Renewable Energy in Europe', a formalised model developed by the Energy Research Centre of the Netherlands (ECN), currently TNO Energy and Materials Transition, has been used to assess employment and turnover in the EU. The approach applied here is based on an evaluation of the economic activity of each renewable sector covered. A consistent and mathematical approach is used to generate the employment levels, turnover effects and gross value added (GVA), allowing for a comparison between the European Union Member States. Distinct characteristics of each economic sector from the EU Member States are taken into account by using input-output tables to determine the renewable employment, turnover and GVA effects. The underlying databases stem from Eurostat, JRC and EurObserv'ER. The focus of this analysis is centred on money flows from four distinct activities in the renewable energy value chain:

1. *Investments in new installations*
2. *Operation and maintenance activities for existing plants including newly added plants*
3. *Production and trade of renewable energy equipment*
4. *Production and trade of biomass feedstock.*

- *For employment indicators, the term 'job' is expressed in full-time equivalents (FTE). The sudden decline or increase in jobs presented in this study does not necessarily correspond with what is observed in scorings by national sector associations which may use different assessment methodologies.*
- *Employment data presented in each chapter refer to gross employment. Developments in non-renewable energy sectors or reduced expenditure in other sectors are not taken into account.*
- *Employment data includes both direct and indirect employment. Direct employment includes renewable equipment manufacturing, renewable plant construction, engineering and management, operation and maintenance, biomass supply and exploitation. Indirect employment refers to secondary activities, such as transport and other services. Induced employment is outside the scope of this analysis.*
- *Employment related to energy efficiency measures, electric mobility or energy storage remains outside the scope of this analysis.*
- *Socio-economic indicators for the bioenergy sectors (biofuels, biomass and biogas) include the upstream activities in the agricultural, farming and forestry sectors.*
- *Investments in renewables can only be traced by the model in the year of commissioning. Activities in project preparation, taking place in previous years, are all allocated to that year. For this reason, large projects with longer lead times (common for technologies such as hydropower, offshore wind power and geothermal energy) cause more volatility in the employment and turnover estimates.*
- *Turnover and GVA figures are expressed in current million euros (€M).*
- *The socio-economic indicators have been rounded to 100 for employment figures and to 10 million euro for turnover and GVA data.*

The chapter concludes with an indicator on the employment effects on fossil fuel chains based on the energy replaced through increased renewables production. This indicator only takes into account direct jobs in fossil sectors, but not replaced investment or the indirect effects.

For more information regarding the methodology used in this chapter, interested readers should refer to the methodology paper that explains the new approach works in more detail. This paper can be downloaded from the EurObserv'ER project website.

WIND POWER

In 2023, the net wind power capacity connected in the European Union increased by almost 16 GW (15.850 MW), with onshore activity driving most of this growth. The rise in offshore wind capacity in 2023 reached 2 270 MW, marking a 14.1% rise compared to 2022 figures. These figures contribute to a notable increase in sector-wide employment. With a total of 333 800 jobs identified for 2023, EurObserv'ER estimates a significant increase in employment for the EU-27, with 60 300 more jobs than in 2022. This surge in employment is accompanied by an increase in turnover (€8.1 billion) and gross value added (€3.4 billion). Similar to the results in our 2022 estimates, the sector's increased turnover in 2023 solidifies its position as the second-highest technology in terms of turnover, following heat pumps.
In terms of individual country results, Lithuania, Luxembourg, and the Netherlands stand out for their substantial relative growth in installed capacity. Lithuania experienced a remarkable 37% increase in its installed wind capacity in 2023, with a cumulative installed capacity of 1 288 MW. Luxembourg and The Netherlands also saw significant growth, with respective increases of 25% (208 MW) and 23% (10 749 MW) in installed capacities in 2023. For Luxembourg this was primarily driven by new onshore installations, whereas for the Netherlands the effect was more prominent due to new offshore installations. Meanwhile, Germany, as the European wind industry leader, saw its employment figures rise from an estimated 85 600 in 2022 to 97 900 in 2023, directly linked to its increased installed capacity and market share of equipment. Spain, the second-largest EU-27 country in this technology, also experienced a notable increase in installed capacity, leading to a rise in employment from 37 100 jobs in 2022 to 43 000 in 2023. Overall, none of the EU-27 countries reported a considerable decrease in their installed capacities in 2023.
This surge in wind energy capacity across Europe underscores the region's collective commitment to transitioning towards renewable energy sources, driving economic growth, and reducing carbon emissions. Importantly, these positive numbers come after a similar increase witnessed in 2022, highlighting the resilience and growth of the wind energy sector in Europe. ■

Employment and turnover

	Employment (direct and indirect jobs)		Turnover (in M€)		Direct GVA (in M€)	
	2022	2023	2022	2023	2022	2023
Germany	85 600	97 900	14 180	16 140	6 220	7 080
Spain	37 100	43 000	4 970	5 720	2 120	2 420
France	36 500	40 200	5 910	6 710	2 400	2 690
Netherlands	11 400	38 400	1 840	5 850	760	2 490
Denmark	22 600	27 700	5 030	6 070	1 990	2 430
Poland	13 700	17 100	1 050	1 300	460	570
Sweden	16 800	12 600	3 220	2 520	1 620	1 290
Italy	9 100	9 400	1 470	1 530	620	640
Finland	13 800	8 400	2 360	1 510	1 020	660
Greece	2 500	7 000	290	670	140	300
Portugal	4 200	6 700	380	540	160	220
Lithuania	4 400	5 800	200	270	100	140
Belgium	4 000	3 200	860	690	330	270
Austria	2 600	3 100	490	570	210	240
Romania	2 200	3 100	190	250	80	110
Ireland	2 800	3 000	480	510	200	210
Croatia	600	2 500	50	160	20	70
Czechia	800	1 200	70	100	30	40
Hungary	800	1 200	60	80	20	30
Estonia	200	900	20	70	10	30
Bulgaria	600	600	40	40	20	20
Luxembourg	100	300	20	50	10	20
Cyprus	100	100	10	10	<10	<10
Latvia	700	100	40	10	10	<10
Malta	<100	<100	<10	<10	<10	<10
Slovenia	<100	<100	<10	<10	<10	<10
Slovakia	<100	<100	<10	<10	<10	<10
Total EU-27	**273 500**	**333 800**	**43 260**	**51 400**	**18 590**	**22 020**

Source: EurObserv'ER

PHOTOVOLTAIC

Overall, EurObserv'ER highlights significant socioeconomic impacts due to photovoltaic (PV) energy growth in 2023, with turnover estimated at €66.3 billion (up from €40.8 billion in 2022), gross value added at €27 790 million (compared to €17 180 million in 2022), and employment reaching 560 300 FTE — a notable 62% increase from 2022. This growth is paralleled by a 24% increase in total installed PV capacity in the EU-27, reaching 256 GW. The additional 61.5 GW capacity added in 2023 exceeds the 36.5 GW increase observed in 2022, further contributing to the surge in employment figures. EurObserv'ER's monitoring indicates remarkable PV and related socioeconomic growth across most EU-27 countries, with a substantial increase in turnover (€25.5 billion) and gross value added (€10.8 billion) projected for 2023.
Germany maintains its position as the leader in PV sector employment within the EU-27, with 139 800 jobs (up from 87 100 in 2022), attributable to a significant increase of 61.5 GWp of new installed capacity in 2023—almost double the 36.5 GWp installed in 2022. Spain emerges as the second-largest employer in the sector in 2023, with 110 100 jobs, marking a remarkable 78% increase in installed capacity to 30.6 GWp. This contributes to the largest absolute growth noted for the amount of jobs within the EU-27, with an increase of 73 800 jobs for Spain. It should be mentioned that the model assumes a strong relationship between growth of installed capacity and growth of employment, which could lead to an overestimation of this sector's employment growth. Several other countries also significantly increased their production capacity, with Finland notably exceeding 1 GW installed capacity for the first time, recording a 72% growth and generating an estimated 2 800 jobs. Additionally, countries such as Italy, the Netherlands, and Poland witnessed the largest growth in production capacity behind aforementioned Germany and Spain, contributing to a combined total of 30 700 new jobs. ■

Employment and turnover

	Employment (direct and indirect jobs)		Turnover (in M€)		Direct GVA (in M€)	
	2022	2023	2022	2023	2022	2023
Germany	87 100	139 800	13 070	20 900	5 810	9 290
Spain	36 300	110 100	3 830	11 470	1 670	5 010
Poland	44 100	49 700	3 100	3 510	1 260	1 420
Italy	26 500	47 800	3 740	6 670	1 460	2 630
Netherlands	30 000	33 800	4 340	4 910	1 640	1 850
France	20 500	27 700	2 930	3 940	1 200	1 620
Hungary	19 500	20 700	1 100	1 180	460	480
Bulgaria	7 600	18 100	380	920	140	330
Portugal	12 000	17 700	640	950	250	370
Greece	12 700	12 200	1 030	990	410	390
Belgium	2 200	11 100	430	2 150	150	770
Austria	6 600	9 700	1 170	1 710	500	730
Sweden	4 900	9 400	850	1 640	400	760
Lithuania	5 100	9 100	220	380	110	200
Denmark	10 500	7 300	2 000	1 510	810	600
Romania	2 900	7 000	200	490	70	190
Finland	3 500	6 300	690	1 230	270	480
Czechia	7 700	4 700	560	380	200	130
Estonia	1 600	4 100	120	300	40	110
Croatia	1 000	3 600	60	200	20	80
Slovenia	2 200	3 300	160	250	60	100
Latvia	500	2 700	30	150	10	50
Ireland	300	1 800	40	250	20	100
Cyprus	1 000	1 000	90	90	30	30
Slovakia	200	900	20	70	10	30
Luxembourg	300	500	40	80	20	30
Malta	100	200	10	20	<10	10
Total EU-27	346 900	560 300	40 850	66 340	17 030	27 790

Source: EurObserv'ER

SOLAR THERMAL

The figures here cover both the flat plate solar thermal sector and concentrated solar power (CSP) technologies. The EurObserv'ER modelling estimates the turnover and employment in the solar thermal sector at €3.0 billion and 23 600 jobs for 2023. A decrease in sector turnover of €0.4 billion is estimated for 2023, following a more significant decrease in the turnover for 2022. Employment levels also are estimated to decrease by 200 jobs, which follows the considerable decrease seen in 2022.

The majority of the decrease in employment comes from a reversing trend of installed capacity growth in Germany, which experienced a relatively small 0.1% decrease in installed capacity throughout 2023, in contrast with a 3% increase in 2022. This decrease can partly be attributed to the decrease in biomass boiler installations due to a reduction in subsidization, as the installation of solar thermal installations is often paired with such biomass boilers[1]. This reduction significantly impacted employment in Germany, resulting in a difference of nearly 3 700 less estimated jobs, although the country still ranks second in terms of absolute number of jobs in the solar thermal sector within the EU-27. Similarly, this decrease is reflected in turnover (a €0.6 billion decrease compared to 2022) and gross value added (a €250 million decrease). Poland records the second highest losses of employment, with a decrease of 500 jobs.

Among the countries that expanded their solar thermal capacities in 2023, France saw the largest relative growth in solar thermal employment, with a 143% increase compared to 2022, totalling 2 000 jobs created. Spain overtook Germany's position as the largest European player in the sector, with a total of 5 900 jobs and revenues reaching €890 million, slightly lower than 2022 levels. The decrease is driven by a slight decrease of the growth of installed capacity, which amounted to only 57 MWth in 2023, compared to 78 MWth of growth in 2022.

Additionally, Spain is home to the largest CSP power plant fleet in the EU (2.3 GWe). The operation and maintenance (O&M) services in the CSP sector positively affect the employment estimates for Spain. The concentrated solar power (CSP) market segment stagnated over the last years with little new installation activity in EU Member States. Employment in CSP sector should thus primarily stem from technology providers and EU based manufacturers of components. The actual installation currently mainly takes place outside the European Union. The only country to show an increase of installed capacity of the CSP technology is Italy, with an increase of 4.26 MWe. This follows a year in which no new CSP deployments were recorded in the EU-27. ■

1. *Meyer, J.P. (2024, June 25). Difficult market environment for residential solar thermal providers in Germany. Solarthermalworld. https://solarthermalworld.org/news/difficult-market-environment-for-residential-solar-thermal-providers-in-germany/.*

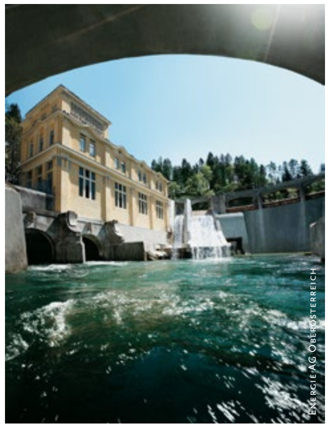
Employment and turnover

	Employment (direct and indirect jobs)		Turnover (in M€)		Direct GVA (in M€)	
	2022	2023	2022	2023	2022	2023
Spain	6 000	5 900	900	890	430	420
France	1 400	3 400	210	530	80	210
Greece	2 900	3 200	260	290	90	110
Germany	6 500	2 800	960	370	420	170
Bulgaria	1 400	1 400	70	70	20	20
Austria	1 800	1 300	340	240	150	100
Italy	1 800	1 300	240	180	90	70
Poland	2 000	1 300	140	90	50	30
Portugal	700	700	30	30	10	10
Denmark	300	400	60	70	20	30
Cyprus	200	200	20	20	10	10
Czechia	200	200	10	10	10	<10
Belgium	100	100	10	20	<10	10
Croatia	100	100	10	10	<10	<10
Hungary	100	100	<10	10	<10	<10
Netherlands	100	100	10	10	<10	<10
Romania	<100	100	<10	10	<10	<10
Sweden	100	100	10	10	<10	<10
Slovakia	100	100	10	10	<10	<10
Estonia	<100	<100	<10	<10	<10	<10
Finland	<100	<100	10	<10	<10	<10
Ireland	<100	<100	10	10	<10	<10
Lithuania	<100	<100	<10	<10	<10	<10
Luxembourg	<100	<100	<10	10	<10	<10
Latvia	<100	<100	<10	<10	<10	<10
Malta	<100	<100	<10	<10	<10	<10
Slovenia	<100	<100	<10	<10	<10	<10
Total EU-27	26 700	23 600	3 390	2 950	1 530	1 340

Source: EurObserv'ER

HYDROPOWER

The vast majority of the hydropower infrastructure within the EU was installed between the 1960s and 1970s and is now in need for rehabilitation and modernisation. The model used captures the employment effect of hydro power installations of all sizes, including pumped hydro and run-of river plants. The model is quite sensitive to sudden increases in capacity, which lead to peaks in employment because employment related to preparation activities are also allocated to the year of commissioning (see methodological note). The effect is especially noticeable for technologies like hydropower with large projects only being finalised sporadically. Since data relating only to new capacities is not available, it is possible that over-estimates may be made for certain countries.



There has been little change recorded in the amount of installed capacity for hydropower in 2023. An overall increase of 411 MW can be observed, which translates to a 0.27% increase. The largest increase of installed capacity is recorded in France, where the amount of hydropower is increased by 362 MW of installed capacity in 2023. Similarly, this country has recorded the highest increase of jobs in this sector in the EU-27, with an increase of 7 500 jobs. It should be mentioned, as outlined in the previous paragraph, that this is likely an overestimation as the construction of additional capacity is now allocated to one year. The increase in turnover and gross value added for France amounted to €1.1 billion and €460 million respectively. This increase is in contrast with the considerable decrease of employment shown in 2022, where a decrease of 11 700 jobs was recorded.

Countries with the largest increase in job estimates outside of France are Germany, Italy, and Portugal. Together these countries show an increase of 5 700 jobs. Their increase in turnover and gross value added is estimated to be €730 million and €300 million respectively. No countries are estimated to show a decrease in the amount of employment of the hydropower sector in 2023.

The overall employment level in the sector increased by 16 000 FTE reaching 41 600 hydropower jobs in the EU-27 in 2023. An increase of the turnover in the sector is observed of €2.1 billion resulting in €5.3 billion in total. Similarly, an increase of the gross value added in the sector is observed of €930 million resulting in €2.24 billion in total. In the countries where no new capacity was added in 2023, the turnover and employment estimates are driven by the operations and maintenance activities of existing hydropower plants. These are highest amongst the countries with the largest existing hydropower fleets. ■

Employment and turnover

	Employment (direct and indirect jobs)		Turnover (in M€)		Direct GVA (in M€)	
	2022	2023	2022	2023	2022	2023
France	3 900	11 400	570	1 650	220	680
Italy	3 700	5 200	520	750	200	290
Germany	1 500	4 300	240	660	110	290
Spain	3 400	3 500	400	420	180	180
Portugal	2 000	3 400	120	200	40	70
Austria	1 900	2 700	350	500	130	200
Sweden	2 000	2 100	370	390	170	190
Romania	1 100	1 700	90	140	30	50
Croatia	500	1 100	30	70	10	30
Bulgaria	800	800	50	50	20	20
Greece	700	800	60	70	20	30
Czechia	500	700	40	50	10	20
Poland	400	600	40	40	10	20
Latvia	500	500	30	30	10	10
Slovenia	400	500	30	40	10	20
Slovakia	500	500	40	40	10	10
Finland	400	400	70	70	30	30
Lithuania	300	300	10	10	10	10
Belgium	200	200	30	30	10	10
Luxembourg	200	200	30	30	10	10
Estonia	<100	100	<10	<10	<10	<10
Ireland	100	100	10	10	<10	<10
Cyprus	<100	<100	<10	<10	<10	<10
Denmark	<100	<100	<10	<10	<10	<10
Hungary	<100	<100	<10	<10	<10	<10
Malta	<100	<100	<10	<10	<10	<10
Netherlands	<100	<100	<10	<10	<10	<10
Total EU-27	25 600	41 600	3 190	5 310	1 310	2 240

Source: EurObserv'ER

GEOTHERMAL ENERGY

Just like in previous years, the (deep) geothermal energy represents the smallest sector of renewable energy in the EU – both in terms of turnover and induced employment. According to the modelling results, overall EU sector turnover decreased by €40 million in comparison to last year, reaching €730 million in 2023. Similarly, employment also decreased to 6 000 in 2023 (from a previous level of 6 200 jobs in 2022).

The total installed geothermal electricity capacity in Europe is largely stable. Capacity additions are rather observed in the district heating system side than on electricity generation in the European Union Member States. In 2023, the largest increases in geothermal capacity for heating occurred in Romania (from 88 to 100.2 MWth), Germany (from 356 to 363.5 MWth) and the Netherlands (from 369 MWth to 376 MWth). Italy leads in employment, as a historically dominant player in the geothermal sector for 2023, with a turnover of €150 million and 1 000 jobs. Hungary follows as it almost doubled the amount of employment between 2022 and 2023, from 500 to 900 jobs respectively. This coincides with a turnover of €60 million.

The largest decreases in employment are observed for France with a loss of 400 jobs, and Italy and Poland where a loss of 200 jobs is observed for both. For both France and Poland this comes out as a significant relative decrease in employment of 50% compared to 2022. It should be mentioned that the data on new projects in France was not complete at the time of writing, so it could be the case that the sector experienced less of a decrease in employment, or even an increase, once more data has been published. ■


Atlas Copco Group

Employment and turnover

	Employment (direct and indirect jobs)		Turnover (in M€)		Direct GVA (in M€)	
	2022	2023	2022	2023	2022	2023
Italy	1 200	1 000	180	150	70	60
France	1 200	900	190	130	70	50
Hungary	500	900	30	60	10	20
Germany	400	400	60	70	30	30
Netherlands	300	400	60	70	20	30
Romania	100	300	10	20	<10	10
Poland	400	200	30	20	10	10
Austria	100	100	20	20	10	10
Portugal	200	100	10	10	<10	<10
Slovenia	<100	100	<10	10	<10	<10
Belgium	<100	<100	<10	10	<10	<10
Bulgaria	<100	<100	<10	<10	<10	<10
Cyprus	<100	<100	<10	<10	<10	<10
Czechia	<100	<100	<10	<10	<10	<10
Denmark	<100	<100	10	10	<10	<10
Estonia	<100	<100	<10	<10	<10	<10
Greece	<100	<100	<10	<10	<10	<10
Spain	<100	<100	<10	<10	<10	<10
Finland	<100	<100	<10	10	<10	<10
Croatia	<100	<100	<10	<10	<10	<10
Ireland	<100	<100	<10	<10	<10	<10
Lithuania	<100	<100	<10	<10	<10	<10
Luxembourg	<100	<100	<10	<10	<10	<10
Latvia	<100	<100	<10	<10	<10	<10
Malta	<100	<100	<10	<10	<10	<10
Sweden	<100	<100	10	10	<10	<10
Slovakia	<100	<100	<10	<10	<10	<10
Total EU-27	6 200	6 100	770	730	420	410

Source: EurObserv'ER

HEAT PUMPS

After a significant increase in industry turnover and EU wide employment in 2022, the heat pump sector in the EU-27 is estimated to have a repeated large, albeit smaller, increase in terms of both estimates in 2023. The modelling resulted in an estimated overall turnover of €58.8 billion (increase of €1.4 billion compared to 2022) and a heat pump employment level of 432 900 workers (an increase of 16 700 jobs compared to 2022). However, it should be mentioned that due to some generalizations of the assumed cost figures of heat pumps this figure could end up being somewhat lower in actuality. Taking into account these results, the heat pump sector is the second largest renewable energy sector in the EU in terms of employment, as only the solar PV sector shows more employment in total. It must be noted that the market data presented in this document from Italy, Spain and France are not directly comparable to other countries as they include heat pumps whose principal function is cooling, an approach that is in line with the EU RES Directive. Additionally, an assumption is made in the model that could result in a slight overestimation of the overall cost of the various types of heat pumps. Together, this could result in an overestimation of employment. The largest increase in estimate of persons employed is observed for Germany (€1.5 billion turnover and 10 100 jobs), mainly due to the increase in the amount of heat pumps installed in France in 2023 compared to 2022. Other countries with a notable increase in the estimated employment and turnover are Spain (€1.1 billion and 9 700 jobs), Portugal (€0.5 billion and 9 200 jobs) and Hungary (€0.27 billion and 4 500 jobs).
Even with these large observed increases in the estimates for 2023, Italy remains the largest in terms of employment (135 900 jobs) and turnover (€19.8 billion) in the heat pump sector (cooling and heating). France, Spain, Portugal and Germany remain large players with over 30 000 persons employed in the sector for each individual country. ■

Employment and turnover

	Employment (direct and indirect jobs)		Turnover (in M€)		Direct GVA (in M€)	
	2022	2023	2022	2023	2022	2023
Italy	135 400	135 900	19 530	19 830	7 530	7 580
France	80 300	73 700	12 250	11 160	4 960	4 520
Germany	31 900	42 000	5 090	6 610	2 200	2 870
Spain	32 200	41 900	3 720	4 840	1 540	1 990
Portugal	24 900	34 100	1 430	1 930	530	730
Netherlands	27 100	26 000	4 340	4 170	1 580	1 520
Sweden	18 300	19 400	3 520	3 680	1 540	1 620
Poland	11 700	10 900	820	770	320	300
Finland	8 900	8 000	1 600	1 440	640	580
Hungary	2 500	7 000	150	420	50	150
Greece	6 000	5 900	630	610	240	230
Austria	3 100	3 900	570	730	240	310
Denmark	4 200	3 300	800	630	330	260
Malta	3 100	3 200	250	260	100	100
Lithuania	4 500	3 000	200	130	100	70
Belgium	5 100	2 800	1 050	560	380	200
Slovenia	2 600	2 500	210	210	80	80
Estonia	2 400	2 200	180	170	60	60
Ireland	1 700	1 600	240	220	100	90
Czechia	4 200	1 400	350	120	120	40
Slovakia	3 600	1 400	300	120	110	40
Romania	1 300	1 300	80	80	30	30
Bulgaria	800	1 100	40	60	10	20
Cyprus	<100	<100	<10	<10	<10	<10
Croatia	<100	<100	<10	<10	<10	<10
Luxembourg	<100	<100	10	10	<10	<10
Latvia	<100	<100	<10	<10	<10	<10
Total EU-27	416 200	432 900	57 390	58 790	22 830	23 430

Source: EurObserv'ER

BIOGAS

Following a rapid rise in the first decade of the century, the momentum of biogas development was not sustained over the ten following years in EU Member States. In 2023, primary energy output from biogas in the European Union slightly decreased compared to 2022. The number of jobs in the biogas sector decreased to 43 900 in 2023 – 5 400 full time jobs less than in 2022. The sector produced a turnover of €5.2 billion, a noticeable decrease from €5.8 billion recorded in the previous year. The gross value added for biogas in the EU-27 decreased in line with the decrease in turnover.
Employment estimates for Italy, Greece and Germany all decrease by 1500-1600 FTE compared to 2022, but the workforce in Germany remain the largest for the biogas sector, with 21 600 jobs. Sector turnover also shows decrease in all these countries. In the second place behind Germany, with a turnover of €690 million, comes Italy with 6 200 jobs. ■

Employment and turnover

	Employment (direct and indirect jobs)		Turnover (in M€)		Direct GVA (in M€)	
	2022	2023	2022	2023	2022	2023
Germany	23 200	21 600	3 180	2 960	1 440	1 340
Italy	7 700	6 200	890	690	440	350
Poland	2 300	3 500	110	190	40	80
Czechia	3 600	3 400	240	230	100	90
France	3 500	2 200	470	280	200	120
Spain	1 200	900	130	90	60	50
Austria	400	700	60	120	30	50
Finland	100	700	20	110	10	50
Belgium	400	400	110	100	40	40
Greece	2 000	400	150	20	60	10
Croatia	500	400	40	30	20	10
Hungary	600	400	30	20	10	10
Netherlands	500	400	80	70	30	30
Portugal	400	400	20	20	10	10
Denmark	300	300	60	50	20	20
Latvia	400	300	20	20	10	10
Sweden	100	300	10	40	<10	20
Slovakia	400	300	40	30	20	10
Bulgaria	300	200	20	10	10	10
Lithuania	300	200	10	10	10	<10
Cyprus	100	100	10	<10	<10	<10
Ireland	100	100	20	20	10	10
Romania	500	100	30	10	10	<10
Slovenia	100	100	10	10	<10	<10
Estonia	<100	<100	<10	<10	<10	<10
Luxembourg	100	<100	<10	<10	<10	<10
Malta	<100	<100	<10	<10	<10	<10
Total EU-27	**49 300**	**43 900**	**5 790**	**5 170**	**2 640**	**2 390**

Source: EurObserv'ER

BIOFUELS

The methodology used to evaluate the biomass industry covers biomass supply activities, i.e. supply in the agricultural sector. The European biofuels sector (EurObserv'ER subsumes biodiesel, bioethanol and biogas for transport in the biofuels technologies) experienced a slight decline during 2023. The sector experienced a decrease in capacity of 3% when compared to the previous year. Overall biofuel consumption decreased by 1.1% between 2022 and 2023. Substantial biofuel production capacities remain idle in the EU. According to EurObserv'ER calculations, the entire European Union biofuel induced industry turnover decreased reaching €11.8 billion in 2023, a decrease of €130 million from 2022. The employment level decreased from 145 700 to 142 400 jobs in 2023. Biofuels remains the fifth largest renewable energy job creator in the EU, following solar PV, heat pumps, wind energy and solid biomass.

Also, it should be noted that the leading countries in terms of employment are not necessarily the largest biofuel consumers such as France and Germany. EU Member States with large agricultural land area such as Romania, Hungary, and Poland also have large employment in the biofuels supply chain. And indeed, Romania (20 700 jobs and €860 million turnover) is the largest in terms of biofuel employment. Poland (19 100 persons employed with a turnover of €880 million) and France (18 600 persons employed and €2.23 billion turnover) follow as second and third largest in the sector.

In turn, large parts of biofuel value creation occur on the production side of the value chain, which explains that economic turnover are highest in Member States with huge biofuel plants (for example France as aforementioned with a turnover of €2.23 billion). France combines a vital agricultural basis with substantial biofuel production capacities. Similarly, Spain is a major biofuel hub. The economic volume of the Spanish biofuel industry is estimated at around €1.1 billion, while the employment level decreased to 10 600 jobs. Biofuel induced turnover slightly increased in Germany (from €1.8 billion in 2022 to €2.0 billion in 2023) and similarly saw an increase in employment of 1 500 jobs to a total of 13 900 jobs in 2023. It should be mentioned that the results for biofuels are impacted by data input related to various crops, such as oil-bearing and sugar crops. This data has not been made available for 2023 at the time of writing, and as such the data has been assumed as 2022 data instead. The results for biofuels should therefore be contextualized with this in mind. ■

Employment and turnover

	Employment (direct and indirect jobs)		Turnover (in M€)		Direct GVA (in M€)	
	2022	2023	2022	2023	2022	2023
Romania	16 900	20 700	700	860	320	390
Poland	22 100	19 100	1 010	880	380	340
France	19 000	18 600	2 280	2 230	970	940
Germany	12 400	13 900	1 770	1 960	790	880
Spain	13 100	10 600	1 300	1 070	680	560
Hungary	16 100	9 700	930	570	440	270
Lithuania	6 900	8 300	340	410	150	170
Sweden	7 300	7 800	450	480	200	200
Italy	5 700	5 400	590	560	300	280
Bulgaria	2 900	4 900	180	310	70	110
Slovakia	4 300	4 700	350	390	160	170
Czechia	4 200	4 600	270	290	110	120
Latvia	3 200	3 500	160	170	50	60
Austria	2 500	2 800	380	430	170	190
Belgium	1 700	1 700	450	460	170	180
Croatia	1 500	1 400	90	90	50	40
Netherlands	1 200	1 200	270	270	110	110
Finland	1 000	1 000	150	130	60	50
Estonia	300	800	20	40	10	10
Ireland	300	700	40	100	20	40
Portugal	300	400	40	40	10	10
Cyprus	<100	<100	<10	<10	<10	<10
Denmark	<100	<100	10	<10	<10	<10
Greece	2 300	<100	110	<10	60	<10
Luxembourg	<100	<100	<10	<10	<10	<10
Malta	<100	<100	<10	<10	<10	<10
Slovenia	<100	<100	<10	<10	<10	<10
Total EU-27	**145 700**	**142 400**	**11 930**	**11 800**	**5 330**	**5 180**

Source: EurObserv'ER

RENEWABLE MUNICIPAL WASTE

By definition, municipal waste is considered 50% renewable matter as household waste contains a substantial biodegradable part. Energy production from waste is largely based on the incineration in Waste-to-Energy (WtE) plants. This sector is relatively hard to quantify and remains one of the smaller RE sectors in the European Union. EurObserv'ER estimates the RMW sector is worth €2.5 billion in turnover in 2023, with €1.1 billion in gross added value. With 14 300 direct and indirect fulltime equivalent jobs, an increase of 1 000 jobs compared to 2022 can be observed. This increase is explained by an increase in growth of heat production from municipal waste, which presented smaller growth in the previous year.

The largest increase in jobs was seen in Lithuania, where the overall employment grew to 1 100 jobs (+1 000 jobs). This significant increase is explained by their growth of primary energy produced through heat, which almost doubled in 2023. Other large increases are observed for Austria at 800 jobs (+600 jobs) and Spain at 800 jobs (+400 jobs).

Noticeable decreases can be observed for Portugal at 200 jobs (-400 jobs) and Hungary at 100 jobs (-300 jobs). For both of these countries this decrease can be mainly explained by the decrease in electricity generation from waste material. Other, smaller, decreases can be observed for Belgium, Ireland, the Netherlands and Sweden, which all saw a decrease of 100 jobs in their renewable municipal waste sector.

According to the EurObserv'ER modelling, Germany is the largest MSW member state in terms of revenue, with €750 million (-€10 million compared to 2022) in turnover in the sector. This is followed by Italy at €260 (+€30 million) and Sweden at €250 (-€20 million) turnover in 2023. ■


RWE

Employment and turnover

	Employment (direct and indirect jobs)		Turnover (in M€)		Direct GVA (in M€)	
	2022	2023	2022	2023	2022	2023
Germany	3 900	3 900	760	750	340	330
Italy	1 300	1 500	230	260	90	100
France	1 200	1 200	230	220	90	90
Lithuania	100	1 100	10	50	<10	30
Sweden	1 100	1 000	270	250	130	120
Austria	200	800	40	140	20	60
Belgium	900	800	200	180	80	70
Spain	400	800	60	100	30	50
Netherlands	900	800	180	170	80	70
Denmark	400	400	100	100	40	40
Finland	200	200	60	50	30	20
Poland	100	200	10	10	10	10
Portugal	600	200	50	20	20	10
Hungary	400	100	30	10	10	<10
Ireland	200	100	30	30	20	10
Bulgaria	<100	<100	<10	<10	<10	<10
Cyprus	<100	<100	<10	<10	<10	<10
Czechia	<100	<100	<10	<10	<10	<10
Estonia	300	<100	20	<10	10	<10
Greece	<100	<100	<10	<10	<10	<10
Croatia	<100	<100	<10	<10	<10	<10
Luxembourg	<100	<100	<10	<10	<10	<10
Latvia	<100	<100	<10	<10	<10	<10
Malta	<100	<100	<10	<10	<10	<10
Romania	<100	<100	<10	<10	<10	<10
Slovenia	<100	<100	<10	<10	<10	<10
Slovakia	<100	<100	<10	<10	<10	<10
Total EU-27	**13 300**	**14 300**	**2 390**	**2 460**	**1 120**	**1 140**

Source: EurObserv'ER

SOLID BIOFUELS

Solid biofuels remain an important renewable energy source in terms of energy production and renewable employment in the EU-27. The reason for this is that unlike the other RE giant, wind power, biofuels also make a substantial contribution towards renewable heat generation. Plus: an important part of the employment activities originates from biomass feedstock supply.

The solid biofuels sector comprises of different technologies that cover various end-user sectors: energy (biomass CHP, co-firing), industry (boilers), and households (pellet boilers and stoves). Solid biofuels are not only used in the form of wood chips and briquettes, but also includes many other forms such as wood waste, pellets, sawdust, straw, bagasse, animal waste as well as black liquors from the papermaking industry. The energy recovery of this matter is channelled into producing heat. The consumption of solid biofuels energy shows a small decrease in the European Union in 2023, following a similar decrease in 2022. This decrease corresponds to a decrease in consumption of -3.6 Mtoe, resulting in a total of 96.6 Mtoe consumed in 2023. More specifically, this decrease can be seen in the electricity production from solid biomass which decreased by 13.5% (from 87.6 GWh in 2022 to 75.8 GWh in 2023). In contrast, a slight increase of heat production from solid biomass is observed, with an increase of 2.1% (from 12.2 Mtoe in 2022 to 12.4 Mtoe in 2023).

These changes have had an impact on the socio-economic results of the sector, with an estimated 265 700 jobs in 2023 (-66 000 compared to 2022) and an estimated turnover of 27.7 billion euros (-8.5 billion compared to 2022). After the large increase in the wind, heat pump and solar PV sectors in 2023, the solid biomass sector has moved from the 3rd to the 4th largest renewable energy sector in 2023 in terms of socio-economic indicators. The EurObserv'ER analysis also covers the forestry and agricultural components of the biomass value chain. Thus, EU Member States with large forest areas also have the best chance of using this renewable energy.

Regarding the individual countries, Germany took the lead and now has the highest solid biofuels turnover (€4.1 billion) and simultaneously slows the second highest employment at 29 800 jobs, although this number has decreased significantly compared to 2022 (-10 500 jobs). In terms of employment, France (26 400 jobs) and Sweden (19 900 jobs) come in third and fourth place. The turnover for these countries is €4.1 billion and €4.0 billion respectively. In terms of employment, Poland, one of the most important agricultural countries in EU, represents 40 400 jobs, although the sector turnover is significantly lower than the aforementioned countries at €1.7 billion. The different ratios between employment and turnover are caused by how different types of activity are modelled ■


Freepik

Employment and turnover

	Employment (direct and indirect jobs)		Turnover (in M€)		Direct GVA (in M€)	
	2022	2023	2022	2023	2022	2023
Poland	33 400	40 400	1 350	1 720	590	750
Germany	40 300	29 800	5 650	4 140	2 980	2 280
France	30 500	26 400	4 620	4 070	2 120	1 920
Sweden	29 600	19 900	5 840	4 030	2 490	1 690
Italy	23 600	15 200	2 160	910	1 080	600
Latvia	15 000	15 000	760	770	290	290
Spain	26 400	13 300	2 060	740	930	380
Finland	14 300	13 200	3 660	3 480	2 310	2 270
Bulgaria	6 100	12 100	250	540	100	200
Lithuania	7 900	11 600	270	420	130	200
Czechia	16 400	9 700	990	540	360	200
Austria	9 800	8 500	2 080	1 830	950	840
Hungary	12 300	6 900	500	210	190	90
Croatia	10 100	6 800	370	220	180	120
Estonia	7 700	6 400	750	630	290	240
Portugal	13 300	5 800	1 040	560	560	330
Slovakia	7 600	5 600	500	350	230	170
Romania	10 000	4 800	520	230	220	100
Denmark	5 400	4 400	880	700	360	290
Netherlands	6 200	4 400	890	630	430	310
Belgium	2 400	1 400	690	600	230	170
Greece	600	1 400	70	130	30	50
Slovenia	900	1 300	80	110	40	50
Ireland	1 600	1 100	140	100	60	40
Cyprus	100	100	<10	<10	<10	<10
Luxembourg	100	100	20	30	10	10
Malta	<100	<100	<10	<10	<10	<10
Total EU-27	**331 700**	**265 700**	**36 160**	**27 710**	**17 180**	**13 610**

Source: EurObserv'ER

CONCLUSION

The EurObserv'ER team uses an employment modelling approach to estimate the employment derived from renewable investments, operation and maintenance activities as well as the production and trading of equipment and biomass feedstock. The EurObserv'ER employment and turnover estimates are based on an evaluation of the economic activity of each renewable sector covered, which is then converted to full-time equivalent (FTE). Summing up the socioeconomic indicator chapter we arrive at the following findings and development trends:

EMPLOYMENT

- Overall, around 1.86 million persons are directly or indirectly employed in the European Union renewable energy sector. This represents a gross increase of 229 500 jobs (14.0%) from 2022 to 2023.
- 22 out of 27 Member States either increased or maintained their number of renewable energy jobs.
- The top 5 countries in terms of employment are: Germany (356 400 jobs, 19% of all EU renewable employment), Spain (230 100 jobs, 12%), Italy (228 900 jobs, 12%), France (205 700 jobs, 11%), and Poland (143 000 jobs, 8%).
- The largest growth in employment estimates were found in Spain (+73 900 new jobs, equal to +47% - almost entirely due to the growth of solar PV), Germany (+63 600, equal to +22%), and the Netherlands (+27 800 jobs, equal to +36%). The greatest decreases were observed in Czechia (-11 700 jobs, equal to -31%), Sweden (-7 600, -9%) and Hungary (-5 800 jobs, equal to -11%).
- Solar PV (560 300 jobs, 30% of the total EU) became the largest sector in terms of renewable energy induced employment, ahead of heat pumps (432 900 jobs, 23%) and wind (333 800 jobs, 18%). The most significant upward jump in employment per technology was in the PV sector with an additional 213 400 jobs (+62%), followed by wind energy that saw an addition of 60 300 new jobs (+22%). Increases were also observed in the hydropower, heat pumps and MSW sectors. The increases balance out declines in the solid biomass, biofuels, biogas, solar thermal and geothermal sectors.

TURNOVER

- In total the renewable energy related industry turnover in EU-27 Member States in 2023 amounted to around €233 billion, representing a gross growth of around €27.5 billion against 2022 (+13%).
- 22 out of 27 EU Member States either increased or maintained their industrial turnover created by renewable energy sources.
- The top 5 Member States in terms of turnover are Germany (€54.6 billion), Italy (€31.5 billion), France (€30.9 billion), Spain (€25.3 billion), and the Netherlands (€16.2 billion). These countries are also the countries where the gross value added is largest, with France and Italy swapping in ranking to respectively 2nd and 3rd place behind Germany.
- The largest growth in turnover according to the EurObserv'ER modelling was observed in Germany (+€9.6 billion), Spain (+€8.0 billion), and the Netherlands (+€4.1 billion). The largest dips in turnover occurred in Sweden (-€1.5 billion) and Czechia (-€0.8 billion).
- The largest renewable energy technologies in terms of industry sector turnover were solar PV with €66.3 billion, followed by heat pumps at €58.8 billion and wind at €51.4 billion. The gross value added was also largest for these sectors: €27.8 billion for solar PV, €23.4 billion for heat pumps and €22.0 billion for wind. ■

2022 EMPLOYMENT DISTRIBUTION BY SECTOR

	Country total	Heat pumps	PV	Solid biofuels	Wind	Biofuels	Biogas	Solar thermal	Hydro	MSW	Geothermal
Germany	292 800	31 900	87 100	40 300	85 600	12 400	23 200	6 500	1 500	3 900	400
Italy	216 000	135 400	26 500	23 600	9 100	5 700	7 700	1 800	3 700	1 300	1 200
France	198 000	80 300	20 500	30 500	36 500	19 000	3 500	1 400	3 900	1 200	1 200
Spain	156 200	32 200	36 300	26 400	37 100	13 100	1 200	6 000	3 400	400	<100
Poland	130 200	11 700	44 100	33 400	13 700	22 100	2 300	2 000	400	100	400
Sweden	80 300	18 300	4 900	29 600	16 800	7 300	100	100	2 000	1 100	<100
Netherlands	77 800	27 100	30 000	6 200	11 400	1 200	500	100	<100	900	300
Portugal	58 600	24 900	12 000	13 300	4 200	300	400	700	2 000	600	200
Hungary	52 900	2 500	19 500	12 300	800	16 100	600	100	<100	400	500
Denmark	44 000	4 200	10 500	5 400	22 600	<100	300	300	<100	400	<100
Finland	42 400	8 900	3 500	14 300	13 800	1 000	100	<100	400	200	<100
Czechia	37 800	4 200	7 700	16 400	800	4 200	3 600	200	500	<100	<100
Romania	35 200	1 300	2 900	10 000	2 200	16 900	500	<100	1 100	<100	100
Greece	29 900	6 000	12 700	600	2 500	2 300	2 000	2 900	700	<100	<100
Lithuania	29 700	4 500	5 100	7 900	4 400	6 900	300	<100	300	100	<100
Austria	29 000	3 100	6 600	9 800	2 600	2 500	400	1 800	1 900	200	100
Bulgaria	20 700	800	7 600	6 100	600	2 900	300	1 400	800	<100	<100
Latvia	20 700	<100	500	15 000	700	3 200	400	<100	500	<100	<100
Belgium	17 100	5 100	2 200	2 400	4 000	1 700	400	100	200	900	<100
Slovakia	17 000	3 600	200	7 600	<100	4 300	400	100	500	<100	<100
Croatia	14 600	<100	1 000	10 100	600	1 500	500	100	500	<100	<100
Estonia	12 900	2 400	1 600	7 700	200	300	<100	<100	<100	300	<100
Ireland	7 300	1 700	300	1 600	2 800	300	100	<100	100	200	<100
Slovenia	6 700	2 600	2 200	900	<100	<100	100	<100	400	<100	<100
Malta	4 000	3 100	100	<100	<100	<100	<100	<100	<100	<100	<100
Cyprus	2 000	<100	1 000	100	100	<100	100	200	<100	<100	<100
Luxembourg	1 300	<100	300	100	100	<100	100	<100	200	<100	<100
Total EU-27	1 635 100	416 200	346 900	331 700	273 500	145 700	49 300	26 700	25 600	13 300	6 200

Source: EurObserv'ER

2023 EMPLOYMENT DISTRIBUTION BY SECTOR

	Country total	PV	Heat pumps	Wind	Solid biofuels	Biofuels	Biogas	Hydro	Solar thermal	MSW	Geothermal
Germany	356 400	139 800	42 000	97 900	29 800	13 900	21 600	4 300	2 800	3 900	400
Spain	230 100	110 100	41 900	43 000	13 300	10 600	900	3 500	5 900	800	<100
Italy	228 900	47 800	135 900	9 400	15 200	5 400	6 200	5 200	1 300	1 500	1 000
France	205 700	27 700	73 700	40 200	26 400	18 600	2 200	11 400	3 400	1 200	900
Poland	143 000	49 700	10 900	17 100	40 400	19 100	3 500	600	1 300	200	200
Netherlands	105 600	33 800	26 000	38 400	4 400	1 200	400	<100	100	800	400
Sweden	72 700	9 400	19 400	12 600	19 900	7 800	300	2 100	100	1 000	<100
Portugal	69 500	17 700	34 100	6 700	5 800	400	400	3 400	700	200	100
Hungary	47 100	20 700	7 000	1 200	6 900	9 700	400	<100	100	100	900
Denmark	44 100	7 300	3 300	27 700	4 400	<100	300	<100	400	400	<100
Lithuania	39 600	9 100	3 000	5 800	11 600	8 300	200	300	<100	1 100	<100
Bulgaria	39 400	18 100	1 100	600	12 100	4 900	200	800	1 400	<100	<100
Romania	39 200	7 000	1 300	3 100	4 800	20 700	100	1 700	100	<100	300
Finland	38 400	6 300	8 000	8 400	13 200	1 000	700	400	<100	200	<100
Austria	33 600	9 700	3 900	3 100	8 500	2 800	700	2 700	1 300	800	100
Greece	31 200	12 200	5 900	7 000	1 400	<100	400	800	3 200	<100	<100
Czechia	26 100	4 700	1 400	1 200	9 700	4 600	3 400	700	200	<100	<100
Latvia	22 500	2 700	<100	100	15 000	3 500	300	500	<100	<100	<100
Belgium	21 800	11 100	2 800	3 200	1 400	1 700	400	200	100	800	<100
Croatia	16 200	3 600	<100	2 500	6 800	1 400	400	1 100	100	<100	<100
Estonia	14 900	4 100	2 200	900	6 400	800	<100	100	<100	<100	<100
Slovakia	13 800	900	1 400	<100	5 600	4 700	300	500	100	<100	<100
Ireland	8 700	1 800	1 600	3 000	1 100	700	100	100	<100	100	<100
Slovenia	8 200	3 300	2 500	<100	1 300	<100	100	500	<100	<100	100
Malta	4 200	200	3 200	<100	<100	<100	<100	<100	<100	<100	<100
Cyprus	2 000	1 000	<100	100	100	<100	100	<100	200	<100	<100
Luxembourg	1 700	500	<100	300	100	<100	<100	200	<100	<100	<100
Total EU-27	1 864 600	560 300	432 900	333 800	265 700	142 400	43 900	41 600	23 600	14 300	6 100

Source: EurObserv'ER

EUROBSERV'ER – THE STATE OF RENEWABLE ENERGIES IN EUROPE – 2024 EDITION

2022 TURNOVER BY SECTOR (€M)

	Country total	Heat pumps	Wind	PV	Solid biofuels	Biofuels	Biogas	Solar thermal	Hydro	MSW	Geothermal
Germany	44 960	5 090	14 180	13 070	5 650	1 770	3 180	960	240	760	60
France	29 660	12 250	5 910	2 930	4 620	2 280	470	210	570	230	190
Italy	29 550	19 530	1 470	3 740	2 160	590	890	240	520	230	180
Spain	17 380	3 720	4 970	3 830	2 060	1 300	130	900	400	60	<10
Sweden	14 550	3 520	3 220	850	5 840	450	10	10	370	270	10
Netherlands	12 020	4 340	1 840	4 340	890	270	80	10	<10	180	60
Denmark	8 960	800	5 030	2 000	880	10	60	60	<10	100	10
Finland	8 630	1 600	2 360	690	3 660	150	20	10	70	60	<10
Poland	7 660	820	1 050	3 100	1 350	1 010	110	140	40	10	30
Austria	5 500	570	490	1 170	2 080	380	60	340	350	40	20
Belgium	3 840	1 050	860	430	690	450	110	10	30	200	<10
Portugal	3 760	1 430	380	640	1 040	40	20	30	120	50	10
Hungary	2 850	150	60	1 100	500	930	30	<10	<10	30	30
Greece	2 620	630	290	1 030	70	110	150	260	60	<10	<10
Czechia	2 550	350	70	560	990	270	240	10	40	<10	<10
Romania	1 840	80	190	200	520	700	30	<10	90	<10	10
Slovakia	1 290	300	<10	20	500	350	40	10	40	<10	<10
Lithuania	1 280	200	200	220	270	340	10	<10	10	10	<10
Estonia	1 150	180	20	120	750	20	<10	<10	<10	20	<10
Latvia	1 080	<10	40	30	760	160	20	<10	30	<10	<10
Bulgaria	1 050	40	40	380	250	180	20	70	50	<10	<10
Ireland	1 020	240	480	40	140	40	20	10	10	30	<10
Croatia	680	<10	50	60	370	90	40	10	30	<10	<10
Slovenia	540	210	<10	160	80	<10	10	<10	30	<10	<10
Malta	340	250	<10	10	<10	<10	<10	<10	<10	<10	<10
Cyprus	190	<10	10	90	<10	<10	10	20	<10	<10	<10
Luxembourg	170	10	20	40	20	<10	<10	<10	30	<10	<10
Total EU-27	205 120	57 390	43 260	40 850	36 160	11 930	5 790	3 390	3 190	2 390	770

Source: EurObserv'ER

2023 TURNOVER BY SECTOR (€M)

	Country total	PV	Heat pumps	Wind	Solid biofuels	Biofuels	Hydro	Biogas	Solar thermal	MSW	Geothermal
Germany	54 560	20 900	6 610	16 140	4 140	1 960	660	2 960	370	750	70
Italy	31 530	6 670	19 830	1 530	910	560	750	690	180	260	150
France	30 920	3 940	11 160	6 710	4 070	2 230	1 650	280	530	220	130
Spain	25 350	11 470	4 840	5 720	740	1 070	420	90	890	100	<10
Netherlands	16 160	4 910	4 170	5 850	630	270	<10	70	10	170	70
Sweden	13 050	1 640	3 680	2 520	4 030	480	390	40	10	250	10
Denmark	9 160	1 510	630	6 070	700	<10	<10	50	70	100	10
Poland	8 530	3 510	770	1 300	1 720	880	40	190	90	10	20
Finland	8 040	1 230	1 440	1 510	3 480	130	70	110	<10	50	10
Austria	6 290	1 710	730	570	1 830	430	500	120	240	140	20
Belgium	4 800	2 150	560	690	600	460	30	100	20	180	10
Portugal	4 300	950	1 930	540	560	40	200	20	30	20	10
Greece	2 810	990	610	670	130	<10	70	20	290	<10	<10
Hungary	2 570	1 180	420	80	210	570	<10	20	10	10	60
Romania	2 100	490	80	250	230	860	140	10	10	<10	20
Bulgaria	2 020	920	60	40	540	310	50	10	70	<10	<10
Czechia	1 740	380	120	100	540	290	50	230	10	<10	<10
Lithuania	1 700	380	130	270	420	410	10	10	<10	50	<10
Estonia	1 260	300	170	70	630	40	<10	<10	<10	<10	<10
Ireland	1 260	250	220	510	100	100	10	20	10	30	<10
Latvia	1 190	150	<10	10	770	170	30	20	<10	<10	<10
Slovakia	1 040	70	120	<10	350	390	40	30	10	<10	<10
Croatia	810	200	<10	160	220	90	70	30	10	<10	<10
Slovenia	670	250	210	<10	110	<10	40	10	<10	<10	10
Malta	360	20	260	<10	<10	<10	<10	<10	<10	<10	<10
Luxembourg	250	80	10	50	30	<10	30	<10	10	<10	<10
Cyprus	190	90	<10	10	<10	<10	<10	<10	20	<10	<10
Total EU-27	232 660	66 340	58 790	51 400	27 710	11 800	5 310	5 170	2 950	2 460	730

Source: EurObserv'ER

2022 GROSS VALUE ADDED BY SECTOR (€M)

	Country total	Heat pumps	Wind	Solid biofuels	PV	Biofuels	Biogas	Solar thermal	Hydro	MSW	Geothermal
Germany	20 340	2 200	6 220	2 980	5 810	790	1 440	420	110	340	30
France	12 310	4 960	2 400	2 120	1 200	970	200	80	220	90	70
Italy	11 880	7 530	620	1 080	1 460	300	440	90	200	90	70
Spain	7 650	1 540	2 120	930	1 670	680	60	430	180	30	<10
Sweden	6 580	1 540	1 620	2 490	400	200	<10	<10	170	130	<10
Netherlands	4 670	1 580	760	430	1 640	110	30	<10	<10	80	20
Finland	4 390	640	1 020	2 310	270	60	10	<10	30	30	<10
Denmark	3 600	330	1 990	360	810	<10	20	20	<10	40	<10
Poland	3 130	320	460	590	1 260	380	40	50	10	10	10
Austria	2 410	240	210	950	500	170	30	150	130	20	10
Portugal	1 600	530	160	560	250	10	10	10	40	20	<10
Belgium	1 410	380	330	230	150	170	40	<10	10	80	<10
Hungary	1 210	50	20	190	460	440	10	<10	<10	10	10
Greece	1 070	240	140	30	410	60	60	90	20	<10	<10
Czechia	960	120	30	360	200	110	100	10	10	<10	<10
Romania	790	30	80	220	70	320	10	<10	30	<10	<10
Lithuania	640	100	100	130	110	150	10	<10	10	<10	<10
Slovakia	580	110	<10	230	10	160	20	<10	10	<10	<10
Estonia	460	60	10	290	40	10	<10	<10	<10	10	<10
Ireland	460	100	200	60	20	20	10	<10	<10	20	<10
Latvia	420	<10	10	290	10	50	10	<10	10	<10	<10
Bulgaria	410	10	20	100	140	70	10	20	20	<10	<10
Croatia	340	<10	20	180	20	50	20	<10	10	<10	<10
Slovenia	250	80	<10	40	60	<10	<10	<10	10	<10	<10
Malta	190	100	<10	<10	<10	<10	<10	<10	<10	<10	<10
Cyprus	120	<10	<10	<10	30	<10	<10	10	<10	<10	<10
Luxembourg	110	<10	10	10	20	<10	<10	<10	10	<10	<10
Total EU-27	87 980	22 830	18 590	17 180	17 030	5 330	2 640	1 530	1 310	1 120	420

Source: EurObserv'ER

2023 GROSS VALUE ADDED BY SECTOR (€M)

	Country total	PV	Heat pumps	Wind	Solid biofuels	Biofuels	Biogas	Hydro	Solar thermal	MSW	Geothermal
Germany	24 560	9 290	2 870	7 080	2 280	880	1 340	290	170	330	30
France	12 840	1 620	4 520	2 690	1 920	940	120	680	210	90	50
Italy	12 600	2 630	7 580	640	600	280	350	290	70	100	60
Spain	11 070	5 010	1 990	2 420	380	560	50	180	420	50	<10
Netherlands	6 430	1 850	1 520	2 490	310	110	30	<10	<10	70	30
Sweden	5 910	760	1 620	1 290	1 690	200	20	190	<10	120	<10
Finland	4 160	480	580	660	2 270	50	50	30	<10	20	<10
Denmark	3 700	600	260	2 430	290	<10	20	<10	30	40	<10
Poland	3 530	1 420	300	570	750	340	80	20	30	10	10
Austria	2 730	730	310	240	840	190	50	200	100	60	10
Portugal	1 770	370	730	220	330	10	10	70	10	10	<10
Belgium	1 730	770	200	270	170	180	40	10	10	70	<10
Greece	1 150	390	230	300	50	<10	10	30	110	<10	<10
Hungary	1 080	480	150	30	90	270	10	<10	<10	<10	20
Romania	910	190	30	110	100	390	<10	50	<10	<10	10
Lithuania	850	200	70	140	200	170	<10	10	<10	30	<10
Bulgaria	750	330	20	20	200	110	10	20	20	<10	<10
Czechia	670	130	40	40	200	120	90	20	<10	<10	<10
Ireland	530	100	90	210	40	40	10	<10	<10	10	<10
Estonia	500	110	60	30	240	10	<10	<10	<10	<10	<10
Latvia	470	50	<10	<10	290	60	10	10	<10	<10	<10
Slovakia	470	30	40	<10	170	170	10	10	<10	<10	<10
Croatia	390	80	<10	70	120	40	10	30	<10	<10	<10
Slovenia	310	100	80	<10	50	<10	<10	20	<10	<10	<10
Malta	190	10	100	<10	<10	<10	<10	<10	<10	<10	<10
Luxembourg	130	30	<10	20	10	<10	<10	10	<10	<10	<10
Cyprus	120	30	<10	<10	<10	<10	<10	<10	10	<10	<10
Total EU-27	99 550	27 790	23 430	22 020	13 610	5 180	2 390	2 240	1 340	1 140	410

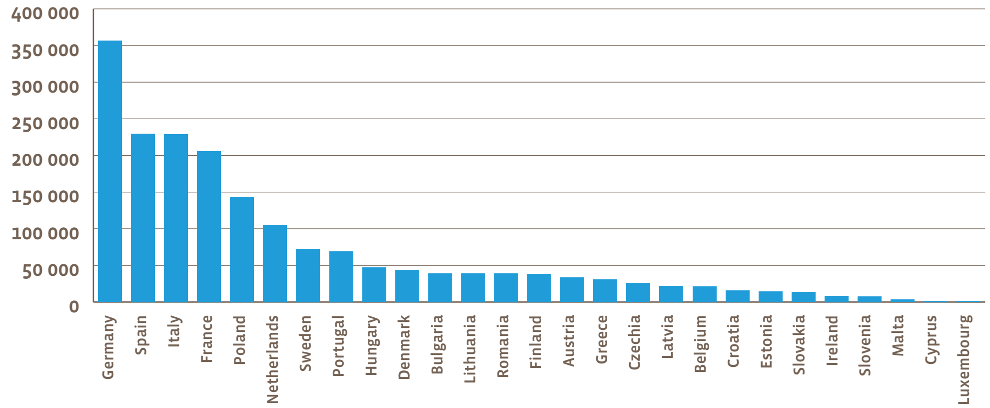
Source: EurObserv'ER

RENEWABLE ENERGY DEVELOPMENT AND ITS INFLUENCE ON FOSSIL FUEL SECTORS

The deployment of renewable energy technologies can have an impact on the economic activity in other sectors and on the fossil fuel based energy sector. In this section EurObserv'ER indicatively estimates this substitution effect, assessing how much employment would be required in the fossil fuel sector if renewable generation would not have displaced fossil based energy. The displacement is formulated in terms of substituted final energy demand. We stress that this is only a partial coverage of more complex real-world interaction between renewable and fossil fuel sectors. This 2024 edition of 'The State of Renewable Energy in Europe' covers the indicator for equivalent replaced fossil employment for all Member States of the European Union, for the year 2023. The effect is estimated for the following six subsectors: power generation, mining, oil for power generation, refining, heat production and extraction and supply of crude oil and fossil gas. The evaluation has been conducted in terms of direct jobs. Our approach only covers the effects on operation and maintenance (O&M) and fuel production activities (effects on O&M are assumed to be proportional to the displaced production). It must be noted that reduced construction activities of new conventional plants are not considered, but at the same time that opposite effects are not considered: effects that influence the fossil sectors through other mechanisms (for example the impact of gas increase on the coal sector). Establishing a full reference picture is outside the scope of this analysis, so the presented indicator for equivalent replaced fossil employment does not give the full spectrum of effects. The figures show that the effects in the fossil fuel sector vary significantly between Member States. The relative impact on the fossil sector, when compared to the gross renewable employment, is for example of a completely different nature in Hungary than it is in Romania. The reason for this lies in the difference in composition of the fossil fuel sector and in the type of renewable technology that is deployed. Countries that have coal mining activities are more sensitive to the influence of renewables development than countries that import coal for power generation. This has been described in the JRC-report 'EU coal regions: opportunities and challenges ahead'. In our methodology, the employment affected by reduced use of fossil gas in gas extraction, gas conversion and gas transport is assumed to be close to zero, while in the power sector there is an effect.
The type of renewable technology deployed is also an important factor. Technologies that use feedstock (biogas, solid biomass, biofuels and MSW) generate a relatively high amount of jobs per MW. Therefore, development of employment in the production of feedstock for such renewable technologies results in a proportionally smaller impact on the fossil fuel sector than the development of, for example, the wind industry. ■

1

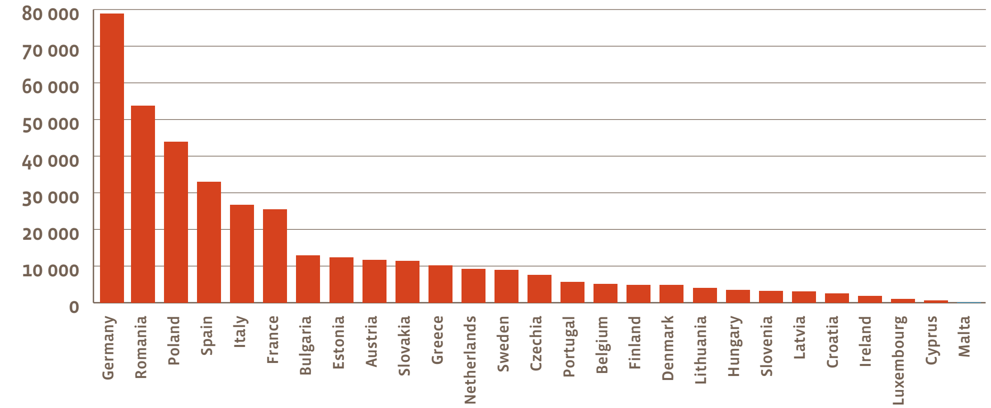
Gross renewable employment from previous sections (data for 2023)



Source: EurObserv'ER

2

Indicator for equivalent replaced fossil employment, looking at operation, maintenance, and fuel production activities only (data for 2023)



Source: EurObserv'ER

INVESTMENT INDICATORS

In this chapter, Eurobserv'ER presents indicators that shed light on the financing side of RES. The investment indicators cover the investment in the application of RE technologies (e.g. building power plants), referring to the asset finance in newly built capacity for all RES sectors in all EU Member States. The EurObserv'ER investment indicators focus on investment in RES capacity, i.e. investments in RES power plants (asset finance). Hence, an overview of investments in capacity across RES in the EU Member States is provided. Furthermore, average investment costs per MW of capacity are calculated for the EU.

Asset finance data is derived from various data sources, including national statistics bureaus, Eurostat, the International Energy Agency (IEA) Photovoltaic Power Systems Programme (PVPS), WindEurope, and Bloomberg reports. It should be mentioned that the data on asset finance presented in this edition cannot be compared to the data in the previous overview barometers. The reason is that the data sources have been changed due to limited resources. The data sources in this barometer cover investment information of renewable energy plants from residential to utility-scale, whereas the previous overview barometers cover only renewable investment in utility-size RES power plants. The methodology has been adjusted accordingly. Hence, the comparability of the figures between this and the previous overview barometers is limited.

Investment in Renewable Energy

Methodological note

Asset finance covers all investments into renewable energy generation projects, including not only utility-scale but also small-scale power plants in the residential sector. The investment indicators are derived from various data sources depending on the RE technology. It is to be noted that the data covered in the previous barometers is deal-based. In this overview barometer, the data is collected differently depending on the data sources. For investment in the wind power sector, asset finance refers to the financing publications from WindEurope, which covers the wind onshore and wind offshore projects in Europe in the analysed years.
As for solar photovoltaic, the annual national survey reports and trends reports from the International Energy Agency (IEA) Photovoltaic Power Systems Programme (PVPS) are referred to. The reports covered, among all, the market and cost development of solar photovoltaics in the focused countries. The data covered in these reports are mainly survey-based. Moreover, investment indicators for the other Member States, which are not disclosed in these reports, are estimated based on capacity added derived from Eurostat, the specific capital expenditure from reports for the neighbouring Member States and the chapter Renewable energy costs and prices.
Besides the above-mentioned sources, national statistics bureaus and Eurostat are also used to complete the analysis qualitatively and quantitatively. Note that the asset finance data does not give an indication of when the capacity will be added. In some cases, the construction starts immediately, while in several cases a financial deal is signed for a project, where construction starts several months (or sometimes years) later. Hence, the data of the associated capacity added shows the estimated capacity added by the asset finance deals closed in the respective year. This capacity might be added either already in the respective year or in the following years.

Bloomberg Energy Transition Investment Trends 2024 reports an investment in the energy transition of $360 billion in EU member states in 2023, doubling the investment volume in 2022. The energy transition investment includes investments in renewable energy, energy storage, electrified transport, electric heat, nuclear, hydrogen, CCS and sustainable materials. Among all EU member states, Germany, France, Spain and Italy invested $95 billion, $55 billion, $32 billion and $30 billion respectively in these low-carbon fields. A lot of momentum has been observed in the electric vehicle market and renewables. Especially in Germany and France, more than half of the investment volume was spent on electrified transport, followed by renewables. In Italy, the investment volume was distributed quite evenly among electrified transport, renewable energy and other fields, while the investment in Spain focused mainly on renewable energy.
The following sections analyse in detail the investments in onshore wind, offshore wind and solar photovoltaic in the EU Member States, with a focus on the asset finance and associated capacity added in 2022 and the first insights in 2023.

WIND POWER

Investments in wind power have slowly recovered from the difficult macroeconomic circumstances. Investments in new capacity in 2022 have dropped substantially to € 14.7 billion in both onshore and offshore wind sectors and reached the lowest since 2009. Despite the limited country-specific information for 2023, WindEurope discloses that the total investments in wind capacity in Europe in 2023 bounced back to around € 48 billion in 2023, of which the EU is estimated to contribute € 39 billion. Correspondingly, the associated capacity added increased by 74% from 11 GW to 18 GW.

Among all Member States, Germany led in wind investment with € 2.4 billion in 2022, which increased almost four-fold to € 8.3 billion in 2023. Finland invested the second most in the wind sector with € 2.1 billion in 2022, followed by Poland and Sweden with each investing almost € 2 million.

STEADY INCREASE IN ONSHORE WIND INVESTMENTS, LED BY GERMANY

The investments in 2022 concentrated almost completely on onshore wind. In 2023, the investment volumes for both onshore and offshore wind increased, with more investments in offshore wind projects. Onshore wind investments in the EU reached € 14.3 billion in 2022 and increased to around € 18 billion in 2023, accounting for 97% and 47 % of the total wind investments respectively.

Among all 27 EU Member States, Germany not only led in the total wind investments but also in onshore wind investments with around € 2.4 billion in 2022, which increased almost three-fold to € 7 billion in 2023. Finland was the only other Member State to invest over € 2 billion in 2022. Moreover, Spain, Sweden and Poland have relatively large onshore markets and low investment costs at the same time in 2022. At a similar level of investment costs, Croatia and Romania only invested a few onshore projects, summing up to € 0.3 billion for each country in 2022.

1

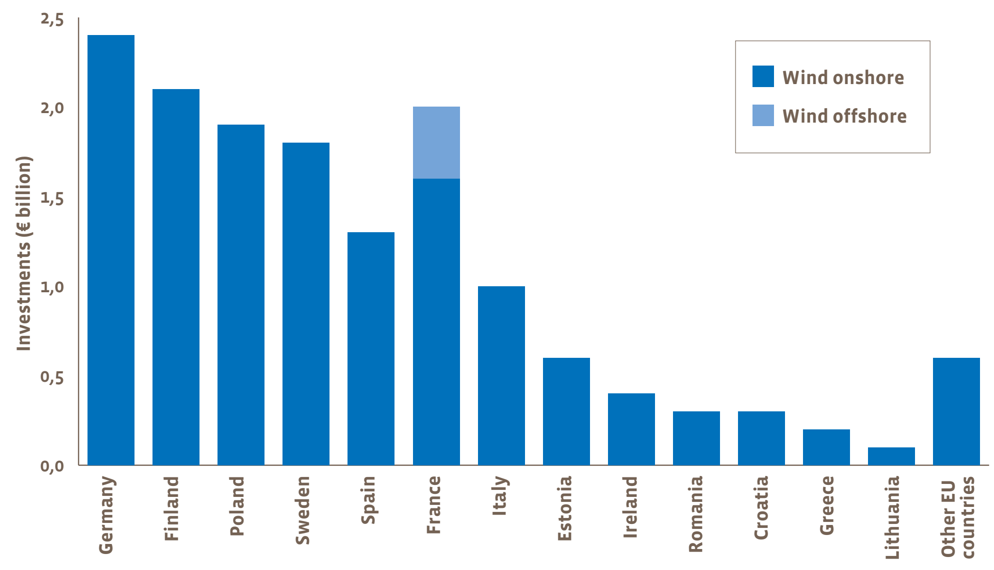
Overview of asset finance in the wind power sector (onshore + offshore) in the EU Member States in 2022

	2022	
	Asset finance - newly built (€ bn)	Associated capacity added (GW)
Germany	2.4	1.7
Finland	2.1	1.5
Poland	1.9	1.5
Sweden	1.8	1.4
France	1.6	0.9
Spain	1.3	1.1
Italy	1.0	0.7
Estonia	0.6	0.4
Ireland	0.4	0.3
Croatia	0.3	0.2
Romania	0.3	0.3
Greece	0.2	0.2
Lithuania	0.1	0.1
Other EU countries	0.6	0.3
Total EU-27	**14.7**	**10.5**

Source: own assessment based on WindEurope and Eurostat.

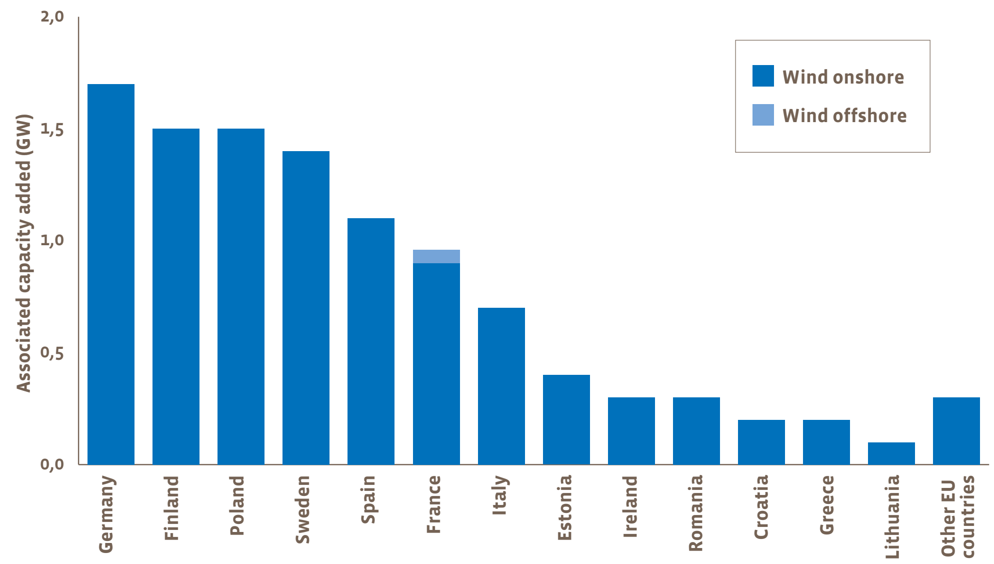
2

Asset finance in the wind power sector in the EU Member States in 2022



3

Associated capacity added (GW) in the wind power sector in the EU Member States in 2022



Source: own assessment based on WindEurope and Eurostat

2

Overview of asset finance in the onshore and offshore wind sector in the EU Member States in 2022

	Onshore		Offshore	
	Asset finance - newly built (€ bn)	Associated capacity added (GW)	Asset finance - newly built (€ bn)	Associated capacity added (GW)
Germany	2.4	1.7	-	-
Finland	2.1	1.5	-	-
Poland	1.9	1.5	-	-
Sweden	1.8	1.4	-	-
Spain	1.3	1.1	-	-
France	1.2	0.8	0.4	0.1
Italy	1.0	0.7	-	-
Estonia	0.6	0.4	-	-
Ireland	0.4	0.3	-	-
Croatia	0.3	0.2	-	-
Romania	0.3	0.3	-	-
Greece	0.2	0.2	-	-
Lithuania	0.1	0.1	-	-
Other EU countries	0.6	0.3	-	-
Total EU-27	14.3	10.4	0.4	0.1

Source: own assessment based on WindEurope and Eurostat.

Consequently, the associated onshore wind capacity increased from 10.4 GW in 2022 to 12 GW in 2023. In 2022, Germany also led the associated capacity added with 1.7 GW, followed by Finland and Poland with 1.5 GW each.
Corresponding to the asset finance increase of 26%, the associated capacity added in the EU has also increased by 14% from 2022 to 2023. This indicates a slight rise in investment costs in the onshore wind sector, from € 1.4 million per MW in 2022 to € 1.5 million per MW in 2023.

RECOVERY OF INVESTMENT IN OFFSHORE WIND

After two years of setbacks caused by special macroeconomic circumstances, the offshore wind sector has finally bounced back from almost no investment in 2022 to € 21 billion in 2023. Nevertheless, the investments in offshore wind plants were still lower than the investment record achieved in 2020. As for the estimated associated capacity added, it increased, even stronger than the investment volumes, from 0.1 GW in 2022 to 6 GW in 2023.

In 2022, the only investment decisions were made in France for two offshore demonstration projects, summing up to € 0.4 billion and associated with 60 MW. Due to the lack of investments, no conclusive observation can be made on the development of investment costs in the offshore wind sector for 2022. Nevertheless, falling investment costs in the offshore wind sector in 2023 can be observed, decreasing from € 3.7 million per MW in 2021 to € 3.2 million per MW in 2023. ■

PHOTOVOLTAIC

When analysing investments in solar PV, two points are particularly important to be kept in mind. First of all, asset financing in the EurObserv'ER report before the edition 2019 only contains utility-scale investments. Starting from the EurObserv'ER report edition 2022, the estimated investment data includes not only utility-scale PV investments but also small-scale investments, i.e. PV installations with capacities below 1 MW, which make up the largest share in PV installations in most of the EU countries.
Overall, the total investment in solar PV in the EU-27 Member States was estimated to reach € 39 billion in 2022, increasing by 18% compared to 2021. The estimated investment volume in 2022 was associated with a total capacity added of 38.7 GW. Around 84% of the investments were evenly distributed in plant size below 30 kW and in utility-scale installations over 1 MW. Due to the limited availability of investment information for the year 2023, no estimation for the total investment in all Member States is made. Nevertheless, the estimated investments in Member States with available information have already shown higher total investment volume as well as higher capacity added in 2023 than in 2022.

GERMANY, SPAIN AND THE NETHERLANDS REMAINED THE TOP THREE OF THE PV MARKET

Thanks to more than doubled the associated capacity added, Germany continued to lead the investment volume in solar PV, with € 7.5 billion in 2022 and € 17.8 billion in 2023. Spain remained the second place, increasing the investment volume by 160% from € 6.4 billion in 2022 to € 16.6 billion in 2023. The Netherlands followed with € 4 billion in 2022 and € 8.9 billion in 2023. Thanks to the high share of utility-scale installations (over 1 MW), Spain invested in more capacity with less expenditure and surpassed Germany in associated capacity added with 8.6 GW in 2022, while the investments in Germany were associated with 7.2 GW in the same year. In 2023, the specific investment costs for utility-scale PV increased while the specific costs for other sizes decreased. Together with the drastic increase in the PV projects in 2023, Germany ranked the first in the associated capacity added with 15 GW, followed by Spain with 9 GW.
The third place in terms of the most associated capa- ↘

1

Overview of estimated investment in the solar photovoltaic sector (residential + commercial) in the EU Member States in 2022

2022		
	Estimated investment (€bn)	Associated capacity added (MW)
Germany	7.5	7 193
Spain	6.4	8 621
Netherlands	4.1	3 900
Poland	3.8	3 630
Italy	2.9	2 490
France	2.6	2 966
Denmark	1.6	1 573
Hungary	1.3	1 267
Greece	1.2	1 153
Austria	1.2	1 009
Belgium	1.2	744
Sweden	1.1	798
Portugal	0.9	890
Slovenia	0.6	165
Lithuania	0.5	317
Bulgaria	0.5	462
Romania	0.4	415
Czechia	0.4	227
Finland	0.3	274
Latvia	0.2	106
Estonia	0.2	125
Other EU countries	0.4	357
Total EU-27	**39.2**	**38 682**

Source: own assessment based on IEA and Eurostat

2

Overview of estimated investment in the solar photovoltaic sector (residential + commercial) in the EU Member States in 2023

2023		
	Estimated investment (€ m)	Associated capacity added (MW)
Germany	17.8	15 005
Spain	16.6	8 987
Netherlands	8.9	4 788
Italy	6.0	5 255
France	4.3	3 961
Poland	3.6	3 630
Belgium	3.3	1 806
Austria	3.3	2 603
Portugal	2.4	1 284
Sweden	1.7	1 602
Czechia	1.4	847
Bulgaria	0.9	1 171
Denmark	0.7	488
Ireland	0.5	544
Slovenia	0.4	405
Finland	0.4	318
Cyprus	0.2	157
Malta	0.02	16

Source: own assessment based on IEA and Eurostat

city belonged to the Netherlands with 4 GW in 2022, which was taken over by Italy with 5 GW in 2023. Overall, the observation suggests the investment costs of PV have been decreasing since 2021.

The distribution of EU PV investments varies considerably across Member States, which also changes year by year. Spain, as an example, focused more on utility-scale grid-connected power plants, which contributed to 73% and 79% of the total investments in 2022 and 2023 respectively. Sweden and Czechia, on the other hand, concentrated on distributed installations smaller than 30 kW with 74% and 86% respectively of the investment in 2023, while these shares were even higher (over 90%) in 2022. ■

RENEWABLE ENERGY COSTS AND PRICES

One of the important drivers in renewables' deployment is their competitiveness. Energy from renewable technologies comes at a cost of the energy, and it competes with conventional energy carriers: fossil fuels and electricity generated from fossil fuels. Through deployment and technology learning the costs of renewable energy may go down, whereas costs for fossil fuels are also fluctuating, for reasons of geopolitical developments and market effects (demand versus supply). This section focuses on renewable energy costs and conventional energy prices. In order to calculate the levelized cost of energy (LCoE) for renewables we present renewable technology investment costs based on literature, an approach to estimate the weighted average cost of capital (WACC) and then the resulting LCoE values.

Finally, EU (weighted) average prices for electricity and gas are presented for households and non-households, including their breakdown in price components. These complete the picture of competitiveness: renewable energy costs (excluding taxes and levies) in the first sections versus actual energy prices (including taxes and levies) in the closing section.

Investment cost data for Europe

INVESTMENT COSTS

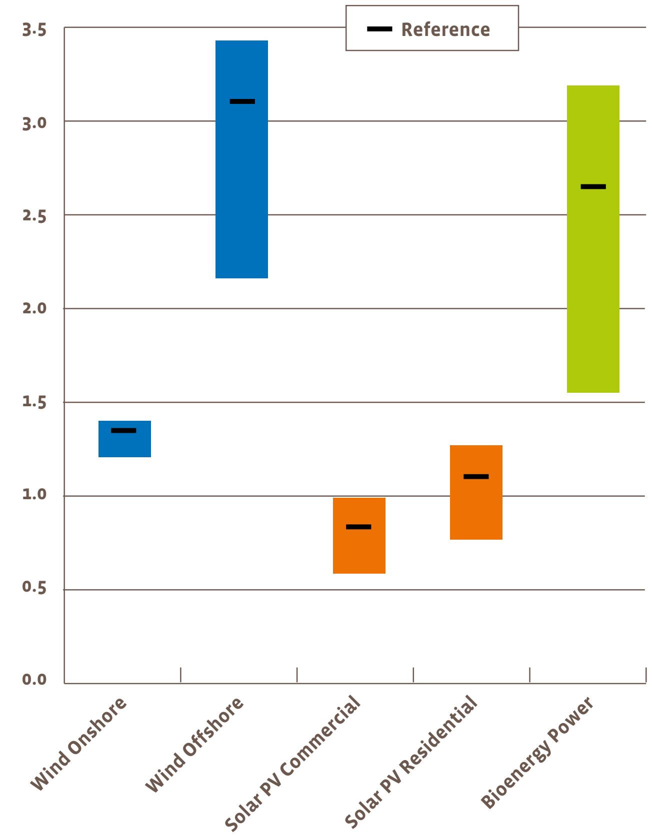
Over the past decades the trend in renewable energy was relatively stable: for solar pv and wind power overall ever lower specific investment costs and increasing energy yields, resulting in lower levelised cost of energy (LCoE) each year. Some periods have shown increased investment costs, but this always appeared temporarily. Additionally, financing costs have shown both increases and decreases during certain periods in time, depending on macro-economic circumstances and technology maturity. In previous EurObserv'ER Barometers the cost decreases were reported in comparison to the year 2005, which showed strong reductions in investment costs for solar pv and wind power. In this edition of the EurObserv'ER Barometer focus is on more recent cost figures.

We'll base the investment cost estimate on a range from literature, with 2024 as a reference year. Source is JRC (2018), which provides technology cost projections.
In the investment cost approach based on the data from JRC (2018) data ranges are defined, which are fed into a Monte Carlo analysis (more info in the section on the levelized cost of energy). In the previous EurObserv'ER Barometer we performed an analysis in which estimates from IRENA (2022) were compared to the extrapolated JRC investment cost estimates, and we found that the ranges used in our approach generally were comparable. In this edition we do not repeat this exercise, but we opt for investment costs that are projected for the year 2024, based on JRC (2018). For O&M-costs we equally refer to the data from JRC (2018).

Jacques Basile

1

Renewable energy investments costs estimated for the year 2024 (M€/MW)



Note: The estimates were based on JRC (2018) and will be used in the LCoE section

It can be observed from Figure 1 that the data ranges are larger for certain technologies compared to others. Wider ranges occur for the innovative technologies such as offshore wind, for which multiple countries are developing farms. Furthermore, local, national and regional circumstances also influence the project investment cost level. Onshore wind power has a narrow bandwidth, but surely projects will exist that fall outside the depicted range. For solar PV two variants are depicted: large scale commercial PV and residential PV. Economies of scale determine the lower investment costs for large PV projects, whereas residential PV has, considered over time, seen important investment cost decreases. The ranges in investment costs are relatively narrow for both solar PV categories. For bioenergy power generation a fluidised bed boiler is taken as a reference, which burns biomass feedstock and provides steam to a steam turbine, and for which investment costs vary considerably.
Another parameter that influences the resulting energy generation costs is the way financing is organised. For calculating the levelized cost of energy (LCoE), project financing is assumed. Project financing is a possible way in which renewable energy technologies are set up: a loan from a bank and own funds (equity) are applied to develop the project and start producing renewable energy. The sales of the renewable electricity, heat or bio-based energy carriers generate income that is used to pay back the loan and to give a reasonable financial return to the investors. The conditions against which loans can be obtained differs from country to country, and differs between different technologies. The weighted average cost of capital (WACC) is a parameter that describes this, and it is introduced in the next section. ■

Weighted average cost of capital (WACC)

The Weighted Average Cost of Capital (WACC) is used to measure the financing costs for a company or project. It is the average, after-tax cost of raising debt and equity capital from different sources. The WACC is not typically a value that is publicly available for individual companies or projects. It is built up of various underlying parameters: equity and debt proportions to total capital; the cost of equity and cost of debt; and the corporate tax rate. Most renewable energy projects for power production are characterised by high up-front capital expenditures, which means that the level of the WACC has a critical impact on the indicators such as the Levelized Cost of Energy (LCoE). Estimating the WACC for different renewables energy technologies across the 27 EU Member States provided a basis for the LCoE calculations in the next section.

Our approach to estimating the WACC is a combination of bottom-up data collection and expert judgement about the various WACC components. An alternative approach would be to carry out a pan-European survey of projects that are implemented with the different technologies in different Member States. Since the WACC also changes over time depending on various factors, such as prevailing economic conditions, policy consistency, technological developments, etc, the estimation approach allows for consistency in results over time, which is an important advantage.

The technology risk categories, cost of equity percentages and debt shares that are used in our cost of capital calculations are shown in Table 1.

Methodology breakdown

We collect data for bottom-up parameters to build the debt and equity components of the cost of capital. The debt interest rate[1], corporate tax rate[2] and the debt share[3] are percentages that are multiplied to calculate the total cost of debt. For the cost of equity, we start with the cost of equity calculations that are used in the Dutch support scheme Stimulation of sustainable energy production and climate transition (SDE++)[4], which are based on data and expert judgement[5]. In our approach, we assume the same technology risk division for all member states as is applied for the Netherlands in the SDE++ calculations. We use the cost of equity for the Netherlands as the starting point for calculating the cost of equity for other member states. We adjust the cost of equity for each member state by subtracting the risk-free rate[6] of the Netherlands from the cost of equity of the Netherlands, then we add the risk-free rate of each member state. The resulting percentage is then multiplied by the equity share to calculate the cost of equity for each member state. This is the formula used for calculating the cost of equity for each member state:

$$CoE_{MS} = CoE_{NL} - r_{f\_NL} + r_{f\_MS}$$

where CoE is the cost of equity, r_f is the risk-free rate, MS stands for Member State and NL for the Netherlands.

1. *Euro-area-statistics.org. 2024. Euro area statistics. Averaged bank lending rates over small and large loans*
2. *PWC. 2024. Worldwide Tax Summaries. https://taxsummaries.pwc.com*
3. *Source: Eindadvies basisbedragen SDE++ https://www.pbl.nl/sde. Debt shares of low, medium and high risk technologies.*
4. *Source: Netherlands Enterprise Agency (RVO), Stimulation of sustainable energy production and climate transition (SDE++).*
5. *Source: Eindadvies basisbedragen SDE++ https://www.pbl.nl/sde. Debt shares of low, medium and high risk technologies. Cost of equity of low, medium and high risk technologies.*
6. *Body of European Regulators for Electronic Communications (BEREC), 2024. BEREC Report on WACC parameter calculations according to the European Commission's WACC Notice of 6th November 2019 (WACC parameters report 2024). European Commission. Risk free rates for all EU-27 countries based on S&P country credit ratings.*

Further explanation of SDE++ risk distinctions

In the Dutch subsidy scheme, SDE++, a distinction is made between low, medium and high risk technologies when calculating the cost of equity. Technologies categorised as low risk are mainstream technologies such as onshore wind and solar PV. There is a pipeline of projects being developed and both project developers and financiers have gained extensive experience in developing and structuring projects, reducing risks over time to current low levels. High risk are innovative technologies such as aquathermal, geothermal and biomass digestion that still need further development, have not yet been widely deployed and/or where there is strong dependence on third parties and at the same time scarcity of supply (e.g. in biomass procurement). These technologies are characterised by higher operational risks and sometimes policy risks. Technologies with a medium risk (e.g. hydropower, solar thermal) are well developed but can be deployed to a limited extent or only on a small scale, making project risks higher. For offshore wind, no financing parameters are set within the SDE++. As indicated below, the risk of offshore wind is considered to be low to medium, but on reflection we assume medium rather than low risk for this technology. This is because larger and more technologically innovative wind turbines are installed offshore in comparison to onshore. More innovative turbines entail greater risks, and the marine environment increases the risk of failure. The higher the risks, the higher the required return, and this is reflected in our cost of equity calculations for offshore wind.

1

Technology risk categories, cost of equity percentages and debt to equity ratios by technology

	Wind onshore	Solar PV	Wind offshore	Hydropower	Bioenergy and other technologies
Technology risk	Low	Low	Medium	Medium to High	High
Cost of equity	8%	7%	8%	9%	11.5%
Debt to equity ratio					
minimum	*60/40*	*70/30*	*65/35*	*60/40*	*50/50*
average	*70/30*	*80/20*	*75/25*	*70/30*	*60/40*
maximum	*80/20*	*90/10*	*85/15*	*80/20*	*70/30*

Source: EurObserv'ER

DISCUSSION ON METHODOLOGY

The methodology we use is a best effort bottom-up approach based on literature review and expert judgement. To improve the methodology assumptions and data, further research is required to identify better data sources and make more accurate estimates of some of the WACC components, in particular the cost of equity. It is important to use reliable data sources, and preferably sources that are annually updated. Furthermore, the key assumptions underlying our approach involve similar technology risks across different member states. For future research, these simplifying assumptions should be addressed.

UPDATES ON WACC PARAMETERS

The WACC values shown in this report are calculated using the most current data available (2024). The methodology uses consistent data and calculations, and provides a more up-to-date, representative overview of the WACC for the EU-27 member states.

The wind power and solar PV categories are more advanced than other technologies and more widely deployed and are thus considered mainstream technologies. For these, operational and policy risks are significantly lower than for the other categories. This is evidenced in part by availability guarantees issued by technology suppliers as standard for wind and solar PV. Returns on equity for solar PV and wind power are also reduced by one percentage point from the previous year to 7.0 and 8.0 percent, respectively.

For categories with significantly higher operational risk or policy risk, bioenergy and other technologies, the return on equity is unchanged at 11.5 percent. This is because these are higher-risk categories, e.g., because of a strong dependence on third parties with scarcity of supply, as in the procurement of raw materials such as biomass.

The observed equity shares in recently financed or to be financed renewable energy projects in the Netherlands range from below 5 percent to above 40 percent. As a guide value, 30 percent equity has been calculated. Exceptions to this are the solar PV categories, for which this share is lower.

During the SDE++ market consultation, various parties argued that with rising interest rates, projects must pay more in interest and loan repayments and can no longer meet the Debt Service Coverage Ratio (DSCR) requirements of banks. To avoid this, developers are trying to extend the term of the loan to 20 years and prepare for other financial methods to secure income after the subsidy period. Despite this, developers have been forced to raise more equity and the leverage for solar PV and wind projects has been adjusted accordingly. Therefore, we decreased the debt to equity ratio of solar PV to 80% / 20%, while we decreased the ratio for wind energy to 70% / 30%. For the other technologies, the current debt and equity is adequate and therefore has not been changed. The debt to equity ratio therefore remains 70% / 30% for bioenergy and other technologies.

We observe that for the low-risk technologies, such as wind onshore and solar PV, the WACC values range from as low as between 3-4% in some Member States (e.g., Germany, Netherlands, Luxembourg) to above 5-6% in other Member States (e.g., Greece, Romania, Poland). For the higher risk technologies, such as bioenergy, the WACC estimates range from between 6-7% in some Member States (e.g., Austria, Belgium, Germany) to 8-9% in other States (e.g., Poland, Hungary, Romania). This can be interpreted as follows: for technologies that are considered relatively mature, and have been deployed at scale, and in member states that have stable economic and political conditions, the WACC is typically lower. The WACC is higher in member states that have low deployment rates for technologies and where the economic and political conditions are less favourable.

The financing conditions are most favourable for onshore wind and solar PV in western European Member States, such as Luxembourg, Germany, France and the Netherlands. At the other end of the spectrum, less favourable financing conditions appear to be available for all technologies in Eastern European Member States, in particular in Hungary, Romania and Poland, and especially for technologies that are considered riskier to deploy.

In conclusion, the final WACC values have decreased across almost all technologies and member states in 2024, compared to 2023. This effect can be explained mainly by the decrease in debt interest rates. Decreasing interest rates lower the cost of debt, making borrowing cheaper, which in turn reduces the overall WACC. The risk-free rate of most EU-27 countries increased and the debt to equity ratios for solar and wind decreased, which would typically exert upward pressure on WACC. However, the impact of declining interest rates and other positive factors outweighed the effect of the rising risk-free rates and decreasing debt to equity ratios, resulting in an overall decrease in final WACC values. The WACC values are used, together with the assumptions on investment costs, operation and maintenance costs, energy yield and lifetime assumptions to estimate the Levelized Cost of Energy (LCoE), which will be presented next. ■


SNCF

2

Estimates for national values for the Weighted Average Cost of Capital (WACC) in 2024, broken down into technology and per member state.

	Wind onshore			Wind offshore			Solar PV			Hydropower			Bioenergy and other technologies*		
	Low estimate	Average estimate	High estimate	Low estimate	Average estimate	High estimate	Low estimate	Average estimate	High estimate	Low estimate	Average estimate	High estimate	Low estimate	Average estimate	High estimate
Austria	4.2%	4.7%	5.2%	n. a.	n. a.	n. a.	3.6%	4.0%	4.4%	4.4%	5.0%	5.6%	5.8%	6.6%	7.5%
Belgium	4.3%	4.8%	5.3%	4.0%	4.5%	5.0%	3.7%	4.1%	4.5%	4.5%	5.1%	5.7%	5.8%	6.7%	7.5%
Bulgaria	5.4%	5.8%	6.2%	n. a.	n. a.	n. a.	5.0%	5.2%	5.5%	5.6%	6.1%	6.6%	6.9%	7.6%	8.4%
Croatia	4.8%	5.3%	5.8%	n. a.	n. a.	n. a.	4.1%	4.6%	5.0%	5.0%	5.6%	6.2%	6.3%	7.2%	8.1%
Republic of Cyprus	5.1%	5.6%	6.1%	n. a.	n. a.	n. a.	4.5%	4.9%	5.3%	5.3%	5.9%	6.5%	6.6%	7.5%	8.3%
Czech Republic	5.4%	5.9%	6.5%	n. a.	n. a.	n. a.	4.7%	5.2%	5.6%	5.6%	6.2%	6.9%	7.0%	7.9%	8.8%
Denmark	4.4%	4.8%	5.3%	4.2%	4.6%	5.1%	3.8%	4.2%	4.5%	4.6%	5.1%	5.7%	5.9%	6.7%	7.5%
Estonia	6.1%	6.4%	6.7%	n. a.	n. a.	n. a.	5.6%	5.9%	6.1%	6.3%	6.7%	7.1%	7.4%	8.1%	8.8%
Finland	4.4%	4.9%	5.4%	4.2%	4.6%	5.1%	3.8%	4.2%	4.6%	4.6%	5.2%	5.8%	5.9%	6.8%	7.6%
France	4.2%	4.7%	5.2%	3.9%	4.4%	4.9%	3.6%	4.0%	4.4%	4.4%	5.0%	5.6%	5.7%	6.6%	7.5%
Germany	4.1%	4.5%	5.0%	3.8%	4.3%	4.8%	3.5%	3.9%	4.2%	4.3%	4.8%	5.4%	5.6%	6.4%	7.2%
Greece	4.9%	5.5%	6.1%	n. a.	n. a.	n. a.	4.3%	4.7%	5.2%	5.1%	5.8%	6.5%	6.6%	7.5%	8.4%
Hungary	6.2%	6.9%	7.6%	n. a.	n. a.	n. a.	5.3%	6.0%	6.6%	6.4%	7.2%	8.0%	7.9%	9.0%	10.1%
Ireland	5.2%	5.6%	6.0%	5.1%	5.4%	5.8%	4.8%	5.0%	5.3%	5.4%	5.9%	6.4%	6.7%	7.4%	8.1%
Italy	4.7%	5.3%	5.9%	4.4%	5.0%	5.6%	4.0%	4.5%	5.0%	4.9%	5.6%	6.3%	6.3%	7.3%	8.2%
Latvia	5.8%	6.1%	6.5%	n. a.	n. a.	n. a.	5.3%	5.6%	5.8%	6.0%	6.4%	6.9%	7.2%	7.9%	8.6%
Lithuania	5.3%	5.7%	6.0%	n. a.	n. a.	n. a.	4.9%	5.1%	5.4%	5.5%	6.0%	6.4%	6.7%	7.4%	8.2%
Luxembourg	3.8%	4.4%	4.9%	n. a.	n. a.	n. a.	3.2%	3.6%	4.1%	4.0%	4.7%	5.3%	5.4%	6.3%	7.2%
Malta	4.4%	5.0%	5.5%	n. a.	n. a.	n. a.	3.7%	4.2%	4.7%	4.6%	5.3%	5.9%	6.0%	6.9%	7.8%
Netherlands	4.2%	4.6%	5.1%	3.9%	4.4%	4.9%	3.6%	4.0%	4.3%	4.4%	4.9%	5.5%	5.7%	6.5%	7.3%
Poland	5.5%	6.2%	6.9%	n. a.	n. a.	n. a.	4.8%	5.3%	5.9%	5.7%	6.5%	7.3%	7.2%	8.3%	9.3%
Portugal	4.5%	5.1%	5.6%	4.3%	4.8%	5.3%	3.9%	4.3%	4.8%	4.7%	5.4%	6.0%	6.1%	7.0%	7.8%
Romania	5.5%	6.4%	7.3%	n. a.	n. a.	n. a.	4.6%	5.3%	6.1%	5.7%	6.7%	7.7%	7.5%	8.7%	9.9%
Slovakia	5.0%	5.4%	5.9%	n. a.	n. a.	n. a.	4.4%	4.8%	5.1%	5.2%	5.7%	6.3%	6.5%	7.3%	8.1%
Slovenia	4.6%	5.1%	5.6%	n. a.	n. a.	n. a.	4.0%	4.4%	4.8%	4.8%	5.4%	6.0%	6.1%	7.0%	7.8%
Spain	4.3%	4.8%	5.4%	4.0%	4.6%	5.1%	3.6%	4.1%	4.5%	4.5%	5.1%	5.8%	5.9%	6.8%	7.7%
Sweden	4.4%	4.8%	5.3%	4.1%	4.6%	5.1%	3.8%	4.2%	4.5%	4.6%	5.1%	5.7%	5.9%	6.7%	7.5%

Other technologies include geothermal, biogas and solid biomass. n. a.: not available.* ***Source: EurObserv'ER*

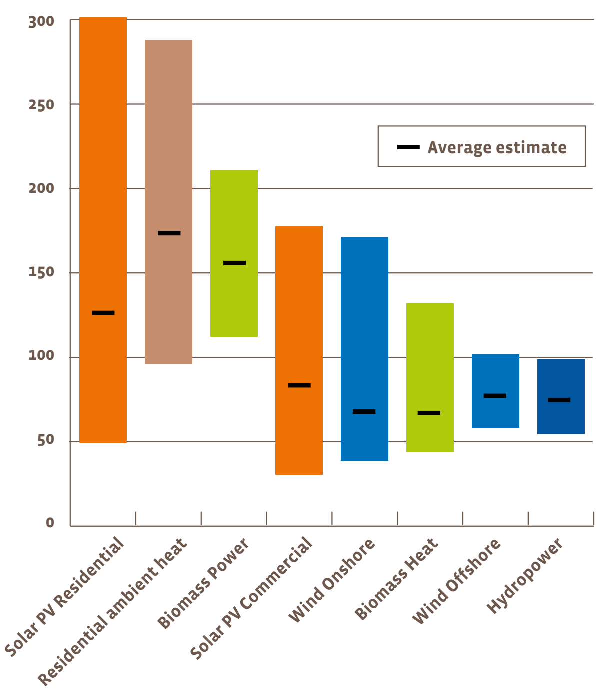
Levelised cost of energy

In this section, levelised costs of energy (LCoE, in €/kWh or €/MWh) are estimated for various renewable energy technologies, based on the investment cost ranges and WACC estimates presented in the previous sections. In addition to the WACC estimates and the investment costs, the renewable energy technology LCoE analysis requires a significant amount of data and assumptions on operational expenditures, fuel costs (for biomass technologies), economic lifetime, annual energy production, auxiliary energy requirements (for heat pumps), fuel conversion efficiency and the project duration. All input parameters are defined as data ranges. A Monte Carlo (MC) approach is then applied to perform the LCoE calculation (5 000 MC draws per LCoE value), resulting in LCoE ranges. Whereas technology costs were taken from (JRC 2014 and 2018), fuel price assumptions were borrowed from (Elbersen et al, 2016) and interpolated from modelled data. Although this data source is already a few years old, the data and projections are still valid. This is because the assumptions on technology learning appear to be adequate, but also because data ranges were used that still are wide enough to cover actual costs. In the previous EurObserv'ER State of Renewable Energies in Europe (Edition 2023) a comparison was made to more recent data from IEA and IRENA. From that analysis it followed that the JRC data were still in line with newer estimates. Due attention is paid to the monetary year of the cost data: the LCoE is expressed in euro's of 2023, meaning that inflation is considered in the cost estimates through the application of the harmonised index of consumer prices for the 27 member states of the European Union. Furthermore, locational and operational aspects, but also design choices and energy yields vary across member states, and therefore the estimated LCoE values are presented in data ranges. To give an example: electricity from wind is usually cheaper in areas with high average wind resources, simply because the turbine produces more electricity compared to an area with lower wind speed. This results in roughly the same investment costs, but higher electricity production, hence lower values for the LCoE.

The technologies addressed are: residential ambient heat from heat pumps (an average of ground source, air source and water source heat pumps), bioenergy (power and heat derived from solid biomass), hydropower, solar photovoltaics (PV, commercial and residential), and wind energy (both onshore and offshore). The data ranges for the calculated levelised cost of renewable energy for the European Union are depicted in Figure 1. The technologies generating renewable electricity are solar PV, biomass and wind power and hydropower. Heat generating technologies are biomass heat and ambient heat. Note that the auxiliary electricity used for heat pumps has been kept unaltered from the assumptions in earlier barometers. The same holds for the biomass prices. This means that the changes in LCoE are driven by two effects: technology progress resulting in investment cost changes (following from the JRC report) and macro-economic changes resulting is updated WACC values (see preceding section).

1

Levelised cost of energy in the European Union [€/MWh] based on investment cost estimates for 2024 and WACC data for 2024



Note: based on investment cost estimates for 2024 and WACC data for 2024.
Source: EurObserv'ER

UPDATED LCOE VALUES

Underlying the update of the LCoE estimates are various effects. Firstly, changes in investment cost estimates and updated WACC values, and secondly the considering of inflation through the harmonised index of consumer prices.

RENEWABLE ELECTRICITY

The first observation when looking at Figure 1 is that for all technologies data ranges are reported. For some technologies the ranges are wider than for others. Reasons underlying this is that the yield of renewable energy is depending on climate conditions in the various member states. Solar irradiation for example is higher in Southern Europe than in Northern Europe, which influences the annual electricity generation from similar systems in different regions. Over the past few years, the LCoE from solar PV has continued to decrease, which has been demonstrated in previous versions of 'The State of Renewable Energies in Europe'. Solar PV in the residential sector is small in system size and therefore is relatively expensive. There are less benefits from economies of scale for modules and inverters, and in relative terms, more labour is involved to install the PV system. Although all cost components in a PV system have seen significant cost reductions over the past decades, it remains among the most expensive renewable technology, although that varies strongly from country to country. The average estimated cost level is 128 EUR/MWh for residential solar PV and 82 EUR/MWh for commercial solar PV. From the calculations it follows that bioenergy power generation is roughly between 114 and 211 EUR/MWh across Europe. The average costs for onshore wind power are lower than for commercial PV, with a comparable cost bandwidth. Offshore wind power has a smaller range because not all 27 member states have projects in place and thus variation in energy yield is less pronounced. Hydropower traditionally has been a cost competitive and mature technology for many years in many countries, and the LCoE estimates can be found between 55 and 98 EUR/MWh.

Note that for individual renewable projects, observed cost ranges may be outside the presented data ranges indicated here. The country variations among Member States are a result of differences in assumed yield (for solar energy and wind power) and financing conditions. Country specific LCoE estimates are available for multiple technologies from the EurObserv'ER website. The graph depicted here show aggregate values for the European Union (EU-27).

RENEWABLE HEAT

For the technologies producing heat, bioenergy heat LCoE is relatively low, indicating it is competitive in many countries. According to the analysis, heat captured from ambient heat via heat pumps (through small-scale equipment) shows relatively high LCoE levels. Another reason for the relative high costs of residential heat pumps is that it is an aggregate of various systems, with quite varying costs: ground source, air source and water source heat pumps. Scaling up to collective systems, possibly in combination with district heating, may decrease the costs further. ■

Prices of energy

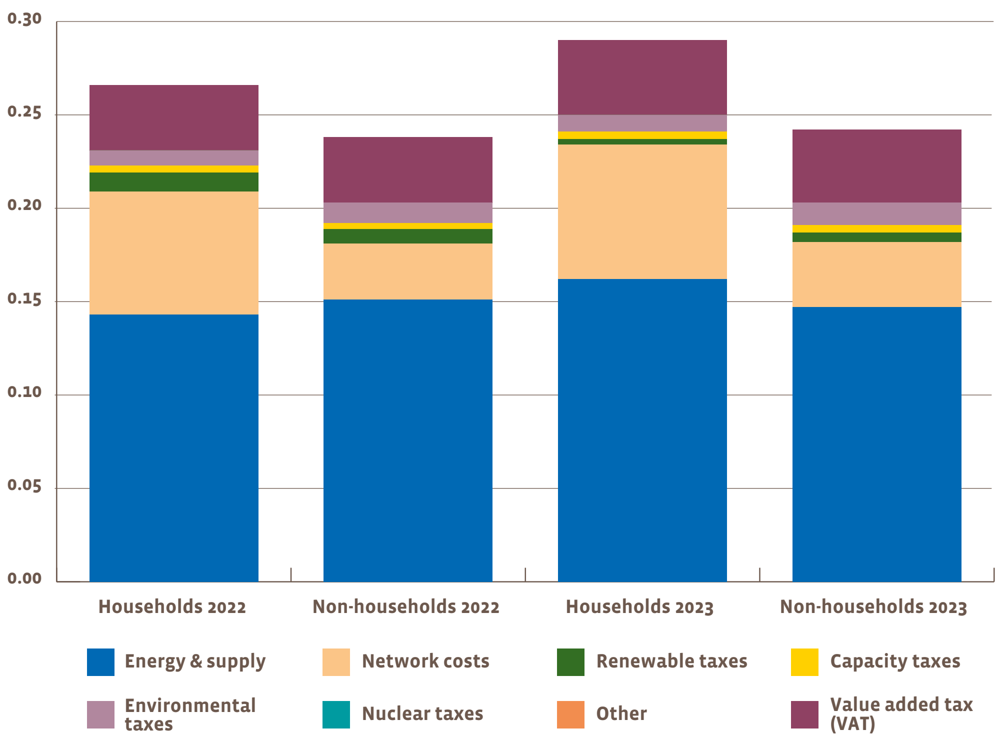
Energy prices for electricity and natural gas are monitored by Eurostat. These prices are listed in Figures 1 and 2 here for the years 2022 and 2023. Energy prices consist of multiple cost components: the cost of the energy carrier itself (energy and supply), network charges and various taxes, fees, charges and levies.

MULTIPLE COMPONENTS IN ENERGY PRICES

For both electricity and natural gas, several price add-ons are imposed on the energy price. Costs related to the network are imposed by the transmission and distribution companies, and represent the upkeep costs for delivering electricity and natural gas to consumers. Taxes, fees, charges and levies are charged by the authorities, which can have different purposes. For example, renewable taxes are imposed on consumers to acquire funds to be redistributed among developers of renewable energy in the form of subsidies. Environmental taxes are usually policy instru-

1

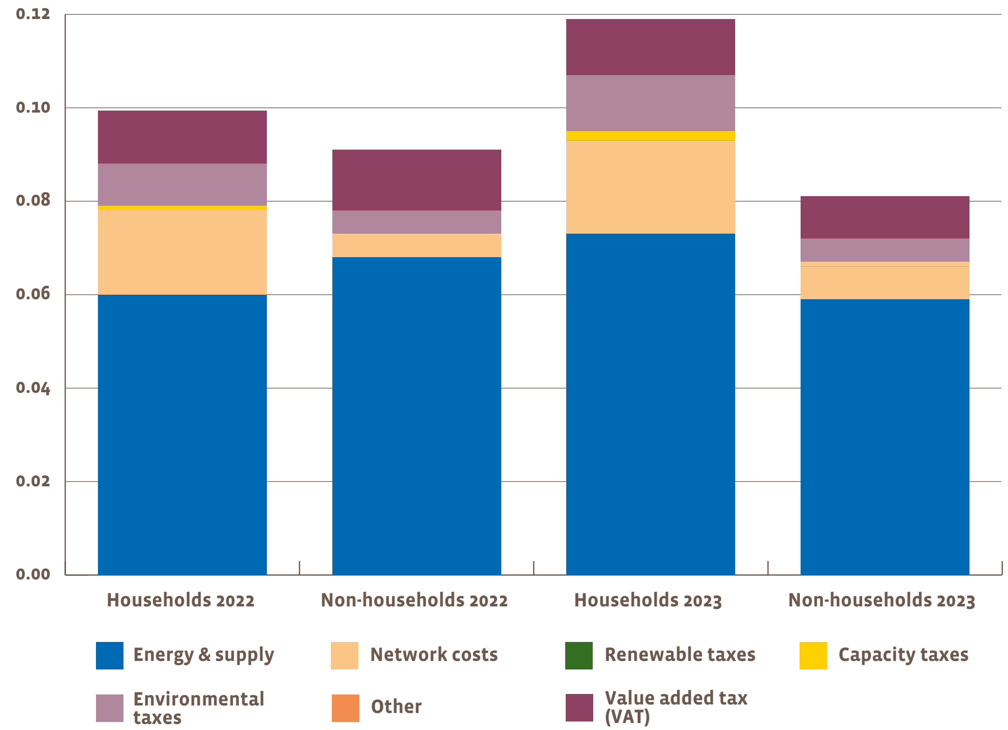
Weighted average electricity prices observed in the European Member States in 2022 and 2023 (€/kWh)



Note: Electricity prices: the electricity price components [EUR/kWh] are based of an average of all electricity consumption bands. Gas prices: the gas price components [EUR/kWh] are based of an average of all gas consumption bands. ***Source: Eurostat***

2

Weighted average natural gas prices observed in the European Member States in 2022 and 2023 (€/kWh)



Electricity prices: the electricity price components [EUR/kWh] are based of an average of all electricity consumption bands. Gas prices: the gas price components [EUR/kWh] are based of an average of all gas consumption bands. ***Source: Eurostat***

ments aimed at changing consumer energy use patterns and they mostly flow into the general budget. The various taxes and allowances have also been used in the past years to compensate end-user prices, both for households and non-households. Capacity taxes refer to the capacity of the consumer's connection. Nuclear taxes are specific to nuclear power generation and only occur in electricity prices in Slovakia. Usually, taxes imposed on household consumers (small consumers compared to most non-household consumers) are relatively high. Renewable and environmental taxes are most important in all taxes. Value added tax (VAT) is imposed on all cost components. The ranges of electricity and natural gas prices observed in the European Member States in 2022 and 2023 are depicted in Figure 1 and Figure 2 respectively, for both households and non-household consumers, and have been taken from Eurostat NRG price tables 202 through 205. ■

AVOIDED FOSSIL FUEL USE AND RESULTING AVOIDED COSTS AND GHG EMISSIONS

MORE RENEWABLE ENERGY MEANS LESS FOSSIL FUELS AND ASSOCIATED COSTS

Progress achieved in EU-wide renewable energy deployment since 2005 is largely attributed to the presence of mandatory national targets. First targets were set for 2020, under the Renewable Energy Directive, or RED (Directive 2009/28/EC).

Looking further, towards 2030, the RED II (Directive 2018/2001/EU) did set a binding EU-wide target of 32 % RES in gross final energy consumption. Member States had to propose an indicative level of effort contributing to the EU binding target for renewables in their first NECPs[1], due by the end of 2019. However, mid 2021 the European Commission adopted the 'fit for 55' package, which adapts existing climate and energy legislation to meet the new EU objective of a minimum 55 % reduction in greenhouse gas (GHG) emissions by 2030. A key element in the 'fit for 55' package is the revision of the Renewable Energy Directive (RED II) and sets a new EU target of a minimum 40 % share of RES in final energy consumption by 2030, accompanied by new sectoral targets. As part of the REPowerEU plan (May 2022), the Commission proposed to further raise this RES target to a 45 % share by 2030. After Trilogue negotiations between the Parliament, the Council and the Commission during 2023, the revised Directive EU/2023/2413 entered into force on 20 November 2023. It sets an overall renewable energy target of at least 42.5% binding at EU level by 2030 - but aiming for 45% and aiming for innovative renewable energy technology of at least 5 % of newly installed renewable energy capacity by 2030.

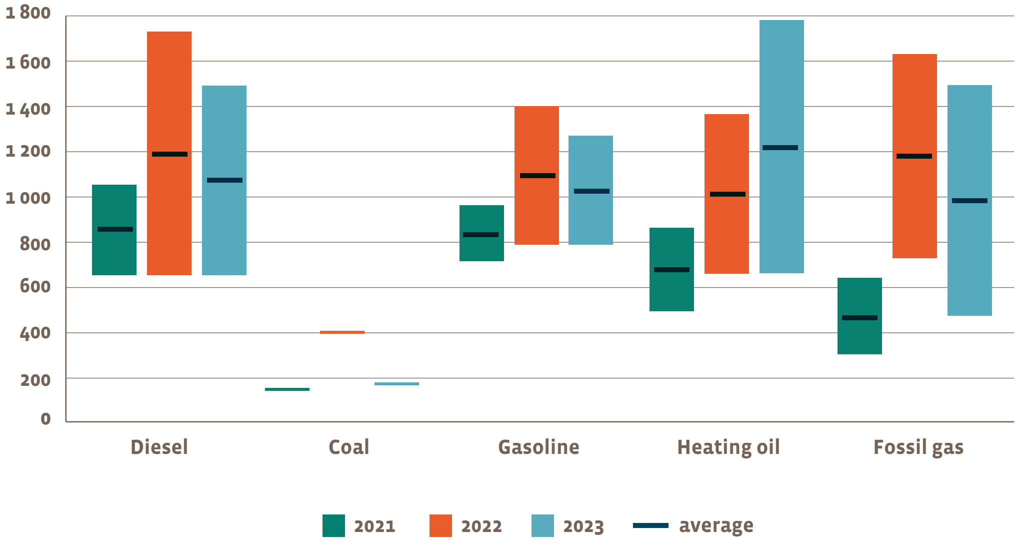
In response to the targets national support instruments were put in place, such as feed-in tariffs, feed-in premiums, auction/tender systems, quotas, tax credits and grants.

The increase in the use of renewable energy leads to less consumption of fossil fuels, both domestic and imported. In this chapter, fossil fuels and non-renewable waste are collectively named fossil fuels. Avoided costs refer to the expenses that do not occur as a result of avoided fossil fuels. These are estimated as follows: cumulative

1. *National Energy and Climate Plans; https://energy.ec.europa.eu/topics/energy-strategy/national-energy-and-climate-plans-necps_en*

1

Fossil fuel prices ranges in the European Union (excluding taxes and levies) (in M€/Mtoe)



Source: Eurostat, European Commission, Nasdaq

amounts of avoided fossil fuels multiplied by the corresponding fuel price levels observed in the various countries.

The amount of avoided fossil fuels is annually analysed by the European Environment Agency ('Renewable energy in Europe 2024 - Recent growth and knock-on effects', (EEA 2024)). The fossil fuel types assumed to be substituted are transport fuels (diesel and gasoline), fuels used for heating (gaseous fuels, petroleum products and non-renewable waste) and fuels used for the production of electricity (a mix of gaseous, solid and oil products). This section makes use of the EEA data as input for the analysis. The avoided fossil fuel costs are based on the country specific fuel prices derived from multiple sources (Eurostat, European Commission, Nasdaq). The figure below highlights the fuel price ranges observed in the 27 EU Member States for 2021, 2022 and 2023 for five energy carriers: coal, diesel, gasoline, natural gas and oil. Prices for coal refer to wholesale prices. For coal no country specific prices are available from the consulted sources and therefore the European price has been taken. Wholesale prices for gas are not available in a continuous timeseries and therefore approximated by prices for band I5[2] for non-household consumers. For transport and heating fuels wholesale prices aren't available, therefore end-user prices are applied as a proxy. These five fuels are assumed to reasonably cover the fuels reported in (EEA, 2024). Note that non-renewable waste has not been priced here as usually the tariff setting of waste is a local issue and not so much driven by a global market.

Looking at the individual energy carriers and their ratios, it can be observed that all fossil fuel prices, except natural gas, decreased to some extent in 2023 after the strong increase in 2022, which was due to the economic recovery after the COVID-crisis, followed by the Russian invasion in Ukraine in 2022 that pushed prices even further up. All observed fuel prices differ widely across member states and along the year and the ranges increased since 2021.

2. Band I5 : 1 000 000 GJ ‹ Consumption ‹ 4 000 000 GJ, gas prices for non-household consumers, nrg_pc_203, Eurostat

EUROBSERV'ER – THE STATE OF RENEWABLE ENERGIES IN EUROPE – 2024 EDITION

Methodological note

- *The focus of the analysis is on the national level, quantifying the avoided costs in the case where all fossil energy carriers are being purchased abroad. As a consequence, all fuel prices considered exclude taxes and levies. Moreover, we do not differentiate caloric values of the fuels to their origin or quality.*
- *For countries producing their own fossil fuels the analysis is similar and no correction is made for the indigenous resources.*
- *The reference is the year 2005. Since progress achieved in EU-wide renewable energy deployment since 2005 is largely attributed to the presence of mandatory national targets for 2020 and for 2030. This is in line with the progress reported by the European Environment Agency (EEA 2024).*
- *The avoided costs through the substitution of natural gas by synthetic natural gas (SNG) is not quantified explicitly.*
- *Only the impact on fossil fuel displacement is being addressed: in the electricity mix nuclear energy is not considered.*
- *Pricing non-renewable waste is not straightforward; therefore, this impact is not quantified in monetary terms.*
- *For liquid biofuels only the biofuels compliant with the Directive (EU) 2018/2001 are included.*
- *Data refer to normalised values for hydropower and wind power.*
- *Energy data [Mtoe] may vary from totals mentioned elsewhere in this EurObserv'ER Barometer because a different base data set was used. The 2023 estimates are proxies, borrowed from EEA (2024).*
- *Gross effects of renewable energy consumption on GHG emissions are based on data available from Eurostat for primary energy consumption and on CO2 emission factors per fuel type (t CO2/TJ; see Annex VI of Commission Regulation 601/2012). The term 'gross avoided GHG emissions' illustrates the theoretical character of the GHG effects estimated this way, as these contributions do not necessarily represent 'net GHG savings per se' or are not based on life-cycle assessment or full carbon accounting. Considering life-cycle emissions could lead to substantially different results.*
- *It is assumed that the contributions from renewable energy carriers (RES-E, RES-H/C and RES-T[1]) to the overall energy mix have replaced contributions that would have otherwise been obtained from initial energy carriers (electricity, heating and transport fuels).*
  - *For RES-E, a generation-weighted average emission factor is determined, i.e., an emission factor weighed based on the type of fuel used to produce electricity in each country, on an annual basis. For this the next technologies/fuels are excluded: nuclear (usually operated as must-run capacity); renewable electricity generation (currently it is unlikely that renewable energy plants are to be displaced by new renewable capacity); blast furnace gas (considered a residue that can be utilised or flared). All other technologies and fuels are included.*
  - *For RES-H/C, country-specific emission factors for heat (EFh) are calculated similarly to the approach applied to determine the reference values for the initial energy carrier electricity, so as to reflect the differences in the fuel mix between Member States.*
  - *For RES-T, the assumption is straightforward that renewable transport fuels (essentially biodiesel and bioethanol) replace the conventional transport fuels petrol and diesel on a one-to-one basis, according to their specific energy content.*
- *In the absence of specific information on current bioenergy systems, CO2 emissions from the combustion of biomass (in solid, liquid and gaseous forms) were not included in national GHG emission totals, a zero emission factor has been applied to all energy uses of biomass.*
- *A detailed description of the method to estimate avoided GHG emissions can be consulted in the first report on Renewable energy in Europe (2015)[2] on p.40 (chapter 3.3.1 The Eurostat based method).*

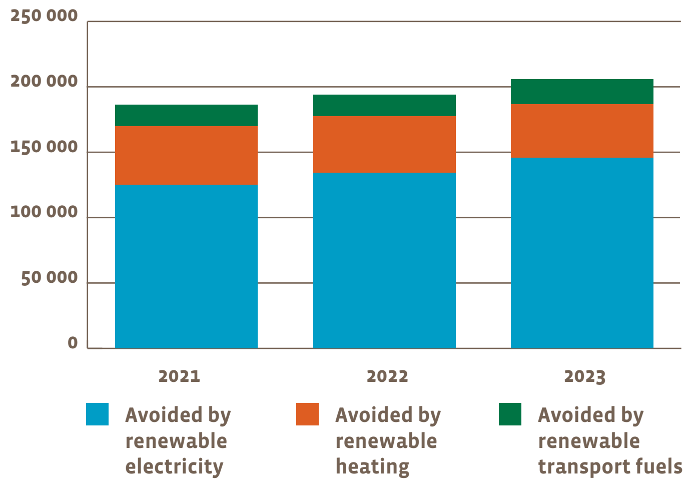
1. RES-E: Renewable electricity; RES-H/C: Renewable heating and cooling; RES-T: Renewable energy consumed in transport

2. Renewable energy in Europe —approximated recent growth and knock-on effects, EEA Technical report No 1/2015, Renewable energy in Europe - Approximated recent growth and knock-on effects — European Environment Agency (europa.eu)

In 2023 and 2022 the use of renewable energy substituted respectively around 206 Mtoe and 194 Mtoe of fossil fuels, compared to the level of use of renewable energy in 2005. These figures correspond to an avoided annual cost of EUR 165 billion for EU-27 collectively in 2022, decreasing to EUR 117 billion in 2023. In 2022 the largest financial contributions derive from renewable electricity and renewable heat at approximately equal contributions together representing about 87% of the avoided expenses. For 2023 the financial contributions from renewable electricity and renewable heat together decrease slightly to 82% because of relatively smaller decreases in financial contributions from fossil transport fuels compared to 2022.

2

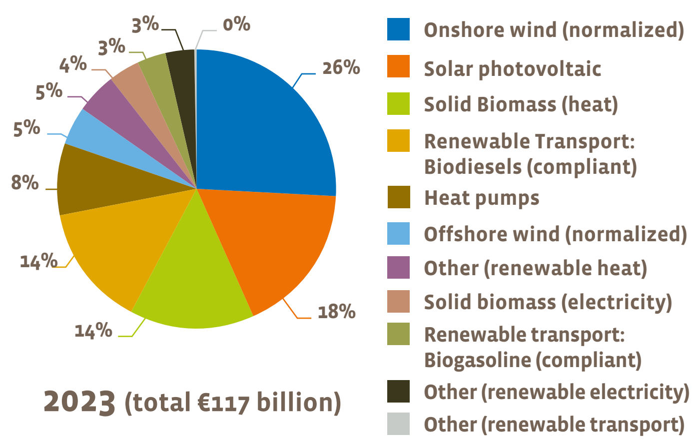
EU-27 avoided fossils fuels per sector (ktoe)



Note : Reference year 2005. Note: for 2023 proxy data are used.
Source: EurObserv'ER based on EEA data.

3

EU-27 avoided expenses through renewables



Note : Reference year 2005. Note: for 2023 proxy data are used.
Source: EurObserv'ER based on EEA data.

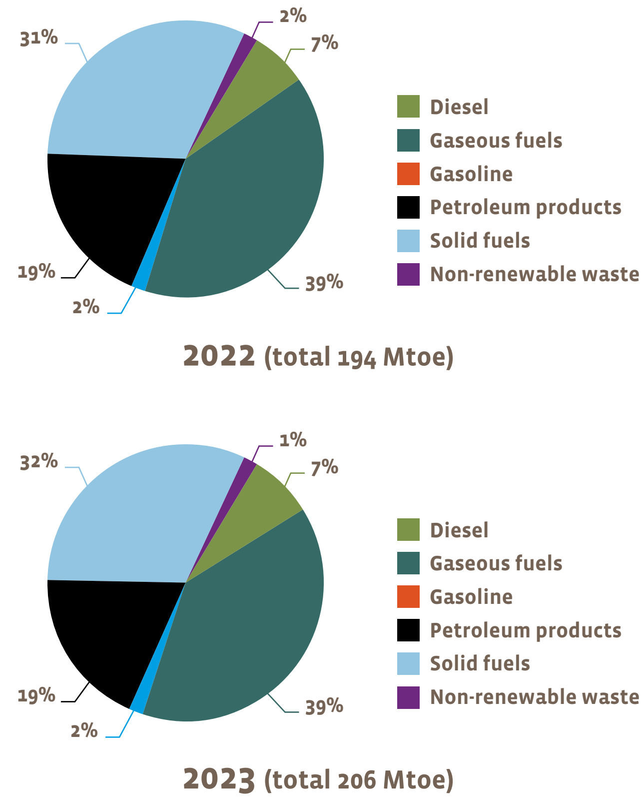
AVOIDED FOSSIL FUEL USE & AVOIDED COSTS PER TECHNOLOGY

The use of renewable electricity contributed to 71% of the total avoided fossil fuels in 2023 (in terms of energy). This is followed by renewables in the heating and cooling sector contributing to 20% of the total avoided fossil fuels and the remaining share was substituted through renewable transport fuels (9%, only fuels compliant with Directive (EU) 2018/2001 are included). In monetary terms, the avoided costs were EUR 96.7 billion in 2022 and EUR 64.4 billion in 2023 in the electricity sector. Second, renewable heat contributed to avoided costs reaching to EUR 47.0 billion in 2022 while in 2023 this decreased to EUR 32.0 billion. Third is renewable transport which contributed to avoided costs of EUR 17.5 billion in 2022 and EUR 20.9 billion in 2023. For correctly interpreting these results it is important to take into account a number of methodological notes, see the text box in the beginning of this chapter. While the penetration of renewable energy (expressed in avoided fossil fuels) expanded by approximately 6% from 2022 to 2023, the effect of the avoided fossil fuel expenses is, with a 29% decrease (from EUR 165 billion to EUR 117 billion) more pronounced than the growth in renewable energy. Reason for this is the strong decrease in fossil fuel prices in 2023 compared to 2022.
Among the RES technologies, onshore wind avoided the purchase of fossil fuels at an amount of EUR 30.4 billion in 2023 (EUR 45.0 billion in 2022, both for normalised production) compared to the level in 2005. Next solar photovoltaic has been responsible for EUR 20.6 billion in 2023 (EUR 28.0 billion in 2022). Solid biomass for heat purposes is third in the row with EUR 17.0 billion in 2023 (EUR 27.4 billion in 2022).
The pie chart shows how each technology contributes to the total avoided expenses in 2023.

The largest share of avoided fossil fuels comes from natural gas (39% both in 2022 and 2023), followed by solid fuels (mainly coal, respectively 31% and 32% for 2022 and 2023). Next are oil products, with a contribution of 19% in both 2022 and 2023. The remaining fuels (transport fuels and non-renewable waste) cover the remaining share (respectively 11% and 10% for 2022 and in 2023).

4

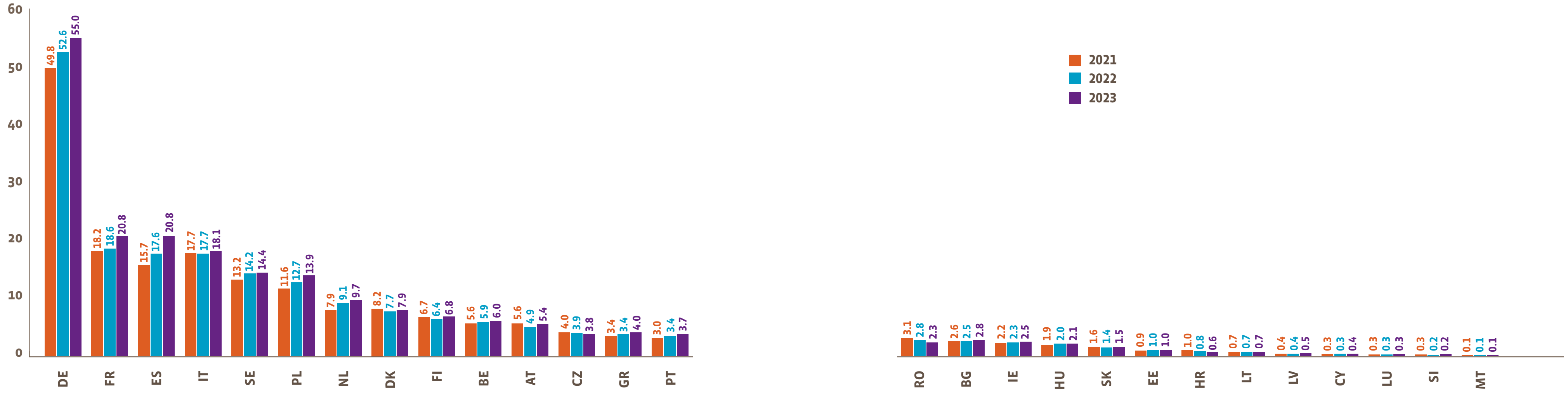
EU-27 substituted fossil fuels during 2022 and 2023



Note : Reference year 2005. Note: for 2023 proxy data are used.
Source: EurObserv'ER based on EEA data.

5

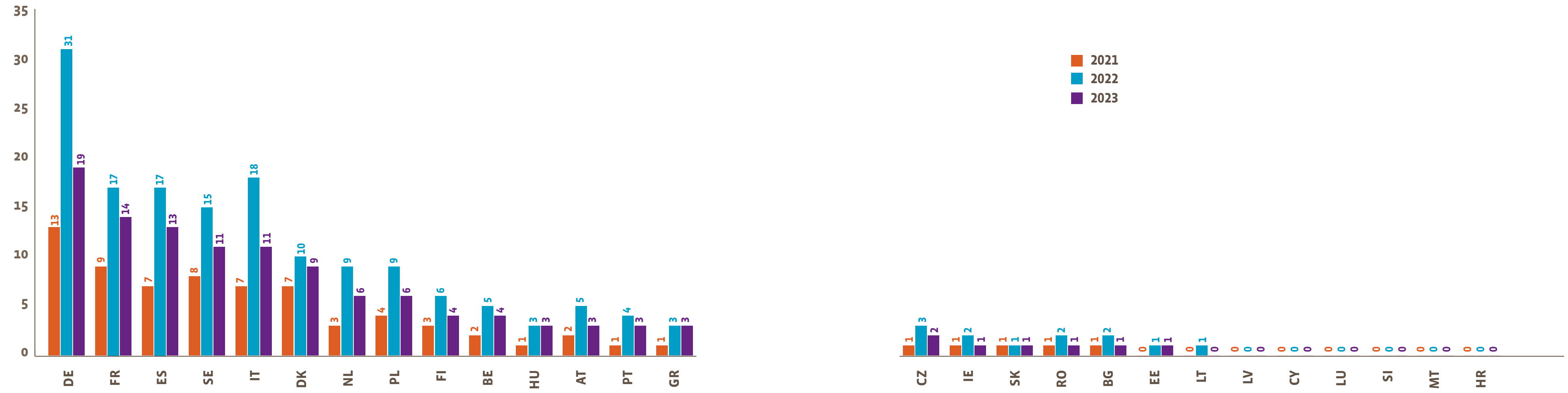
Avoided fossil fuels per country (Mtoe)



Note : Reference year 2005. Note: for 2023 proxy data are used. **Source: EurObserv'ER based on EEA data.**

6

Avoided expenses per country (€ billion)



Note : Reference year 2005. Note: for 2022 proxy data are used. **Source: EurObserv'ER based on EEA data.**

AVOIDED FOSSIL FUELS & EXPENSES PER MEMBER STATE

At Member State level, the amount of avoided fossil fuels and the avoided costs have been estimated as described in the methodological notes. Note that there is a strong correlation between the avoided amount and the size of a country. As can be expected, the avoided cost follows the fuel price development with fossil fuel prices lower in 2023 compared to 2022.

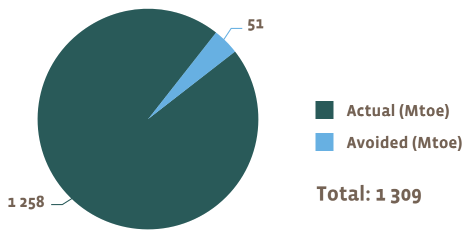
It can be observed from the results that countries with higher avoided fossil fuels figures not necessarily end up with higher avoided expenses, which is because these countries usually show a relatively lower growth in biogenic transport fuels which displace expensive fossil fuels, such as diesel and gasoline.

The data have been displayed graphically in the figures 5 and 6

Next, the figures 7 and 8 indicate how the amounts of estimated avoided fuel due to increased RES consumption since 2005 relate to the total EU-27 primary energy consumption. The relevant parameter for comparing the avoided fuel use with is the primary energy consumption, which indicates the gross inland consumption excluding all non-energy use of energy carriers (e.g. natural gas used not for combustion but for producing chemicals).

7

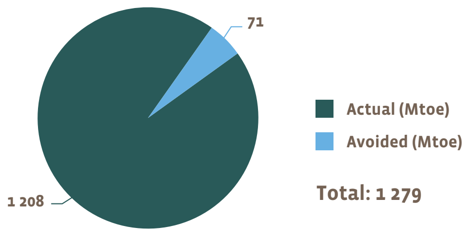
Effect on primary energy consumption (Mtoe) in 2022



Note : Reference year 2005. Note: for 2023 proxy data are used.
Source: EurObserv'ER based on EEA data.

8

Effect on primary energy consumption (Mtoe) in 2023



Note : Reference year 2005. Note: for 2023 proxy data are used.
Source: EurObserv'ER based on EEA data.

AVOIDED GHG EMISSIONS IN EU-27 AND PER MEMBER STATE

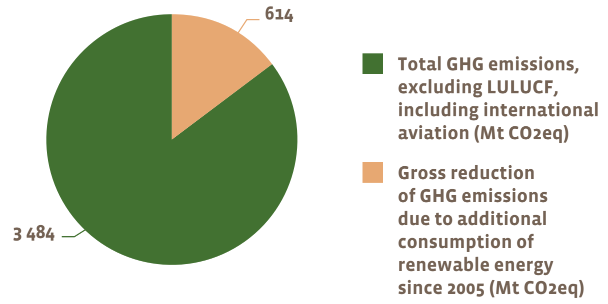
Finally, the figures 9 to 11 indicate the estimated savings in GHG emissions in 2022 and 2023 due to increased RES consumption since 2005, for the EU as a whole and per Member State.

In 2023, for the EU-27 a gross reduction of 653 Mt CO2eq of GHG emissions has been realised due to the additional consumption of renewable energy. While total EU 27 GHG emissions were approximately 3239 Mt CO2eq in 2023, the additional uptake of renewable energy has led to a gross reduction of GHG emissions of 16.8% in 2023, compared to the reference year 2005.

The gross reduction of GHG emissions due to the additional consumption of renewable energy has increased from 614 Mt CO2eq in 2022 to approximately 653 Mt CO2eq in 2023.

9

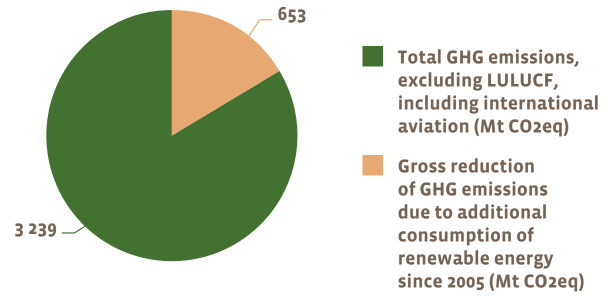
Effect on GHG emissions in EU-27 in 2022



Note: Reference year 2005. ***Source: Eurostat, EurObserv'ER based on EEA data.***

10

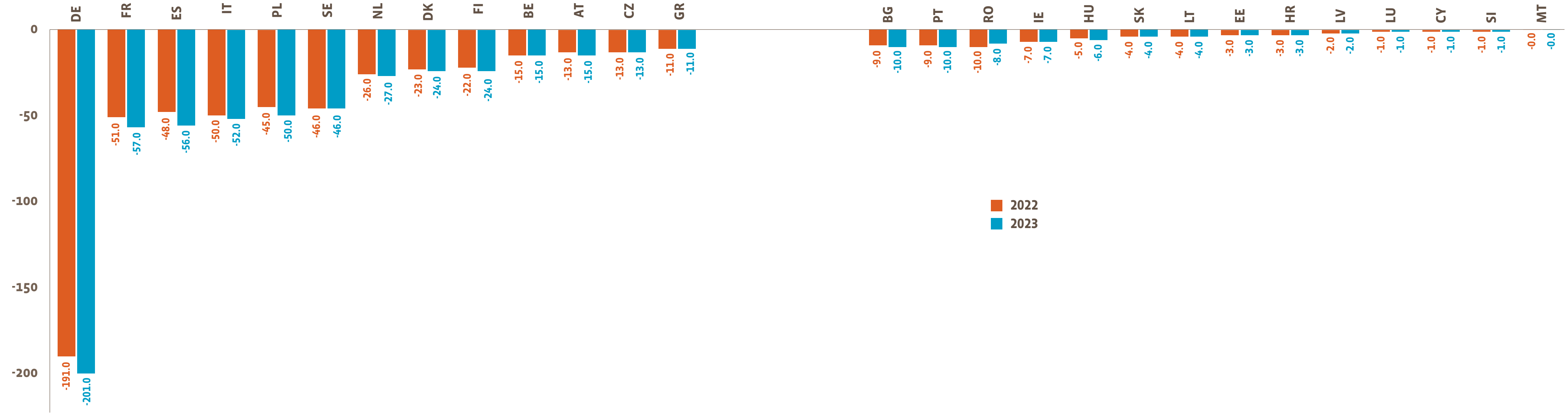
Effect on GHG emissions in EU-27 in 2023



Note: Reference year 2005. ***Source: Eurostat, EurObserv'ER based on EEA data.***

11

Estimated gross reduction of GHG emissions, due to RES per country (Mt CO_2)



Note: Reference year 2005. Note: for 2023 proxy data are used. ***Source: Eurostat, EurObserv'ER based on EEA data.***

In terms of gross avoided GHG emissions in 2023, the countries with the largest estimated gross reductions were Germany (201 Mt CO_2), France and Spain (both around 57 Mt CO_2) and Italy (52 Mt CO_2). ■

INDICATORS ON INNOVATION AND COMPETITIVENESS

The Energy Union strives to provide a secure, sustainable, affordable energy supply by increasing renewable energy use, energy efficiency, internal energy market integration and competitiveness. The energy transition results in new jobs, growth and at the same time it is an investment in the future of Europe, as stated by the European Commission. This understanding is also underpinned by economic theory, which sees expenditures for research and development as investments into new or better processes, products or services that might create new markets or increase market shares and strengthen competitiveness of firms, sectors, and nations. Regarding renewable energy technology (RET), research and development (R&D) investments drive RET innovations, which are often measured by the number or share of patent applications in the respective technology field. How well the R&D output translates into a strong market position, i.e., competitiveness in RET, on the other hand can be measured for example by the trade share in RET products. These three indicators are depicted in the following chapters: R&D expenditures (public & private) showing the efforts or investments of countries with respect to RET, patent applications reflecting the output of R&D efforts and finally trade shares in RET displaying how competitive a country is in RET products.

R&D Investments

Investments into R&D and innovation are commonly seen as the basis for technological changes and hence competitiveness. Consequently, they are an important factor for or driver of economic growth. From a macroeconomic perspective, R&D investments can be viewed as a major indicator to measure innovative performance of economies or innovation systems, which is able to display the position of a country in international competition regarding innovation.

Methodological approach

Overall, R&D expenditures are financed by private and public resources, while R&D is performed by both private (business) and public (government and higher education) sectors. This differentiation into financing (gray area) and performing (white area) is depicted in Figure 1. In this section, we will analyze public and private R&D expenditures of a selected set of countries regarding renewable energy technologies, i.e., research investments originating from the public sector (see light gray). For this report, the data on public and private R&D investment were provided by JRC SETIS. Its R&D data rely on IEA statistics, which collects and depicts national R&D investments. They address 20 of the EU Member States with varying regularity and granularity of technology detail. Furthermore, the European Commission has a separate budget for spending on R&D, this is indicated as a separate 'country', which has no correlation with the EU-27 totals. However, there is a two-year time delay in reporting for most Member States, thus data for 2021 is by and large complete, while the data for 2022 contain gaps and is (still) incomplete. For the data on private R&D, the time delay is even longer (2020 and 2021) as JRC's assessment is based on patent data. The methodology is described in more detail in the JRC Science for Policy Report "Monitoring R&D in Low Carbon Energy Technologies: Methodology for the R&I indicators in the State of the Energy Union Report, - 2016 Edition".[2] Data gaps are supplemented by the Member States through the area in Figure 1) as well as from the private sector are considered (see dark gray area in Figure 1). R&D investments from the public sector are supposed to boost innovation in the private sector. Although the specific returns to public sector R&D investments are largely unknown, the basic idea is to create follow-up investments from the private sector and generate spill-over effects. For this report, the data on public and private R&D investment were provided by JRC SETIS. Its R&D data rely on IEA statistics.[1], which collects and depicts national R&D investments. They address the EU Member States with varying regularity and granularity of technology detail (for public R&D, 19 member states have data, and data is available with various degrees of regularity for the other indicators (the same holds for private R&D, where all EU member states have some data: note that private R&D data is only available for EU member states)). Furthermore, the European Commission has a separate budget for spending on R&D, this is indicated as a separate 'country', which has no correlation with the EU-27 totals (when reporting the European Commission's activity relative to GDP, we used the GDP of the EU, which is the sum of the GDPs of its member states).

There is also some reporting delay that varies per member state. As such, we have chosen the most recent years with the most available data. These years are 2021 and 2022 for public R&D, and 2020 and 2021 for private R&D and patent indicators (note that the data is provisional).
The methodology is described in more detail in the JRC Science for Policy Report "Monitoring R&D in Low Carbon Energy Technologies: Methodology for the R&I indicators in the State of the Energy Union Report, - 2016 Edition".[2]
Data gaps are supplemented by the Member States through the SET Plan Steering Group or through targeted data mining.
Besides providing absolute figures for R&D expenditures (Euro) of the given countries, the share of R&D expenditures by GDP (%) is calculated to get an impression of the relative size of a country's investments in RET technologies. For the GDP, we used data from the World Bank.[3] (both values in current US$ and average yearly conversion rates from US$ to €).

1. *IEA. International Energy Agency RD&D Online Data Service. Available from: https://www.iea.org/data-and-statistics/data-product/energy-technology-rd-and-d-budget-database-2*
2. *A. Fiorini, A. Georgakaki, F. Pasimeni, E. Tzimas, "Monitoring R&I in Low-Carbon Energy Technologies", EUR 28446 EN (2017), doi: 10.2760/447418. Available from: https://publications.jrc.ec.europa.eu/repository/handle/JRC105642*
3. *https://data.worldbank.org/ via the API: https://pypi.org/project/wbgapi/ https://blogs.worldbank.org/opendata/introducing-wbgapi-new-python-package-accessing-world-bank-data*

Sectors by financing and performing of R&D

	Total R&D spending		
Financing sectors	Private sector	Public sector	
Performing sectors	Business	Government	Higher education

PUBLIC R&D INVESTMENTS

Public R&D investments are split by RE technologies for 2021 and 2022.

PRIVATE R&D INVESTMENTS

Private R&D investments are split by RE technologies for 2020 and 2021 and are only available for EU Member States..

PUBLIC R&D INVESTMENTS

SOLAR ENERGY

		Public R&D Exp. (in € m)		Share of Public R&D Exp. by GDP	
		2021	2022	2021	2022
EU-27	Germany	103.88	83.99	0.0028%	0.0021%
	France	76.44	79.49	0.0030%	0.0030%
	Spain	40.22	40.46	0.0033%	0.0029%
	Netherlands	21.19	29.34	0.0024%	0.0030%
	Austria	4.81	11.06	0.0012%	0.0025%
	Sweden	11.23	8.95	0.0021%	0.0016%
	Poland	8.25	7.43	0.0014%	0.0011%
	Belgium	0.36	4.69	0.0001%	0.0008%
	Denmark	3.06	3.02	0.0009%	0.0008%
	Finland	4.44	2.80	0.0018%	0.0011%
	Lithuania	1.02	2.24	0.0018%	0.0033%
	Ireland	0.67	1.28	0.0001%	0.0002%
	Estonia	0.26	0.59	0.0008%	0.0016%
	Czechia	0.99	0.53	0.0004%	0.0002%
	Slovakia	0.30	0.42	0.0003%	0.0004%
	Hungary	6.27	0.08	0.0041%	0.0000%
	Italy	50.98	n.a.	0.0028%	n.a.
	European Union	334.36	276.37	0.0023%	0.0017%
	EU Commission	112.52	251.22	0.0008%	0.0016%
Other Countries	United States	236.88	276.02	0.0012%	0.0011%
	Korea	63.23	61.70	0.0041%	0.0039%
	Switzerland	37.70	38.96	0.0055%	0.0050%
	Canada	32.61	30.81	0.0019%	0.0015%
	Japan	27.60	25.63	0.0006%	0.0006%
	Australia	23.86	25.13	0.0018%	0.0016%
	United Kingdom	28.02	18.76	0.0011%	0.0006%
	Norway	10.72	9.69	0.0025%	0.0017%
	Turkey	5.44	2.13	0.0008%	0.0002%
	New Zealand	0.42	0.33	0.0002%	0.0001%

Source: JRC SETIS, World Bank (WBGAPI)

In the field of solar energy, the largest player in terms of public R&D investment is the EU (as sum of its members). They are followed by the USA, with the investments by the European Commission coming in third place. This holds both for 2021 and 2022. Korea follows, ahead of a group including Switzerland, Canada, the United Kingdom, Japan, and Australia. Within the EU-27, the biggest players are Germany and France, followed by Spain. For most countries, the 2021 and 2022 figures are relatively close, with a few exceptions, with the European Commission having by far the largest increase (and the USA to a lesser extent) and a notable drop for the European Union's members (chiefly through Germany and Italy, though the latter may be due to missing data).
In terms of public investment relative to GDP, Switzerland comes on top. It is followed by Korea and Lithuania in 2022, while the runners-up in 2021 were Hungary and Korea. The relative values to GDP also show that solar is one of the three main public investment sectors. Figures for China as well as some other countries are not available. ■

PUBLIC R&D INVESTMENTS

GEOTHERMAL ENERGY

		Public R&D Exp. (in € m)		Share of Public R&D Exp. by GDP	
		2021	2022	2021	2022
EU-27	Germany	24.89	26.23	0.0007%	0.0007%
	Netherlands	4.71	18.95	0.0005%	0.0019%
	France	10.26	10.44	0.0004%	0.0004%
	Poland	0.53	3.29	0.0001%	0.0005%
	Austria	0.57	2.03	0.0001%	0.0005%
	Ireland	1.16	1.69	0.0003%	0.0003%
	Belgium	n.a.	1.20	n.a.	0.0002%
	Finland	0.67	1.08	0.0003%	0.0004%
	Czechia	0.75	0.75	0.0003%	0.0003%
	Denmark	n.a.	0.33	n.a.	0.0001%
	Hungary	0.30	0.05	0.0002%	0.0000%
	Spain	0.32	n.a.	0.0000%	n.a.
	Sweden	0.23	n.a.	0.0000%	n.a.
	European Union	44.38	66.04	0.0003%	0.0004%
	EU Commission	13.08	18.12	0.0001%	0.0001%
Other Countries	United States	89.68	104.22	0.0004%	0.0004%
	Japan	16.34	16.66	0.0004%	0.0004%
	Switzerland	8.21	12.95	0.0012%	0.0017%
	Canada	4.29	5.43	0.0003%	0.0003%
	New Zealand	3.54	3.61	0.0017%	0.0015%
	Norway	1.34	1.72	0.0003%	0.0003%
	United Kingdom	1.03	1.45	0.0000%	0.0000%
	Australia	0.06	1.17	0.0000%	0.0001%
	Korea	3.23	0.43	0.0002%	0.0000%
	Turkey	0.08	0.03	0.0000%	0.0000%

Source: JRC SETIS, World Bank (WBGAPI)

In the field of geothermal energy, the largest player in terms of public R&D investment is the USA. They are followed by the EU (as sum of its members), with Germany coming in third both for 2021 and 2022.
For most countries, the 2021 and 2022 figures are relatively close, with a few exceptions, with the USA, the European Union (chiefly through The Netherlands), the European Commission, and Switzerland having notable increases, and with Korea showing a notable drop. In terms of public investment relative to GDP, The Netherlands come ahead of Switzerland and New Zealand in 2022, while New Zealand was ahead of Switzerland and Germany in 2021. Figures for China as well as some other countries are not available. ■

PUBLIC R&D INVESTMENTS

HYDRO ENERGY

		Public R&D Exp. (in € m)		Share of Public R&D Exp. by GDP	
		2021	2022	2021	2022
EU-27	Sweden	3.48	3.17	0.0006%	0.0006%
	Austria	2.38	2.06	0.0006%	0.0005%
	France	3.59	1.87	0.0001%	0.0001%
	Czechia	0.61	1.07	0.0002%	0.0004%
	Poland	0.69	0.82	0.0001%	0.0001%
	Germany	0.93	0.31	0.0000%	0.0000%
	Finland	0.23	0.24	0.0001%	0.0001%
	Spain	2.26	n.a.	0.0002%	n.a.
	Total EU-27	0.96	18.03	0.0000%	0.0001%
	European Union	14.17	9.55	0.0001%	0.0001%
Other Countries	Canada	14.90	15.47	0.0009%	0.0008%
	Switzerland	12.17	10.33	0.0018%	0.0013%
	Norway	7.84	8.19	0.0018%	0.0015%
	Korea	4.28	2.59	0.0003%	0.0002%
	Turkey	3.58	1.44	0.0005%	0.0002%
	United Kingdom	0.11	0.28	0.0000%	0.0000%
	New Zealand	0.03	0.12	0.0000%	0.0000%
	Australia	0.07	0.09	0.0000%	0.0000%
	United States	115.83	n.a.	0.0006%	n.a.

Source: JRC SETIS, World Bank (WBGAPI)

In the field of hydro energy, the largest player in terms of public R&D investment is the USA, by a veru wide margin. However, the USA had no data fo 2022. In 2022, the European Commission was ahead of Canada and Switzerland, while the USA were followed at a very large distance by Canada and the European Union in 2021.

In terms of changes, the most notable features are the large growth for the European Commissions and the drop for the European Union (mostly through a drop for France though the non-availability of data for Spain might play a role too), as well as the lack of data for the USA in 2022.

In terms of public investment relative to GDP, Norway is on top, followed by Switzerland and Canada both in 2021 and 2022. The relative values to GDP also show that hydro energy is a minor public investment sector. Figures for China as well as some other countries are not available. ■

PUBLIC R&D INVESTMENTS

BIOFUELS

		Public R&D Exp. (in € m)		Share of Public R&D Exp. by GDP	
		2021	2022	2021	2022
EU-27	Spain	16.02	157.34	0.0013%	0.0115%
	France	62.60	61.47	0.0025%	0.0023%
	Germany	64.95	45.68	0.0018%	0.0012%
	Sweden	21.92	20.29	0.0041%	0.0037%
	Poland	2.00	10.27	0.0003%	0.0016%
	Austria	8.53	9.86	0.0021%	0.0022%
	Finland	9.37	8.41	0.0038%	0.0032%
	Netherlands	13.27	7.68	0.0015%	0.0008%
	Denmark	23.05	4.64	0.0067%	0.0012%
	Czechia	6.24	3.80	0.0025%	0.0013%
	Belgium	0.12	3.45	0.0000%	0.0006%
	Ireland	2.82	1.88	0.0006%	0.0004%
	Lithuania	0.90	1.40	0.0016%	0.0021%
	Slovakia	n.a.	0.04	n.a.	0.0000%
	Italy	25.14	n.a.	0.0014%	n.a.
	Hungary	4.88	n.a.	0.0032%	n.a.
	Malta	0.00	n.a.	0.0000%	n.a.
	Romania	0.01	n.a.	0.0000%	n.a.
	Slovakia	0.01	n.a.	0.0000%	n.a.
	Total EU-27	261.80	336.20	0.0018%	0.0021%
	EU Commission	58.04	168.97	0.0004%	0.0010%
Other Countries	United States	215.73	249.37	0.0011%	0.0010%
	Japan	69.36	92.88	0.0016%	0.0023%
	Norway	20.29	67.92	0.0048%	0.0120%
	Canada	45.74	58.81	0.0027%	0.0029%
	United Kingdom	30.39	39.57	0.0011%	0.0013%
	Switzerland	19.47	24.80	0.0028%	0.0032%
	Korea	17.58	7.52	0.0011%	0.0005%
	New Zealand	1.72	2.17	0.0008%	0.0009%
	Australia	4.94	1.11	0.0004%	0.0001%
	Turkey	0.19	0.31	0.0000%	0.0000%

Source: JRC SETIS, World Bank (WBGAPI)

For biofuels, the largest player in terms of public R&D investment is the EU (with Sapin, Germany, and France as main players), followed by the USA in both 2021 and 2022. The (distant) third place in 2022 goes to the European Commission, while that goes to Japan in 2021. There are two big groups of movers between 2021 and 2022. The biggest growers are Spain (by far the largest increase), Poland, Belgium, the European Commission, and Norway. The most notable decreases are for Germany, The Neteherlands, Denmark, and Korea.

In terms of public investment relative to GDP, 2022 sees Spain far ahead of Sweden, The Netherlands, and Switzerland, while 2021 sees Denmark ahead of Norway and Sweden. The relative values to GDP also show that biofuels are one of the three main public investment sectors. Figures for China as well as some other countries are not available.. ■

PUBLIC R&D INVESTMENTS

WIND ENERGY

		Public R&D Exp. (in € m)		Share of Public R&D Exp. by GDP	
		2021	2022	2021	2022
EU-27	France	30.65	115.85	0.0012%	0.0044%
	Germany	82.87	89.19	0.0023%	0.0023%
	Spain	12.00	38.40	0.0010%	0.0028%
	Netherlands	14.15	37.82	0.0016%	0.0038%
	Belgium	6.90	20.55	0.0014%	0.0036%
	Denmark	17.14	17.93	0.0050%	0.0047%
	Ireland	2.47	4.75	0.0005%	0.0009%
	Sweden	3.96	3.52	0.0007%	0.0006%
	Austria	2.39	2.20	0.0006%	0.0005%
	Poland	0.53	1.44	0.0001%	0.0002%
	Finland	2.05	1.44	0.0008%	0.0005%
	Hungary	0.01	0.33	0.0000%	0.0002%
	Czechia	0.13	0.05	0.0001%	0.0000%
	Lithuania	0.33	n.a.	0.0006%	n.a.
	Total EU-27	175.58	333.44	0.0012%	0.0021%
	EU Commission	88.27	170.09	0.0006%	0.0011%
Other Countries	United States	93.06	108.51	0.0005%	0.0004%
	Japan	170.83	93.86	0.0040%	0.0023%
	Korea	57.18	55.83	0.0037%	0.0035%
	United Kingdom	43.26	46.27	0.0016%	0.0016%
	Norway	21.37	12.26	0.0050%	0.0022%
	Canada	6.53	6.68	0.0004%	0.0003%

Source: JRC SETIS, World Bank (WBGAPI)

In the field of wind energy, the largest player in terms of public R&D investment is the EU (as sum of its members, mostly through France and Germany). They are followed by European Commission, the USA, and Japan in 2022, while the order of these three is invereted in 2021.

There are two big groups of movers between 2021 and 2022. The growers are France, Spain, The Netherlands, Belgium, and the European Commission. The decreases are most notable for Japan and Norway.

In terms of public investment relative to GDP, Denmark is ahead of France and Korea in 2022, while in 2021 Norway was on top, followed by Denmark and Japan in 2021. The relative values to GDP also show that wind is one of the three main public investment sectors. ■

PUBLIC R&D INVESTMENTS

OCEAN ENERGY

		Public R&D Exp. (in € m)		Share of Public R&D Exp. by GDP	
		2021	2022	2021	2022
EU-27	Spain	3.37	29.06	0.0003%	0.0021%
	France	12.24	10.80	0.0005%	0.0004%
	Ireland	2.23	3.12	0.0005%	0.0006%
	Denmark	0.03	2.89	0.0000%	0.0008%
	Sweden	4.52	2.40	0.0008%	0.0004%
	Netherlands	n.a.	0.14	n.a.	0.0000%
	Poland	0.02	n.a.	0.0000%	n.a.
	Total EU-27	11.56	56.08	0.0001%	0.0003%
	European Union	22.41	48.40	0.0002%	0.0003%
Other Countries	United Kingdom	19.23	12.09	0.0007%	0.0004%
	Canada	7.74	9.41	0.0005%	0.0005%
	Japan	3.18	7.12	0.0001%	0.0002%
	Australia	0.14	0.25	0.0000%	0.0000%
	Norway	0.10	0.10	0.0000%	0.0000%
	Turkey	0.04	0.03	0.0000%	0.0000%
	United States	0.00	n.a.	0.0000%	n.a.

Source: JRC SETIS, World Bank (WBGAPI)

In the field of ocean energy, the largest player in terms of public R&D investment is the European Commission, followed by EU (as sum of its members, essentially through Spain (in 2022) and France (both years)) in 2022, while the order is flipped in 2021. For both years, the United Kingdom is third.

There are two big groups of movers between 2021 and 2022. The growers are Spain and the European Commission (ad Denmark and Japan to a lesser extent). The decreases are most notable for the UK and Sweden.

In terms of public investment relative to GDP, , Spain is far ahead of Denmark and Ireland in 2022, while Sweden was on top in 2021, followed by UK and Ireland in 2021. The relative values to GDP also show that ocean energy is a minor public investment sector.. ■

PUBLIC R&D INVESTMENTS

RENEWABLE ENERGY TECHNOLOGIES IN TOTAL

		Public R&D Exp. (in € m)		Share of Public R&D Exp. by GDP	
		2021	2022	2021	2022
EU-27	France	195.78	279.92	0.0078%	0.0105%
	Spain	74.19	265.26	0.0060%	0.0193%
	Germany	277.52	245.40	0.0075%	0.0062%
	Netherlands	53.32	93.93	0.0060%	0.0095%
	Sweden	45.34	38.32	0.0084%	0.0070%
	Belgium	7.37	29.89	0.0015%	0.0053%
	Denmark	43.28	28.81	0.0125%	0.0075%
	Austria	18.69	27.21	0.0046%	0.0061%
	Poland	12.03	23.25	0.0021%	0.0035%
	Finland	16.76	13.97	0.0067%	0.0052%
	Ireland	9.35	12.71	0.0021%	0.0024%
	Czechia	8.71	6.20	0.0035%	0.0022%
	Lithuania	2.25	3.64	0.0040%	0.0054%
	Estonia	0.26	0.59	0.0008%	0.0016%
	Hungary	11.46	0.46	0.0074%	0.0003%
	Slovakia	0.30	0.45	0.0003%	0.0004%
	Bulgaria	0.00	0.00	0.0000%	0.0000%
	Greece	0.00	0.00	0.0000%	0.0000%
	Croatia	0.00	0.00	0.0000%	0.0000%
	Italy	76.12	0.00	0.0041%	0.0000%
	Cyprus	0.00	0.00	0.0000%	0.0000%
	Latvia	0.00	0.00	0.0000%	0.0000%
	Luxembourg	0.00	0.00	0.0000%	0.0000%
	Malta	0.00	0.00	0.0000%	0.0000%
	Portugal	0.00	0.00	0.0000%	0.0000%
	Romania	0.00	0.00	0.0000%	0.0000%
	Slovenia	0.00	0.00	0.0000%	0.0000%
	Total EU-27	852.71	1 070.00	0.0058%	0.0066%

Continues overleaf

For the total, we set the non-available values to zero to sum the values to avoid having only countries that invested in all technologies showing up in the totals. This means that some of the numbers can be underestimates. For example, the USA don't have data for wind in 2022, which leads to a total decrease from 2021 to 2022, while even halving their hydro effort would lead to a total increase. Similarly, Italy does not have any data for 2022, while it has a figure of €76 million for 2021.

The aggregated results of public R&D investments for all renewable energy technologies shows the European Union (with France, Spain, and Germany being the most prominent contributors) ahead of the USA in 2021, followed by the European Commission. In 2021, Japan is just ahead of the European Commission. Note that the 2022 figures for the USA are likely to be an underestimate, due to the lack of availability of data for investments in hydro energy. The sam holds for the European Union and the lack of data for 2022 in Italy.

The countries whose public investments grew the most are the European Commission, Spain, France, The Netherlands, , and Belgium. The countries whose public investments decreased the most are Denmark (through a drop in biofuels) and Hungary (thorugh a drop in solar). Note that Hungary lacks data for biofuels in 2022, but provisional data for 2023 shows that the investment seems to have dropped there as well (€0.4 million).

In terms of public investment relative to GDP Spain is ahead of Norway and Switzerland, while Norway was ahead of Switzerland and Denmark in 2021. The major contributors to public investment are solar, biofuels, and wind, while geothermal, hydro, and ocean have a minor role. ■

	EU Commission	284.44	682.51	0.0019%	0.0042%
Other Countries	United States	751.18	738.12	0.0038%	0.0030%
	Japan	287.30	236.16	0.0067%	0.0058%
	Korea	145.50	128.07	0.0095%	0.0081%
	Canada	111.81	126.61	0.0066%	0.0062%
	United Kingdom	122.05	118.42	0.0046%	0.0040%
	Norway	61.65	99.88	0.0145%	0.0177%
	Switzerland	86.40	93.21	0.0126%	0.0120%
	Australia	29.61	28.49	0.0022%	0.0018%
	New Zealand	5.71	6.30	0.0027%	0.0027%
	Turkey	9.77	4.39	0.0014%	0.0005%

Source: JRC SETIS, World Bank (WBGAPI).

PRIVATE R&D INVESTMENTS

SOLAR ENERGY

		Private R&D Exp. (in € m)		Share of Private R&D Exp. by GDP	
		2020	2021	2020	2021
EU-27	Germany	770.60	166.72	0.0223%	0.0045%
	France	104.72	56.14	0.0045%	0.0022%
	Italy	42.22	42.12	0.0025%	0.0023%
	Netherlands	30.84	22.41	0.0038%	0.0025%
	Sweden	46.47	16.11	0.0097%	0.0030%
	Austria	96.67	8.81	0.0254%	0.0022%
	Spain	13.57	8.75	0.0012%	0.0007%
	Finland	5.30	6.36	0.0022%	0.0026%
	Belgium	10.99	4.78	0.0024%	0.0009%
	Greece	2.65	4.77	0.0016%	0.0026%
	Romania	n.a.	4.77	n.a.	0.0020%
	Denmark	8.38	1.19	0.0027%	0.0003%
	Bulgaria	0.88	n.a.	0.0014%	n.a.
	Estonia	2.12	n.a.	0.0076%	n.a.
	Poland	8.17	n.a.	0.0015%	n.a.
	Portugal	1.32	n.a.	0.0007%	n.a.
	Total EU-27	1 144.91	342.95	0.0084%	0.0023%

Source: JRC SETIS, World Bank (WBGAPI)

In terms of private investments in R&D for solar energy, Germany is far ahead of all other countries. France is the runner-up, with Italy (2021) and Austria (2020) being third. The most remarkable change between 2020 and 2021 is a laarge drop across the board, most notably for Germany, France, Austria, and Sweden.

In terms, of private investment per GDP, Germany comes ahead of Austria and Belgium and Greece in 2021. In 2020, Austria was ahead of Germany and Sweden. The relative values to GDP also show that solar is one of the three main private investment sectors. ■

PRIVATE R&D INVESTMENTS

GEOTHERMAL ENERGY

		Private R&D Exp. (in € m)		Share of Private R&D Exp. by GDP	
		2020	2021	2020	2021
EU-27	Sweden	n.a.	7.77	n.a.	0.0014%
	France	2.79	4.45	0.0001%	0.0002%
	Italy	n.a.	2.77	n.a.	0.0002%
	Luxembourg	n.a.	2.77	n.a.	0.0038%
	Finland	1.70	2.77	0.0007%	0.0011%
	Netherlands	2.12	0.24	0.0003%	0.0000%
	Germany	2.55	n.a.	0.0001%	n.a.
	Total EU-27	9.17	20.76	0.0001%	0.0001%

Source: JRC SETIS, World Bank (WBGAPI)

In terms of private investments in R&D for geothermal energy, Sweden is ahead of France in 2021, while France was ahead of Germany in 2020.

The lack of data does not allow for an analysis in terms of increase/decrease or private investment per GDP.

The relative values to GDP shows that geothermal is a minor private investment sector. ■

PRIVATE R&D INVESTMENTS

HYDRO ENERGY

		Private R&D Exp. (in € m)		Share of Private R&D Exp. by GDP	
		2020	2021	2020	2021
EU-27	Germany	16.62	12.95	0.0005%	0.0004%
	Denmark	n.a.	2.37	n.a.	0.0007%
	Austria	n.a.	2.37	n.a.	0.0006%
	Belgium	n.a.	2.14	n.a.	0.0004%
	Italy	3.90	2.14	0.0002%	0.0001%
	Ireland	n.a.	0.71	n.a.	0.0002%
	Netherlands	0.24	0.47	0.0000%	0.0001%
	Spain	1.95	n.a.	0.0002%	n.a.
	France	4.16	n.a.	0.0002%	n.a.
	Sweden	1.23	n.a.	0.0003%	n.a.
	Total EU-27	28.10	23.15	0.0002%	0.0002%

Source: JRC SETIS, World Bank (WBGAPI)

In terms of private investments in R&D for hydro energy, Germany is on top both in 2020 and 2021.
The lack of data does not allow for an analysis in terms of increase/decrease or private investment per GDP.
The relative values to GDP also show that hydro energy is a minor private investment sector. ■

PRIVATE R&D INVESTMENTS

BIOFUELS

		Private R&D Exp. (in € m)		Share of Private R&D Exp. by GDP	
		2020	2021	2020	2021
EU-27	Denmark	155.14	57.61	0.0498%	0.0167%
	Netherlands	47.68	37.80	0.0058%	0.0042%
	Finland	44.24	31.88	0.0187%	0.0128%
	Italy	26.43	21.27	0.0016%	0.0012%
	France	58.16	20.50	0.0025%	0.0008%
	Germany	39.36	16.53	0.0011%	0.0004%
	Sweden	48.87	9.02	0.0102%	0.0017%
	Belgium	3.48	6.90	0.0007%	0.0014%
	Spain	15.82	4.84	0.0014%	0.0004%
	Ireland	n.a.	4.43	n.a.	0.0010%
	Hungary	27.54	4.43	0.0200%	0.0029%
	Poland	5.01	4.43	0.0009%	0.0008%
	Portugal	n.a.	4.43	n.a.	0.0020%
	Luxembourg	10.47	2.37	0.0162%	0.0033%
	Czechia	5.01	2.22	0.0023%	0.0009%
	Cyprus	2.50	n.a.	0.0112%	n.a.
	Austria	9.26	n.a.	0.0024%	n.a.
	Total EU-27	498.97	228.67	0.0037%	0.0015%

Source: JRC SETIS, World Bank (WBGAPI)

In terms of private investments in R&D for biofuels, Denmark is ahead both in 2021 and 2020. They are followed by The Netherlands and Finland in 2021, and by France, Sweden, The Netherlands, and Finland in 2020.
The data shows a decrease across the board, most notably for Denmark, France, and Germany.
In terms of private investment per GDP, Denmark comes ahead. They are followed by Finland and The Netherlands in 2021, and Hungary and Finland in 2020. The relative values to GDP also show that biofuels are one of the three main private investment sectors. ■

PRIVATE R&D INVESTMENTS
WIND ENERGY

		Private R&D Exp. (in € m)		Share of Private R&D Exp. by GDP	
		2020	2021	2020	2021
EU-27	Denmark	628.18	712.33	0.2018%	0.2063%
	Germany	317.40	260.94	0.0092%	0.0071%
	Spain	124.24	220.77	0.0110%	0.0179%
	France	65.11	65.21	0.0028%	0.0026%
	Nether-lands	35.85	48.07	0.0044%	0.0054%
	Sweden	27.57	35.11	0.0058%	0.0065%
	Austria	36.99	12.07	0.0097%	0.0030%
	Belgium	15.26	9.61	0.0033%	0.0019%
	Italy	4.68	4.70	0.0003%	0.0003%
	Czechia	n.a.	2.73	n.a.	0.0011%
	Cyprus	n.a.	2.73	n.a.	0.0106%
	Ireland	n.a.	2.28	n.a.	0.0005%
	Finland	2.55	1.09	0.0011%	0.0004%
	Poland	3.35	0.68	0.0006%	0.0001%
	Greece	1.15	n.a.	0.0007%	n.a.
	Romania	1.15	n.a.	0.0005%	n.a.
	Total EU-27	1 263.48	1 378.33	0.0093%	0.0093%

Source: JRC SETIS, World Bank (WBGAPI)

In In terms of private investments in R&D for wind energy, Denmark is far ahead of Germany and Spain (with the other countries far behind) in 2020 and 2021.
The countries that increased their investment between 2020 and 2021 are: Denmark, Spain, and The Netherlands. The countries that decreased their investment between 2020 and 2021 are: Germany, Austria, and Belgium.
In terms of private investment per GDP, Denmark comes far ahead (and far ahead of any values for any RET in any country) of Spain. The relative values to GDP also show that wind energy is one of the three main private investment sectors. ■

PRIVATE R&D INVESTMENTS
OCEAN ENERGY

		Private R&D Exp. (in € m)		Share of Private R&D Exp. by GDP	
		2020	2021	2020	2021
EU-27	Italy	3.48	16.89	0.0002%	0.0009%
	Denmark	0.82	10.19	0.0003%	0.0029%
	Germany	n.a.	6.75	n.a.	0.0002%
	Sweden	5.36	2.37	0.0011%	0.0004%
	Nether-lands	2.61	1.93	0.0003%	0.0002%
	France	4.72	0.24	0.0002%	0.0000%
	Finland	2.90	n.a.	0.0012%	n.a.
	Total EU-27	19.89	38.37	0.0001%	0.0003%

Source: JRC SETIS, World Bank (WBGAPI)

In In terms of private investments in R&D for ocean energy, Italy is ahead od Denmark and Germany in 2021, while Sweden was ahead of France and Italy in 2020.
Italy and Denmark have considerable increases between 2020 and 2021, while France and Swden decrease (note that further conclusions could be drawn if some countries had data for both years).
In terms of private investment per GDP, Denmark comes ahead of Italy in 2021, while Finalnd and Sweden came ahead in 2020. The relative values to GDP also show that ocean energy is a minor private investment sector. ■

PRIVATE R&D INVESTMENTS

RENEWABLE ENERGY TECHNOLOGIES IN TOTAL

	Private R&D Exp. (in € m)		Share of Private R&D Exp. by GDP	
	2020	2021	2020	2021
Denmark	792.52	783.69	0.2545%	0.2270%
Germany	1 146.54	463.89	0.0332%	0.0126%
Spain	155.58	234.36	0.0138%	0.0190%
France	239.66	146.53	0.0103%	0.0058%
Netherlands	119.34	110.92	0.0146%	0.0124%
Italy	80.70	89.89	0.0048%	0.0049%
Sweden	129.51	70.38	0.0271%	0.0131%
Finland	56.69	42.11	0.0240%	0.0169%
Belgium	29.73	23.42	0.0064%	0.0046%
Austria	142.92	23.26	0.0376%	0.0057%
Ireland	0.00	7.42	0.0000%	0.0017%
Luxembourg	10.47	5.14	0.0162%	0.0071%
Poland	16.53	5.12	0.0031%	0.0009%
Czechia	5.01	4.95	0.0023%	0.0020%
Greece	3.80	4.77	0.0023%	0.0026%
Romania	1.15	4.77	0.0005%	0.0020%
Hungary	27.54	4.43	0.0200%	0.0029%
Portugal	1.32	4.43	0.0007%	0.0020%
Cyprus	2.50	2.73	0.0112%	0.0106%
Bulgaria	0.88	0.00	0.0014%	0.0000%
Estonia	2.12	0.00	0.0076%	0.0000%
Croatia	0.00	0.00	0.0000%	0.0000%
Latvia	0.00	0.00	0.0000%	0.0000%
Lithuania	0.00	0.00	0.0000%	0.0000%
Malta	0.00	0.00	0.0000%	0.0000%
Slovenia	0.00	0.00	0.0000%	0.0000%
Slovakia	0.00	0.00	0.0000%	0.0000%
Total EU-27	2 964.52	2 032.23	0.0218%	0.0137%

Source: JRC SETIS, World Bank (WBGAPI)

Looking at total private investments, we see Denmark and Germany far ahead of the rest of the countries. Denmark is ahead of Germany in 2021, while the reverse is true in 2020. The following range of countries in 2021 includes Spain, France, and The Netherlands. In 2020, this range includes France, Spain, and Austria.

With the notable exception of Spain, there is a general trend of lower total investment between 2020 and 2021, most notably for Germany, France, and Austria.

In terms of investments per GDP, Denmark is an order of magnitude ahead of all other countries, with Spain, Finland, and Sweden leading the rest of the field.

Due to missing data for non-EU-27 countries, the investments cannot be compared to the rest of the world. ■

PUBLIC AND PRIVATE R&D CONCLUSIONS

Due to missing data, especially for China but also for other non-European countries regarding private R&D expenditures, it is difficult to draw conclusions on a global scale. China is currently the largest investor in RET installations (wind and solar power), followed by the USA. Furthermore, China is the main exporter in PV as well as in hydro power. Based on the rationale that competitiveness is correlated with innovation, China can be assumed to allocate significant financial resources for R&D to these technologies as well.

Nevertheless, it can be stated that many countries have specialized in certain technology fields within RET technologies. This can be found for public as well as for private R&D investments:

- For solar energy, the EU-27 (2021/2022) and the US are the frontrunners in public R&D spending, followed by the European Commission and Korea (data for China is not available). Within the EU-27, the largest investments in 2022 are due to Germany, France, and Spain. For private R&D investments within the EU-27, Germany, France, and Italy are the leading countries (2021).
- Regarding geothermal energy, the U.S. ranks first with a substantial difference from the EU (mostly through Germany and The Netherlands), followed by the European Commission. Private R&D expenditures in the EU-27 are highest in Sweden and France.
- In hydro energy, the U.S. dominates in public R&D investments (in 2021, as data for the USA was not available fo 2022), followed by the European Commission and Canada. Within the EU-27, Sweden is in the lead, followed by Austria and France. As for the private R&D investments in the EU-27, the largest values are noted for Germany.
- Within biofuels, the EU is in the head position regarding public R&D investments, followed by the USA and the European Commission (2022). Within the EU-27, the largest contributions are due to Spain and France. As for the private R&D investments within the EU-27, Denmark, The Netherlands, and Finland are in the lead (2021).
- In wind energy, the EU-27 shows the largest public R&D spending in 2021, followed by the European Commissions and the USA. Within the EU-27, the largest contributions come mainly from France, followed by Germany and Spain (2022). Regarding private R&D spending in the EU-27 (2021), Denmark is ahead of Germany and Spain.
- In ocean energy – a rather small field in terms of public R&D – the European Commission and the EU-27 show the largest public R&D expenditures. Within the EU-27, the largest contributions are provided by Spain and France. Concerning private R&D investments within the EU-27, Italy and Denmark are the most committed countries in 2021.
- Regarding the total public R&D expenditures the EU-27 (sum of all member states), the European Commission, and the US are clearly the most significant among the assessed entities worldwide. With some distance behind, Japan, Korea, and the UK follow outside of the EU-27. France, Spain, and Germany clearly show the highest expenditures of public R&D within the EU-27.
- Overall, this analysis shows that private R&D financing by far exceeds public R&D financing. Within the EU-27, Denmark and Germany are leading, followed by Spain, France, and The Netherlands (2021). ■


ABOWIND

Patent Filings

The technological performance of countries or innovation systems is commonly measured by patent filings as well as patent grants, which can be viewed as the major output indicators for R&D processes. Countries with a high patent output are assumed to have a strong technological competitiveness, which might be translated into an overall macroeconomic competitiveness. Patents can be analyzed from different angles and with different aims, and the methods and definitions applied for these analyses do differ. Here, we focus on a domestic, macroeconomic perspective by providing information on the technological capabilities of economies within renewable energies technologies.

Methodological approach

The patent data for this report were provided by JRC SETIS. The data originate from the EPO Worldwide Patent Statistical Database (PATSTAT)[1]. The PATSTAT database 2022 spring version was used (JRC update: 2022)[2]. A full dataset for a given year is completed with a 3.5-year delay. Thus, data used for the assessment of indicators have a 4-year delay. Estimates with a 2-year lag are provided at EU level only. The data specifically address advances in low carbon energy and climate mitigation technologies (Y-code of the Cooperative Patent Classification (CPC)[3]). Datasets are processed by JRC SETIS to eliminate errors and inconsistencies. Patent statistics are based on the priority date, simple patent families[4] and fractional counts of submissions made both to national and international authorities to avoid multiple counting of patents. Within the count of patent families, filings at single offices, also known as «singletons», are included. This implies that the results regarding the global technological competitiveness could be biased towards countries with large domestic markets and specialties in their patent systems, e.g., China, Japan, and Korea. Thus, these results might wrongly signal a strong international competitiveness.

For the analyses of patents in different renewable energy technologies, not only the number of filings but also a specialization indicator is provided. For this purpose, the Revealed Patent Advantage (RPA) is estimated, which builds on the works by Balassa (Balassa 1965), who has created this indicator to analyze international trade. The RPA indicates in which RET fields a country is strongly or weakly represented compared to the total patent applications in the field of energy technologies. Thus, the RPA for country i in field RET measures the share of RET patents of country i in all energy technologies compared to the RET world share of patents in all energy technologies. If a country i's share is larger than the world share, country i is said to be specialized in renewable energies within its energy field. The data were transformed, so values between 0 and 1 imply a below average interest or focus on this renewable technology, while values above 1 indicate a positive specialization, i.e., a strong focus on this RET compared to all energy technologies. It should be noted that the specialization indicator refers to energy technologies, and not to all technologies. This makes the indicator more sensitive to small changes in RET patent filings, i.e., it displays more ups and downs, and depicts small numbers in renewable patents as large specialization effects if the patent portfolio in energy technologies is small, i.e., the country is small. To account for this size effect of the country or economy and to make patent data more comparable between countries, patent filings per GDP (in trillion €) are depicted as well.

The methodology is described in more detail in the JRC Science for Policy Report "Monitoring R&D in Low Carbon Energy Technologies: Methodology for the R&D indicators in the State of the Energy Union Report, - 2016 Edition".[5] The number of patent applications - domestic or international -, the patent specialization as well as patent per GDP are depicted by RE technologies for 2018 and 2019. Note that in the non-EU countries, ROW is defined as the rest of the world, including UK values.

1. *EPO. Worldwide Patent Statistical Database (PATSTAT), European Patent Office. Available from: https://www.epo.org/searching-for-patents/business/patstat.html#tab1*
2. *Mountraki, A., Georgakaki, A., Shtjefni, D., Ince, E. and Charleston, G., RandI data for SETIS and the State of the Energy Union Report, European Commission, 2022, JRC130405. http://data.europa.eu/89h/jrc-10115-10001*
3. *EPO and USPTO. Cooperative Patent Classification (CPC), European Patent Office & United States Trademark and Patent Office. Available from http://www.cooperativepatentclassification.org/index.html*
4. *Patents allow companies to protect their research and innovations efforts. Patents cov-ering the domestic market only (single patent families), provide only a protection at the domestic level, while patents filed at the WIPO or the EPO provide a protection outside the domestic market (i.e. they are forwarded to other national offices), and hence signal an international competitiveness of the company.*
5. *A. Fiorini, A. Georgakaki, F. Pasimeni, E. Tzimas, "Monitoring R&D in Low-Carbon Energy Technologies", EUR 28446 EN (2017). Available from: https://setis.ec.europa.eu/related-jrc-activities/jrc-setis-reports/monitoring-ri-low-carbon-energy-technologies*

SOLAR ENERGY

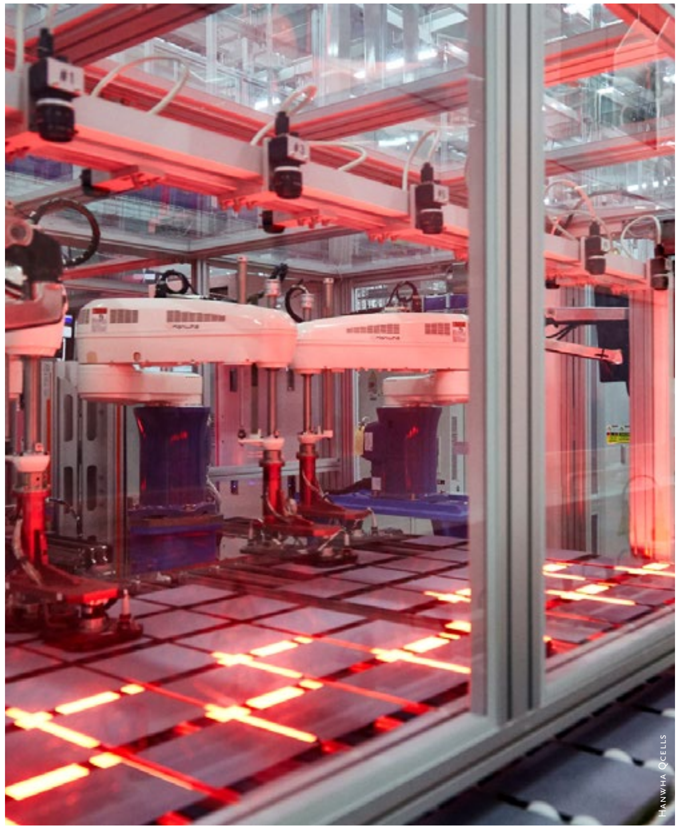
	Number of patent families		Patent specialization		Patents per € trillion GDP	
	2020	2021	2020	2021	2020	2021
EU-27						
Germany	202.3	60.8	0.6	0.6	58.6	16.5
Spain	42.9	34.2	2.4	2.1	38.0	27.7
France	102.5	28.0	0.9	0.6	44.2	11.2
Italy	33.7	25.3	1.0	1.0	20.2	13.7
Netherlands	29.5	14.2	1.0	1.0	36.2	16.0
Poland	25.6	13.2	1.7	1.9	48.2	22.7
Romania	4.3	5.0	1.3	1.7	19.3	20.6
Ireland	2.5	4.0	0.6	1.3	6.5	8.9
Greece	4.0	3.8	2.8	2.4	23.9	20.8
Belgium	9.4	3.8	0.8	0.6	20.2	7.6
Sweden	11.2	3.4	0.5	0.2	23.4	6.4
Austria	23.2	2.7	1.2	0.5	61.0	6.6
Czechia	2.0	2.5	0.6	0.9	9.2	10.2
Finland	3.0	2.3	0.2	0.3	12.7	9.4
Denmark	4.7	1.6	0.2	0.1	15.0	4.6
Croatia	n.a.	1.0	n.a.	2.6	n.a.	17.1
Cyprus	1.0	1.0	2.7	5.0	44.7	38.9
Lithuania	1.0	0.5	2.5	2.5	19.9	8.8
Malta	n.a.	0.4	n.a.	3.0	n.a.	24.0
Bulgaria	1.0	n.a.	1.6	n.a.	16.2	n.a.
Estonia	0.5	n.a.	1.4	n.a.	19.7	n.a.
Luxembourg	1.1	n.a.	0.4	n.a.	16.8	n.a.
Portugal	1.6	n.a.	0.6	n.a.	8.0	n.a.
Slovakia	2.5	n.a.	3.6	n.a.	26.5	n.a.
European Union	**509.3**	**207.9**	**0.8**	**0.7**	**37.5**	**14.1**

Continues overleaf

Other Countries						
China	7 296.5	8 829.3	1.0	1.0	567.4	586.0
Korea	1 507.8	1 412.3	1.5	1.4	1 047.4	918.6
Japan	577.5	541.6	0.6	0.5	130.5	127.2
United States	383.5	295.4	0.7	0.9	20.5	14.8
Rest of the world*	386.3	266.9	1.2	1.2	16.0	9.9
out of which United Kingdom	*21.6*	*19.0*	*0.4*	*0.6*	*9.2*	*7.1*

** including UK. Note : The value 0 signals that there is no patent application. N.a. signals that the data was not available. Note: single patent families (singletons) have been included). **Source: JRC SETIS, World Bank (WBGAPI).***

In the field of solar energy, China is the uncontested frontrunner in terms of patents (filed domestically or internationally), although Korea has higher levels of patents per trillion of GDP. China is followed in number of patents by Korea and Japan and then the US and the EU-27. Within the EU-27, Germany has filed the largest number of patents, followed by Spain, France, and Italy (in 2021). Among the more significant patent filing countries, Spain is scoring highest in terms of patents per GDP within the EU-27, but they lag very far behind Korea and China (and are behind Japan). Countries with significant patent filing levels showed little variation in their specialization index between 2020 and 2021, with Cyprus and Malta showing the highest specialization indices amongst EU-27 countries. Similarly to investment levels, the patent filing levels show that solar is one of the three major RETs. ■

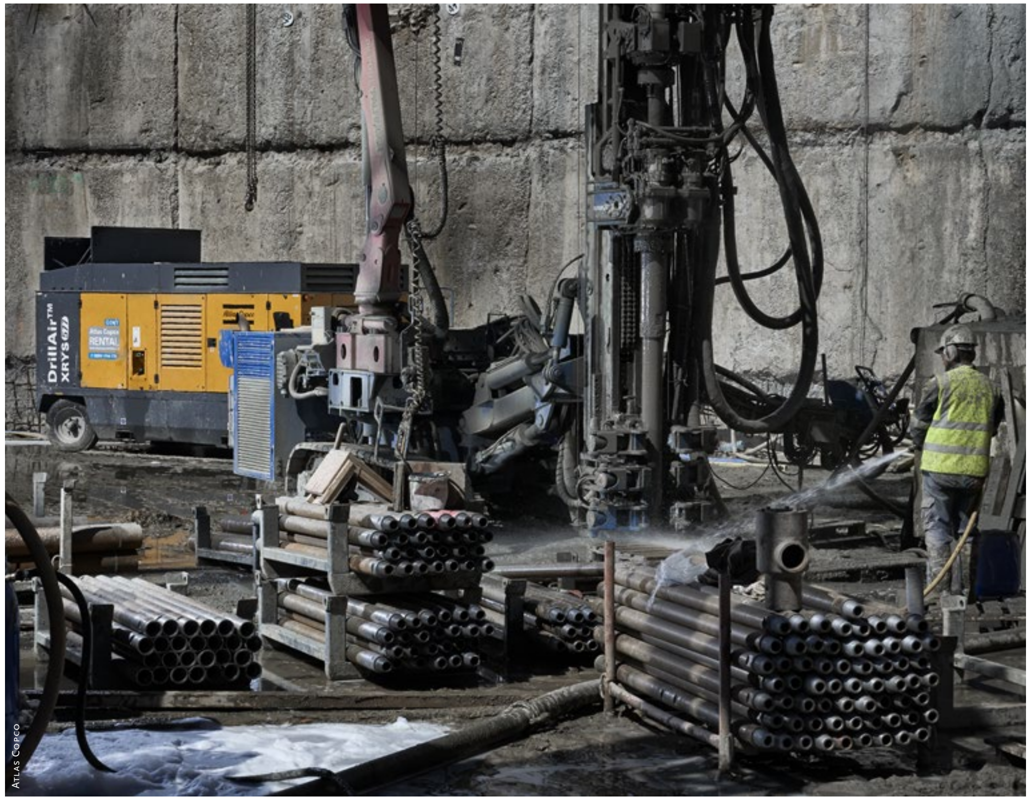


GEOTHERMAL ENERGY

	Number of patent families		Patent specialization		Patents per € trillion GDP	
	2020	2021	2020	2021	2020	2021
EU-27						
France	2.1	4.8	0.4	1.7	0.9	1.9
Sweden	0.3	3.0	0.3	2.2	0.7	5.6
Germany	3.9	2.0	0.3	0.3	1.1	0.5
Belgium	n.a.	1.0	n.a.	2.3	n.a.	2.0
Italy	n.a.	1.0	n.a.	0.6	n.a.	0.5
Latvia	n.a.	1.0	n.a.	n.a.	n.a.	31.0
Luxembourg	n.a.	1.0	n.a.	8.0	n.a.	13.8
Poland	1.5	1.0	2.3	2.2	2.8	1.7
Finland	1.0	1.0	1.7	2.0	4.2	4.0
Netherlands	4.1	0.2	3.2	0.3	5.0	0.3
Austria	n.a.	0.1	n.a.	0.3	n.a.	0.3
Denmark	0.8	n.a.	0.6	n.a.	2.6	n.a.
Hungary	n.a.	n.a.	11.4	n.a.	n.a.	n.a.
Portugal	0.5	n.a.	4.4	n.a.	2.5	n.a.
European Union	**14.7**	**15.2**	**0.5**	**0.8**	**1.1**	**1.0**
Other Countries						
China	341.4	579.7	1.1	1.0	26.5	38.5
United States	20.1	52.4	0.9	2.4	1.1	2.6
Korea	38.7	34.5	0.9	0.5	26.9	22.5
Japan	24.2	25.5	0.6	0.4	5.5	6.0
Rest of the world*	28.9	30.7	2.0	2.1	1.2	1.1
out of which United Kingdom	*3.7*	*3.0*	*1.6*	*1.5*	*1.6*	*1.1*

** including UK. Note : The value 0 signals that there is no patent application. N.a. signals that the data was not available. Note: single patent families (singletons) have been included).* ***Source: JRC SETIS, World Bank (WBGAPI).***

In the field of geothermal energy, China is the uncontested frontrunner in terms of patents (filed domestically or internationally). It also has the highest levels of patents per trillion of GDP. China is followed in number of patents by Korea and Japan. Within the EU, France and Sweden have filed the largest number of patents (in 2021). Sweden saw an increase between 2020 and 2021, leading to a relatively large patent specialization index. It is important to keep in mind that this jump occurs at relatively low levels (from 0.3 to 2.2), so it might be a one-time event. Korea and China are once again very far ahead in terms of patents per GDP. Similarly to investment levels, the patent filing levels show that geothermal is a minor RET in terms of patent focus. ■



Atlas Copco

HYDROENERGY

	Number of patent families		Patent specialization		Patents per € trillion GDP	
	2020	2021	2020	2021	2020	2021
EU-27						
Germany	19.7	12.3	0.7	0.4	5.7	3.6
Czechia	3.8	8.8	1.6	3.3	2.1	5.3
Italy	6.3	5.8	5.5	4.9	11.9	11.1
Greece	8.9	5.0	0.9	0.6	3.7	2.2
Denmark	0.7	4.0	0.3	1.8	1.4	8.4
Poland	1.0	2.3	0.8	1.3	0.8	2.1
Belgium	0.3	2.2	0.2	1.2	0.8	5.7
Spain	1.0	1.5	21.5	10.7	5.5	9.1
France	1.0	1.5	0.9	1.2	4.2	6.3
Austria	0.5	1.5	0.2	0.5	0.6	1.8
Romania	0.2	1.3	5.8	30.4	5.1	26.7
Luxembourg	1.6	0.8	5.7	3.1	7.0	3.4
Netherlands	n.a.	0.5	0.0	10.5	n.a.	18.2
Ireland	n.a.	n.a.	0.0	0.0	n.a.	n.a.
Estonia	n.a.	n.a.	0.0	0.0	n.a.	n.a.
Lithuania	n.a.	n.a.	0.0	0.0	n.a.	n.a.
Finland	n.a.	n.a.	0.0	0.0	n.a.	n.a.
Sweden	1.0	n.a.	2.4	0.0	2.8	n.a.
European Union	**46.5**	**47.6**	**0.8**	**0.8**	**3.3**	**3.5**
Other Countries						
China	1 041.5	1 628.6	1.2	1.1	81.0	108.1
Japan	78.4	124.2	0.7	0.7	17.7	29.2
Korea	73.5	114.9	0.6	0.7	51.1	74.7
United States	16.9	25.8	0.3	0.4	0.9	1.3
Rest of the world*	65.9	31.9	1.6	0.8	2.7	1.2
out of which United Kingdom	*4.8*	*0.7*	*0.7*	*0.1*	*2.0*	*0.2*

** including UK. NNote : The value 0 signals that there is no patent application. N.a. signals that the data was not available. Note: single patent families (singletons) have been included). **Source: JRC SETIS, World Bank (WBGAPI).***

In the field of hydro energy, China is the uncontested frontrunner in terms of patents (filed domestically or internationally). It also has the highest levels of patents per trillion of GDP. China is followed in number of patents by Japan and Korea. Within the EU, Germany is ahead of Italy and Czechia, (in 2021). China saw considerable growth in terms of patents (and a resulting patents per GDP growth) between 2020 and 2021. Some EU country such as Greece and Czechia show a higher-than-average patent specialization index, but this might be more linked to a low number of patents. Similarly to investment levels, the patent filing levels show that hydro energy is a minor RET in terms of patent focus. ■


Energie AG Oberösterreich

BIOFUELS

	Number of patent families		Patent specialization		Patents per € trillion GDP	
	2020	2021	2020	2021	2020	2021
EU-27						
Italy	11.6	20.5	2.0	4.8	6.9	11.1
France	60.5	20.0	3.0	2.6	26.1	8.0
Netherlands	14.8	18.6	3.0	7.3	18.1	20.8
Germany	30.0	12.6	0.6	0.8	8.7	3.4
Poland	27.3	10.7	10.8	8.7	51.4	18.3
Spain	9.2	9.0	3.0	3.2	8.2	7.3
Denmark	19.0	8.0	3.9	2.2	61.2	23.2
Finland	20.0	7.2	8.9	5.4	84.5	29.0
Romania	2.0	6.0	3.7	11.9	9.1	24.8
Sweden	10.1	4.7	2.5	1.2	21.2	8.7
Portugal	3.5	4.0	8.0	23.5	17.4	18.5
Belgium	4.7	3.7	2.5	3.1	10.1	7.4
Greece	0.6	3.0	2.5	10.8	3.6	16.3
Czechia	1.3	2.2	2.2	4.4	5.9	8.8
Luxembourg	1.0	2.0	2.5	5.9	15.5	27.6
Ireland	0.0	1.0	0.0	1.9	0.1	2.2
Hungary	5.5	1.0	32.6	11.8	39.9	6.5
Slovakia	n.a.	1.0	n.a.	22.2	n.a.	9.8
Austria	4.2	0.4	1.3	0.4	11.1	1.1
Bulgaria	1.5	n.a.	14.3	n.a.	24.2	n.a.
Estonia	0.4	n.a.	5.6	n.a.	13.5	n.a.
Cyprus	0.5	n.a.	8.1	n.a.	22.3	n.a.
European Union	**227.7**	**135.6**	**2.1**	**2.8**	**16.8**	**9.2**
Other Countries						
China	1 008.5	1 318.9	0.8	0.9	78.4	87.5
Korea	172.0	196.3	1.0	1.1	119.5	127.7
Japan	126.2	142.8	0.8	0.8	28.5	33.6
United States	128.6	129.5	1.4	2.2	6.9	6.5
Rest of the world*	133.7	84.6	2.4	2.1	5.6	3.1
out of which United Kingdom	*24.7*	*6.3*	*2.8*	*1.1*	*10.5*	*2.4*

Continues overleaf

** including UK. Note : The value 0 signals that there is no patent application. N.a. signals that the data was not available. Note: single patent families (singletons) have been included).* ***Source: JRC SETIS, World Bank (WBGAPI).***

In the field of biofuels, China is the uncontested frontrunner in terms of patents (filed domestically or internationally), although Korea has higher levels of patents per trillion of GDP. China is followed in number of patents by Korea and Japan. Within the EU-27, Italy has filed the largest number of patents, followed by France, and The Netherlands(in 2021, in 2020, France was ahead). Among the more significant patent filing countries, Italy, France, The Netherlands, and Poland are scoring highest in terms of patents per GDP within the EU-27, but they lag very far behind Korea and China. Amongst the significant EU-27 countries, Italy and The Netherlands sow some growth in their patent specialization index from 2020 to 2021. Similarly to investment levels, the patent filing levels show that biofuels are one of the three major RETs. ■

Mika Pakarinen - Gasum

WIND ENERGY

	Number of patent families		Patent specialization		Patents per € trillion GDP	
	2020	2021	2020	2021	2020	2021
EU-27						
Denmark	290.4	280.1	26.7	29.6	932.8	811.3
Germany	183.7	140.7	1.5	3.2	53.3	38.3
Spain	75.0	125.1	11.1	16.9	66.5	101.2
France	41.0	31.8	0.9	1.6	17.7	12.7
Netherlands	31.4	31.3	2.9	4.7	38.5	35.1
Italy	10.6	13.7	0.8	1.2	6.3	7.4
Sweden	13.2	11.5	1.5	1.2	27.6	21.3
Poland	14.5	9.0	2.6	2.8	27.4	15.4
Belgium	8.4	6.3	2.0	2.0	18.0	12.5
Austria	17.2	6.3	2.3	2.3	45.2	15.6
Greece	2.3	4.0	4.3	5.5	13.9	21.7
Romania	4.6	3.5	3.8	2.7	20.8	14.4
Latvia	2.3	2.0	6.9	8.2	77.0	61.9
Finland	3.6	1.4	0.7	0.4	15.3	5.6
Ireland	n.a.	1.1	n.a.	0.8	n.a.	2.4
Czechia	1.0	1.0	0.8	0.8	4.5	4.1
Cyprus	0.7	1.0	4.8	11.0	29.8	38.9
Portugal	1.5	1.0	1.5	2.3	7.5	4.6
Luxembourg	n.a.	0.5	n.a.	0.6	n.a.	6.9
Croatia	n.a.	0.1	n.a.	0.5	n.a.	1.6
Bulgaria	1.0	n.a.	4.3	n.a.	16.2	n.a.
Hungary	1.0	n.a.	2.7	n.a.	7.3	n.a.
European Union	**703.4**	**671.3**	**2.9**	**5.3**	**51.8**	**45.4**
Other Countries						
China	2 686.4	3 809.3	1.0	1.0	208.9	252.8
Korea	200.2	305.8	0.5	0.7	139.1	198.9
Japan	122.1	189.7	0.4	0.4	27.6	44.6
United States	122.5	113.1	0.6	0.7	6.6	5.6
Rest of the world*	169.2	141.5	1.4	1.4	7.0	5.2
out of which United Kingdom	*28.5*	*26.0*	*1.5*	*1.8*	*12.1*	*9.8*

** including UK. Note : The value 0 signals that there is no patent application. N.a. signals that the data was not available. Note: single patent families (singletons) have been included). **Source: JRC SETIS, World Bank (WBGAPI).***

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In the field of wind energy, China is the uncontested frontrunner in terms of patents (filed domestically or internationally), though Denmark is far ahead in terms of levels of patents per trillion of GDP. China is followed in number of patents by the EU and Korea. Within the EU-27, Denmark has filed the largest number of patents by far, followed by Germany and Spain. In terms of patents per GDP, Denmark is far ahead of China and Korea. Denmark (and Spain to a lesser extent) has a very significant degree of patent specialization. Similarly to investment levels, the patent filing levels show that wind energy is one of the three major RETs. ■

OCEAN ENERGY

	Number of patent families		Patent specialization		Patents per € trillion GDP	
	2020	2021	2020	2021	2020	2021
EU-27						
Italy	6.4	14.0	3.5	12.2	3.8	7.6
Germany	2.7	5.0	0.2	1.1	0.8	1.4
Denmark	2.1	3.0	1.3	3.1	6.6	8.7
Ireland	0.7	1.8	2.9	13.2	1.7	4.1
France	9.7	1.8	1.5	0.9	4.2	0.7
Spain	1.2	1.0	1.2	1.3	1.0	0.8
Sweden	2.5	1.0	2.0	1.0	5.3	1.9
Netherlands	2.6	0.8	1.7	1.1	3.2	0.8
Luxembourg	1.0	n.a.	7.8	n.a.	15.5	n.a.
Poland	1.8	n.a.	2.3	n.a.	3.5	n.a.
Romania	0.8	n.a.	4.4	n.a.	3.4	n.a.
Finland	1.6	n.a.	2.3	n.a.	6.8	n.a.
European Union	33.0	28.3	0.9	2.2	2.4	1.9
Other Countries						
China	424.0	374.9	1.1	0.9	33.0	24.9
United States	22.4	35.7	0.8	2.2	1.2	1.8
Korea	22.5	32.7	0.4	0.7	15.7	21.3
Japan	10.0	20.5	0.2	0.4	2.3	4.8
Rest of the world*	53.3	46.0	3.1	4.3	2.2	1.7
out of which United Kingdom	*18.2*	*11.0*	*6.6*	*7.3*	*7.7*	*4.1*

** including UK. Note : The value 0 signals that there is no patent application. N.a. signals that the data was not available. Note: single patent families (singletons) have been included).* ***Source: JRC SETIS, World Bank (WBGAPI).***

In the field of ocean energy, China is the uncontested frontrunner in terms of patents (filed domestically or internationally). It also has the highest levels of patents per trillion of GDP. China is followed in number of patents by the USA and Korea. Within the EU, Italy is ahaead in 2021, while France was ahead in 2020. The specialization index is relatively low across the board, with some exceptions for countries with a low number of patents (though the UK has average levels of both). Similarly to investment levels, the patent filing levels show that ocean energy is a minor RET in terms of patent focus. ■

RENEWABLE ENERGY TECHNOLOGIES IN TOTAL

	Number of patent families		Patents per € trillion GDP	
	2020	2021	2020	2021
EU-27				
Denmark	317.0	293.7	1018.1	850.6
Germany	435.7	228.1	126.3	62.0
Spain	131.5	170.3	116.4	137.8
France	223.1	87.4	96.3	34.9
Italy	70.1	77.5	42.0	42.0
Netherlands	83.7	65.6	102.5	73.5
Poland	76.3	34.9	143.8	59.9
Sweden	41.1	23.6	86.1	43.7
Belgium	22.4	15.9	48.4	31.4
Romania	12.3	15.5	55.9	64.0
Greece	8.2	12.3	48.8	66.8
Finland	30.7	12.0	129.8	48.1
Austria	46.3	10.6	121.7	26.0
Czechia	4.3	8.7	19.6	35.2
Ireland	3.2	8.3	8.3	18.4
Portugal	7.1	5.0	35.4	23.1
Luxembourg	3.1	4.0	47.8	55.3
Latvia	2.3	3.0	77.0	92.9
Cyprus	2.2	2.0	96.8	77.9
Croatia	0.0	1.1	0.0	18.7
Hungary	6.5	1.0	47.2	6.5
Slovakia	2.5	1.0	26.5	9.8
Lithuania	3.0	0.5	59.7	8.8
Malta	0.0	0.4	0.0	24.0
Bulgaria	3.5	0.0	56.5	0.0
Estonia	1.4	0.0	51.1	0.0
Slovenia	0.0	0.0	0.0	0.0
European Union	1 537.8	1 081.1	113.3	73.1

Continues overleaf

Other Countries				
China	12 798.3	16 540.8	995.3	1 097.8
Korea	2 014.8	2 096.6	1 399.5	1 363.7
Japan	938.4	1 044.3	212.0	245.3
United States	694.0	651.9	37.1	32.6
Rest of the world*	837.4	601.5	34.8	22.2
out of which United Kingdom	*101.6*	*65.8*	*43.0*	*24.8*

** including UK. Note : The value 0 signals that there is no patent application. N.a. signals that the data was not available. Note: single patent families (singletons) have been included).*
Source: JRC SETIS, World Bank (WBGAPI).

A final look at the patenting figures in all renewable energies technologies shows that China has filed by far the largest number of patents in 2021, followed by Korea, the EU-27, Japan, and the US. Within the EU-27, a strong position of Denmark is noted followed by Germny (in 2021, it was the other way around in 2020), Spain, and France (in 2021, they are switched around in 2020). When measured in terms of GDP shares, Denmark is (far) ahead of other EU member states. This high level for Denmark is boosted by its leadership position in wind energy and brings it close to China and Korea in terms of patents per GDP in all RETs. ■

EUROBSERV'ER – THE STATE OF RENEWABLE ENERGIES IN EUROPE – 2024 EDITION

CONCLUSIONS

Across nearly all fields in renewable energies technologies, the Asian countries, in particular China, display the highest patenting activities in absolute and relative (GDP) numbers when including patent filings that refer only to the domestic market (singletons). The EU-27 is in a good position behind the Asian countries but ahead of the US. Within the EU-27, it is mostly Germany (boosted by its size) and Denmark (boosted by its focus oon wind) that file the largest number of patents. Analysis in terms of patents per GDP shows Denmark in an uncontested first position in Europe (again, mostly due to its focus on wind). Germany is also one of the few countries that show a certain activity level across all renewable energy technology fields, while most other countries are specialized in only one or two RET technologies. Denmark, for example, shows remarkable filing figures in wind energy, while Italy shows a lot of activity in biofuels. Regarding RE technologies, solar energy has the largest number of patent filings worldwide, while in the EU-27, wind energy ranks highest in number of patent filings. In contrast to the large R&D investments into biofuels, the patent statistics show relatively modest results for biofuels, i.e., it is the third largest field behind solar energy and wind energy. Regarding ocean energy, in terms of patents and R&D spending it is less significant, albeit its resource and technological development potentials. ■

References:

*Joint Research Centre (JRC) based on data from the European Patent Office (EPO)**

- *Patent data based on PATSTAT database 2021 spring version (JRC update: May 2021). The methodology behind the indicators is provided in Fiorini et al. (2017), Pasimeni et al. (2019), Pasimeni (2019), and Pasimeni et al. (2021)*

International Trade

Analysing international trade and trade-flows has become an important topic in trade economics because it is understood that an increase in trade generally benefits all trading partners. The mainstream in international trade theories predict that the international trade of goods occurs because of comparative advantages, i.e. different advantages in manufacturing goods between two countries essentially lead to trade between these two countries. Empirical data, however, has shown that not only factor endowment but also the technological capabilities of a country affect its export performance. Firms that develop new products or integrate superior technology will thus dominate the export markets of these products (e.g. Dosi and Soete 1983, 1991; Krugman 1979; Posner 1961; Vernon 1966, 1979). In sum, it can be stated that innovation is positively correlated with export performance. This is why a closer look is taken at the export performance. It is considered as an important output indicator of innovative performance within renewable energy technologies.

Methodological approach

In order to depict trade, the absolute (export) advantage in terms of global export shares as well as net exports, i.e. exports minus imports of a given country, are analysed. Net exports reveal whether there is a surplus generated by exporting goods and services. Moreover, a closer look is taken at the comparative advantage, which refers to the relative costs of a product in terms of a country vis-à-vis another country. Early economists believed that absolute advantage in a certain product category would be a necessary condition for trade. Yet, it has been shown that international trade is mutually beneficial under the weaker condition of comparative advantage (meaning that productivity of one good relative to another differs between countries). The analysis of trade-flows has thus become an important topic in trade economics. The most widely used indicator is the Revealed Comparative Advantage (RCA) developed by (Balassa 1965) because an increase in trade benefits all trading partners under very general conditions. Thus, the RCA is a very valuable indicator to analyse and describe specialisation in certain products or sectors.

$$RCA_{ij} = 100 \cdot \tanh yp\left(\log \frac{E_{ij} / \sum_{k=1}^{J} E_{ik}}{\sum_{h=1}^{I} E_{hj} / \sum_{h=1}^{I} \sum_{k=1}^{J} E_{hk}} \right)$$

The share of a country i's RET exports is compared to the world's (sum of all other countries) RET export share. The RET shares itself show RET exports in relation to all exports. Therefore, the RCA for country i measures the share of e.g. wind power technology exports of country i compared to the world's share of wind power technology exports. If a country i's share is larger than the world share, country i is said to be specialised in this field. The tanhyp-log transformation does not change this general interpretation, but it symmetrises this indicator by normalising it to an interval ranging from -100 to +100 in contrast to the RPA. Further, the RCA refers to all product groups traded, while the RPA indicator refers to energy technologies.
The RCA must be interpreted in relation to the remaining portfolio of the country and the world share. For example, if countries only have a minimal (below average) share of renewable energies within their total trade portfolio, all values would be negative. In contrast, some countries e.g. Denmark, Japan, China and Spain have in relation to all exported goods an above average share of RET in their export portfolio.
The analysis looks at renewable energy technologies exports as a whole, but also at the disaggregated RET fields. These fields comprise photovoltaics (PV), wind energy and hydroelectricity and biofuels for the reporting years 2022 and 2023. The export data were extracted from the UN Comtrade database. The fields were identified based on a selection of Harmonized System Codes (HS 2012). Note that in 2022, the PV codes have changed; previously, all PV trade data came from 854140, whereas after 2022, the total PV trade data is an addition of two separate codes: 854142 and 854143. As in previous years, certain data points are missing. In such cases, no specific conclusions were drawn, and the missing data were left unaltered.

1. *The HS 2012 codes used for the demarcation are: Photovoltaics (854142 & 854143), wind energy (850231) and hydroelectricity (841011, 841012, 841013, 841090). For biofuels, the codes (220710, 220720) are based on the classification by JRC SETIS in Pasimeni F., EU energy technology trade: Import and export, EUR 28652 EN, Publications Office of the European Union, Luxembourg, 2017, ISBN 978-92-79-69670-1, doi:10.2760/607980, JRC107048.*

***Note regarding the maps in the chapter:** the relation between the sizes of the circles and the volume of the trade differs from one map to the other.*

ALL RES

EU-27 trade (incl. intra-EU trade). 2022 - all RES

	Imports (in € m)	Exports (in € m)	Net exports (in € m)	Share of global exports	Exports specialisation (RCA)
Denmark	629	1 309	680	1,6%	42
Hungary	447	670	223	0,8%	10
Slovakia	102	127	25	0,2%	-45
Malta	4	0	-4	0,0%	-100
Luxembourg	63	52	-11	0,1%	-6
Cyprus	48	0	-47	0,0%	-95
Latvia	62	11	-51	0,0%	-71
Slovenia	178	126	-52	0,2%	-19
Estonia	59	5	-54	0,0%	-83
Croatia	155	52	-104	0,1%	-24
Belgium	808	691	-117	0,8%	-36
Lithuania	188	57	-131	0,1%	-43
Ireland	282	5	-277	0,0%	-97
Austria	764	433	-331	0,5%	-23
Finland	350	5	-344	0,0%	-94
Czechia	633	282	-351	0,3%	-45
Bulgaria	494	130	-365	0,2%	-14
Portugal	1 231	735	-495	0,9%	38
Romania	568	13	-554	0,0%	-89
Sweden	920	243	-677	0,3%	-43
Greece	1 347	367	-980	0,5%	25
Poland	1 446	317	-1 129	0,4%	-53
France	2 277	891	-1 385	1,1%	-37
Italy	1 921	239	-1 682	0,3%	-76
Germany	5 865	3 512	-2 353	4,3%	-23
Netherlands	6 306	3 624	-2 682	4,4%	12
Spain	3 603	773	-2 830	0,9%	-28
Total EU-27	29 625	14 607	-15 018	18%	-21

Main EU partners' trade with the rest of the world (including EU-27). 2022 - all RES

	Imports (in € m)	Exports (in € m)	Net exports (in € m)	Share of global exports	Exports specialisation (RCA)
China	1 473	43 890	42 417	53,9%	49
Russia	-	-	-	0,0%	n. a.
Norway	209	1	-208	0,0%	-99
India	1 458	1 003	-455	1,2%	-20
Switzerland	652	18	-634	0,0%	-96
Turkey	1 362	244	-1 118	0,3%	-51
United Kingdom	2 059	336	-1 723	0,4%	-64
Canada	2 246	392	-1 854	0,5%	-62
Brazil	4 022	1 734	-2 288	2,1%	16
Japan	2 944	66	-2 877	0,1%	-92
USA	11 141	3 806	-7 335	4,7%	-28
Rest of the world	13 228	15 359	2 132	18,9%	-20

Source: EurObserv'ER

In 2022, the largest importers of photovoltaics, wind energy equipment, biofuels, and hydropower equipment in the EU-27 were the Netherlands (€6 306 million), Germany (€5 865 million) and Spain (€3 603 million). The Netherlands and Germany were also the two main exporters of RET in 2022 with €3 624 million and €3 512 million respectively. From the main trading partners, China has seen a significant decrease in imports (€1 473 million in 2022), while they remain the biggest exporter by far with €43 890 million in exports in 2022. The USA was the leading importer of in 2022, with €11 141 million, followed by Brazil with €4 022 million.

The net exports, i.e. the exports of an economy minus its imports, allow us to provide a little more detail on the above described trends. Net exports can be interpreted as a trade balance and aims at answering the question whether a country is exporting more than it is importing and vice versa. China has a very positive trade balance, i.e. the largest balance among the countries in comparison. China is followed by Denmark, Hungary and Slovakia. Since these countries exported more RET goods than they imported in 2022, their trade balance is positive. All other countries in this comparison have negative trade balances. The countries with the most negative trade balances are the U.S., India, Spain, the Netherlands, Germany and Brazil.

When looking at the export shares in all four selected renewable energy technologies, it can be observed China has the largest values in 2022 with 54%. The EU-27 follows with export shares of 18% in 2022. The U.S., the Netherlands, Germany, Brazil and

EU-27 trade (incl. intra-EU trade). 2023 - all RES

	Imports (in € m)	Exports (in € m)	Net exports (in € m)	Share of global exports	Exports specialisation (RCA)
Denmark	920	1 500	581	1,7%	43
Hungary	260	529	269	0,6%	-6
Slovakia	82	137	55	0,2%	-48
Malta	5	-	-5	0,0%	n. a.
Luxembourg	60	49	-11	0,1%	-11
Cyprus	39	0	-39	0,0%	-98
Slovenia	178	120	-58	0,1%	-27
Latvia	87	11	-76	0,0%	-70
Croatia	138	41	-98	0,0%	-36
Estonia	120	5	-115	0,0%	-83
Ireland	203	11	-192	0,0%	-95
Lithuania	304	110	-194	0,1%	-17
Finland	273	5	-268	0,0%	-95
Czechia	502	228	-274	0,3%	-56
Bulgaria	506	131	-375	0,2%	-15
Belgium	1 121	570	-551	0,7%	-40
Sweden	810	217	-593	0,2%	-50
Portugal	1 203	609	-594	0,7%	27
Austria	844	197	-647	0,2%	-56
Romania	703	17	-686	0,0%	-88
Greece	1 110	386	-724	0,4%	25
Poland	1 341	287	-1 054	0,3%	-59
France	2 777	1 329	-1 449	1,5%	-26
Netherlands	5 424	3 723	-1 700	4,3%	11
Germany	5 207	3 070	-2 137	3,5%	-32
Italy	2 435	266	-2 169	0,3%	-76
Spain	3 103	881	-2 222	1,0%	-26
Total EU-27	29 755	14 430	-15 325	17%	-25

Main EU partners' trade with the rest of the world (including EU-27). 2023 - all RES

	Imports (in € m)	Exports (in € m)	Net exports (in € m)	Share of global exports	Exports specialisation (RCA)
China	632	42 753	42 120	49,1%	47
Russia	-	-	-	0,0%	n. a.
Norway	186	2	-183	0,0%	-99
Switzerland	787	29	-758	0,0%	-94
Turkey	1 919	525	-1 394	0,6%	-27
Canada	2 566	422	-2 144	0,5%	-61
United Kingdom	2 502	297	-2 205	0,3%	-68
Brazil	3 964	1 562	-2 403	1,8%	7
Japan	2 594	153	-2 440	0,2%	-85
India	5 039	2 110	-2 929	2,4%	10
USA	19 818	4 296	-15 523	4,9%	-25
Rest of the world	16 178	20 561	4 384	23,6%	-11

Source: EurObserv'ER

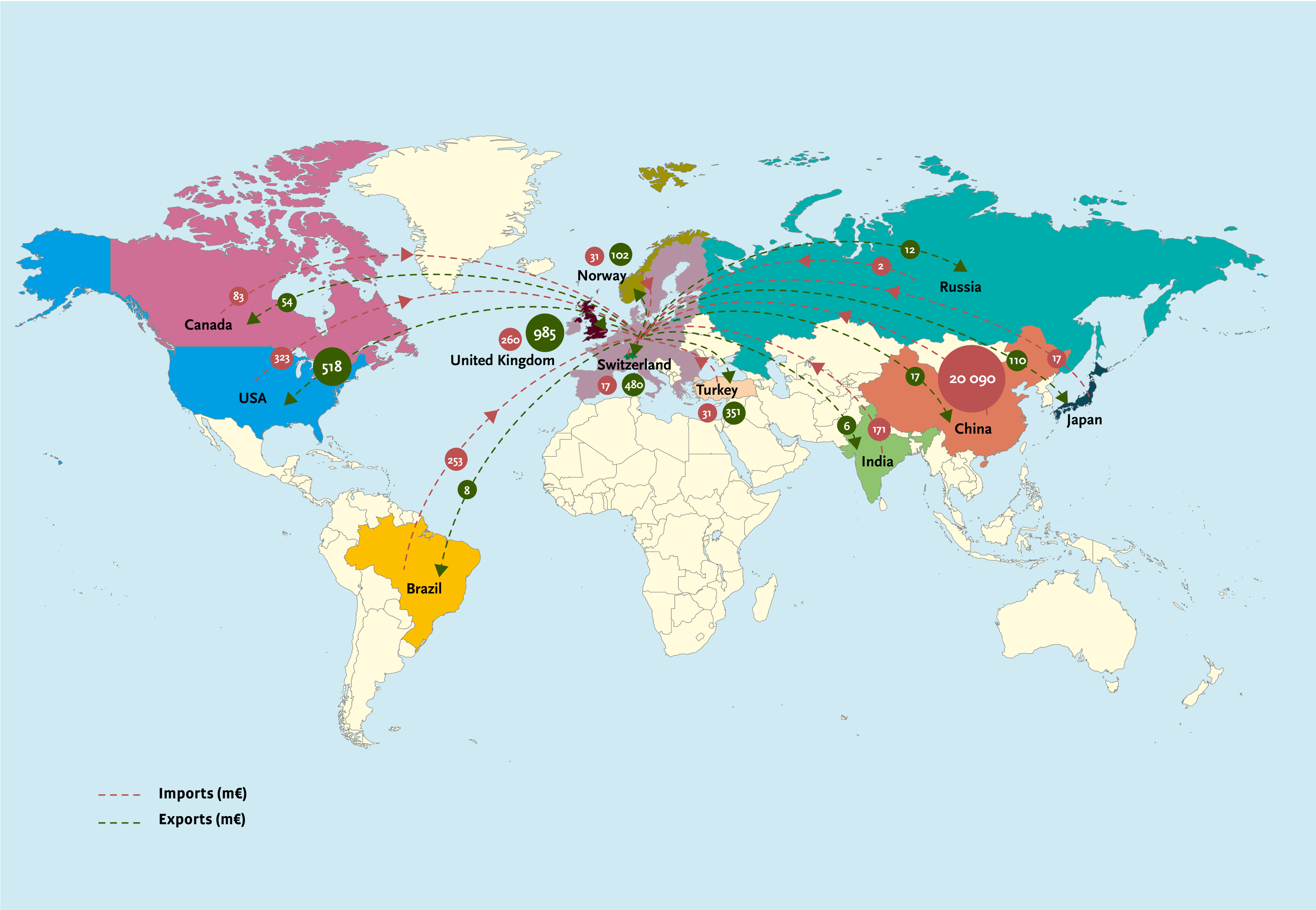
Denmark displays the largest shares after China. The countries with the smallest shares in the comparison are Malta, Cyprus, Latvia, Finland, Romania, Ireland and Norway.

In a final step, we take a closer look at the export specialisation (RCA). Of the EU-27 countries, Denmark scores ahead of the remaining countries, i.e. goods related to RET technologies have a large weight in Denmark's export portfolio. Positive specialisation values can also be found for China, Portugal, the Netherlands, Brazil, Greece and Hungary while all other countries (including the «rest of the world» group) show a negative specialisation regarding the export of goods related to RET technologies in 2022.

Both the total RET import values for the EU-27 increased slightly in 2023 compared to 2022, by approximately €129 million. The total RET export values have decreased by 1,2% (€177 million). The most significant relative increases in imports can be observed for Italy (€514 million), France (€501 million), Belgium (€313 million) and Denmark (€291 million). Countries that have shown the largest decrease in imports are the Netherlands (€883 million), Germany (€659 million) and Spain (€500 million). The exports in Germany decreased most of all the EU-27 (€443 million). A few other countries also show large relative decreases in export, most notably Austria, Hungary and Portugal. Net exports declined significantly in Italy, due to an increase in PV imports and a decrease in wind energy exports. Belgium, Austria and Romania also showed significant decreases in net exports, mainly as a result of increase in PV imports and a decrease in wind energy exports.

When looking at the main trading partners we see a very large increase in imports in the USA (€8 678 million), followed by a large increase in India (€3 581 million) in 2023 compared to 2022. Other decreases in imports can be seen for China (€841 million), Japan (€350 million), the Brazil (€58 million) and Norway (€23

EU-27 trade with its main trading partners. 2023 - all RES



Source: EurObserv'ER

million). For exports we see the largest decrease in China (€1 138 million), and the largest increase in India (€1 107 million). The trade balances follow these trends, with China showing the largest increase in the trade balance. The U.S.A. has a large negative trade balance in 2023 compared to 2022. Brazil, Canada, India, the United Kingdom still have a negative trade balance and have worsened their positions between 2022 and 2023.
When taking a look at the export shares in all four selected renewable energies technologies, it can be observed China has the largest values in 2023 with 49%. For the EU-27, we see a decrease in export shares from 18% in 2022 to 17% in 2023.

The trade in RET between the EU-27 and main trading partners is illustrated in the figure. The net trade balance with China is very negative, i.e. much more is imported from China to the EU-27 than the reverse. Imports from China decreased by around €1 500 million in 2023 compared to 2022. The EU-27 also has a negative RET trade balance with Brazil, India, and Canada in 2023. On the other hand, the EU-27 has a significant positive RET trade balance with the U.K., Switzerland, Turkey and the U.S.A.. Imports from and exports to Russia have significantly decreased by around €17 million and €43 million respectively in 2023. Furthermore, the EU-27 shows a significant decrease in imports from the U.S.A (€158 million), while exports to the U.S.A. have increased significantly (€231 million). ■

WIND ENERGY

EU-27 trade (incl. intra-EU trade). 2022 - wind energy

	Imports (in € m)	Exports (in € m)	Net exports (in € m)	Share of global exports	Exports specialisation (RCA)
Germany	127	1 483	1 356	31,2%	56
Denmark	55	1 274	1 219	26,8%	93
Spain	99	273	174	5,8%	46
Hungary	0	2	1	0,0%	-86
Slovakia	0	1	0	0,0%	-93
Portugal	20	21	0	0,4%	9
Luxembourg	0	-	-0	0,0%	n. a.
Cyprus	0	-	-0	0,0%	n. a.
Latvia	0	-	-0	0,0%	n. a.
Slovenia	0	-	-0	0,0%	n. a.
Malta	0	-	-0	0,0%	n. a.
Croatia	0	0	-0	0,0%	-96
Bulgaria	0	0	-0	0,0%	-94
Czechia	2	1	-1	0,0%	-92
Romania	1	0	-1	0,0%	-100
Estonia	9	0	-8	0,0%	-79
Lithuania	26	12	-14	0,2%	8
Ireland	25	3	-23	0,1%	-83
Belgium	26	1	-25	0,0%	-96
Austria	26	1	-25	0,0%	-94
Greece	91	25	-66	0,5%	32
Italy	93	1	-93	0,0%	-98
Poland	143	2	-141	0,0%	-92
France	158	2	-156	0,0%	-94
Finland	161	0	-161	0,0%	-93
Sweden	181	0	-181	0,0%	-96
Netherlands	322	35	-287	0,7%	-57
Total EU-27	1 569	3 139	1 570	66%	34

Main EU partners' trade with the rest of the world (including EU-27). 2022 - wind energy

	Imports (in € m)	Exports (in € m)	Net exports (in € m)	Share of global exports	Exports specialisation (RCA)
Brazil	3	921	918	19,4%	9
Canada	3	339	336	7,1%	51
China	-	-	-	0,0%	n. a.
India	0	0	-0	0,0%	-100
Japan	62	0	-62	0,0%	-100
Norway	143	67	-76	1,4%	-1
Russia	99	1	-98	0,0%	-92
Switzerland	174	1	-173	0,0%	-98
Turkey	408	162	-246	3,4%	-40
United Kingdom	387	112	-275	2,4%	1
USA	455	1	-454	0,0%	-98
Rest of the world	2 462	5	-2 663	0,1%	-99

Source: EurObserv'ER

In wind power, Germany (31%) and Denmark (27%) are the major players in terms of export shares. They are followed by Spain, which also shows large export shares in wind energy of almost 6%. Around 66% of worldwide exports in wind technologies originate from these three countries. Chinese export shares have decreased slightly to 19.4% in 2022, while India's export shares increased from 4.1% in 2022 to 7.1% in 2023. The Netherlands has significantly increased its imports by almost €322 million, becoming the biggest importer of wind power in the EU-27 in 2022. Similar patterns can also be observed for the trade balance. Here, the largest values can be found for Germany, followed by Denmark, China and Spain. In terms of export specialisation (RCA), Denmark is the most highly specialised in trade of wind technology related goods. Germany and Spain are also highly specialised in wind technology exports. India's export specialisation in wind technology increased to 51 in 2022, showcasing the rapidly changing position of India in the global trade of wind technology goods.

EU-27 trade (incl. intra-EU trade). 2023 - wind energy

	Imports (in € m)	Exports (in € m)	Net exports (in € m)	Share of global exports	Exports specialisation (RCA)
Germany	211	1 450	1 239	29,0%	53
Denmark	525	1 454	929	29,1%	93
France	104	435	331	8,7%	45
Spain	46	266	220	5,3%	43
Portugal	6	8	2	0,2%	-37
Slovakia	0	1	0	0,0%	-94
Cyprus	0	-	-0	0,0%	n. a.
Luxembourg	0	-	-0	0,0%	n. a.
Slovenia	0	-	-0	0,0%	n. a.
Malta	0	-	-0	0,0%	n. a.
Latvia	0	-	-0	0,0%	n. a.
Croatia	0	-	-0	0,0%	n. a.
Hungary	0	0	-0	0,0%	-99
Bulgaria	0	0	-0	0,0%	-98
Czechia	3	1	-1	0,0%	-92
Belgium	9	0	-9	0,0%	-100
Ireland	12	2	-11	0,0%	-88
Romania	16	0	-15	0,0%	-96
Estonia	16	0	-15	0,0%	-88
Lithuania	23	1	-21	0,0%	-70
Austria	28	1	-27	0,0%	-96
Poland	63	4	-59	0,1%	-85
Italy	84	4	-80	0,1%	-92
Greece	114	14	-99	0,3%	7
Finland	110	1	-109	0,0%	-84
Sweden	134	0	-134	0,0%	-99
Netherlands	445	84	-361	1,7%	-29
Total EU-27	**1 949**	**3 727**	**1 779**	**75%**	**37**

Main EU partners' trade with the rest of the world (including EU-27). 2023 - wind energy

	Imports (in € m)	Exports (in € m)	Net exports (in € m)	Share of global exports	Exports specialisation (RCA)
China	3	671	667	13,4%	-5
India	9	193	184	3,9%	30
USA	226	378	153	7,6%	-7
Russia	-	-	-	0,0%	n. a.
Norway	1	0	-1	0,0%	-99
Switzerland	10	0	-10	0,0%	-99
Brazil	114	1	-114	0,0%	-96
Japan	266	2	-264	0,0%	-95
Turkey	353	4	-349	0,1%	-81
Canada	473	1	-472	0,0%	-96
United Kingdom	562	7	-556	0,1%	-85
Rest of the world	2 014	11	-2 091	0,2%	-97

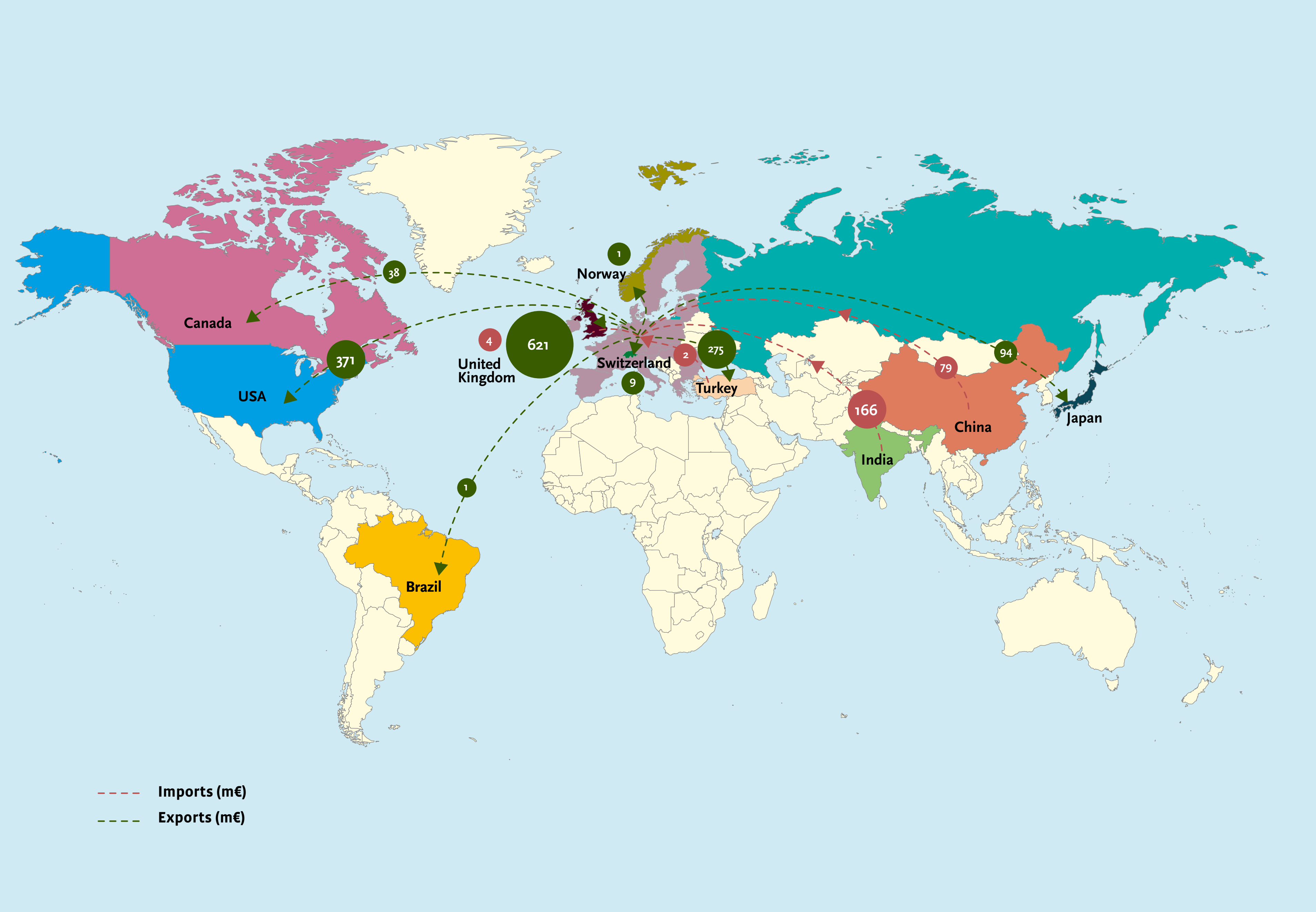
Source: EurObserv'ER

In 2022, Germany (29%) and Denmark (29%) remain major players in terms of export shares, despite the slight decrease in exports from Germany compared to 2022. Spain showed a decrease in export share to 5%. In total, the net exports of the EU-27 increased from 66% in 2022 to 75% in 2023, mainly due to the upcoming net exporter of wind power France (8.7%). Chinese export shares have decreased to 13% in 2023, showing a lesser dependence of China in global wind energy. Exports from the India and U.S. have decreased to 4.9%%, while the export share of the U.S.A. has increased extensively to 7.6% in 2023.

In 2023, Germany and Denmark showed slight decreases in net exports, €1.2 billion and €0.9 billion respectively. China followed at €0.7 billion in net exports. The Netherlands showed the biggest decrease in net exports of the EU-27 to €361 million in 2022.

Denmark remains the most specialised wind energy exporter, followed by Germany and Spain. In 2023 we also observe a high (45) positive RCA in wind energy for France. China's export specialisation in wind technology became negative (-5) in 2023.

EU-27 trade with its main trading partners. 2023 - wind energy



Source: EurObserv'ER

In terms of trade balance, we observe a positive trade balance for the EU with most of the main trading partners, including the U.K., the U.S., Turkey, Norway, and Japan. Net exports to Norway, Turkey, the U.K. and the U.S.A decreased significantly. The total exports from wind energy to countries outside the EU-27 increased to €1.4 billion.

The EU was a net importer from China and India in 2023. However, net imports from China and India decreased significantly by about €372 million and €72 million compared to 2022, respectively. ■

PHOTOVOLTAIC

EU-27 trade (incl. intra-EU trade). 2022 - photovoltaic

	Imports (in € m)	Exports (in € m)	Net exports (in € m)	Share of global exports	Exports specialisation (RCA)
Malta	4	0	-4	0,0%	-100
Luxembourg	59	52	-7	0,1%	5
Latvia	33	4	-30	0,0%	-84
Estonia	44	4	-39	0,0%	-82
Cyprus	46	0	-46	0,0%	-94
Slovakia	66	8	-57	0,0%	-91
Slovenia	161	89	-72	0,1%	-23
Lithuania	91	10	-81	0,0%	-80
Finland	90	1	-89	0,0%	-98
Croatia	140	49	-91	0,1%	-15
Ireland	187	1	-186	0,0%	-100
Sweden	265	9	-256	0,0%	-95
Denmark	319	14	-305	0,0%	-89
Czechia	551	218	-333	0,3%	-45
Romania	380	12	-368	0,0%	-88
Hungary	413	19	-394	0,0%	-87
Belgium	583	172	-411	0,3%	-70
Bulgaria	484	21	-463	0,0%	-67
Portugal	1 176	706	-470	1,1%	46
Austria	651	104	-547	0,2%	-63
Greece	1 082	342	-741	0,5%	32
France	1 262	211	-1 050	0,3%	-72
Poland	1 125	62	-1 063	0,1%	-83
Italy	1 534	84	-1 450	0,1%	-87
Netherlands	3 966	1 752	-2 214	2,8%	-8
Germany	4 194	1 448	-2 746	2,3%	-47
Spain	3 329	155	-3 174	0,2%	-70
Total EU-27	**21 108**	**5 485**	**-15 624**	**9%**	**-49**

Main EU partners' trade with the rest of the world (including EU-27). 2022 - photovoltaic

	Imports (in € m)	Exports (in € m)	Net exports (in € m)	Share of global exports	Exports specialisation (RCA)
China	1 466	42 796	41 330	67,9%	56
Russia	-	-	-	0,0%	n. a.
Norway	73	0	-72	0,0%	-100
Canada	395	179	-216	0,3%	-75
Switzerland	454	5	-450	0,0%	-98
United Kingdom	638	23	-616	0,0%	-95
India	1 231	528	-702	0,8%	-36
Turkey	1 161	221	-940	0,4%	-46
Japan	2 108	58	-2 050	0,1%	-91
Brazil	3 673	0	-3 672	0,0%	-100
USA	10 130	44	-10 086	0,1%	-97
Rest of the world	8 215	13 658	5 899	21,7%	-14

Source: EurObserv'ER

In photovoltaics, China remains the largest player with almost 68% of global exports. They are followed at quite some distance by the Netherlands (2.8%), Germany (2.3%) and Portugal (1.1%). In total, the EU-27 reach a 9% share in 2022. The share of the «rest of the world» category is also high (22% in 2022), showing that there are large exporters not included in the above list. Regarding net exports in PV, only China has a significant positive balance. All other countries in this comparison have a negative trade balance, i.e. they are importing more PV technologies than they export. The most negative one can be found for the U.S., followed by Brazil, Spain and Germany, implying that these countries are highly dependent on imports from other countries in PV technologies. These trends are also reflected in the RCA values. China is most highly specialised in goods related to PV, followed by Portugal, Greece and Luxembourg. All other countries show negative RCA values.

EU-27 trade (incl. intra-EU trade). 2023 - photovoltaic

	Imports (in € m)	Exports (in € m)	Net exports (in € m)	Share of global exports	Exports specialisation (RCA)
Malta	4	-	-4	0,0%	n. a.
Luxembourg	56	49	-8	0,1%	-1
Cyprus	38	0	-38	0,0%	-98
Slovakia	68	8	-59	0,0%	-93
Slovenia	164	94	-70	0,1%	-28
Latvia	77	4	-73	0,0%	-84
Croatia	127	37	-90	0,1%	-29
Estonia	97	5	-92	0,0%	-81
Finland	106	2	-103	0,0%	-96
Ireland	132	7	-125	0,0%	-96
Denmark	187	44	-143	0,1%	-75
Lithuania	188	25	-163	0,0%	-61
Hungary	228	17	-212	0,0%	-90
Czechia	406	156	-250	0,2%	-60
Sweden	332	13	-319	0,0%	-93
Bulgaria	496	33	-463	0,0%	-57
Romania	522	9	-513	0,0%	-91
Greece	904	371	-533	0,5%	33
Austria	688	131	-557	0,2%	-61
Belgium	719	153	-566	0,2%	-71
Portugal	1 160	591	-569	0,9%	35
Poland	1 125	62	-1 063	0,1%	-83
France	1 522	229	-1 293	0,3%	-73
Netherlands	3 457	1 636	-1 822	2,4%	-14
Italy	2 053	85	-1 968	0,1%	-88
Germany	3 675	1 134	-2 541	1,7%	-58
Spain	2 750	181	-2 569	0,3%	-69
Total EU-27	**20 156**	**5 012**	**-16 208**	**7%**	**-55**

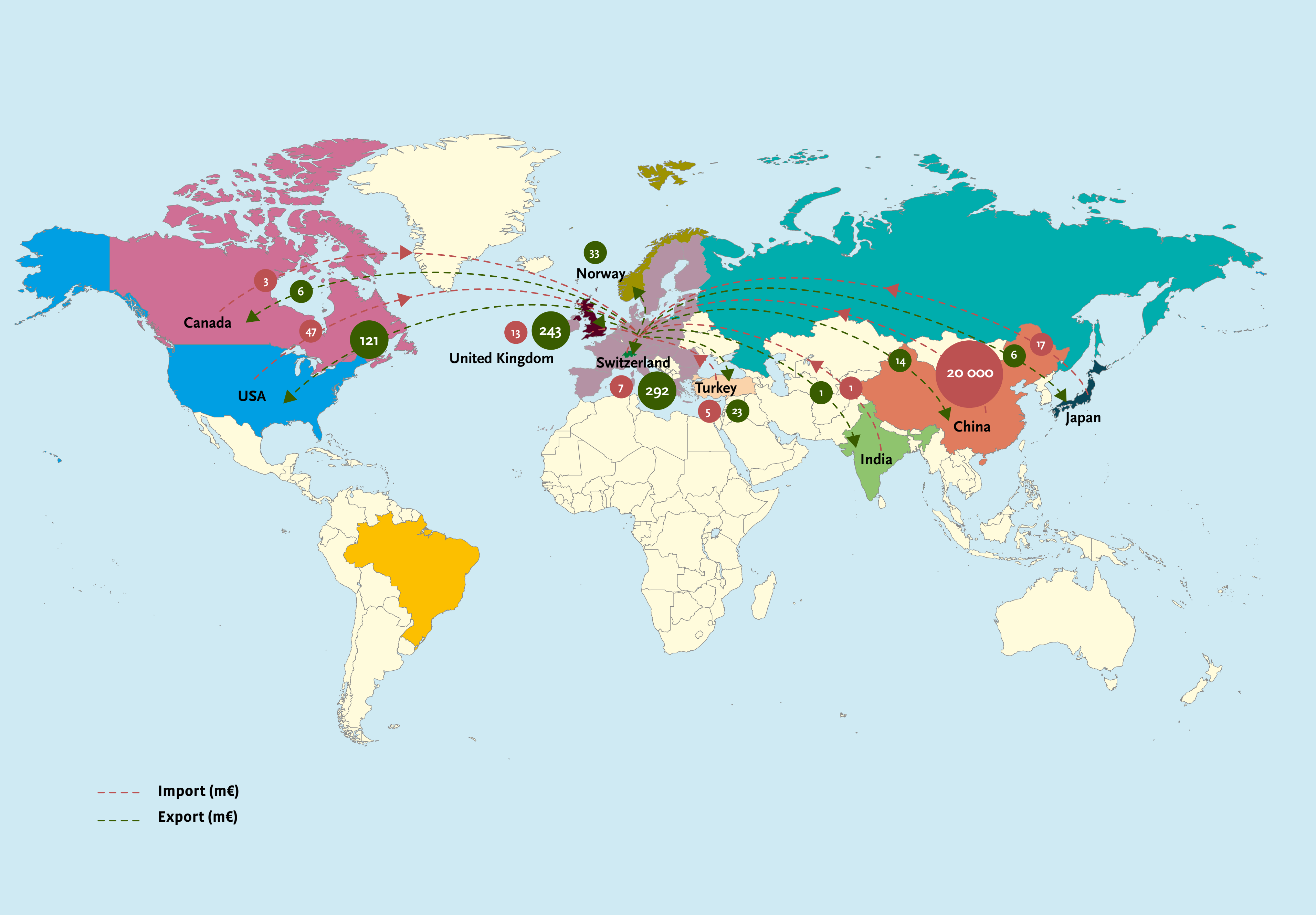
Main EU partners' trade with the rest of the world (including EU-27). 2023 - photovoltaic

	Imports (in € m)	Exports (in € m)	Net exports (in € m)	Share of global exports	Exports specialisation (RCA)
China	625	41 828	41 203	61,0%	54
Russia	-	-	-	0,0%	n. a.
Norway	101	1	-100	0,0%	-99
Canada	456	207	-249	0,3%	-73
Switzerland	579	15	-564	0,0%	-96
United Kingdom	918	37	-881	0,1%	-93
Turkey	1 486	493	-994	0,7%	-20
Japan	1 640	145	-1 495	0,2%	-83
India	4 807	1 757	-3 050	2,6%	13
Brazil	3 807	0	-3 807	0,0%	-100
USA	19 149	89	-19 059	0,1%	-95
Rest of the world	12 462	18 970	6 796	27,7%	-4

Source: EurObserv'ER

The top position of China can be confirmed again in 2023, with a big increase to a total of 61% of worldwide exports in PV originating from China. They are followed by upcoming India (2.6%), the Netherlands (2.4%), Germany (1.7%) and Portugal (0.9%). The EU-27 decreased its share of exports to 7% in 2022. Regarding net exports in PV, China remains the only net exporter, at a significant positive value. All other countries, including countries in the EU in this comparison have a negative trade balance. The U.S.A. decreased net exports by over €9 billion and India decreased net exports by €1 billion. China remains the most highly specialised in goods related to PV, followed by Portugal and Greece. India significantly increased its positive RCA, while other countries show negative RCA values.

EU-27 trade with its main trading partners. 2023 – photovoltaic



Source: EurObserv'ER

The figure illustrates that the EU is a large net importer of photovoltaics from China. In fact, net imports from China are around €20 billion in 2023, down from €21 billion in 2022. The EU also has a negative trade balance in PV with Japan and India. On the other hand, the EU is a net exporter of PV to the remaining countries in the comparison. The most positive trade balances observed are with Switzerland, the U.K., the U.S.A., Norway and Turkey. ■

BIOFUELS

EU-27 trade (incl. intra-EU trade). 2022 - Biofuels

	Imports (in € m)	Exports (in € m)	Net exports (in € m)	Share of global exports	Exports specialisation (RCA)
Hungary	30	648	617	5,0%	71
Belgium	199	517	318	4,0%	29
Austria	51	212	162	1,6%	25
Spain	167	327	160	2,5%	13
Bulgaria	9	105	96	0,8%	51
Slovakia	36	118	82	0,9%	28
Poland	177	251	74	1,9%	11
Malta	0	0	-0	0,0%	-100
Cyprus	1	0	-1	0,0%	-100
Luxembourg	3	0	-3	0,0%	-97
Estonia	7	0	-6	0,0%	-90
Slovenia	8	1	-7	0,0%	-94
Croatia	14	0	-14	0,0%	-94
Latvia	28	7	-21	0,1%	-26
Portugal	34	4	-29	0,0%	-77
Lithuania	71	35	-36	0,3%	13
Czechia	78	30	-47	0,2%	-57
Ireland	69	2	-68	0,0%	-95
Finland	96	-	-96	0,0%	n. a.
Greece	171	0	-170	0,0%	-98
Netherlands	2 018	1 834	-184	14,2%	56
Romania	186	1	-184	0,0%	-93
Italy	279	90	-188	0,7%	-55
France	843	654	-189	5,0%	27
Denmark	254	20	-234	0,2%	-51
Sweden	470	231	-240	1,8%	30
Germany	1 525	513	-1 012	4,0%	-26
Total EU-27	6 824	5 601	-1 223	43%	16

Main EU partners' trade with the rest of the world (including EU-27). 2022 - Biofuels

	Imports (in € m)	Exports (in € m)	Net exports (in € m)	Share of global exports	Exports specialisation (RCA)
USA	564	3 576	3 012	27,6%	45
Brazil	202	1 622	1 420	12,5%	73
China	3	11	8	0,1%	-98
Russia	-	-	-	0,0%	n. a.
Norway	53	0	-53	0,0%	-100
Turkey	94	11	-84	0,1%	-81
India	221	91	-130	0,7%	-42
Switzerland	175	7	-169	0,1%	-91
Japan	649	1	-648	0,0%	-99
United Kingdom	1 019	184	-834	1,4%	-21
Canada	1 364	197	-1 168	1,5%	-23
Rest of the world	2 218	1 656	-561	12,8%	-35

Source: EurObserv'ER

In biofuels (i.e. ethyl alcohols with a strength of 80 degrees or more as well as other denatured spirits), we see a different picture. In this field the EU-27, the U.S. and Brazil score the top positions when looking at the shares on global exports. More than 80% of worldwide exports in biofuels originate from these three regions (2022 as well as 2023). The largest EU countries in terms of trade shares are the Netherlands, France, Hungary, Belgium, and Germany. When looking at net exports, the large positive value for the U.S.A. implies that the U.S.A. is exporting far more biofuels than they import. The next largest net export values can be observed for Brazil, Hungary and Belgium. The most negative trade balance becomes visible for Canada, Germany, the U.K., and Japan, implying that these countries are highly dependent on imports from other countries with regard to biofuels. Once again, these trends can be confirmed when looking at the RCA values. Brazil is the country that is most highly specialised in goods related to biofuels, followed by Hungary, the Netherlands, Bulgaria and the U.S.A.

EU-27 trade (incl. intra-EU trade). 2023 - Biofuels

	Imports (in € m)	Exports (in € m)	Net exports (in € m)	Share of global exports	Exports specialisation (RCA)
Hungary	31	509	478	4,0%	64
Netherlands	1 521	1 998	477	15,6%	59
Slovakia	14	128	114	1,0%	28
Spain	300	404	104	3,2%	23
Bulgaria	9	92	84	0,7%	49
Poland	152	219	67	1,7%	4
Belgium	393	416	23	3,3%	26
Malta	0	-	-0	0,0%	n. a.
Cyprus	1	-	-1	0,0%	n. a.
Luxembourg	3	0	-2	0,0%	-95
Latvia	9	7	-3	0,1%	-24
Slovenia	6	0	-6	0,0%	-96
Estonia	7	0	-7	0,0%	-94
Lithuania	93	83	-9	0,7%	49
Croatia	11	0	-10	0,0%	-96
Portugal	37	7	-30	0,1%	-68
Finland	55	-	-55	0,0%	n. a.
Ireland	57	2	-56	0,0%	-95
Czechia	90	32	-59	0,2%	-58
Austria	89	-	-89	0,0%	n. a.
Greece	90	0	-90	0,0%	-97
Sweden	340	201	-139	1,6%	25
Romania	163	5	-158	0,0%	-79
Italy	273	112	-161	0,9%	-49
Denmark	207	2	-205	0,0%	-92
France	1 134	640	-494	5,0%	24
Germany	1 299	406	-893	3,2%	-36
Total EU-27	6 385	5 265	-1 120	41%	14

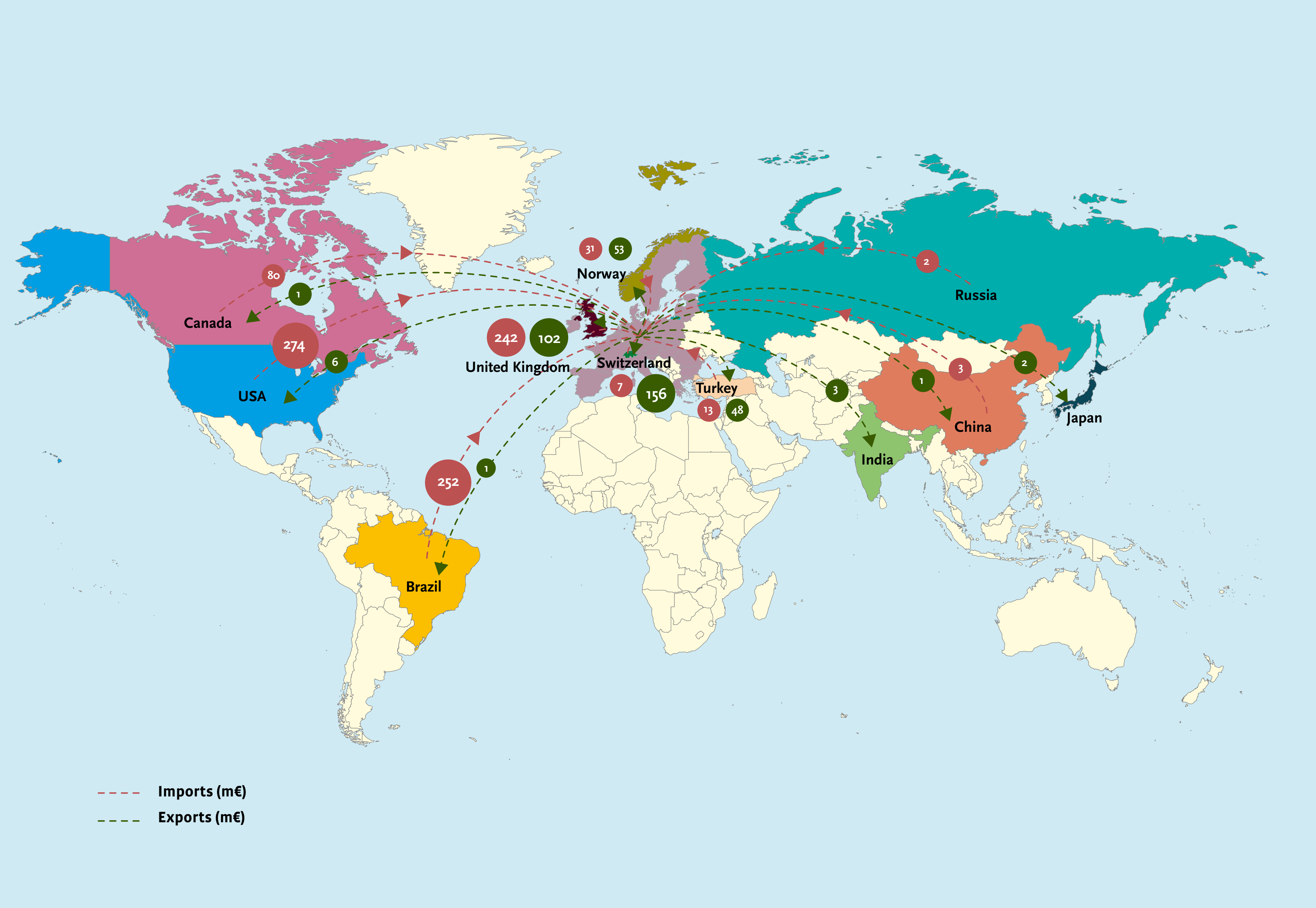
Main EU partners' trade with the rest of the world (including EU-27). 2023 - Biofuels

	Imports (in € m)	Exports (in € m)	Net exports (in € m)	Share of global exports	Exports specialisation (RCA)
USA	399	3 784	3 386	29,6%	48
Brazil	38	1 540	1 502	12,1%	72
China	2	27	25	0,2%	-95
Russia	-	-	-	0,0%	n. a.
Turkey	73	9	-64	0,1%	-84
Norway	69	0	-69	0,0%	-100
India	216	112	-105	0,9%	-33
Switzerland	174	8	-166	0,1%	-90
Japan	674	1	-673	0,0%	-99
United Kingdom	991	232	-759	1,8%	-11
Canada	1 611	201	-1 409	1,6%	-20
Rest of the world	2 441	1 592	-849	12,5%	-37

Source: EurObserv'ER

In 2023, both imports and exports of biofuels decreased in the EU, and net imports decreased slightly to €1 120 million. The share of global exports decreased from 43% in 2022 to 41% in 2023. The U.S.A., the Netherlands and Brazil remain the largest biofuel exporters. While the U.S.A.'s net exports increased with €343 million, Canada's net exports decreased with €242 million in 2023. Brazil remains the most specialised in biofuels trade.

EU-27 trade with its main trading partners. 2023 – Biofuels



Source: EurObserv'ER

In 2023 the EU was a net importer of biofuels from the U.S.A., Brazil, the U.K. and Canada. Net imports increased from the U.S.A. and Brazil when compared to 2022. Of the biofuels exported by the EU, the largest amounts go to the U.S.A., Brazil and the U.K. The EU also has a positive trade balance with the U.S.A. and Brazil. ■

HYDROELECTRICITY

EU-27 trade (incl. intra-EU trade). 2022 - hydroelectricity

	Imports (in € m)	Exports (in € m)	Net exports (in € m)	Share of global exports	Exports specialisation (RCA)
Austria	36	116	79	15,3%	84
Italy	15	64	49	8,5%	44
Germany	18	67	49	8,9%	8
Czechia	3	33	30	4,3%	54
Slovenia	9	36	27	4,8%	86
France	14	24	10	3,2%	7
Spain	8	17	9	2,3%	9
Portugal	0	4	4	0,5%	17
Bulgaria	1	3	3	0,4%	30
Netherlands	0	3	2	0,4%	-73
Croatia	0	2	2	0,3%	42
Finland	2	4	1	0,5%	10
Poland	1	2	1	0,3%	-62
Belgium	0	1	1	0,1%	-82
Malta	0	-	-0	0,0%	n. a.
Lithuania	0	0	-0	0,0%	-98
Denmark	0	0	-0	0,0%	-79
Cyprus	0	-	-0	0,0%	n. a.
Slovakia	0	0	-0	0,0%	-93
Estonia	0	0	-0	0,0%	-100
Ireland	1	0	-1	0,0%	-93
Latvia	1	0	-1	0,0%	-87
Sweden	4	3	-1	0,4%	-35
Romania	2	1	-1	0,1%	-58
Luxembourg	1	0	-1	0,0%	-92
Hungary	3	2	-2	0,2%	-43
Greece	3	0	-3	0,0%	-99
Total EU-27	124	382	258	50%	23

Main EU partners' trade with the rest of the world (including EU-27). 2022 - hydroelectricity

	Imports (in € m)	Exports (in € m)	Net exports (in € m)	Share of global exports	Exports specialisation (RCA)
China	2	162	161	19,8%	14
India	4	45	41	5,5%	44
Brazil	4	45	41	5,5%	54
Turkey	8	11	3	1,3%	10
United Kingdom	15	17	1	2,0%	-2
Russia	-	-	-	0,0%	n. a.
Japan	14	7	-7	0,8%	-52
USA	39	24	-15	3,0%	-42
Switzerland	22	7	-15	0,8%	-29
Canada	32	16	-16	1,9%	-9
Norway	21	1	-20	0,2%	-69
Rest of the world	333	40	-293	4,9%	-64

Source: EurObserv'ER

In hydropower, we can see a more balanced picture than in the case of PV and wind energy. Within the EU-27, the largest export shares can be found for Austria (15%), Germany (9%), Italy (9%), Slovenia (5%), Czechia (4%) and France (3%). In sum, the EU-27 is responsible for more than 50% of the worldwide exports within hydropower. As a single country, China also shows a large value of 20%. China is followed by Brazil and India at 5.5%. The largest positive net export values within the EU-27 are displayed for Austria, Germany, Italy, Slovenia, Czechia, France and Spain. Yet, the largest value globally can be found for China. Russia, Switzerland, Japan and Norway display a negative trade balance. The specialisation values in hydroelectricity show a rather positive picture for Europe, with nine EU-27 members having a positive RCA value. Slovenia and Austria are most highly specialised in the export of hydropower goods, followed by Brazil, Italy and India. China also shows positive RCA values, but its specialisation in PV is still much higher than it is in hydroelectricity.

EU-27 trade (incl. intra-EU trade). 2023 - hydroelectricity

	Imports (in € m)	Exports (in € m)	Net exports (in € m)	Share of global exports	Exports specialisation (RCA)
Germany	21	80	59	9,8%	11
Italy	25	65	40	8,0%	40
Czechia	3	39	36	4,7%	55
Austria	40	66	25	8,0%	73
Spain	7	31	24	3,8%	29
Slovenia	8	26	18	3,2%	80
France	17	25	7	3,0%	2
Netherlands	0	6	5	0,7%	-59
Bulgaria	1	6	5	0,7%	49
Croatia	0	3	3	0,4%	48
Hungary	0	3	3	0,3%	-33
Portugal	1	3	2	0,4%	4
Poland	0	2	1	0,2%	-69
Belgium	0	1	1	0,1%	-86
Latvia	0	0	0	0,0%	-45
Cyprus	0	0	0	0,0%	-96
Lithuania	0	0	0	0,0%	-70
Malta	0	-	-0	0,0%	n. a.
Estonia	0	-	-0	0,0%	n. a.
Slovakia	0	0	-0	0,0%	-92
Romania	2	2	-0	0,3%	-22
Ireland	1	0	-0	0,0%	-88
Denmark	1	0	-0	0,0%	-91
Sweden	5	4	-1	0,5%	-28
Finland	2	1	-1	0,2%	-31
Luxembourg	1	0	-1	0,0%	-35
Greece	2	0	-1	0,0%	-71
Total EU-27	**140**	**363**	**224**	**44%**	**17**

Main EU partners' trade with the rest of the world (including EU-27). 2023 - hydroelectricity

	Imports (in € m)	Exports (in € m)	Net exports (in € m)	Share of global exports	Exports specialisation (RCA)
China	2	227	225	26,6%	26
India	7	48	41	5,6%	45
Brazil	5	21	16	2,4%	22
Turkey	7	19	12	2,2%	29
Russia	-	-	-	0,0%	n. a.
USA	45	44	-2	5,1%	-22
Japan	14	5	-9	0,6%	-59
United Kingdom	30	21	-9	2,4%	4
Norway	14	2	-13	0,2%	-53
Canada	26	12	-14	1,5%	-22
Switzerland	23	6	-18	0,7%	-41
Rest of the world	386	51	-335	5,9%	-60

Source: EurObserv'ER

In 2023, net exports of hydropower goods in the EU-27 decreased compared to 2022. The export share of the EU decreased to 44% of global exports. The largest decrease in exports is observed for Austria, down from 15% in 2022 to 8% of the total export in 2023.
China's and the U.S.A.'s exports also increased, as did its share of global exports. Brazil and the Canada, on the other hand, decreased their export and export shares. Germany, Spain and Czechia showed increases of their share of exports. Furthermore, there are no large shifts in net exports.

When it comes to export specialisation, two countries in EU-27 stand out with the highest RCAs: Slovenia and Austria. Other countries that show high specialisation indices are Czechia and India.

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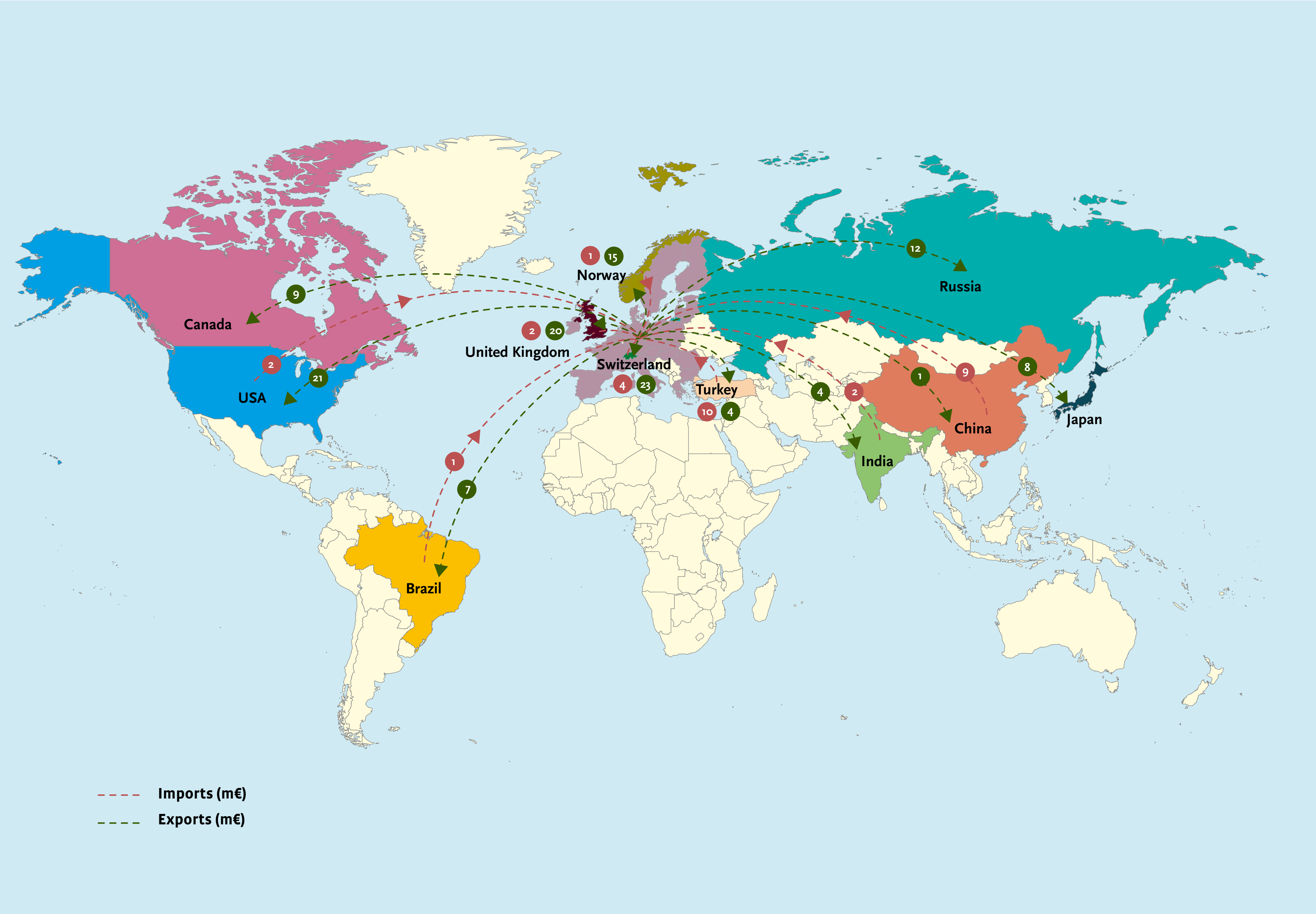
EU-27 trade with its main trading partners. 2023 – hydroelectricity



Source: EurObserv'ER

The figure illustrates that the trade flows for hydropower are small compared to photovoltaics, wind energy and biofuels. The EU has a positive trade balance with most of the main trade partners. Largest surpluses are observed for trade with Switzerland, the U.S.A., the U.K. and Norway. Negative trade balances for hydropower are observed with China, Turkey and India. ■

CONCLUSIONS

The export data in RET technologies provide evidence of the strong position of China in the last years. The Chinese strength in RET exports mostly originates from its strengths in photovoltaics and to a lesser extent hydropower. China is also the country the EU-27 imports the largest amount of RET from, led by large imports of photovoltaics. When it comes to photovoltaics, the EU-27 share in world exports is small (7%) compared to China's share (61%). In wind energy, especially Germany and Denmark, but also France, Spain and the U.S.A. can be seen as strong competitive countries, with large roles in the worldwide export markets. These five countries in sum generate a worldwide export share of 80%. The role of China in wind energy technology exports has been growing steadily in recent years, while 2023 showed a decline in share of exports (to 13%), ranking third in net exports behind Germany and Denmark. The EU is a large player in the biofuels market, with a 41% share in global exports. The U.S.A. and Brazil are responsible for another 42% of global exports, showing the large role of these countries and the EU. In the EU, the Netherlands, France and Hungary are the largest exporters. They are followed by Belgium, Germany and Spain. Germany, however, imports much more biofuels than they export and therefore has a large negative trade balance. Apart from France, the other three EU countries have a positive trade balance. In hydroelectricity, the picture is very balanced. Several European countries are active on worldwide export markets, while China is also responsible for comparably large shares. The EU's share in global exports decreased below 50% again to 44% in 2023, with the biggest share coming from Germany. Overall, the EU displays a strong competitiveness in all RET fields, yet the total export share decreased slightly to 17% in 2023, from 18% in 2022. The U.S.A. is mainly strong in biofuels, and is enforcing its position there, while in other RET its contribution is far below that of the EU. The EU has a positive trade balance with the U.K., Switzerland, Turkey, the U.S.A., Japan, Norway and Russia. China's exports increased significantly, exporting just short of 50% of the total RET exports in 2023. ■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LATVIA
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LITHUANIA
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LUXEMBOURG
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