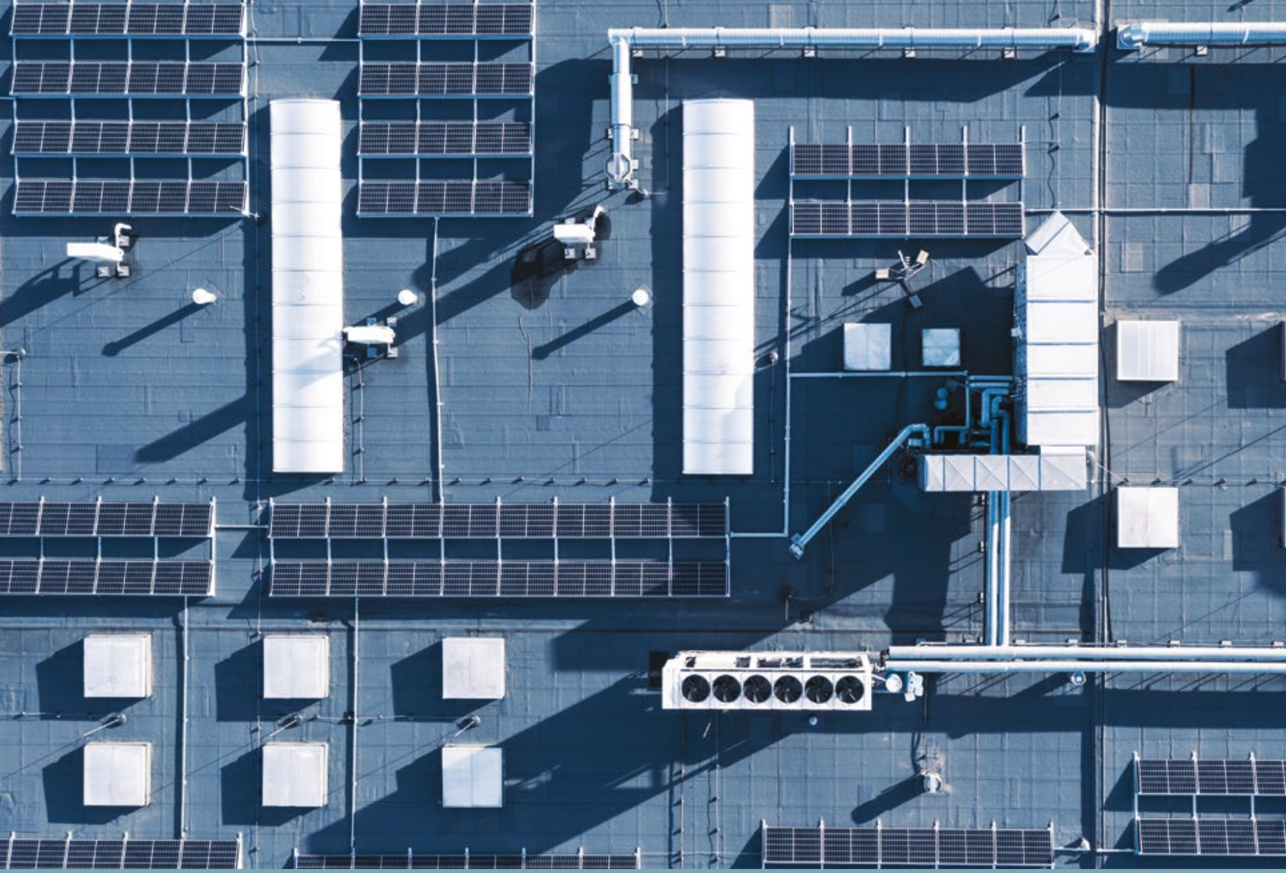

THE STATE OF RENEWABLE ENERGIES IN EUROPE

EDITION 2022

21st 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).

Funded by the European Commission

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PLAUDITS

Vincent Jacques le Seigneur, president of Observ'ER

In 2021, renewable energies covered 21.8% of gross final energy consumption in the EU-27. The target set in the 2008 climate and energy package has thus been exceeded and we can only welcome this at a time when it is fashionable to cast doubt on the benefits of European integration. This is all the more valid because in doing so, Europe has proved that it can come up with initiatives and coordination in a field, that of energy, despite being under the Member States' remit. We can only welcome the decisions taken yesterday that were implemented within the allotted time and currently contribute to our resilience, now that war is on our doorstep with the threat of energy shortages and/or price inflation.

As this new edition of the EurObserv'ER Barometer – the 21st – shows, radical transformation of the energy mixes of the Member States has been underway for two decades. The renewable shares now stand at 37.5% of gross electricity consumption and 22.9% of heat and cooling.
More detailed examination allows us to break down the renewable electricity sources: wind power takes the lion's share (386.5 TWh), followed by hydro (348.3 TWh) and biomass (173.4 TWh), while photovoltaics comes in fourth place with 163.8 TWh. As far as renewable heat and cold consumption is concerned, most of it (74.6%) comes from solid biomass, followed, far behind, by heat pumps.
Of course, those who are unhappy will say that the easiest part of the journey has been completed, but that the rest of the trajectory will be difficult, if not impossible, to respect. We can demonstrate to these naysayers that while the movement set in motion can be slowed down, it now seems irreversible. If further persuasion is needed, suffice it to note that 97% of all the new electrical capacities connected in 2021 were from renewable sources. Ergo, not only the public authorities but also the investors and all the economic players have switched to the next world. They are not merely wishful thinkers, activists, or philanthropists. Renewable energies generated 184.9 billion euros that year and created some 1.5 million full-time equivalent jobs… a windfall that no decision-maker can afford to ignore.
The sound of boots marching has changed the situation. It is true that in December 2019, the European Commission's Green Deal adopted a set of measures aimed at accelerating ecological transition to achieve climate neutrality by 2050; and to do so, proposed a set of administrative and financial tools making it possible to mobilise 65-75 billion euros over the period 2021 to 2027.
Russia's invasion of Ukraine prompted the Commission to change tack in May 2022 by proposing the REPowerEU Plan to make Europe independent of Russian fossil fuels by 2030. The already ambitious targets have been increased. The share of renewables in gross electricity consumption has been raised from 40% to 45%, doubling what has already been achieved. Last December, the European Council adopted an emergency regulation to speed up the deployment of renewable energies: renewable energy production installations, their connection to the grid and storage assets are now considered to be in the «overriding public interest». This text is directly applicable in national law as it is a regulation.
The European Union's energy transition will be long and certainly fraught with difficulties. The efforts made will be no-regret investments if we consider that they will allow us to reduce our carbon emissions and safeguard our energy security simultaneously. ■

21ST EUROBSERV'ER REPORT MAIN HIGHLIGHTS

Energy indicators

2021 was a special year in terms of monitoring renewable energy in the balance sheets of each EU country as it was the first year in which the specific calculation provisions of the Renewable Energy Directive (EU) 2018/2001 (so-called RED II) were taken into account. The results for 2021 are therefore not directly comparable with those for 2020, which took into account the calculation provisions inherent in the previous directive 2009/28/EC (known as RED I).

The main statistical breaks between the two directives come from the new sustainability criteria for solid and gaseous biofuels, which have made part of the biomass energy ineligible from 2021 for the calculation of the renewable energy targets of the new directive. A new calculation method for renewable electricity in transport is also included.

- The renewable share of gross electricity consumption reached 37.5% in 2021. 1,079.1 TWh of renewable electricity were produced in 2021, with wind power being the most important source (386.5 TWh, i.e. 35.8% of all renewable electricity production). This is followed by hydro (348.3 TWh) and biomass (173.4 TWh). Photovoltaics came fourth with 163.8 TWh.
- 97% of all new electricity capacity connected in 2021 came from renewable sources (37.4 out of a total of 38.6 GW). Only 3% came from gas or coal plants.
- In 2021, the renewable share of heat and cooling consumption was 22.9%. 113.2 Mtoe were produced of which 74.6% came from solid biomass (84.4 Mtoe) which benefited from colder winter conditions than the previous year. Heat pumps came second with 15.3 Mtoe.
- Renewable energies covered 21.8% of gross final energy consumption in the EU-27 in 2021. The pace must greatly accelerate to reach the 45% target proposed by the REPowerEU programme by the end of 2030.

Socio-economic indicators

- The total direct and indirect employment from the renewable sectors is estimated at 1.47 million full-time equivalents by 2021. This figure is 12% higher than in 2020[1]. The leading sector was heat pumps with 377 300 full-time equivalents..
- The economic activity around renewable energies in 2021 is estimated at €184.9 billion (+ 13% compared to 2020). As for jobs, heat pumps are the sector that has generated the highest turnover with €52.2 billion.

Investment indicators

- In 2021, investments in new wind farms (onshore and offshore) in the EU countries are estimated at €27.8 billion. 72% of this investment volume was contributed by onshore facilities.
- In the wind energy sector, Germany was the country that invested the most (€8 billion), followed by France (€4.6 billion), Spain, Finland and Sweden (€3.2 billion each).
- In the photovoltaic sector, investments in new installations summed up to €19 billion in 2021. Although this figure only covers a group of 10 countries for which data was available, the investment volume has already exceed the value estimated for the EU-27 in 2020. Germany remains the largest investor in the field with €5.2 billion in 2021 compared to €4.2 billion in 2020.

Renewable energy costs and prices

The volatile and uncertain macro-economic circumstances in the years 2021 and 2022 make it difficult to generalise the current situation and present up to date estimates for investment costs and levelized costs of energy. Estimates for the weighted average cost of capital (WACC) were updated according to similar sources. However, due to the uncertainty and sometimes contradicting information, the investment costs have not been updated since the previous Edition of the State of Renewable Energies.

Levelised cost of electricity highlights for 2021:

- For electricity production, hydroelectricity has the lowest average LCoE in 2021 (47 €/MWh) ahead of onshore wind (50 €/MWh) and offshore wind, on a par with photovoltaic on commercial buildings (65 €/MWh).
- For heat production, the lowest average LCoE is for biomass (52 €/MWh) far ahead of heat pumps (149 €/MWh). However, the development of collective equipment and the association with heat networks can help to reduce the costs of heat pumps.
- Prices for natural gas and electricity for households and non-households show an increase from 2020 to 2021, which is most pronounced for the non-households.

Avoided Fossil fuel and resulting avoided costs

- In 2021, the use of renewable energy substituted 192 Mtoe of fossil fuels compared to the level of renewable energy use in 2005. These figures correspond to an annual avoided cost of €48 billion for the EU27.

Indicators on innovation and competitiveness

- €688 million of public investment in R&D was invested in 2020 in the EU-27 for renewable technologies. €2 476 million was committed by private actors in 2019 (latest year available).
- The EU filed 1 269 patents in renewable energy in 2019 with Germany being the most active country (378 patents). China remains the world leader in number of patents filed in renewable energy with 8 813 patents.
- 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 2021 of EUR €5 034 million. The main partner remains China, which exported €9 671 million of goods and services in renewable technologies to the EU-27.

1. The increase in 2021 is partly caused by a change in the processing of input data about heat pumps sector. Excluding heat pumps, we see an increase of almost 100 000 FTE across the remaining RES sectors.

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 2022 for the wind power, photovoltaic, solar thermal, CSP, ocean energy, 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 2020 and 2021.

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: heat pumps, hydropower, geothermal energy, ocean energy, biogas 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 reproduce the most recent figures available for each sector. Bearing in mind the publication date of this edition, most of the energy indicators released in this work originate from the Eurostat database updated on 22 January 2023 (Complete energy balances), and from those specific to the Renewable Energy Directive indicators provided by the EU 2018/2001 directive (RED II) update of the Eurostat SHARES tool (updated on 24 January 2023 (https://ec.europa.eu/eurostat/web/energy/data/shares). 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 metres), 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 available through the following link: https://ec.europa.eu/eurostat/fr/web/energy/methodology/annual. 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. 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. The United Kingdom, that officially left the European Union on 1 February 2020, no longer features in the European Union energy indicators.

WIND ENERGY

THE EUROPEAN UNION'S INSTALLATION PACE HAS FALTERED

Eurostat reports that the net wind turbine capacity installed in 2021, (defined as the net maximum capacity that can be injected into the grid) in the EU-27 increased by 11.3 GW (11 311.9 MW) including 0.6 GW (594.8 MW) of offshore capacity on the previous year's level. It took the net total wind turbine capacity of the European Union countries to 188.4 GW (188 370.8 MW), including 15.1 GW offshore (15 104.9 MW). This additional net capacity is higher than the 2020 installation figure of 9.9 GW (9 918.8 MW), including 2.5 GW (2 465.8 MW) offshore. If we look at the Eurostat database, it is the second best performance of the last ten years, the best being that of 2015 (when 11 538.2 MW was added). Despite this result, the European Union's wind energy development pace is much too slow to achieve the climate targets it has set for 2030. The sector players claim that three times as much capacity must be installed annually if the negotiated 40 % renewable energy goal in final energy consumption is to be reached in 2030.

This increase in net useable capacity factors in related decommissioning and repowering activity, and so differs from the total usable capacity of the turbines installed in 2021. As developers can restrain the capacity of their turbines to comply with the connection contracts, it does not equate to the sum of the nominal (peak) capacity of wind turbines in service, which is a little higher. We should point out that repowering denotes the "full replacement" of electricity production units by new, more powerful units. A repowering operation enables operators to take advantage of the latest technological innovations to replace old wind turbines with bigger models with more powerful and longer blades that offer better yield. A key benefit is increasing a site's electricity output while reducing its running costs.

Sweden's 2021 capacity installation drive was the most active with 2 140 MW, all of which was onshore. Germany came second adding 1 632 MW of capacity (1 459 MW in 2020), while France came third with 1 226 MW just beating the Netherlands (1 121.5 MW) and Spain (1 088.5 MW).

WIND POWER PRODUCTION BUCKS THE TREND

Wind power production increases depend on the investments made in new wind farms, but also weather conditions in the main production areas. In contrast with 2020, many European Union countries had poor winds, and Germany suffered particularly badly along with Ireland, France, Belgium and the countries to the north. Onshore and offshore wind power output contracted by 2.7% between 2020 and 2021, according to Eurostat, from 397.8 to 386.9 TWh (a 10.9 TWh drop), despite the commissioning of new production capacities. This contrasts with wind power output in 2020 when much stronger winds prevailed, generating an 8.4% year-on-year increase on the 2019 level of 367.2 TWh.

Offshore wind power output is steadier and less prone to variations. It increased by 0.8% year-on-year (from 47.4 to 47.7 TWh), despite the considerable deficit of Germany's wind farms. The offshore wind power share of total wind power output increased by 11.9% in 2020 and 12.3% in 2021. Offshore wind shares were as high as 57.7% in Belgium, 47.3% in Denmark, 44.2% in the Netherlands and 21.3% in Germany in 2021.

GRADUAL BUILD-UP OF OFFSHORE CAPACITY BETWEEN 2022 AND 2026

European Union offshore wind energy had a lacklustre year in 2021. Denmark was the only country to get things moving with 604.8 MW of additional capacity. Four times less offshore wind power capacity was connected than in 2020 (2 465.8 MW). The extra capacity comprises the commissioning of the Kriegers Flak wind farm with its 72 Siemens-Gamesa SG 8.4-167 DD turbines. By the end of 2021, total EU offshore wind turbine capacity amounted to 15 104.9 MW, spread across the waters of seven countries (Germany, the Netherlands, Denmark, Belgium, Sweden, Finland and Portugal), namely 8.0% of its total installed wind turbine capacity. EurObserv'ER claims that the EU's offshore wind turbine capacity is a little higher because Ireland also has a 25.2-MW offshore wind farm (Arklow Bank), that went on stream in 2004. However, as it stands, Ireland does not communicate this figure to Eurostat separately from its total wind turbine capacity figure.

We could add the 2 MW of the Floatgen floating wind turbine installed and generating power off the coast of Le Croisic on the Centrale Nantes engineering school's multi-technology SEM REV offshore test site to the official figures.

The Floatgen wind turbine

1

Wind power capacity installed in the European Union at the end of 2021 (MW)*

	2020	*of which Offshore*	2021	*of which Offshore*
Germany	62 201.0	*7 787.0*	63 833.0	*7 787.0*
Spain	26 819.2	*0.0*	27 907.7	*0.0*
France	17 514.0	*0.0*	18 740.0	*0.0*
Sweden	9 976.0	*203.0*	12 116.0	*193.0*
Italy	10 870.6	*0.0*	11 253.7	*0.0*
Netherlands	6 647.9	*2 459.5*	7 769.4	*2 459.5*
Denmark	6 267.0	*1 700.8*	7 020.8	*2 305.6*
Poland	6 298.3	*0.0*	6 967.3	*0.0*
Portugal	5 122.3	*25.0*	5 427.3	*25.0*
Belgium	4 672.7	*2 261.8*	4 948.4	*2 261.8*
Greece	4 119.3	*0.0*	4 649.1	*0.0*
Ireland	4 306.7	*0.0*	4 339.0	*0.0*
Austria	3 226.0	*0.0*	3 407.8	*0.0*
Finland	2 586.0	*73.0*	3 257.0	*73.0*
Romania	3 012.5	*0.0*	3 015.0	*0.0*
Croatia	801.3	*0.0*	986.9	*0.0*
Bulgaria	702.8	*0.0*	704.4	*0.0*
Lithuania	540.0	*0.0*	671.0	*0.0*
Czechia	339.4	*0.0*	339.4	*0.0*
Hungary	323.0	*0.0*	324.0	*0.0*
Estonia	317.0	*0.0*	315.0	*0.0*
Cyprus	157.7	*0.0*	157.5	*0.0*
Luxembourg	152.7	*0.0*	136.4	*0.0*
Latvia	78.1	*0.0*	77.1	*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	**177 058.8**	*14 510.1*	**188 370.8**	*15 104.9*

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

will be dismantled in autumn 2023 and be replaced by a 5-MW turbine. Likewise, we could add the 5-MW Elisa prototype that went on stream off the coast of Gran Canaria (Canary Islands, Spain) in 2019. Outside the European Union, the UK has fully connected three new wind farms – Triton Knoll (875 MW), Moray East (950 MW) and the Kincardine (48 MW) floating wind farm off the Scottish coast. Part of the Hornsea Two wind farms have been connected (i.e., 462 MW in 2021 of a total of 1 386 MW). Hornsea Two, which will be spread over an area of 462 km² will comprise 165 Siemens Gamesa 8.4-MW turbines and will be the world's biggest offshore wind farm when it becomes fully operational in 2022. Norway installed a 3.6-MW floating wind turbine demonstrator in 2021 (Tetra Spar foundation).

Many major projects are under construction in the European Union, which will significantly increase its installed capacity over the next three years. France has officially launched its offshore production venture and is now the ninth EU country to have its own offshore sector. It fully commissioned the Saint-Nazaire (480-MW) wind farm in November 2022 with 80 General Electric Haliade 150 wind turbines with 6 MW of capacity each. On 16 December 2020, the German energy group RWE fully connected its Kaskasi (342-MW) offshore wind farm, which has 38 Siemens-Gamesa SG 8.0-167 DD wind turbines, 35 km off the north coast of Heligoland Island. This wind farm features recyclable wind turbine blades... a first. It is scheduled to start delivering commercially at the start of 2023.

Other major projects under construction include the Dutch Hollandse Kust Zuid I-II (due to go on stream in 2022/2023) and Hollandse Kust Zuid III-IV (2023) each 770 MW, and the French projects of Fécamp (497 MW, 2023), Saint-Brieuc (496 MW, 2023) and Calvados (448 MW, 2024). No new turbines or foundations were installed in Germany during 2021. The offshore wind farms allotted during the first auction rounds in 2018 will be gradually installed between 2022 and 2025 as their connection is held up by grid infrastructure work. The offshore wind farms awarded during the 2021 bidding rounds should start up in 2026. After the Kaskasi (342-MW) project has gone on stream, it should be followed by Arcadis Ost1 (247-MW) in 2023, Baltic Eagle (476.3MW) and God Wind 3 (241.8MW) in 2024, Borkum Riffgrund 3 (900MW) and EnBW He Dreiht (900MW) in 2025 and N-3.7 (225MW), Nordsee Two (433-MW) and Windanker (300-MW) in 2026. If all the awarded projects are fully completed, Germany's offshore wind turbine capacity will rise to almost 12 GW by the end of 2026 (7.8 GW in 2021).

Attention will soon turn to the Netherlands and its upcoming tenders for the IJmuiden Ver Wind Farm (IJVWFZ) maritime zone located 62 km off its west coast. Four wind farm sites accommodating 4 000 MW of capacity will be designated in the area: IJV Wind Farm Site I, II, III and IV, over an area of roughly 400 km². A tender to develop IJVWFS I and II is planned for 2023. A second round of tendering for IJWFS III and IV is planned for 2025. In February 2022, the government increased the Netherlands' offshore wind turbine capacity target to 21 GW by 2030, which equates to three-quarters of the country's current power consumption. Last September, it set a new goal of 70 GW of offshore capacity by 2050. In addition to generating electricity, the Dutch government is planning to use part of its offshore capacity for large-scale production of green hydrogen in the North Sea. Its goal for 2050 was announced on 16 September, shortly after the Netherlands along with the other North Seas Energy Cooperation (NSEC) members agreed to install at least 260 GW of offshore wind turbine capacity by 2050, which amounts to over 85% of Europe's ambition to reach 300 GW by the same timeline. In June 2022, Denmark also raised its offshore wind energy targets and now plans to deploy a total of 12.9 GW of offshore capacity by 2030, which is 4 GW higher than its previous target. This decision was taken just after the May 2022 Esbjerg Declaration revealed that Germany, Belgium, the Netherlands and Denmark had set an ambitious joint offshore wind target of at least 65 GW by 2030. They aim to more than double their North Sea offshore wind capacity to at least 150 GW by 2050 as Europe's green power plant, to supply more than half the capacity required to achieve the EU's climate neutrality in keeping with the European Commission's offshore renewable energy strategy.

Poland also has ambitions for offshore wind energy with projects in the Baltic Sea under development such as OWF Bałtyk I (1560 MW), II (720 MW) and III (720 MW). The government plans to install 5.9 GW by 2030 and 11 GW by 2040, and the first tenders are expected in 2025. Spain has announced a

2

Gross electricity production from wind power in the European Union in 2020 et 2021 (TWh)

	2020	*of which Offshore*	2021	*of which Offshore*
Germany	132.102	*27.306*	114.647	*24.375*
Spain	56.444	*0.000*	62.061	*0.000*
France	39.861	*0.000*	36.831	*0.000*
Sweden	27.526	*0.633*	27.244	*0.547*
Italy	18.762	*0.000*	20.927	*0.000*
Netherlands	15.278	*5.484*	18.005	*7.952*
Poland	15.800	*0.000*	16.234	*0.000*
Denmark	16.330	*6.603*	16.054	*7.593*
Portugal	12.299	*0.051*	13.216	*0.051*
Belgium	12.819	*6.974*	11.998	*6.926*
Greece	9.310	*0.000*	10.483	*0.000*
Ireland	11.549	*0.000*	9.776	*0.000*
Finland	8.256	*0.305*	8.507	*0.267*
Austria	6.792	*0.000*	6.740	*0.000*
Romania	6.945	*0.000*	6.576	*0.000*
Croatia	1.721	*0.000*	2.062	*0.000*
Bulgaria	1.477	*0.000*	1.434	*0.000*
Lithuania	1.552	*0.000*	1.362	*0.000*
Estonia	0.844	*0.000*	0.733	*0.000*
Hungary	0.655	*0.000*	0.664	*0.000*
Czechia	0.699	*0.000*	0.602	*0.000*
Luxembourg	0.351	*0.000*	0.314	*0.000*
Cyprus	0.240	*0.000*	0.246	*0.000*
Latvia	0.177	*0.000*	0.141	*0.000*
Slovenia	0.006	*0.000*	0.006	*0.000*
Slovakia	0.004	*0.000*	0.005	*0.000*
Malta	0.000	*0.000*	0.000	*0.000*
Total EU 27	397.799	*47.356*	386.866	*47.712*

Source: Eurostat

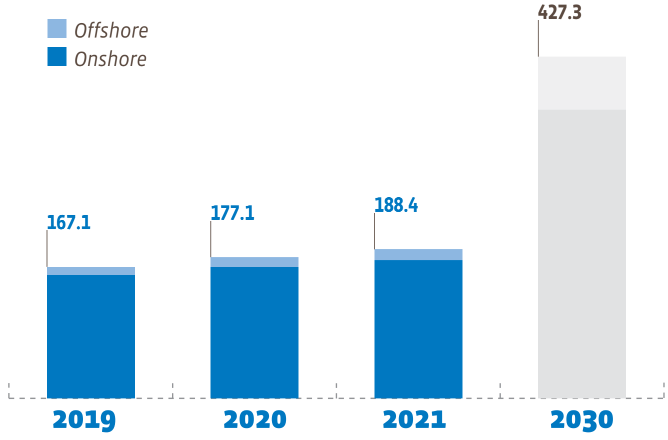
3-GW target in 2030 as part of its first offshore wind energy roadmap published in December 2021. The Estonian and Latvian governments signed a protocol agreement in July 2020 for the JV construction of a wind farm of up to 1 GW in the Gulf of Riga, due to go on stream in 2030. As part of its climate energy plan, Belgium intends to raise its offshore wind turbine capacity to 4 GW (4 011 MW) by 2030, to put out an initial tender for 700 MW in the first quarter of 2023 due to start up in 2025, and a second tender for 1 050 MW in 2025 due to start operating in 2027.

A RACE AGAINST TIME

The European Union governments have no alternative but to take drastic measures, given the fact that they have been backed into a corner by the climate imperative and the vital need to wean themselves off their dependency on fossil fuels supplied by overtly hostile countries. The war in Ukraine sparked off by the world's largest fossil gas exporter and the resulting energy price hike, were the catalysts. On 18 May 2022, the European Commission presented its REPowerEU plan to swiftly pare back its reliance on Russian fossil fuels and accelerate ecological transition. In particular, the plan recommends combatting the lengthy and complex licensing procedures for major renewable energy projects and makes a proposal to make a targeted modification to the Renewable Energy Directive to acknowledge renewable energies as being of overriding public interest. The Commission proposes to raise the EU's current 2030 renewable energy target from 40 to 45%. The REPowerEU plan would raise total renewable

3

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



Source: Eurostat

energy production capacity from 1 067 GW as envisaged in the "Fit for 55" package to 1 236 GW by 2030. The new EU legislation will accelerate wind and solar farm licensing procedures: renewable energies are now of overriding public interest, "suitable areas" are introduced in the Member States on low environmental-risk territories, and more regulatory incentives are planned for innovative technologies. An agreement to this effect on a European Council regulation was passed on 24 November 2022 that establishes a temporary 18-month framework to fast-track the licensing and project deployment procedure for renewable energy projects.
According to a WindPower Europe press release dated 11 January 2023, initial indications for 2022 suggest that 15 GW of new wind farms were installed, a third more than in 2021. The association says that this installation level which looks like a new installation record across the European Union was achieved despite the challenges faced by the industry in 2022. Energy and raw material price rises hit manufacturers and European turbine suppliers hard. They had to face procurement bottlenecks for certain materials and components, as well as poor auction design in some countries. The European wind energy association explains that the measures introduced by the REPowerEU Plan will be very useful for unlocking the 80 GW of wind energy projects ensnared by authorization procedures across Europe. But it also observes that the Member States' interventionism in the electricity markets, compounding inflation, has had the unfortunate effect of limiting investments in new wind farms that undermines the fulfilment of the 2030 targets. The forthcoming EU electricity market reform must give investors greater visibility about the applicable rules so that they invest much more in renewable energies. ■

PHOTOVOLTAIC

During the course of 2021, the European Union's solar photovoltaic market remained vibrant, despite the tough post-COVID economic context of disrupted supply chains and more expensive solar system components. Solar photovoltaic remained highly attractive in 2021 because of the electricity market's high prices and solar electricity's competitiveness. According to Eurostat, the maximum net capacity of the European Union of 27 increased by 40.7% – at least 25 702.9 MW – compared to the sector's 2020 performance (18 272.8 MW). Combined installed capacity of the European Union thus reached 161 879.2 MW by the end of 2021 (161.9 GW), which represents 18.9% growth over the previous year.

PHOTOVOLTAIC REGISTERS STRONG GROWTH IN THE MEMBER STATES

In 2021, the European Union set a new installation record for net additional photovoltaic capacity, exceeding its previous, decade-old record when 22 253.8 MW was added in 2011). The main difference is that in 2011, the market's installations peaked only to suffer a downturn in activity, whereas the 2021 level should be regarded as a stepping stone to very much higher installation levels. The solar electricity payment situation has radically changed since 2011. The installation rush towards the end of the 2000s was largely speculative, as developers sought to take up the attractive guaranteed feed-in tariffs while they waited for photovoltaic module prices to come down. Growth is healthier and more sustainable nowadays because it is based on market mechanisms and benefits from solar electricity's competitive edge over other electricity generating sources. Another difference, is that nowadays, it is shared by an overwhelming majority of European Union countries and no longer by a few trailblazers. Between 2020 and 2021, 21 EU countries enjoyed double-digit increases in their total photovoltaic capacity bases. The Polish and Estonian bases almost doubled in just twelve months (by 87.5% and 90.1% respectively) and the installed bases of five countries (Ireland, Portugal, Lithuania, Luxembourg and Sweden) increased by about half. The installed bases of the Netherlands, Spain, Greece, Hungary, Austria, Denmark, Finland and Cyprus also increased by more than 30% in a year.

Consequently, the sharp rise in production capacities led to considerable growth in solar power output. Eurostat puts the European Union's gross solar power output at 158.6 TWh in 2021, marking 13.2% year-on-year growth. The highest growth rates were recorded in Poland, which doubled its output in 2021 (by 101% year-on-year, equating to an increase of 2 TWh), Spain (39.9%, adding 6.2 TWh), the Netherlands (34.2%, adding 2.9 TWh), France (16.9%, adding 2.8 TWh), Hungary (54.4%, adding 1.3 TW), Portugal (30.4%, adding 522 GWh) and Sweden (45.2%, adding 475 GWh). It comes as a paradox that the output of the top two European Union solar photovoltaic bases hardly changed in 2021. Lower sunshine levels resulted in Germany posting a slight drop (by 0.3%, contracting by 156 GWh) while that of Italy, rose slightly (by 0.4%, adding 97 GWh).

1

Installed solar photovoltaic capacity in the European Union at the end of 2021 (MW)*

	2020	2021
Germany	53 669.0	59 371.0
Italy	21 650.0	22 594.3
Netherlands	11 108.4	14 910.7
France	12 056.0	14 810.4
Spain	10 135.6	13 715.2
Poland	3 955.0	7 415.5
Belgium	5 572.8	6 012.4
Greece	3 287.7	4 277.4
Hungary	2 131.0	2 968.0
Austria	2 042.9	2 782.6
Czechia	2 172.0	2 246.1
Denmark	1 304.3	1 704.0
Portugal	1 100.3	1 646.0
Sweden	1 107.0	1 606.0
Romania	1 382.5	1 393.9
Bulgaria	1 100.2	1 274.7
Slovakia	535.0	537.0
Slovenia	369.8	461.2
Finland	318.0	425.0
Estonia	207.7	394.8
Cyprus	229.1	314.5
Luxembourg	186.6	277.2
Lithuania	164.0	255.0
Malta	187.9	205.7
Croatia	108.5	138.3
Ireland	89.9	135.3
Latvia	5.1	7.2
Total EU 27	**136 176.4**	**161 879.2**

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

GERMANY PASSES A NEW RENEWABLE ENERGY LAW

Germany remained the liveliest EU solar photovoltaic market in 2021. According to Eurostat, it increased its net maximum photovoltaic capacity by 5 702 MW (4 757 MW in 2020) which took Germany's installed photovoltaic capacity to 59 371 GW by the end of 2021. The country's intention to wean itself off Russian fossil gas as fast as possible prompted it to apply new means to speed up its renewable energy sector developments and increase installations volumes as early as 2022. Data released by the German grid agency (in January 2023) put the newly commissioned photovoltaic capacity in 2022 at 7 182 MW. Provisional electricity output data appears to have surged by 61.9 TWh in 2022.

Germany raised its renewable energy targets again. On 6 April 2022, the Bundestag announced that it would be raising its clean energy goal from the previous 65% share to 80% of the electricity mix from 2030 onwards, and to about 100% as soon as 2035. Thus, a minimum of 600 terawatt hours per annum should come from renewable energies by that timeline. The decision serves as a response to the climate challenge and Germany's dependence on Russian fossil gas. The publication of its new renewable energy act, due to come into effect on 1 July 2022, was brought forward because of Russia's invasion of Ukraine. Robert Habeck, the minister for Economic Affairs and Climate Action declared, "It is the largest energy policy revision for decades". The law includes a clause that identifies renewable energies as being in the interest of public security. The volumes up for auction, which in previous years have tended to be undersubscribed, will be considerably increased. In the case of solar photovoltaic, they will rise from about 6 GW in 2022 to 22 GW per annum starting in 2026 and continue rising through to 2035 if not later. This growth rate should take Germany's photovoltaic capacity to at least 215 GW by the end of this decade.

2

Gross electricity production from solar photovoltaic in the European Union in 2020 and 2021 (in TWh)

	2020	2021
Germany	49.496	49.340
Italy	24.942	25.039
Spain	15.675	21.922
France	13.459	15.732
Netherlands	8.568	11.495
Belgium	5.112	5.618
Greece	4.447	5.251
Poland	1.958	3.934
Hungary	2.459	3.796
Austria	2.043	2.783
Czechia	2.338	2.316
Portugal	1.716	2.237
Romania	1.733	1.703
Sweden	1.051	1.526
Bulgaria	1.469	1.467
Denmark	1.181	1.309
Slovakia	0.663	0.671
Cyprus	0.296	0.468
Slovenia	0.368	0.453
Estonia	0.245	0.354
Finland	0.218	0.298
Malta	0.237	0.256
Lithuania	0.129	0.191
Luxembourg	0.161	0.180
Croatia	0.096	0.149
Ireland	0.062	0.093
Latvia	0.005	0.007
Total EU 27	**140.125**	**158.588**

Source: Eurostat

MORE THAN 14.9 GW INSTALLED BY THE END OF 2021 IN THE NETHERLANDS

The Netherlands remained very active during 2021 according to Eurostat, adding 3 802.3 MW of net capacity (3 882.4 MW in 2020), which took its cumulative solar photovoltaic capacity to 14 910 MW in 2021. The Netherlands' per capita photovoltaic capacity (0.853 kW/inhab.) is now the highest in the European Union, ahead of Germany (at 0.714 kW/inhab.) and Belgium (at 0.520 kW/inhab.). Naturally, solar electricity output rose sharply (by 34.2% between 2020 and 2021). It stood at 11.5 TWh in 2021 compared to 8.6 TWh in 2020. Solar energy's two main drivers in the Netherlands are net invoicing for the residential and small business segments, while the business markets and major power plants rely on the SDE+ auctioning system, where solar PV is in competition with the other renewable energy sources. According to SolarPower Europe, the Dutch market would be bigger, but at least 12 GW worth of projects are stuck in the pipeline, beset by challenges to secure grid connections and sites.

PPA AND TENDERS – SPAIN'S WINNING DUO

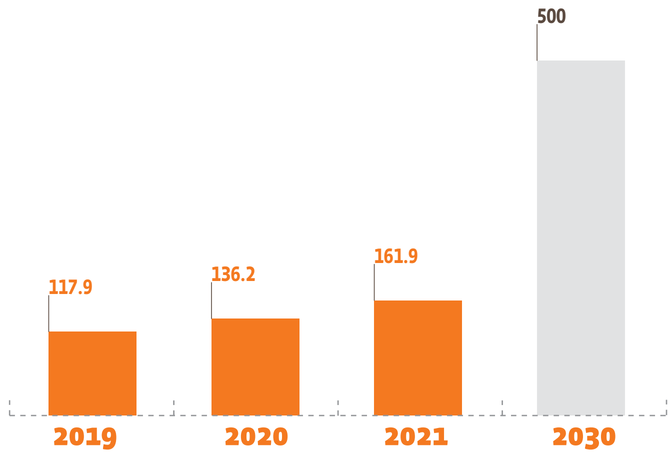
According to Eurostat, Spain had net maximum photovoltaic capacity of 13 715.2 MW by the end of 2021, which is 3 579.6 MW more than in 2020. About 3 GW of this total was installed through electricity purchase contracts, which makes the Spanish markets one of the biggest solar markets to operate without subsidies or state-guaranteed prices. Spain's grid access capacities are holding back the market, leading to a very long PPA project waiting list. In 2023, the solar photovoltaic market will be boosted as the REER (Renewable Energy Economic Regime) tenders regulated by Royal Decree 23/2020 of 23 June 2020) launched in 2021 come on line. Another observation is that the self-consumption roof-mounted solar market has started to pick up over the last two years since a royal decree was adopted in April 2019 abolishing the solar tax while accompanying and promoting collective and individual self-consumption.

600 GW BY THE END OF 2030

According to the European Commission, ending EU reliance on Russian fossil fuels calls for massive increase in renewable energy use and the acceleration of the electrification and replacement of fossil fuels in heat production for industry, buildings and transport. The implementation of an EU solar energy strategy was unveiled in May 2022, under the REPowerEU plan with the aim of stimulating the deployment of solar photovoltaic power, so that more than 320 GW is injected into the grid by 2025 (i.e., twice as much as in 2020) and almost 600 GW by 2030. These additional capacities deployed at the beginning of the period will replace annual consumption of 9 million m³ of fossil gas through to 2027. The installation pace must be ramped up dramatically if the European Commission's proposed 2030 renewable energy target and the REPowerEU targets are to be met. The EU will have to install about 45 GW per annum during the current decade. This strategy includes a European solar panel installation initiative – the gradual obligation to install solar panels on the roofs of certain buildings, combined with renovations, while encouraging self-consumption and energy communities, a European alliance for the solar photovoltaic industry to create an innovative and resilient photovoltaic value chain in the EU and a broad European skills partnership so that the rollout of renewable energies runs smoothly and creates local jobs throughout the EU. In the context of the energy crisis and geopolitical tensions, implementation of the strategy and these key solar energy initiatives proposed for the EU and its Member States are matters of extreme urgency. ■

3

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



Source: EurObserv'ER

SOLAR THERMAL

In several key European Union markets the pieces seem to have fallen back into place as solar thermal returns to growth. The sector has taken up the opportunities offered by more appropriate aids and benefitted from higher fossil energy and electricity prices. According to EurObserv'ER, the 2021 market returned above the 2 million m² mark, taking all the European Union solar thermal applications together (solar hot water heating, solar, industrial and urban heating). This is particularly well-timed for tackling climate change and our dependency on Russian hydrocarbons.
Following on after 2020, which was a very tough year for the solar thermal sector that suffered particularly badly during the Covid-19 epidemic, the European market returned to growth in 2021. Estimates point to an installation level in excess of 2.1 million m² (2 127 084 m²), or 7.1% growth compared to 2020 (1 986 789 m²). The year's newly installed surface equates to about 1 489 MWth of thermal capacity (up from 1 390.8 MWth in 2020). Incidentally, the glazed surface of a 1-m² solar thermal collector offers 0.7 kWth of thermal capacity. However, this pick-up in the European market's fortunes is patchy and remains largely dependent on incentive systems and regulatory contexts. Another major contributory factor is the 2021 hike in fossil energy (gas and heating oil) and electricity prices, resulting from post-Covid economic recovery. These prices soared again following Russia's invasion of Ukraine in February 2022, which has sucked the European Union into an energy security crisis.
The market data includes systems that use flat glazed and vacuum collectors, geared to domestic hot water production and heating in the residential sector and heat and hot water production for district heating networks and industrial processes. The data also includes non-glazed collectors that tend to be used for heating pools, even if this technology is less diligently monitored by the statistical organizations. Lastly, concentration mirrors used for hot water production are excluded from the data as are hybrid PV-T collectors that use water as the heat carrier.

THE EU SOLAR THERMAL MARKET BOUNCES BACK

While the European Union solar thermal market is looking healthier overall, differences persist in individual countries. The European market leader Germany, which bounced back with vim and vigour in 2020, did no better in 2021. After a particularly tough year, the Greek market resurfaced (increasing by 17.9% over 2020 with 359 000 m² installed in 2021), largely driven by thermosiphon systems. Now, the Italian market, it is enjoying a huge revival thanks to the rollout of a new, particularly attractive "Superbonus" incentive system. The country's installation level has leapt by 84.4%, from 122 000 to 225 000 m² propelling it into third place in the European Union rankings. The Polish market, aided by municipal tenders backed by a European funding programme, bounced back (with a 17.3% surge) after two years in decline and lies in fourth place with 189 100 m² sold in 2021. The French market (taking mainland and overseas departments and regions together) found renewed growth,


Newheat - Pons

1

Annual installed surfaces in 2020 per collector type (in m²) and capacity equivalent (in MWth)

	Glazed collectors		Unglazed collectors	Total (m²)	Equivalent capacity (MWth)
	Flat plate collectors	Vacuum collectors			
Germany	544 000	99 000		643 000	450.1
Greece	304 500			304 500	213.2
Spain	177 073	7 539	2 798	187 410	131.2
Poland	159 370	1 830		161 200	112.8
France*	138 160			138 160	96.7
Italy	110 439	11 561		122 000	85.4
Austria	72 210	1 400	1 730	75 340	52.7
Cyprus	74 193			74 193	51.9
Portugal	49 874			49 874	34.9
Hungary+	42 000			42 000	29.4
Netherlands	20 640	9 487	2 621	32 748	22.9
Czechia	15 000	7 000		22 000	15.4
Bulgaria+	20 060			20 060	14.0
Belgium	15 300	2 900		18 200	12.7
Denmark	17 613			17 613	12.3
Romania++	15 960			15 960	11.2
Croatia+	15 800			15 800	11.1
Slovakia+	13 000			13 000	9.1
Ireland	11 114			11 114	7.8
Finland+	7 000			7 000	4.9
Sweden	4 898			4 898	3.4
Luxembourg	3 913			3 913	2.7
Lithuania++	1 700			1 700	1.2
Latvia++	1 600			1 600	1.1
Estonia++	1 425			1 425	1.0
Slovenia++	1 400			1 400	1.0
Malta	681			681	0.5
Total EU 27	**1 838 923**	**140 717**	**7 149**	**1 986 789**	**1 390.8**

*+ EurObserv'ER estimation based on Eurostat database. ++ Estimation from Solar heat Europe «Solar Heat markets in Europe - Trends and Market statistics 2020». * including 91.352 m² in the overseas departments.* ***Source: EurObserv'ER 2022***

2

Annual installed surfaces in 2021 per collector type (in m²) and capacity equivalent (in MWth)*

	Glazed collectors		Unglazed collectors	Total (m²)	Equivalent capacity (MWth)
	Flat plate collectors	Vacuum collectors			
Germany	542 000	98 000		640 000	448.0
Greece	359 000			359 000	251.3
Italy	207 548	17 452		225 000	157.5
Poland	186 100	3 000		189 100	132.4
France**	164 300			164 300	115.0
Spain	141 500	8 800	2 000	152 300	106.6
Portugal	72 000			72 000	50.4
Cyprus	70 360			70 360	49.3
Austria	64 570	3 810	930	69 310	48.5
Netherlands	34 393			34 393	24.1
Bulgaria	24 296			24 296	17.0
Czechia	17 097	1 903		19 000	13.3
Slovakia	17 000			17 000	11.9
Romania	15 960			15 960	11.2
Hungary	14 000			14 000	9.8
Belgium	10 300	2 900		13 200	9.2
Croatia	12 000			12 000	8.4
Denmark	8 013			8 013	5.6
Finland	8 000			8 000	5.6
Sweden+	5 000			5 000	3.5
Ireland	3 839			3 839	2.7
Luxembourg	3 574			3 574	2.5
Lithuania+	1 700			1 700	1.2
Latvia+	1 600			1 600	1.1
Estonia+	1 425			1 425	1.0
Slovenia+	1 400			1 400	1.0
Malta	1 051	263		1 314	0.9
Total EU 27	**1 988 026**	**136 128**	**2 930**	**2 127 084**	**1 489.0**

*+ 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. ** including 90 000 m² in the overseas departments.* ***Source: EurObserv'ER 2022***

EUROBSERV'ER – THE STATE OF RENEWABLE ENERGIES IN EUROPE – 2022 EDITION

3

Cumulated capacity of thermal solar collectors installed in the European Union in 2020 and 2021 (in m² and in MWth)*

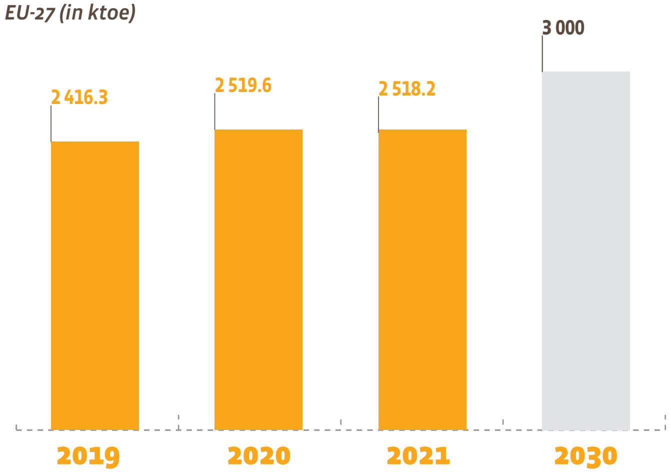
	2020		2021	
	m²	MWth	m²	MWth
Germany	21 416 000	14 991.2	21 785 000	15 249.5
Greece	4 991 000	3 493.7	5 175 000	3 622.5
Austria	4 922 944	3 446.1	4 774 554	3 342.2
Italy	4 457 525	3 120.3	4 657 622	3 260.3
Spain	4 235 678	2 965.0	4 359 743	3 051.8
France	3 397 731	2 378.4	3 503 824	2 452.7
Poland	3 006 690	2 104.7	3 195 690	2 237.0
Denmark	2 051 096	1 435.8	2 035 096	1 424.6
Portugal	1 406 955	984.9	1 478 955	1 035.3
Cyprus	1 102 430	771.7	1 121 667	785.2
Belgium	740 300	518.2	748 000	523.6
Netherlands	669 000	468.3	662 000	463.4
Czechia	567 000	396.9	586 000	410.2
Bulgaria	445 538	311.9	469 834	328.9
Sweden	451 000	315.7	445 000	311.5
Hungary	392 000	274.4	406 000	284.2
Ireland	346 150	242.3	344 829	241.4
Croatia	288 000	201.6	300 000	210.0
Slovakia	232 000	162.4	249 000	174.3
Slovenia	222 398	155.7	220 000	154.0
Romania	218 910	153.2	218 910	153.2
Finland	80 000	56.0	88 000	61.6
Luxembourg	73 802	51.7	77 376	54.2
Malta	74 084	51.9	75 397	52.8
Latvia	21 700	15.2	21 672	15.2
Total EU 27	**55 809 931**	**39 067.0**	**56 999 169**	**39 899.4**

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

increasing by 18.9% to 164 300 m² in 2021. However, we should point out that more than half of the French market – about 90 000 m² – is based in its overseas departments. The mainland roof-mounted solar thermal market (individual solar hot water heaters, combined solar systems, collective hot water systems) recovered (with 16% year-on-year growth) as 53 600 m² of collectors were installed following an 8-year decline. The French market also benefitted from the commissioning of four district heating networks as well as Europe's biggest industrial solar heating project (see below), while no similar installations were connected in 2020. On the other hand, Spain's solar thermal market decline went unchecked, falling a further 18.7% for a total of 152 300 m² (not including PV-T hybrid systems). Undeterred, the ASIT (Spanish Solar Thermal Industry Association) is much more optimistic about 2022, because of the construction sector recovery and higher aid from the PRTR programme managed by the autonomous regions. This year's growth prospects are mainly positive across the EU. Preliminary data released by the German solar energy association, BSW-Solar, indicate that the German market has picked up with 710 000 m² installed in 2022 (a 10.9% year-on-year rise), while an increase is also expected in Italy with very encouraging sales figures for the first half of 2022. On the downside, EurObserv'ER notes that a few countries (incl. France and Poland) are facing system delivery pressures, due to the lack of raw materials and manufacturing components.

4

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 2022

NEW SHOWCASES FOR HEATING NETWORKS AND INDUSTRIAL HEAT

The solar thermal district heating network market (SDH for Solar District Heating) is a separate market segment with specific players and collector technologies for much greater surface areas (up to fifteen m² per collector). Denmark has the highest number of solar-based district heating networks. France was the most active EU country in 2021, as it commissioned four new solar heating networks (at Narbonne, Pons, Creutzwald and Cadaujac) with a combined total of 11 219 m² of collector surface, ahead of Denmark (8 013 m², with one equipped network, Præstø). The biggest plant, at Creutzwald (5 621 m², 4.3 MWth) is operated by La Française de l'Énergie (LFDE). Austria was the third most active country, as it connected 7 950 m² of collectors in 2021 including the Nahwärme Friesach plant (5 750 m², 4 MWth) and also extended the Graz heating network's solar thermal collector field. Only one heating network, that of Mülhausen (5 691 m²), was equipped with solar collectors in Germany in 2021, which is far below the previous year's activity level, when 7 district heating networks for a combined collector area of 31 200 m² were connected. Yet, according to the Solites research institute, eight or nine projects are set to go on stream in 2022 or 2023, with a combined collector area of 38 000 m². The latter include the Greifswald project which, with its 18 000 m² (13 MWth) of collector area, will overtake Ludwigsburg (14 800 m²) to become Germany's biggest solar heating network. Another specific market segment, that of solar thermal systems for industrial processes, is being carved out. This sector is shaping up with the arrival of increasingly ambitious projects


SavoSolar – Sollested

in areas as diverse as the agri-food industry, papermaking and hothouse heating. The largest industrial project to go on stream in 2021 was the Issoudun plant in France. It is France's biggest solar heating system and Europe's most extensive solar thermal system to produce industrial heat with a 13 243-m² field (comprising 893 Savo 15 SG-M, Savosolar-branded collectors). Kyotherm, which specializes in third-party funding of renewable heat projects, owns this plant. The solar unit will supply heat to a malt drying plant operated by Malteries Franco-suisses.

A 57 MILLION M² SOLAR THERMAL BASE BY THE END OF 2021

While the official bodies do not apply a specific monitoring indicator to the market data, the total solar thermal collector area in service is monitored through the Annual renewables and wastes questionnaire (administered by Eurostat and the International Energy Agency). Based on this, Eurostat quantifies the total collector area of the European Union's solar thermal base at just under 57 million m² at the end of 2021 (55.8 million m² in 2020). Official data on the EU collector base points to a year-on-year increase of 1.2 million m². But a decommissioning phenomenon should be felt in the next few years arising from the higher installation levels of the first decade of this millennium, which peaked at almost 4.6 million m² in 2008. This official data shows that the Austrian, Swedish, Slovenian, Irish and Dutch collector bases are contracting as the decommissioned area outstrips the newly-installed area. This trend raises the issue of maintaining the solar heat contribution to the European Union's targets unless this market segment makes a significant and sustained recovery. Eurostat finds that the solar thermal heat contribution, including heat directly used by final users (households, service sector, industry, etc.) and heat production in solar district heating networks, stabilized at 2.5 Mtoe across the EU-27 between 2020 and 2021. The declines in output in Germany (39.2 ktoe) and Austria (5.6 ktoe), because of less sunshine over the year, and the lower production from the Danish heating networks (9.2 ktoe less) were entirely made up for by the output rises in other European Union countries, and in particular Greece (10.8 ktoe), Italy (10.5 ktoe), Spain (9.6 ktoe), France (7.4 ktoe), Poland (5 ktoe) and Portugal (4.8 ktoe).

SOLAR HEAT GOES ON THE OFFENSIVE

The energy security crisis spurred the European Union into presenting its REPowerEU battle plan on 18 May. The plan aims to end the EU's dependency on Russian fossil fuels, that are being used as an economic and political weapon and combat the climate crisis. In addition to economic and energy procurement diversification measures, it provides for increasing the renewable energy target within the framework of the "Fit for 55 package" from 40 to 45% in 2030, as well as launching several initiatives such as the "EU solar energy strategy". The Commission points out in the latter that solar photovoltaic and solar thermal technologies can be rapidly rolled out and will enable household and businesses to combat climate change while reducing their energy bills. While the plan highlights photovoltaic technology, major common measures apply to all solar technologies such as the European initiative for solar roofs combined with a legal obligation to phase in the installation of solar panels on new public and business buildings or on new residential buildings The possibility for Member States to apply reduced rates of VAT on energy-efficient and low-emission heating systems such as solar water heating systems is mooted. The EU's solar energy strategy also emphasizes that the energy demand covered by solar heat (likewise for geothermal heat) should increase threefold at least by 2030, which equates to about 114 GWth of thermal capacity.

The solar thermal industry, long overshadowed by solar photovoltaic, is determined to go back on the offensive and fully play its role in decarbonizing heating requirements. In a piece published on 16 June, Costas Travasaros reiterates that neither the energy security crisis nor the climate change crisis can be solved unless the decarbonisation of heat is made a priority. It must be simultaneously based on two main vectors – renewable electricity and renewable heat. Costas Travasaros acknowledges that significant efforts are being rolled out to promote the electrification of heat, but that does not necessarily imply the decarbonisation of heat because the electricity produced in Europe is far from being decarbonized. ■

HYDROPOWER

According to Eurostat, EU-27 production of renewable hydroelectricity, or actual hydropower output from natural water flow, i.e., disregarding the electricity produced by pumping, stood at 348.3 TWh in 2021, which is an 0.3% increase on the previous year's level (347.2 TWh). If we add pumped hydropower output, European Union hydroelectricity production stood at 374.8 TWh in 2021 compared to 375.5 TWh in 2020, which equates to a slight drop of 0.2%. While hydropower has ceded its place as the top European Union renewable electricity producer sector to wind power, its top position worldwide for renewable electricity remains unassailed according to the International Energy Agency, with 4 327 TWh in 2021 (0.4% less than in 2020, equating to a 15-TWh drop). Wind is the leading non-hydraulic renewable energy source globally with 1 870 TWh of output (a 17%, or 273 TWh increase on 2020).
The slight increase in hydropower output excluding

1

Hydraulic capacity of pure hydro plants, mixed plants and pure pumped plants in the European Union countries in 2020 and in 2021 (in MW)*

	2020				2021			
	Pure hydro power	Mixed hydro power	Pure pumped hydro power	Total	Pure hydro power	Mixed hydro power	Pure pumped hydro power	Total
France	18 867	5 360	1 728	25 955	19 191	5 373	1 728	26 291
Italy	15 443	3 312	3 940	22 695	15 529	3 281	3 940	22 750
Spain	13 704	3 082	3 331	20 117	13 719	3 082	3 331	20 132
Sweden	16 307	99	0	16 406	16 308	99	0	16 407
Austria	8 903	5 731	0	14 635	8 987	5 761	0	14 748
Germany	4 320	1 134	5 354	10 808	4 356	1 134	5 354	10 844
Portugal	4 476	2 764	0	7 241	4 491	2 764	0	7 255
Romania	6 282	279	92	6 652	6 291	279	92	6 662
Greece	2 718	699	0	3 417	2 722	699	0	3 421
Bulgaria	2 363	149	864	3 376	2 356	149	864	3 369
Finland	3 164	0	0	3 164	3 171	0	0	3 171
Slovakia	1 613	0	916	2 529	1 615	0	916	2 531
Poland	601	376	1 423	2 400	599	376	1 423	2 398
Czechia	1 094	0	1 172	2 265	1 113	0	1 172	2 285
Croatia	1 924	275	0	2 200	1 925	275	0	2 201
Latvia	1 586	0	0	1 586	1 587	0	0	1 587
Belgium	106	0	1 307	1 413	111	0	1 307	1 418
Slovenia	1 172	0	180	1 352	1 172	0	180	1 352
Luxembourg	35	0	1 296	1 331	35	0	1 296	1 331
Lithuania	117	0	760	877	117	0	760	877
Ireland	237	0	292	529	237	0	292	529
Hungary	58	0	0	58	60	0	0	60
Netherlands	37	0	0	37	37	0	0	37
Denmark	7	0	0	7	7	0	0	7
Estonia	8	0	0	8	6	0	0	6
Total EU 27	105 142	23 260	22 654	151 056	105 741	23 272	22 654	151 668

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

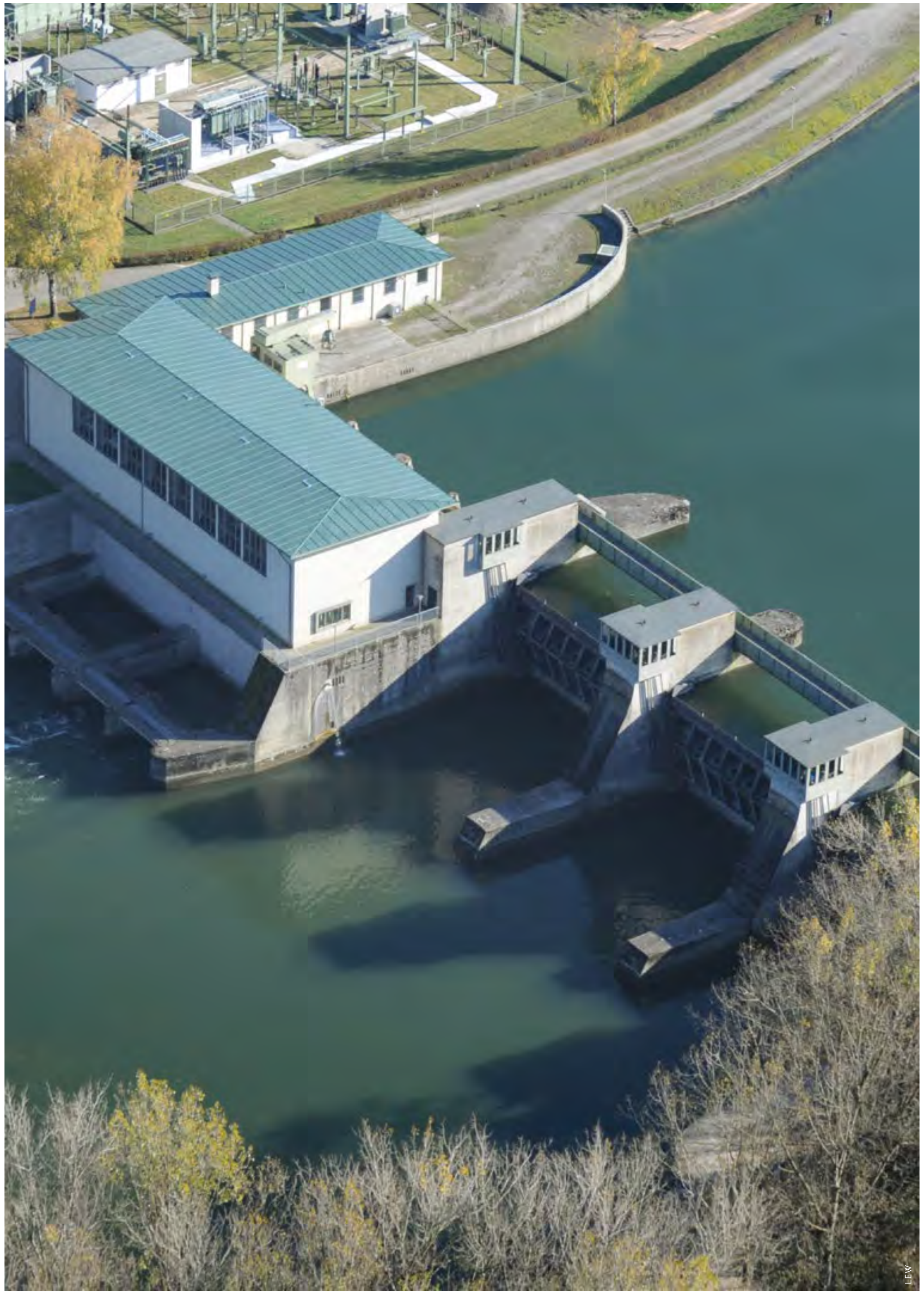
pumped output in European Union masks the disparity in the Member States' performances. Of the top five producer countries (Sweden, France, Italy, Austria and Spain), only Sweden's output increased on the 2020 level (by 2.1%, or 1.5 TWh). The sharpest drops in output volume were recorded in France (4.7%, 3 TWh), Italy (4.6%, 2.2 TWh) and Austria (7.7%, 3.2 TWh). These drops were offset EU-wide by the surge in hydropower output enjoyed by Greece (76.6%, 2.6 TWh), Romania (13.2%, 2 TWh), Bulgaria (70.9%, 2 TWh) and Croatia (25.9%, 1.5 TWh).
Note, that for the purposes of calculating the Member States' renewable energy targets, whose methodology is defined by the Renewable Energy Directive, hydroelectricity production is normalized over the last 15 years to mitigate the effect of variations in runoff. The SHARES statistics tool, used for calculating these targets, adopted 348.3 TWh as the normalized hydroelectricity output across the European Union in 2021... 0.6% more than in 2020 (345.2 TWh). Thus, the normalized hydropower output figure for 2021 across the European Union, was similar to actual hydropower output (excluding pumping).
As for 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

2

Hydraulic gross electricity production (pumping excluded) in the European Union (in TWh) in 2020 and 2021

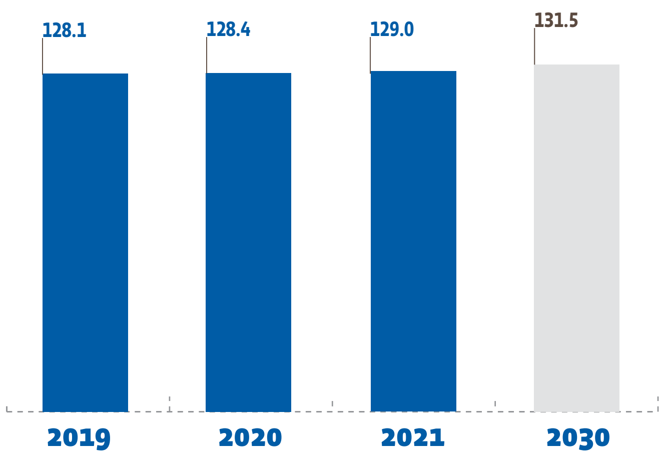
	2020	2021
Sweden	72.389	73.885
France	62.594	59.625
Italy	47.552	45.388
Austria	41.998	38.751
Spain	30.507	29.626
Germany	18.721	19.658
Romania	15.381	17.412
Finland	15.883	15.792
Portugal	12.083	11.908
Croatia	5.662	7.128
Greece	3.344	5.903
Bulgaria	2.820	4.819
Slovenia	4.934	4.713
Slovakia	4.517	4.258
Latvia	2.603	2.708
Czechia	2.144	2.409
Poland	2.118	2.339
Ireland	0.933	0.749
Belgium	0.267	0.418
Lithuania	0.301	0.384
Hungary	0.244	0.212
Luxembourg	0.092	0.107
Netherlands	0.046	0.088
Estonia	0.030	0.023
Denmark	0.017	0.016
Total EU 27	**347.180**	**348.319**

Source: Eurostat



3

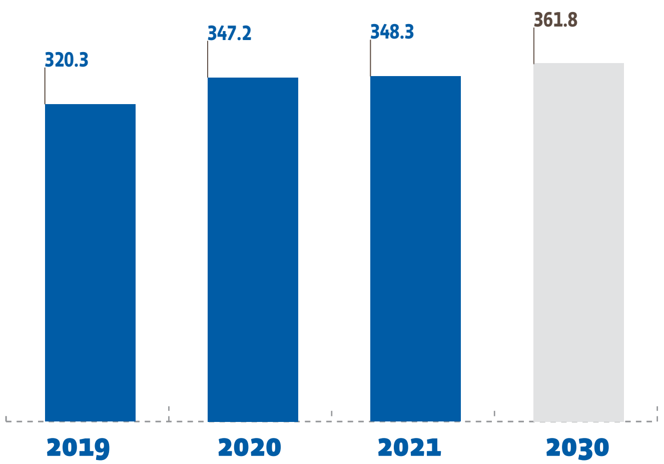
EurObserv'ER projection of the net hydraulic capacity (pure pumping excluded) in the EU 27 (in GW)



Source: EurObserv'ER

4

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



Source: EurObserv'ER

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 plants (PHES) 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 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 gauged net maximum capacity of the EU-27 pure hydro plants at 105 741 MW in 2021 (105 142 MW in 2020), compared to the net maximum capacity of mixed hydro plants at 23 272 MW in 2021 (23 260 MW in 2020).
The five best-equipped countries with pure hydro plants, (2021 data) are France (19 191 MW), Sweden (16 308 MW), Italy (15 529 MW), Spain (13 719 MW) and Austria (8 987 MW).

OUTPUT OF ABOUT 362 TWH IS EXPECTED IN 2030

In the European Union, increasing hydropower's contribution poses a challenge bearing in mind the accelerating disruption of the availability of water caused by climate change and the aging stock of hydropower plants. The sector's growth potential is largely contingent on the modernization of its existing installations and the extension of existing hydropower complexes rather than the construction of new projects, which are few and far between, such as the one in Portugal (see below). The increasingly recurrent droughts, primarily in the southern and Alpine countries, seriously challenge energy supply security. A particular case in point was 2022, when major hydropower shortfalls affected the Iberian peninsula during the first half of the year, and also in Italy and France, which compounded the energy crisis triggered by Russia's invasion of Ukraine. Hydropower capacity-building for seasonal storage, and also daytime storage opportunities for excess wind and solar energy output, have kindled new political interest in constructing or extending pumped hydroelectric energy storage (PHES). Plentiful generation of photovoltaic energy in the middle of the day, for example, can be used by pumping stations to replenish stocks upstream of the dam and restore it during the peak consumer demand periods at the end of the day. This new interest is leading to the announcement of dam PHES-equipped projects, which nonetheless are contingent on the lifting of several curbs such as the regulatory framework, local acceptability, but above all the implementation of specific remuneration for flexibility and funding through European funds. One of the most important GW-scale projects, is the extension of the Aguayo pumped storage hydroelectric plant, located at San Miguel de Aguayo (Cantabria). The project, called Aguayo 2, presented by the REPSOL energy group in 2021, is designed to increase the PSP's installed capacity by 1 GW to raise total capacity to 1.4 GW, which will make it the second biggest facility of this type in Spain. Extension of the power plant will be configured with four groups of reversible turbines each with approximately 250 MW of capacity and will raise the site's annual electricity output to 2 000 GWh. The regional government of Cantabria and Repsol hope to be granted European funds to complete the project. In France, EDF has two large hydraulic pumping station projects in the pipeline, namely Redenat (1 GW) on the Dordogne River, a 1 billion euro project, and the extension of Montézic in Aveyron (430 additional MW for a total of 1 350 MW), a 500 million euros project. Once again, EDF conditions these investments to payment for a storage service, and also the renewal of its concession agreements. As it stands, the European Commission's request to open up Franc's hydroelectric facilities to competition, gives the energy operator no visibility to carry out these investments.
Another project is nearing completion in the European Union. It is the Tâmega Hydropower complex in Portugal (1 158 MW), on the Tâmega River, a tributary of the Douro River near Oporto in Northern Portugal. It comprises three dams and three power plants (Gouvães, Daivões and Alto Tâmega). A 118-MW hydro power plant works in conjunction with the Daivões Dam, while a 160-MW power plant will work in tandem with the Alto Tâmega Dam that is still under construction. The Daivões Dam is also the lower pool of the Gouvães (880-MW) pumped storage plant. This plant built in an underground cavern dug into the mountain is linked to the top reservoir 650 metres above it. The plant is reversible, which means that it can pump water from the Daivões reservoir into the top reservoir, Gouvães, during excess electricity production periods and release it to the turbines during consumption peaks. The Gouvães and Daivões power plants went on stream in 2021 and early in 2022 and the Alto Tâmega plant is scheduled to start up in 2024. This will be a hybrid facility given that two wind farms with 300 MW of combined capacity will be built near the site and be linked to the pumping station. The hydropower complex is designed to generate 1 766 GWh with enough storage capacity to cover the daily consumption of 2 million Portuguese households. This project, led by Iberdrola at a cost of over € 1.5 billion, has benefitted from a € 650 million European Investment Bank (EIB) loan.
The European Commission's MIX scenario provides for 131 477 MW of net installed hydropower capacity (excluding pure pumping) in 2030 for the EU-27 including 89 535 MW from mountain lakes and 41 942 MW from run-of-the-river power plants. The resulting renewable electricity output should be 361.8 TWh in 2030 (190.3 TWh from lakes and 171.5 TWh from run-of-the-river power plants). Therefore, this simulation assumes that 3 363 MW of net additional capacity (excluding pure pumping) will be added in the decade up to 2030. ■

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 2020 and 2021 (in MWe)*

	2020		2021	
	Capacity installed	Net capacity	Capacity installed	Net capacity
Italy	915.5	771.8	915.5	771.8
Germany	47.0	40.0	54.0	46.0
Portugal	34.0	29.1	34.0	29.1
Croatia	16.5	10.0	16.5	10.0
France	17.1	16.2	17.1	16.2
Hungary	3.0	3.0	3.0	3.0
Austria	1.3	0.9	1.3	0.9
Romania	0.05	0.05	0.05	0.05
Total EU 27	**1 034.4**	**871.0**	**1 041.4**	**877.0**

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

Groupe ES Géothermie

2

Gross electricity generation from geothermal energy in the European Union countries in 2020 and 2021 (in GWh)

	2020	2021
Italy	6 026.1	5 913.8
Germany	231.0	244.0
Portugal	217.2	178.5
France	133.2	100.3
Croatia	93.7	89.7
Hungary	16.0	12.0
Austria	0.1	0.0
Romania	0.0	0.0
Total EU 27	**6 717.3**	**6 538.4**

Source: Eurostat


Groupe ES Géothermie

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 geothermal heating networks. It reports that there were 262 heating networks with 2 163.5 MW of combined capacity operating in the European Union in 2021. These include projects or project extensions amounting to 131.7 MWth of additional capacity that went on stream in France – 3 systems (51.5 MWth), Poland – 1 (44.6 MWth), the Netherlands – 3 (22 MWth), Germany–1 (12 MWth), Finland – 1 (1 MWth) and Cyprus – 1 (0.6 MWth). France alone installed 39% of the European Union's new capacity. The purchasable EGEC Geothermal Market Report 2021 published in August 2022 gives distribution of geothermal heating network details by individual country.

The Vélizy-Villacoublay geothermal heating network (16 MWth of capacity) is one of the latest to be commissioned, on 7 December 2021. The plant, located between Versailles and Paris in the Paris basin deploys the new "Multi-drain Drilling" technology which optimises the aquifer heat's transmissivity in comparison to traditional doublet technology. A geothermal doublet comprises two wells: a production well through which the hot water is pumped to the boiler plant, and a reinjection well where the water cools. Multi-drains technology increases the number of crossings permissible in the geothermal reservoir through the U-shaped geometry of drains, compared to a conventional well-bore. This innovation, developed by ENGIE, the energy operator, extends the development potential of deep geothermal energy to less favourable areas. The geothermal part of the Vélizy-Villacoublay network supplies 60% of the 19-km long urban heating system. The geothermal energy supplies space heating and domestic hot water to 12 000 households, making an annual 22 800-tonne saving of CO_2. Heat pumps are used to raise the geothermal heat temperature from 63 to 85°C. The project cost a total of 25 million euros.

Eurostat monitors geothermal heat production data. Its 2021 heat figures for the EU-27 are 336.3 ktoe for heat from the processing sector, which is generally sold on to heating networks (319.7 ktoe in 2020) and an estimated 575.7 ktoe (556.3 ktoe in 2020) for heat directly used by final consumers. When added together, we arrive at a total of 911.9 ktoe of geothermal heat used in 2021 (876 ktoe in 2020).

ELECTRICITY PRODUCTION

The geothermal electricity capacity of the European Union countries increased only slightly between 2020 and 2021. In 2021, Germany was the only country to raise its capacity by connecting the Garching an der Altz plant, in Bavaria at the start of the year. The plant is of the ORC type (Organic Rankine Cycle), which uses an intermediate heat carried medium (binary cycle). The geothermal fluid in an ORC plant is pressurized and driven to a heat exchanger where it releases its energy to an organic fluid that can vaporise at low pressure and temperature. The Garching plant, which has a maximum capacity of 5.3 MWe, has been injecting electricity into the grid since March 2021. Its almost 4 000-metre deep production well can extract 125 litres of thermal water at 123°C per second. E-On, the electricity provider has also equipped the geothermal plant at Kirchweidach, Bavaria, with a 1-MWe electricity production module, also of the ORC type, which went on stream at the end of 2021. E-On aims to raise the installation's electricity capacity to 6 MWe. The plant takes the number of German geothermal plants with capacity of one or more megawatts to 12.

EurObserv'ER reckons that the EU's geothermal electrical capacity including these additions, has risen to 1 041.4 MWe, spread across 58 plants. Eurostat puts net capacity in 2021, which is the maximum capacity presumed to be exploitable, at 877 MWe (6 MWe higher than in 2020) but reports that the European Union's gross electricity output dipped slightly (2.7%) between 2020 to 2021 to 6.5 TWh. Germany was the only country to produce more geothermal power. The drop in Portugal's output can be put down to maintenance work that started in September 2021 and was completed in February 2022. Following a prefectural inspection in August 2021, maintenance and compliance work was imposed on France's Bouillante site in Guadeloupe. Partial resumption was authorized from 16 September 2021 and normal running from the start of January 2022.

Limited construction work on new geothermal plants should continue, and is likely to continue in the next few years in the European Union. There are ongoing projects in Italy, Germany and Croatia. By way of illustration, we mention the AAT Geothermae project at Draškovec in Croatia which made a successful Croatian energy market operator (HROTE) bid for 10 MWe of capacity in July 2022. This project is now eligible for a 1 263.96 HRK (168.26 EUR) premium per MWh.

3

Heat consumption from geothermal energy in the countries of the European Union in 2020 and 2021 (in ktoe)

	2020			2021		
	Total	*of which final energy consumption*	*of which derived heat**	**Total**	*of which final energy consumption*	*of which derived heat**
France	201.4	40.2	161.2	209.1	40.2	169.0
Netherlands	147.7	147.7	0.0	151.1	151.1	0.0
Germany	128.2	81.8	46.3	140.7	94.6	46.0
Italy	140.6	119.7	20.8	140.6	115.0	25.6
Hungary	128.5	62.3	66.2	138.8	68.6	70.2
Bulgaria	35.7	35.7	0.0	36.1	36.1	0.0
Poland	25.6	25.6	0.0	28.4	28.4	0.0
Austria	24.1	11.8	12.3	23.4	10.2	13.2
Romania	11.9	5.8	6.1	15.3	9.0	6.2
Slovenia	10.9	10.5	0.5	11.3	10.8	0.5
Croatia	7.2	7.2	0.0	5.0	5.0	0.0
Greece	5.6	5.6	0.0	4.3	4.3	0.0
Slovakia	5.0	0.7	4.3	4.0	0.7	3.2
Belgium	1.4	0.0	1.4	1.6	0.0	1.6
Portugal	1.3	1.3	0.0	1.4	1.4	0.0
Denmark	0.5	0.0	0.5	0.6	0.0	0.6
Spain	0.2	0.2	0.0	0.2	0.2	0.0
Total EU 27	**876.0**	**556.3**	**319.7**	**911.9**	**575.7**	**336.3**

** Gross heat production in the transformation sector.* ***Source: Eurostat***

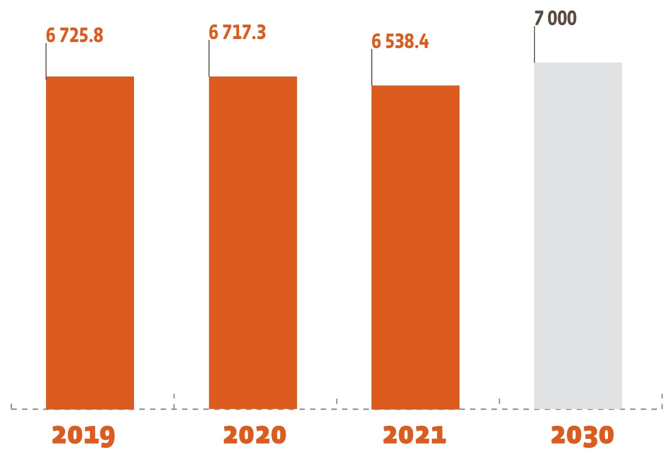
ENERGY STOCKPILED UNDERFOOT

Following an indifferent year in 2020 because of the COVID-19 pandemic, 2021 marked a year of recovery within the European Union for direct uses of deep geothermal energy. Installed geothermal electricity capacity also recovered as a >5 MW binary cycle plant went on stream, which has paved the way to higher capacity binary cycle plants, in excess of 10 MWe, in Europe (Italy, Croatia, and so on). In order to develop and turn the sector into a major lever for carbon neutrality, deep geothermal energy needs a suitable framework. It calls for an ambitious renewable heat and cooling policy with stronger support mechanisms. It also needs specific measures for the production of industrial, food processing heat and greenhouse heating. The German government has raised the stakes in this sense. Its Federal Ministry of the Economy and Climate Protection (BMWK) revived its geothermal heat ambitions with the publication of a document entitled “Key elements of a geothermal campaign” in November 2022 which plans to roll out 100 new geothermal projects (heating networks, industrial heat, etc.) by 2030 with a production target of 10 TWh.

Another development priority is to develop geothermal electrical power, on the continent or in overseas territories, by associating it with the co-production of European lithium – a strategic raw material for energy transition. The company Vulcan Energy, which aims to produce carbon-neutral lithium from the activity of German geothermal plants, hopes to extract 40 000 tonnes of lithium hydroxide in the Rhine Valley. This amount is likely to produce the equivalent of one million EV batteries per annum as soon as 2025. According to Philippe Dumas, Secretary General of EGEC: “2021 proved that geothermal is the most reliable, cost-effective and ‘go-to’ solution for local authorities, industry, households and commercial buildings”. Now it is important for regulators to give it the same recognition and support as other technologies to ensure energy independence and climate security before 2030”. ■

4

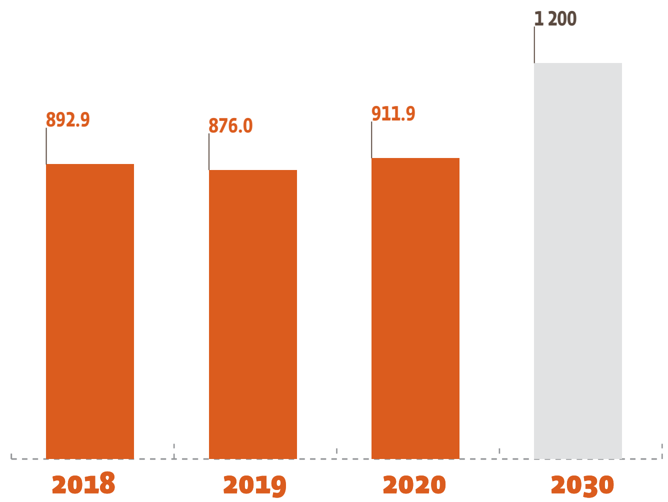
EurObserv’ER projection of geothermal electricity production in the EU 27 (in GWh)



Source: EurObserv’ER

5

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



**Final energy consumption 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. The European Union market data for 2021 confirms this technology's continued penetration into the heating segment. This shift can be attributed to EU policymakers' resolve to promote the electrification of heating requirements, discourage the use of fuel oil and gas-fired heating, and to the growing demand for summer comfort to cope with torrid heatwaves.

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 main if not the only mode of use. Hence, some air-to-air HP markets in the European Union are not directly comparable. Furthermore, the HP usage and power ranges used 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.

AIR-SOURCE HPS DOMINATE THE MARKET

According to EurObserv'ER, over 5.2 million HPs were sold in the European Union during 2021, all power ranges and technologies (aerothermal, hydrothermal and geothermal) taken together, posting a 17.8% year-on-year rise (4.4 million units sold). These statistics cover the residential and tertiary markets in particular (with power ranges starting at a few kW to several tens of kW). The medium- and high-capacity HP market is much smaller. It should be borne in mind that the diverse types of HPs produce different amounts of renewable energy. This output depends on the thermal energy source tapped (ground, water, air), the application (for 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 HP installed in Finland or Sweden.
Reversible air-to-air HPs dominate European Union HP system sales. EurObserv'ER puts the figure at over 4.2 million systems sold in 2021, which is a 13.6% year-on-year rise. Much of this growth can be ascribed to Italy's particularly high replacement rate. According to the GSE, which is responsible for renewable energy accounting, sales of Italian reversible air-to-air HPs increased by 31.1% between 2020 and 2021 (i.e., 2 million air-to-air HPs sold compared to just over 1.5 million units in 2020).
The water borne ASHP market specifically caters for heating needs. Sales in this market segment were spectacular, increasing by 47.5% between 2020 and 2021, to 854 878 systems (in 20 countries), as 275 049 systems were added to the 2020 figure. Annual growth in this market segment was particularly sharp in Italy (124.4%), Ireland (149.2%), Estonia (252.3%) and Poland (88%). The market upturn was very strong in the northern European countries (Finland, Sweden, Denmark), where this heating method is very widespread.
The (water borne) geothermal HP segment also caters specifically for heating requirements but is less popular. Segment growth was positive across the European Union and increased by 11.9% over the previous year's performance, with 111 393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units sold in the 21 EU countries monitored. Denmark witnessed the highest annual surge (74.4%) with 4033 units sold in 2021, according to the Danish Energy Agency. The volume of water borne HP sales taken together, (air-to-water and ground source) came close to one million units in 2021 (966 271 systems) – a 42.3% year-on-year increase.

THE EUROPEAN HP BASE STANDS AT OVER 44 MILLION UNITS

Estimating the number of HPs in service is a tricky task as the exercise depends on 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 44.1 million units (42.3 million ASHPs and 1.8 million GSHPs). This figure is not restricted to HPs used for heating, but also includes those that offer cooling and heating applications, provided that the system performance coefficients meet the Renewable Energy Directive criteria. Even if HPs meet the criteria and are likely to produce renewable heat and cooling

1

Market of aerothermal heat pumps in 2020 and 2021 in the European Union (number of units sold)

	2020				2021			
	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	1 573 941	1 525 805	48 136	0	2 108 000	2 000 000	108 000	0
France	987 626	812 404	175 222	0	1 104 850	837 629	267 221	0
Spain	400 373	351 275	49 098	0	438 000	385 290	52 710	0
Netherlands	360 401	317 089	43 312	0	346 350	296 584	49 766	0
Portugal	222 837	222 389	448	0	207 910	207 536	374	0
Germany	121 770	0	96 170	25 600	150 870	0	127 870	23 000
Finland	93 649	82 188	7 892	3 569	119 859	103 136	12 416	4 307
Sweden	103 667	70 000	14 727	18 940	108 003	70 000	17 865	20 138
Belgium	98 487	86 723	11 764	0	99 915	86 915	13 000	0
Poland	54 155	11 924	42 201	30	90 383	11 018	79 350	15
Denmark	62 571	48 893	13 474	204	70 236	50 030	19 971	235
Malta	70 236	70 236	0	0	60 796	60 796		0
Slovakia	42 118	38 626	3 468	24	43 778	38 961	4 626	191
Greece	40 224	37 138	3 086	0	30 378	30 378	0	0
Czechia	22 684	0	22 615	69	28 542	0	28 380	162
Slovenia	25 446	18 946	6 500	0	28 400	18 900	9 500	0
Austria	20 437	237	20 200	0	25 914	173	25 741	0
Ireland	14 397	6 892	7 045	460	25 288	6 397	17 554	1 337
Lithuania	19 940	12 450	7 490	0	24 420	15 180	9 240	0
Estonia	15 010	13 700	1 280	30	18 448	13 902	4 509	37
Hungary	5 820	400	5 420	0	6 504	0	6 504	0
Luxembourg	150	0	150	0	281	0	281	0
Total UE 27	**4 355 940**	**3 727 315**	**579 698**	**48 926**	**5 137 124**	**4 232 825**	**854 878**	**49 422**

Note: Market data for air-air heat pumps for Italy, France, Spain, Portugal and Malta are not directly comparable to others, because they include high part of reversible heat pumps whose principal function is cooling. Only heat pumps that meet the efficiency criteria (seasonal performance factor) defined by Directive 2009/28/EC for the year 2020 and defined by Directive 2018/2001 (EU) for the year 2021 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 2020 et 2021 in the European Union (number of units sold)*

	2020	2021
Sweden	23 757	25 499
Germany	22 200	24 500
Netherlands	19 356	21 792
Finland	8 644	9 516
Poland	5 260	5 650
Austria	4 557	5 298
Denmark	2 312	4 033
Belgium	3 193	3 605
France	3 005	3 220
Estonia	1 750	2 191
Czechia	1 440	1 637
Slovenia	924	1 164
Italy	1 242	953
Lithuania	580	710
Hungary	347	416
Spain	234	326
Slovakia	216	274
Ireland	316	190
Luxembourg	159	184
Greece	n.a.	178
Portugal	64	57
Total UE 27	**99 556**	**111 393**

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

3

*Total number of heat pumps in operation in 2020 and 2021 in the European Union **

	2020			2021		
	Aerothermal HP	Geothermal HP	Total	Aerothermal HP	Geothermal HP	Total
Italy	17 939 358	16 145	17 955 503	18 007 709	17 098	18 024 807
France	7 600 000	173 000	7 773 000	8 600 000	172 000	8 772 000
Spain	4 558 334	3 490	4 561 824	4 996 334	3 816	5 000 150
Sweden	1 441 828	561 033	2 002 861	1 534 985	560 333	2 095 318
Portugal	1 937 887	1 048	1 938 935	2 139 188	1 105	2 140 293
Germany	878 829	411 198	1 290 027	1 024 196	431 134	1 455 330
Finland	930 269	136 608	1 066 877	1 050 128	146 124	1 196 252
Netherlands	1 020 047	87 919	1 107 966	1 364 349	106 265	1 470 614
Denmark	445 455	72 459	517 914	511 528	77 796	589 324
Malta	485 289	0	485 289	534 578	0	534 578
Belgium	420 080	18 997	439 077	519 995	22 602	542 597
Greece	327 448	7 536	362 194	357 826	3 878	361 704
Slovenia	251 100	13 654	264 754	266 100	14 818	280 918
Austria	146 604	112 143	258 747	172 058	114 919	286 977
Poland	167 075	65 818	232 893	257 458	71 468	328 926
Bulgarie	214 971	4 272	219 243	214 971	4 272	219 243
Czechia	180 622	27 756	208 378	209 164	29 393	238 557
Estonia	176 727	19 375	196 102	195 175	21 566	216 741
Slovakia	136 860	4 180	141 040	180 638	4 454	185 092
Lithuania	63 491	4 749	68 240	87 911	5 459	93 370
Ireland	50 833	5 038	55 871	76 121	5 228	81 349
Hungary	18 620	3 092	21 712	25 124	3 508	28 632
Luxembourg	2 511	1 330	3 841	2 792	1 514	4 306
Total UE 27	39 394 238	1 750 840	41 172 288	42 328 328	1 818 750	44 147 078

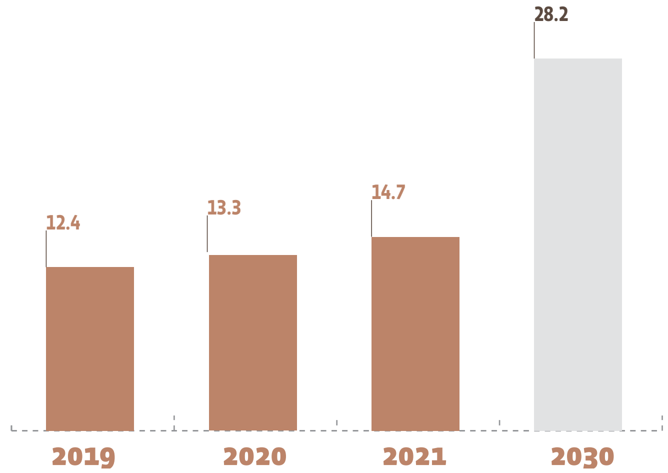
*Note: Data from Italian, French, Spanish Portuguese and Maltese aerothermal heat pumps market are not directly comparable to others, because they include high part of reversible heat pumps whose principal function is cooling. Only heat pumps that meet the efficiency criteria (seasonal performance factor) defined by Directive 2009/28/EC for the year 2020 and defined by Directive 2018/2001 (EU) for the year 2021 are taken into account. *Estimation.* ***Source: EurObserv'ER***

as defined by the RED Directive, a few countries such as France, apply corrective measures when calculating the renewable energy output of their HP base. EurObserv'ER believes that more detailed studies of HP usage modes will probably fine tune the renewable energy output statistics.

Incidentally, EHPA, in its 2022 European Heat Pump Market and Statistics report, puts the total 2021 European HP base in service primarily for heating purposes at about 16.96 million units with a hypothetical service life of 20 years. This estimate implies that about two-thirds of the HP base primarily meet cooling needs. There are about 120 million residential buildings in Europe, thus, the heat pump market share of the building stock is about 14%.

4

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



Results from 2019 to 2020 take into account specific calculation provisions as in place in Directive 2009/28/EC, whereas results for 2021 follow Directive (EU) 2018/2001.
Source: EurObserv'ER

DECISION-MAKING IS OF THE ESSENCE

Heat pumps are not only identified as a key technology for decarbonating the building sector, but their technologies contribute much to increasing renewable energy production. Regarding heating only, the Eurostat Shares tool calculates heat pumps' total contribution to EU-27 renewable heat output at 14 682 ktoe in 2021, i.e., 1 366.1 ktoe more than in 2020. In 2021, ASHPs and hydrothermal HPs accounted for 11 953.2 ktoe of renewable energy output compared to 2 729.2 ktoe by GSHPs. Eurostat also puts the installed capacity of the current HP base at 290 GW (6.8% more than in 2020) in detail 271.3 GW for ASHPs, 17.4 GW for GSHPs and 1.4 GW for hydrothermal HPs. ASHP ratings break down into 220.2 GW for air-to-air HPs, 49.1 GW for air-to-water HPs and 2 GW for exhaust air HPs.

Everything is in place this decade to accelerate the contribution made by HPs to achieve our climate goals. A much more aggressive building energy renovation policy is required to fuel this acceleration.

The European Commission's "Fit for 55" package, published on 14 July 2021, is clearly a step in this direction. It comprises a string of legal texts that should reduce CO_2 emissions by 55% from their 1990 level, which is crucial to achieving carbon neutrality. The building sector which uses 40% of the energy consumed in the EU, and which generates about 36% of its energy-related CO_2 emissions is kernel to the Commission's legislative proposals. The proposed revision to the Renewable Energy Directive provides measures for accelerating heating and cooling systems' transition to renewable energies in the context of renovations. Thus, the Commission plans to set a reference value of 49% of renewable energies in buildings by 2030, which could be provided by the electrification of heating and cooling needs with heat pumps alongside direct use of renewable heat (biomass heating, geothermal and solar thermal energy partially via heating networks). The Commission also proposes to oblige its Member States to increase renewable energy use in heating and cooling by 1.1 of a percentage point by 2030. Apart from housing, public buildings must also be renovated, to use more renewable energies and be more energy efficient. Accordingly, the Commission plans to set the Member States an annual binding renovation target of at least 3% of the total floor area of all public buildings. ■

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BIOGAS

Methanation is a natural biological process in which many micro-organisms (bacteria) break down organic matter in an oxygen-free environment. Methanation biogas from anaerobic fermentation breaks down into three sub-sectors, segmented by waste origin and treatment. It includes biogas from non-hazardous waste storage facility biogas ("landfill gas"), methanation of wastewater treatment plant sludge ("sewage sludge gas") and methanation of non-hazardous waste or raw plant matter ("other biogas").
International institutions monitor a fourth segment, whose biogas is the product of a heat treatment process ("biogases from thermal processes") involving thermal gasification of solid biomass (wood, forest residue, solid and fermentable household waste) or hydrothermal gasification of liquid biomass. These processes produce a methane-rich syngas that produces biomethane when purified.

14.9 MILLION TOE OF BIOGAS PRODUCED IN THE EUROPEAN UNION

Primary biogas energy output across the European Union increased slightly in 2021, by 1.6% year-on-year according to Eurostat, to reach 14.9 Mtoe (14 928.9 ktoe), which is half the previous year's growth rate (3.8%). Methanation biogas from non-hazardous waste or raw plant matter (category «Others biogas») dominates this output (at 83.5% in 2021), outstripping sewage sludge gas (7.8%), landfill biogas (7.7%), and thermal biogas (0.9%).
Growth in output across the EU in 2021 was lower than the previous year (at 242 ktoe compared to 541.2 ktoe). Lower outputs between 2020 and 2021 from Germany (247 ktoe) and Austria (50.2 ktoe) provide the underlying reason for this contraction, but it was made up for by sharp growth in output by France (314.1 ktoe), Denmark (120.4 ktoe) and Italy (60.3 ktoe). While Germany's lower annual output stood at over 7.5 Mtoe (3.2%), it still accounted for half (50.4%) of total European Union biogas produc-

MT-BioMethan GmbH

1

Primary energy production from biogas in the European Union in 2020 and 2021 (in ktoe)

	2020					2021				
	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	113.7	481.5	7170.0	0.0	7765.2	112.8	480.5	6924.9	0.0	7518.2
Italy	281.2	51.3	1678.6	6.7	2017.9	267.0	49.8	1754.0	7.3	2078.1
France	311.5	35.8	742.8	0.0	1090.1	325.8	23.5	1054.9	0.0	1404.2
Denmark	3.2	24.8	477.2	0.0	505.2	3.3	25.5	596.8	0.0	625.6
Czechia	19.9	42.0	532.6	0.0	594.5	19.6	41.5	529.8	0.0	590.8
Netherlands	9.9	66.7	339.6	0.0	416.3	9.6	70.6	348.0	0.0	428.2
Spain	137.0	115.0	71.3	0.0	323.4	147.3	98.5	77.3	2.8	325.9
Poland	49.6	121.1	151.7	0.0	322.4	47.6	119.2	152.6	0.0	319.4
Belgium	17.1	26.9	197.6	3.4	245.1	16.2	28.3	200.0	1.4	245.8
Sweden	5.8	76.2	103.8	0.0	185.8	6.6	76.3	111.8	0.0	194.8
Finland	12.8	17.1	33.1	106.0	169.1	12.5	17.7	39.8	124.5	194.4
Austria	1.1	26.1	182.6	0.0	209.9	1.0	35.2	123.4	0.0	159.7
Slovakia	5.7	7.5	117.6	0.0	130.9	6.9	6.9	116.9	0.0	130.7
Greece	61.1	21.8	52.4	0.0	135.3	47.0	20.4	59.8	0.0	127.2
Croatia	6.8	2.9	73.5	0.0	83.1	7.1	3.5	88.6	0.0	99.2
Portugal	65.7	6.9	10.1	0.0	82.7	69.0	7.4	10.8	0.0	87.2
Hungary	9.8	29.4	50.3	0.0	89.5	7.7	30.2	46.1	0.0	84.0
Latvia	7.7	1.8	70.7	0.0	80.2	7.9	1.9	56.2	0.0	66.0
Bulgaria	0.0	6.1	47.2	0.0	53.3	0.0	5.9	53.8	0.0	59.7
Ireland	29.3	7.3	13.7	0.0	50.3	29.4	7.7	15.0	0.0	52.0
Lithuania	6.5	7.2	24.9	0.0	38.6	5.5	8.1	26.5	0.0	40.2
Slovenia	1.4	1.2	24.4	0.0	27.0	1.3	1.2	22.4	0.0	24.9
Romania	0.0	0.0	18.4	0.0	18.4	0.0	0.0	23.2	0.0	23.2
Estonia	1.6	7.4	10.8	0.0	19.9	1.0	6.6	10.6	0.0	18.2
Luxembourg	0.0	1.3	16.7	0.0	18.0	0.0	0.9	15.5	0.0	16.5
Cyprus	0.0	0.8	12.5	0.0	13.3	0.1	0.8	12.4	0.0	13.4
Malta	0.0	0.0	1.4	0.0	1.4	0.0	0.0	1.3	0.0	1.3
Total EU 27	1 158.8	1 186.3	12 225.6	116.2	14 686.8	1 152.2	1 168.1	12 472.5	136.0	14 928.9

Source: Eurostat

tion. If we consider the various biogas source trends, methanation biogas from non-hazardous waste and raw plant matter (the "other biogas" category) was responsible for almost all of the 2021 increase in output (247 ktoe), the outputs of landfill biogas and sewage sludge gas slipped slightly (by 6.6 ktoe and 18.2 ktoe respectively). The output of "biothermal" biogas, which is now identified in four countries (Finland, Italy, Spain and Belgium) increased by 19.9 ktoe. Finland produces most of it (124.5 ktoe of a total of 136 ktoe in 2021) and has been operating the European Union's biggest biomass gasification plant at Vaasa since 2013. This 140-MW power plant, owned by Vaskiluodon Voima uses biogas produced from wood waste.

Biogas, whose methane content is about 60%, can be used directly as final energy in the form of heat when burned in a suitably adapted gas boiler, and as electricity when the released energy powers a generator, or through cogeneration (combined heat and power production).

Biogas can also be purified to remove its carbon dioxide and hydrogen sulphide content to produce biomethane, which can then be used on site as electricity, heat or even biofuel for bioNGV vehicles that run on fossil gas. Another option that is gaining ground, is to inject biomethane into the existing fossil gas grid. The biomethane can thus be harnessed in the same way as fossil gas, in the form of electricity, heat or fuel.

2

Gross electricity production from pure biogas and from biogas blended in the grid in the European Union in 2020 and 2021 (in GWh)

	2020				2021			
	Electricity only plants	CHP plants	Total electricity from pure biogas	Electricity from biogas blended in the grid	Electricity only plants	CHP plants	Total electricity from pure biogas	Electricity from biogas blended in the grid
Germany	6 892.0	26 606.0	33 498.0	0.0	6 726.2	23 269.0	29 995.2	3 134.0
Italy	2 727.2	5 439.2	8 166.4	188.0	2 508.6	5 615.6	8 124.2	0.0
France	293.6	2 472.9	2 766.5	172.4	353.4	2 800.3	3 153.7	298.5
Czechia	37.4	2 559.0	2 596.4	0.6	37.2	2 555.6	2 592.8	0.9
Poland	0.0	1 233.9	1 233.9	0.0	0.0	1 307.3	1 307.3	0.0
Spain	699.0	182.0	881.0	20.5	727.0	252.0	979.0	18.9
Belgium	68.7	945.9	1 014.6	2.1	59.2	917.1	976.3	9.9
Netherlands	13.9	856.0	869.9	274.9	13.3	802.0	815.3	238.1
Denmark	1.3	671.3	672.6	171.0	1.5	611.1	612.6	280.9
Austria	579.2	49.5	628.7	14.5	557.2	44.4	601.6	14.4
Slovakia	95.0	415.0	510.0	0.0	85.0	402.0	487.0	0.0
Greece	55.0	348.9	403.9	0.0	80.4	376.5	456.8	0.0
Croatia	39.1	380.3	419.4	0.0	39.0	401.2	440.2	0.0
Finland	2.5	294.1	296.7	15.9	4.1	324.9	329.0	8.9
Hungary	65.0	259.0	324.0	4.8	52.0	243.0	295.0	4.6
Latvia	0.0	344.7	344.7	0.0	0.0	291.9	291.9	0.0
Portugal	240.6	18.9	259.5	0.0	248.6	19.0	267.6	0.0
Bulgaria	67.5	158.1	225.6	0.0	52.0	164.2	216.2	0.0
Ireland	117.0	50.7	167.7	0.3	118.7	54.0	172.7	1.3
Lithuania	0.0	149.4	149.4	0.0	0.0	156.7	156.7	0.0
Slovenia	1.3	111.7	113.0	0.0	1.5	101.1	102.6	0.0
Romania	32.2	20.9	53.0	0.0	20.6	52.3	72.9	0.0
Luxembourg	0.0	63.2	63.2	1.4	0.0	61.0	61.0	1.1
Cyprus	0.0	60.6	60.6	0.0	0.0	59.9	59.9	0.0
Estonia	0.0	31.0	31.0	0.0	0.0	16.4	16.4	0.0
Sweden	0.0	10.0	10.0	2.9	0.0	12.0	12.0	10.3
Malta	0.0	5.9	5.9	0.0	0.0	7.2	7.2	0.0
Total EU 27	12 027.5	43 738.1	55 765.6	869.2	11 685.5	40 917.8	52 603.3	4 021.8

Source: Eurostat

GRID INJECTION AFFECTS THE PURE BIOGAS STATISTICS

For the purposes of statistics, electricity or heat (heat produced by the processing sector and final energy consumption) produced from mixing biomethane with the fossil gas in the grid, are not included in the official biogas indicators published in the Eurostat database (in «Complete energy balances» indicators). Thus, these indicators apply to the use of "pure biogas" in dedicated plants or production units. Nonetheless, the Eurostat SHARE tool specifically quantifies electricity and heat output derived from biomethane mixed into the fossil gas grid so it can be included in the Member States' renewable energy target calculations. Germany is a special case because of the size of its biogas sector, and formerly included an estimate of the final biogas energy mixed in the fossil gas grid in its final biogas energy (electricity and heat) indicators. It changed its methodology in 2021 by differentiating the output of final energy sourced from "pure biogas" from the energy sourced from the "biogas blended in the fossil gas grid". In so doing, it created a statistical break in its final biogas energy indicators between 2020 and 2021.

So, the drop in European Union "pure biogas" electricity output measured by Eurostat from 55.8 TWh in 2020 to 52.6 TWh in 2021 does not reflect an actual drop in output and can be explained by this reallocation of German production. If we add together the "pure biogas" electricity and "biogas mixed into the natu-

3

Gross heat production in the transformation sector from pure biogas and from biogas blended in the grid in the European Union in 2020 and in 2021 (in ktoe)

	2020				2021			
	Heat only plants	CHP plants	Total heat* from pure biogas	Heat* from biogas blended in the grid	Heat only plants	CHP plants	Total heat* from pure biogas	Heat* from biogas blended in the grid
Italy	0.1	274.1	**274.1**	4.9	0.1	290.8	**290.9**	0.0
Germany	11.5	420.9	**432.4**	0.0	5.4	254.3	**259.6**	204.3
France	2.2	74.9	**77.1**	7.8	3.0	82.9	**85.9**	15.0
Denmark	1.3	50.4	**51.7**	48.9	2.0	47.2	**49.2**	62.0
Poland	0.7	21.4	**22.2**	0.0	0.9	22.0	**22.9**	0.0
Belgium	0.0	19.1	**19.1**	0.0	0.0	21.4	**21.4**	0.2
Finland	5.4	13.6	**19.0**	2.1	7.3	14.0	**21.3**	1.1
Latvia	0.4	19.4	**19.7**	0.0	0.2	19.3	**19.6**	0.0
Slovakia	0.9	16.4	**17.3**	0.0	0.1	17.6	**17.7**	0.0
Czechia	0.0	17.0	**17.0**	0.1	0.0	17.6	**17.6**	0.1
Croatia	0.0	12.6	**12.6**	0.0	0.0	16.9	**16.9**	0.0
Netherlands	0.0	9.7	**9.7**	5.0	0.0	7.4	**7.4**	5.7
Sweden	2.4	3.8	**6.2**	0.8	1.5	3.8	**5.3**	3.3
Austria	1.3	4.3	**5.6**	1.0	1.2	3.6	**4.8**	1.1
Romania	2.6	1.3	**3.9**	0.0	1.8	2.9	**4.6**	0.0
Bulgaria	0.0	4.5	**4.5**	0.0	0.0	3.8	**3.8**	0.0
Slovenia	0.0	4.4	**4.4**	0.0	0.0	3.7	**3.7**	0.0
Luxembourg	0.0	2.6	**2.6**	0.3	0.0	2.8	**2.8**	0.2
Hungary	0.0	3.1	**3.1**	0.4	0.0	2.7	**2.7**	0.4
Lithuania	0.0	2.3	**2.3**	0.0	0.0	2.4	**2.4**	0.0
Estonia	0.4	2.4	**2.8**	0.0	0.3	1.3	**1.6**	0.0
Cyprus	0.0	0.9	**0.9**	0.0	0.0	0.9	**0.9**	0.0
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
Portugal	0.0	0.0	**0.0**	0.0	0.0	0.0	**0.0**	0.0
Total EU 27	**29.1**	**979.1**	**1 008.1**	**71.2**	**23.6**	**839.3**	**862.9**	**293.4**

** Gross heat production in the transformation sector.* ***Source: Eurostat***

ral gas grid" output figures, the biogas electricity output figure hardly changed between 2020 and 2021 (by 0.0%) and was stable at 56.6 TWh. While drops in output were measured particularly in Germany (of 368.7 GWh between 2020 and 2021) and Italy (230.2 GWh), they were offset by the rise in biogas electricity production in France (513.3 GWh).

The same logic applies to the other final energy indicators for heat, namely biogas heat output from the processing sector and final energy consumption (other than in the transport sector). The heat output decline across the European Union from "pure biogas" processing from 1 008.1 ktoe in 2020 to 862.9 ktoe in 2021, and final energy consumption (excluding transport) from 2 514.9 ktoe in 2020 to 2 324.4 ktoe in 2021, are not meaningful and can be attributed to the statistical break in Germany's data. Once we integrate the biogas mixed into the fossil gas grid, the processing sector's biogas heat output figure rises from 1 079.3 ktoe in 2020 to 1 156.3 ktoe in 2021 (by 7.1%). Likewise, final biogas energy consumption (excluding transport) rises from 2 998.2 ktoe to 3 146.2 ktoe (by 4.9%). These trends fit in perfectly with the 2021 increase in primary biogas energy production that benefitted heat production.

France currently has the most vibrant biogas sector in the European Union, and particularly the injection segment. According to the SDES (Monitoring and Statistics Directorate) dashboard for gas grid-injected biomethane, 365 installations injected biomethane, after biogas production and purification, into the fossil gas grids on 31 December 2021. Their combi-

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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 2020 and in 2021 (in ktoe)

	2020		2021	
	Pure biogas	Biogas blended in the grid	Pure biogas	Biogas blended in the grid
Germany	1344.5	0.0	1130.5	153.7
France	232.7	128.4	255.3	260.0
Czechia	152.2	0.4	152.6	0.6
Netherlands	137.8	59.8	141.7	71.7
Spain	121.2	4.0	102.9	3.9
Finland	84.2	2.7	97.9	1.8
Belgium	101.1	0.7	96.8	4.4
Poland	91.9	0.0	87.7	0.0
Sweden	41.7	13.8	41.2	17.1
Italy	36.4	43.4	35.5	0.0
Greece	36.2	0.0	34.5	0.0
Austria	17.3	6.5	25.4	6.5
Slovakia	24.0	0.0	25.0	0.0
Denmark	18.1	216.2	20.8	295.3
Hungary	13.3	3.0	14.0	2.9
Ireland	12.1	0.0	12.4	0.2
Bulgaria	6.7	0.0	10.3	0.0
Lithuania	9.1	0.0	10.2	0.0
Portugal	7.1	0.0	7.2	0.0
Latvia	7.7	0.0	6.9	0.0
Cyprus	5.2	0.0	5.4	0.0
Slovenia	3.0	0.0	2.7	0.0
Estonia	3.3	0.0	2.7	0.0
Romania	4.5	0.0	2.6	0.0
Luxembourg	2.3	4.3	1.2	3.7
Malta	0.8	0.0	0.5	0.0
Croatia	0.4	0.0	0.5	0.0
Total EU 27	**2514.9**	**483.3**	**2324.4**	**821.8**

Source: Eurostat

5

Gross electricity production from biogas (pure and blended in the grid) in the European Union in 2021, of which compliant with the Directive (EU) 2018/2001 (in GWh)*

	2021		
	Biogas (pure and blended in the grid)	of which compliant	% compliant
Germany	33 129.2	33 129.0	100.0%
Italy	8 124.2	8 124.2	100.0%
France	3 452.2	3 452.2	100.0%
Czechia	2 593.6	2 592.8	100.0%
Poland	1 307.3	1 307.3	100.0%
Netherlands	1 053.3	650.8	61.8%
Spain	997.9	997.9	100.0%
Belgium	986.2	976.9	99.1%
Denmark	893.5	459.4	51.4%
Austria	616.0	616.0	100.0%
Slovakia	487.0	487.0	100.0%
Greece	456.8	456.8	100.0%
Croatia	440.2	440.2	100.0%
Finland	337.9	294.7	87.2%
Hungary	299.6	131.6	43.9%
Latvia	291.9	291.9	100.0%
Portugal	267.6	267.6	100.0%
Bulgaria	216.2	137.3	63.5%
Ireland	174.1	55.8	32.0%
Lithuania	156.7	156.7	100.0%
Slovenia	102.6	102.6	100.0%
Romania	72.9	72.9	100.0%
Luxembourg	62.0	62.0	100.0%
Cyprus	59.9	59.9	100.0%
Sweden	22.3	22.3	100.0%
Estonia	16.4	16.4	99.8%
Malta	7.2	7.2	100.0%
Total EU 27	**56 625.1**	**55 369.6**	**97.8%**

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

ned annual capacity was 6.4 TWh, which represents a 56% annual increase. An additional 2.3 TWh of capacity was installed during 2021, which is more than in the previous year (1.7 TWh). Furthermore, France commissioned the country's biggest methanation plant on 18 January 2023, the Biobéarn project, led by TotalEnergies, that will produce 160 GWh of biomethane every year (equating to the mean annual consumption of 32 000 inhabitants) by recovering 200 000 tonnes of organic waste provided by over 200 farmers, agrifood industries and local authority waste. The TotalEnergies group claims that this project raises its total biogas production capacity to 700 GWh and marks a new milestone in the aim to achieve 20 TWh by the 2030 timeline.

The new Renewable Energies Directive (RED II) 2018 /2001, which has been in force since 2021, introduces an additional complexity because only energy produced by biomass fuels that comply with the sustainability and GHG emission reduction criteria defined in the Directive's article 29 are deemed to contribute to the renewable energy targets. This applies to all the final energy sourced from biogas, regardless of whether it is used pure or mixed in the fossil gas grid. The data published in the Eurostat Shares tool indicates that almost all of the biogas electricity output (97.8% in 2021) complies with the new directive's requirements. The conformity percentages were 94.5 for the processing sector's heat output and 92.4 for final energy consumption excluding transport.

6

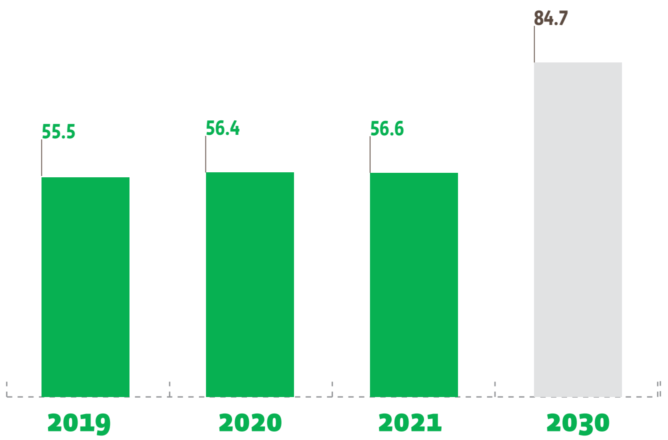
Heat consumption from biogas (pure and blended in the grid), of which compliant with the Directive (EU) 2018/2001** in the European Union in 2021 (in ktoe)*

	Gross heat in the transformation sector			Final energy consumption (in Industry and other sectors)			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	463.9	463.9	100.0%	1284.2	1284.2	100.0%	1748.1	1748.1	100.0%
France	101.0	101.0	100.0%	515.2	515.2	100.0%	616.2	616.2	100.0%
Denmark	111.2	57.8	52.0%	316.2	167.1	52.8%	427.3	224.9	52.6%
Italy	290.9	290.9	100.0%	35.5	35.5	100.0%	326.3	326.3	100.0%
Netherlands	13.1	8.6	65.8%	213.4	158.8	74.4%	226.4	167.4	73.9%
Czechia	17.7	17.7	100.0%	153.3	152.6	99.6%	171.0	170.4	99.6%
Belgium	21.6	21.4	99.3%	101.3	101.3	100.0%	122.9	122.7	99.9%
Finland	22.5	19.6	87.2%	99.7	86.9	87.2%	122.1	106.5	87.2%
Poland	22.9	22.9	100.0%	87.7	87.7	100.0%	110.6	110.6	100.0%
Spain	0.0	0.0	-	106.7	106.8	100.0%	106.7	106.8	100.0%
Sweden	8.5	8.5	100.0%	58.4	58.4	100.0%	66.9	66.9	100.0%
Slovakia	17.7	17.7	100.0%	25.0	25.0	100.0%	42.7	42.7	100.0%
Austria	5.8	5.8	100.0%	31.9	31.9	100.0%	37.8	37.8	100.0%
Greece	0.0	0.0	-	34.5	34.5	100.0%	34.5	34.5	100.0%
Latvia	19.6	19.6	100.0%	6.9	0.0	0.0%	26.5	19.6	73.9%
Hungary	3.1	2.3	73.3%	16.9	12.6	74.3%	20.1	14.9	74.2%
Croatia	16.9	16.9	100.0%	0.5	0.0	0.0%	17.4	16.9	97.4%
Bulgaria	3.8	1.4	36.3%	10.3	7.8	75.3%	14.2	9.2	64.8%
Lithuania	2.4	2.4	100.0%	10.2	10.2	100.0%	12.6	12.6	100.0%
Ireland	0.0	0.0	-	12.6	3.9	31.0%	12.6	3.9	31.0%
Luxembourg	3.0	3.0	100.0%	4.9	4.9	100.0%	7.9	7.9	100.0%
Romania	4.6	4.6	99.5%	2.6	2.6	98.8%	7.3	7.2	99.2%
Portugal	0.0	0.0	-	7.2	7.2	99.5%	7.2	7.2	99.5%
Slovenia	3.7	3.7	100.0%	2.7	2.7	100.0%	6.4	6.4	100.0%
Cyprus	0.9	0.9	100.0%	5.4	5.4	100.0%	6.2	6.2	100.0%
Estonia	1.6	1.6	100.0%	2.7	2.7	100.0%	4.2	4.2	100.0%
Malta	0.0	0.0	-	0.5	0.5	99.9%	0.5	0.5	99.9%
Total EU 27	**1 156.3**	**1 092.2**	**94.5%**	**3 146.2**	**2 906.2**	**92.4%**	**4 302.5**	**3 998.3**	**92.9%**

** 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***

7

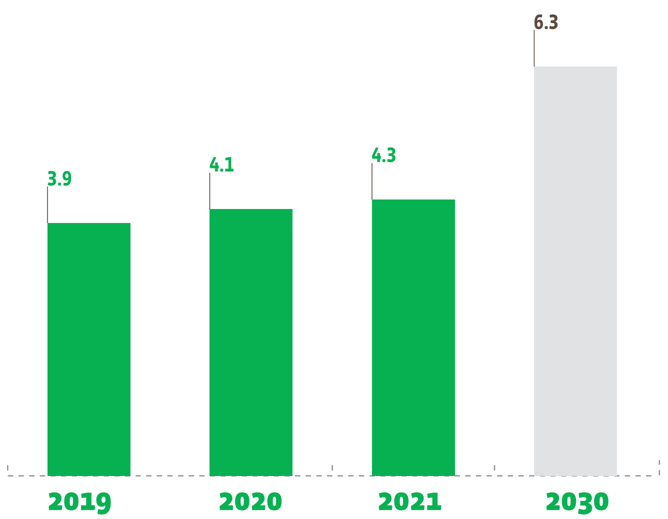
EurObserv'ER projection of electricity production from biogas in the EU 27 (in TWh)*



** 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 and gross heat production in the transformation sector.*
*** Pure biogas and biogas blended in the grid compliant and not compliant.*
Source: EurObserv'ER

TARGET: 35 BILLION M³ OF BIOMETHANE BY 2030

Since Russia invaded Ukraine, the investments already made in the biogas sector, motivated by the Member States' environmental considerations and in equal measure the resolve to reduce energy dependency on gas, have taken on real meaning. The European Union's excessive reliance on Russian gas has had disastrous consequences for household, local authority and businesses' spiralling energy bills. The European Union responded as well as it could when it rolled out its REPowerEU plan in May 2022, that aims to release the EU from its dependence on Russian gas by 2027. The European Commission has dual pressing needs to transform the European energy system: firstly to curtail the EU's reliance on Russian fossil fuels, which are being exploited as an economic and political weapon and that cost European tax payers almost 100 billion euros per annum, and secondly to combat the climate crisis. One of the Commission's landmark measures, has been to devise an action plan for biomethane that defines tools such as a new industrial partnership for the sector and financial incentives to raise output to 35 billion m³ by 2030, including within the framework of the Common Agricultural Policy. According to the EBA (European Biogas Association), REPowerEU has changed that state of affairs in the EU's policy cycle. The climate and energy targets have been boosted by this strategy while needs have set a new pace on policy making.

The various renewable gas sector players say they are ready to help the European Commission achieve its ambitions. They emphasize the advantages of gas distribution networks for managing renewable electricity production fluctuations, primarily highlighting the technical ease and storage capacities, the advantages of a hybrid energy infrastructure built on the robust construction of the gas and electricity grids that they claim form the backbone of a decarbonized European energy system. ■

Grégory Brandel

RENEWABLE MUNICIPAL WASTE

Eurostat, claims that in 2021, 9.3 Mtoe of primary energy (9 299.2 ktoe to be precise) was generated from renewable municipal waste treated in waste-to-energy plants (WtE) in the European Union of 27. Output was 125 ktoe higher (1.4%) than the previous year's, but this figure does not include all the energy recovered in WtE plants. It 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 the equivalent amount of energy (9 104.6 ktoe in 2021, while slipping 0.1% on its 2020 figure). Convention has it that the waste accounted for as renewably sourced is put at 50% of all incinerated urban waste, as it is difficult to distinguish biodegradable waste from other waste, unless a Member State conducts specific studies.
What is more, Eurostat also counts the renewable fraction of industrial waste (quantified at 1.5 Mtoe in 2021 for the EU-27) but it is usually integrated into the solid biofuels category, which has its own fact file in this opus. The non-renewable fraction of industrial waste is consigned to a specific category and monitoring operation. EU primary energy output for 2021 is quantified at 4.8 Mtoe.
Between 2020 and 2021, the vast majority of European Union countries, either kept up or slightly increased their primary energy output recovered from renewable municipal waste. The most significant production upswings in 2021 occurred in Spain, which added 47.1 ktoe to its output (by 20% year-on-year) for a total of 283.2 ktoe and Finland which added 35.8 ktoe (by 10.8% year-on-year), for a total of 366.2 ktoe. Incidentally, Lithuania almost doubled its output (by 91.9% year-on-year) which took its total output to 54.2 ktoe. The most significant decline was felt in Sweden, whose output contracted by 105.1 ktoe (12.5%) between 2020 and 2021, producing 737.3 ktoe. As to be expected, the sizes of Germany's and France's populations enable them to recover the most energy from renewable municipal waste. Germany's output has been fairly stable in recent years and increased slightly by 1.1% (35.1 ktoe) between 2020 and 2021, generating 3 148.4 ktoe in 2021. The same holds true for France whose output increased by 2% (25 ktoe) to reach 1 257.2 ktoe in 2021. It should be borne in mind that countries that invest in prevention, composting and recycling reduce their incinerable waste volume, and so lower the energy recovery potential of their WtE plants.
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


Dalkia Wastenergy

1

Primary energy production of renewable municipal waste in the European Union in 2020 and 2021 (in ktoe)*

	2020	2021
Germany	3 113.3	3 148.4
France	1 232.1	1 257.2
Netherlands	836.6	865.8
Italy	843.2	829.8
Sweden	842.4	737.3
Denmark	466.8	466.2
Belgium	375.4	397.8
Finland	330.4	366.2
Spain	236.1	283.2
Austria	191.4	204.9
Ireland	145.0	143.9
Poland	143.5	140.1
Portugal	111.6	118.6
Czechia	95.8	95.9
Hungary	58.4	62.5
Lithuania	28.2	54.2
Bulgaria	41.9	42.5
Slovakia	31.8	38.5
Estonia	26.5	21.2
Luxembourg	13.0	12.8
Latvia	6.7	6.5
Cyprus	1.9	3.8
Romania	2.0	2.1
Total EU 27	**9 174.2**	**9 299.2**

Source: Eurostat

2

Gross electricity production from renewable municipal waste in the European Union in 2020 and 2021 (in GWh)*

	2020			2021		
	Electricity only plants	CHP plants	Total	Electricity only plants	CHP plants	Total
Germany	3 823.0	1 997.0	5 820.0	3 591.0	2 213.0	5 804.0
Italy	1 065.2	1 264.5	2 329.7	1 094.4	1 213.9	2 308.3
Netherlands	0.0	2 193.1	2 193.1	0.0	2 208.2	2 208.2
France	911.5	1 225.8	2 137.3	896.2	1 232.1	2 128.3
Sweden	0.0	1 646.0	1 646.0	0.0	1 813.0	1 813.0
Denmark	0.0	944.8	944.8	0.0	971.1	971.1
Belgium	339.2	570.8	910.0	367.0	569.6	936.6
Spain	633.0	70.0	703.0	750.0	104.5	854.6
Finland	0.0	513.2	513.2	0.0	581.9	581.9
Austria	200.7	127.0	327.7	219.3	135.2	354.5
Poland	0.0	181.8	181.8	0.0	353.8	353.8
Ireland	326.1	0.0	326.1	351.8	0.0	351.8
Portugal	320.1	0.0	320.1	343.4	0.0	343.4
Hungary	12.0	155.0	167.0	13.0	148.0	161.0
Lithuania	0.0	71.3	71.3	0.0	142.1	142.1
Czechia	0.0	119.4	119.4	0.0	127.3	127.3
Estonia	48.4	26.2	74.6	25.8	32.6	58.4
Luxembourg	0.0	43.4	43.4	0.0	42.6	42.6
Slovakia	0.0	43.0	43.0	0.0	32.0	32.0
Bulgaria	0.8	0.7	1.5	0.0	0.0	0.0
Total EU 27	7 680.1	11 193.0	18 873.1	7 652.0	11 920.7	19 572.7

Source: Eurostat

easily exported to supply an urban heating network or as process heat for an industrial site. The latest CEWEP figures show that 500 urban waste-to-energy recovery plants operated in Europe (at least 432 in the EU-27), treating just under 96 million tonnes of renewable and other waste (83 million tonnes in the EU-27).

If only the renewable fraction of household waste is considered for quantification, then the WtE plants generated 19.6 TWh of renewable electricity in 2021 – an increase of 3.7%. Cogeneration is the main energy recovery method used by these plants and electricity accounted for 60.9% of their output in 2021. The best performances in value terms for growth in renewable electricity production from urban waste came from Poland, Sweden and Spain (which added 172 GWh, 167 GWh and 151.6 GWh respectively). Eurostat reports that by the end of 2021,the net maximum electrical capacity of the plants treating municipal waste in the EU-27 had dropped to

3

Gross heat production in the transformation sector from renewable municipal waste in the European Union in 2020 and in 2021 (in ktoe)*

	2020			2021		
	Heat only plants	CHP plants	Total	Heat only plants	CHP plants	Total
Germany	254.4	573.4	827.8	260.2	643.4	903.7
Sweden	77.6	586.5	664.0	82.2	565.7	647.9
France	90.3	269.1	359.4	101.8	298.6	400.4
Denmark	32.4	361.2	393.5	31.8	345.1	376.9
Netherlands	0.0	174.1	174.1	0.0	209.6	209.6
Finland	53.4	120.6	174.0	54.2	135.6	189.8
Italy	0.0	128.2	128.2	0.0	123.1	123.1
Austria	13.9	63.7	77.7	13.9	73.6	87.5
Belgium	0.1	31.9	32.0	0.4	40.8	41.2
Czechia	0.0	42.4	42.4	0.0	40.2	40.2
Poland	0.0	38.5	38.5	0.7	37.5	38.2
Lithuania	0.0	16.9	16.9	0.0	34.7	34.7
Hungary	0.0	17.4	17.4	0.0	18.8	18.8
Estonia	0.0	14.0	14.0	0.0	14.1	14.1
Slovakia	0.0	1.8	1.8	0.0	2.0	2.0
Luxembourg	0.0	0.7	0.7	0.0	1.0	1.0
Bulgaria	0.0	0.0	0.0	0.0	0.0	0.0
Total EU 27	522.1	2 440.5	2 962.6	545.1	2 583.8	3 129.0

Source: Eurostat

7 798 MW (from 8 149.3 MW), mainly because Sweden has reduced its use of WtE plants.
Heat sales constitute the other major outlet for these CHP plants. Between 2020 and 2021, sales of renewable heat sourced from urban waste rose by 5.6% to 3 129 ktoe (2 962.6 ktoe in 2020), 82.6% of which was generated in CHP plants. In value terms, Germany, France and the Netherlands were the best performers in this segment in 2021 (adding 75.8 ktoe, 41 ktoe and 35.5 ktoe respectively). Poland is now investing heavily in new household WtE plants, backed by European Union funding. A new WtE plant with capacity to treat 110 000 tonnes will shortly be built in Olsztyn, in the Warmian-Masurian region (commissioning scheduled for 2023). This investment will guarantee

4

Final energy consumption of renewable municipal waste in the European Union in 2020 and 2021 (in ktoe)*

	2020	2021
Germany	560.0	535.0
France	75.9	105.6
Denmark	49.7	49.6
Ireland	43.4	46.7
Bulgaria	41.5	42.5
Netherlands	42.2	40.4
Finland	42.9	40.2
Latvia	35.5	39.3
Cyprus	32.9	35.4
Poland	58.1	34.8
Slovakia	11.9	21.4
Czechia	21.3	21.3
Hungary	6.0	14.2
Spain	4.7	6.9
Romania	2.0	2.1
Estonia	0.5	0.0
Total EU 27	**1 028.5**	**1 035.2**

Source: Eurostat

effective waste management in line with EU waste hierarchy categories and contribute to covering local residents' energy needs by recovering heat and electricity from the treated municipal waste. The size of the investment at Olsztyn will be 183.3 million euros, while the European Union Cohesion Fund will add a further 39.6 million euros. The plant will have 48 MWth of thermal capacity and supply 22 MWe of electricity to the grid.

Another plant will be built in Warsaw designed to treat 265 200 tonnes of waste, scheduled to come on stream in 2024. This new plant, whose construction was commissioned by the Varsovie MPO waste treatment company, will supply 20 MW of electricity and heat by treating 730 tonnes of rubbish thrown away every day by the city's 850 000 residents.

In a few years' time Germany is expected to build several new plants to increase its activity. These include one in the city of Wiesbaden in central western Germany, which is due to be constructed in 2024. It will be designed to treat 140 000 tonnes of waste annually, with about 80 MWth (max 85 MWth) of thermal capacity, and to produce 22 MW of electricity, while supplying a 40-MW district heating network.

THE "LONG" ROAD TO THE NEGATIVE CARBON BALANCE

The European Union waste to energy recovery sector is ready to make its contribution towards achieving the new EU 55% GHG emission reduction targets by 2030 and climate neutrality by 2050. It is already doing so by diverting waste from landfills, reducing methane emissions into the atmosphere, permitting clinker metal recycling and by substituting fossil fuels with energy recovered from waste.

CEWEP, the association that represents the sector's operators, has calculated that the total amount of energy (renewable + carbon components) produced by the WtE plants could potentially reach 186 TWh by 2035 (equating to 16 Mtoe), if the circular economy targets of the Framework Directive on Waste and the Landfill Directive are met.

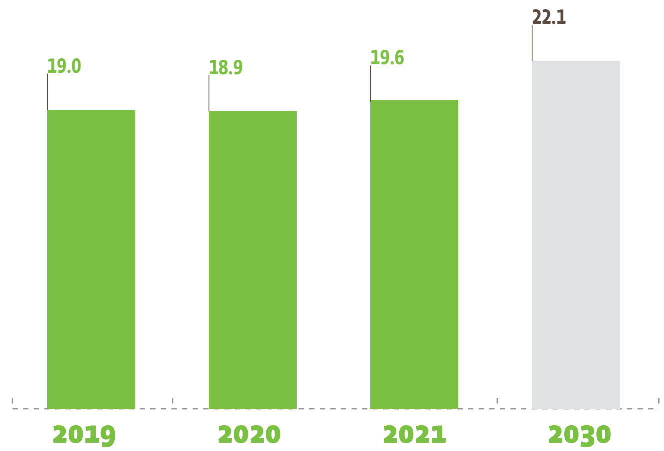
The sector is prepared to go even further by putting carbon capture technologies into practice, but it points out that these technologies call for heavy investment that must be accompanied by a market and legislation to dispose of and use the captured CO_2. Thus, the issue of funding these technological developments will be crucial for guaranteeing climate-neutral treatment of waste produced by society.

The WtE sector took another step in this direction in June 2022 when it published its "Waste-to-Energy Climate Roadmap, the path to carbon negative" document. In this roadmap, CEWEP considers Carbon Capture, Utilization and Storage (CCUS) as an additional tool to further reduce its carbon footprint, with the potential to reach net negative CO_2 emissions, once capture includes waste produced from fossil energy. The negative emissions concept is linked to the fact that the biogenic CO_2 climate load is equal to zero, because it is part of carbon's natural cycle. Consequently, when a WtE facility captures both the fossil and biogenic CO_2 of its processes, it also eliminates atmospheric CO_2. The fossil and biogenic carbon contained in residual waste can be captured and injected permanently into deep geological storage. Alternatively, the captured CO_2 can be used as a resource for other industries or as raw material for new products such as synthetic fuels, which are currently based on fossil fuel imports such as oil and gas.

An initial installation of this type has been operating since 2019. The AVR waste-to-energy recovery company, located at Duiven in the Netherlands has started that captures and supplies CO_2 to a commercial grower's greenhouses. The capture installation has a total annual CO_2 capture capacity of 100 000 tonnes. Producing hydrogen from WtE plant electrolysers for local use is another innovative way of reducing the sector's emissions. In France, the Créteil (Val-de-Marne) incinerator generates electricity, space heating heat and domestic hot water and will shortly generate hydrogen. In 2024, the site will be equipped with an electrolyser that will supply 500 kg of green hydrogen powered by its own electricity produced on site. ■

5

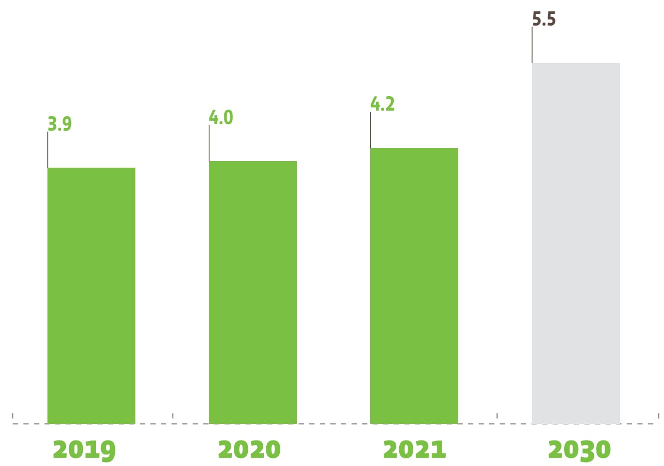
EurObserv'ER projection of electricity production from renewable municipal waste in the EU 27 (in TWh)



Source: EurObserv'ER

6

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



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

SOLID BIOFUELS

European Union solid biomass energy consumption reached new peaks in 2021, and this trend extends to all forms sourced from log wood, to pellets, wood waste and by-products, across most of the Northern Europe, and also to France, Germany and a few other countries. Eurostat put this 2021 figure at 104.1 Mtoe, which amounts to an 8.3% year-on-year rise. The reasons for this significant 8-Mtoe increase are the harsher 2021 winter resulting in a longer heating period in the main EU climate zones and the fossil energy price hike in the second half of the year that made biomass fuels more competitive. The additional consumption improved the European Union's solid biomass electricity output which generated 9.8 TWh more than in 2020 to reach 92.8 TWh and heat consumption (heat from the processing sector or directly consumed by end users) which rose to 84.4 Mtoe, an increase of almost 6.2 Mtoe.

THE BIOMASS USED IS ESSENTIALLY OF EUROPEAN ORIGIN

Solid biomass production, namely the solid biomass taken from European soil, is quantified at about 100.5 Mtoe for 2021… 7.7% more than in 2020 and amounts to a 7.2-Mtoe increase. The difference between national production data and gross domestic consumption equates to the balance of imports and exports, and stock variation. Across the European Union, net imports of solid biomass remain low at about 3.5% of consumption and are primarily supplied by North American pellet imports and biomass fuel imports (wood and pellets) from the European countries outside of the European Union.

The distribution between the various biomass fuels in domestic solid biomass production of the European Union countries is clearly dominated by the “wood, wood residue and by-products” category. In 2021, the ranking in line with Eurostat data was first at 80.0% for this category (including 5.9% of wood pellets), followed by 13.5% of black liquor (a by-product of the paper pulp industry), 4.2% of other plant materials and residues, 1.5% of renewable industrial waste, 0.6% of bagasse and 0.2% of animal waste.

SHARP RISE IN FINAL ENERGY CONSUMPTION

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. Eurostat differentiates these two types of final solid biomass energy use as electricity and heat. Distinction is made between solid biomass heat from the processing sector, i.e., distributed via heating networks and the heat used directly by end users (in the residential, industrial and agricultural sectors).

In the EU-27, solid biomass electricity output in 2021 was measured at 92.8 TWh, of which 76.3% was supplied by combined heat and power plants, posting double-digit growth (11.8%) in a year. Finland, having forfeited its top biomass electricity producer rank in 2020, recaptured it in 2021 with 12.7 TWh (producing 1.9 TWh more than in 2020). Sweden came second with 11.2 TWh (a 1.7 TWh increase). Germany slipped into third place (10.9 TWh) with output dropping by 0.4 TWh. The biggest

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1

Primary energy production and gross inland consumption of solid biofuels in the European Union in 2020 and 2021 (in Mtoe)*

	2020		2021	
	Production	Consumption	Production	Consumption
Germany	12.648	12.636	13.971	14.043
France	9.765	9.820	10.745	10.888
Sweden	9.502	9.487	10.264	10.199
Finland	7.935	8.402	9.040	9.541
Poland	8.964	9.330	8.881	9.082
Italy	7.124	8.353	7.590	8.874
Spain	5.049	5.049	5.278	5.278
Austria	4.798	4.660	5.147	5.038
Czechia	3.522	3.367	3.913	3.689
Denmark	1.439	2.993	1.527	3.644
Romania	3.401	3.395	3.625	3.639
Netherlands	1.531	2.252	1.725	2.741
Portugal	2.904	2.645	2.922	2.700
Hungary	2.036	2.052	2.194	2.193
Belgium	1.182	1.852	1.320	1.895
Bulgaria	1.680	1.609	1.812	1.783
Latvia	2.285	1.407	2.314	1.505
Slovakia	1.321	1.313	1.496	1.484
Croatia	1.511	1.312	1.670	1.438
Lithuania	1.273	1.284	1.396	1.419
Estonia	1.706	1.135	1.810	1.138
Greece	0.741	0.787	0.787	0.816
Slovenia	0.545	0.545	0.604	0.604
Ireland	0.225	0.270	0.248	0.293
Luxembourg	0.173	0.167	0.183	0.180
Cyprus	0.023	0.027	0.024	0.028
Malta	0.000	0.001	0.000	0.002
Total EU 27	93.283	96.151	100.486	104.134

Excluding charcoal.* ***Source: Eurostat*

rises in output occurred in Denmark and the Netherlands, whose imports increased massively (particularly of wood pellets), not in the two leading forestry countries, Finland and Sweden. Denmark's output increased by 65.8% to 7.1 TWh (a 2.8-TWh increase) and the Netherland's output by 35.9% to 7.9 TWh (a 2.1-TWh increase).
Heat production gained the most from the 2021 increase in solid biomass energy consumption. Eurostat reckons that end user consumption of solid biomass heat increased by 6.5% between 2020 and 2021 to 71.2 Mtoe, which is a 4.4 Mtoe gain on 2020. Most of this increase can be put down to the strong demand for heat in the residential sector, especially in Germany (1.5-Mtoe increase, a 15.8% year-on-year rise) and France (0.9-Mtoe increase, a 11.2% year-on-year rise). Significant growth rates were also posted in other major solid biomass consumer countries such as Belgium (15.2%), Austria (11.2%), and Italy (9.5%).
Growth in the amount of solid biomass heat sold to heating networks (from the processing sector) rose to 16.5%. It reached 13.1 Mtoe in 2021 (an increase of 1.9 Mtoe), mostly supplied by cogeneration plants, amounting to a 60.8% share (62.2% in 2020). Solid biomass heat output increased in almost all the European Union countries. Of the main countries to have expanded their biomass heating networks, the best performances came from Sweden (578 ktoe, a 26.7% rise) and Finland (447 ktoe, a 27.4% rise). High growth levels were also recorded in Denmark (234 ktoe, a 15.8% rise), France (180 ktoe, a 16.1% rise) and Austria (82 ktoe, an 8.6% rise). These are the five EU countries whose processing sector biomass heat output exceeds the one Mtoe threshold.
Since the rollout of the new renewable energy directive 2018/2001 in 2021, only energy produced from biomass fuels that comply with the sustainability and GHG emission reduction criteria defined in its article 29 can contribute to the European Union's target and Member States' renewable energy shares. Implementing these criteria in practice is somewhat fraught. In brief, all the energy produced can be included in the calculations provided it is used in rated thermal input installations of <20 MW that produce electricity, heat and cooling. In the case of ≥20 MWth installations, biomass-sourced fuels must meet the criteria defined in article 29, §§ 2–7 and 10 & 11 of RED II. However, biomass fuels sourced from waste and resi-

2

Gross electricity production from solid biofuels in the European Union in 2020 and 2021 (in TWh)*

	2020			2021				
	Electricity only plants	CHP plants	Total	Electricity only plants	CHP plants	Total	Compliant**	Compliant (%)
Finland	0.000	10.760	10.760	0.000	12.668	12.668	11.046	87.2%
Sweden	0.000	9.501	9.501	0.000	11.174	11.174	11.174	100.0%
Germany	5.232	6.074	11.306	5.059	5.850	10.909	10.909	100.0%
Netherlands	1.012	4.773	5.785	2.453	5.406	7.860	3.694	47.0%
Denmark	0.000	4.302	4.302	0.000	7.133	7.133	3.647	51.1%
Poland	1.557	5.376	6.933	1.713	4.686	6.398	6.398	100.0%
Spain	3.646	0.895	4.541	4.116	0.979	5.095	4.901	96.2%
Italy	2.180	2.291	4.470	2.385	2.144	4.529	4.529	100.0%
France	0.459	3.396	3.854	0.691	3.623	4.314	4.314	100.0%
Austria	0.890	2.745	3.634	0.709	2.815	3.523	3.523	100.0%
Portugal	1.453	1.753	3.206	1.346	2.046	3.392	3.392	100.0%
Belgium	2.034	1.285	3.319	1.458	1.306	2.763	2.763	100.0%
Czechia	0.002	2.497	2.499	0.001	2.663	2.665	2.665	100.0%
Bulgaria	0.173	1.300	1.472	0.372	2.001	2.373	0.006	0.3%
Hungary	0.563	1.101	1.664	0.610	1.165	1.775	1.654	93.2%
Estonia	0.320	1.426	1.746	0.609	1.085	1.694	1.694	100.0%
Slovakia	0.000	1.120	1.120	0.000	1.325	1.325	1.325	100.0%
Croatia	0.000	0.559	0.559	0.000	0.660	0.660	0.660	100.0%
Romania	0.061	0.433	0.494	0.032	0.548	0.580	0.580	100.0%
Latvia	0.000	0.520	0.520	0.000	0.570	0.570	0.570	100.0%
Ireland	0.408	0.022	0.430	0.447	0.024	0.471	0.021	4.5%
Lithuania	0.000	0.373	0.373	0.000	0.387	0.387	0.387	100.0%
Luxembourg	0.000	0.266	0.266	0.000	0.285	0.285	0.285	100.0%
Slovenia	0.000	0.155	0.155	0.000	0.169	0.169	0.169	100.0%
Greece	0.012	0.038	0.050	0.016	0.026	0.042	0.042	100.0%
Total EU 27	**20.000**	**62.959**	**82.959**	**22.017**	**70.736**	**92.753**	**80.349**	**86.6%**

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

3

Gross heat production in the transformation sector from solid biofuels in the European Union in 2020 and 2021 (in Mtoe)*

	2020			2021				
	Heat only plants	CHP plants	Total	Heat only plants	CHP plants	Total	Compliant**	Compliant %
Sweden	0.604	1.561	2.165	0.761	1.982	2.743	2.743	100.0%
Finland	0.784	0.849	1.633	1.024	1.056	2.080	1.814	87.2%
Denmark	0.481	1.002	1.483	0.538	1.179	1.717	1.104	64.3%
France	0.549	0.567	1.115	0.679	0.616	1.295	1.295	100.0%
Austria	0.598	0.349	0.947	0.661	0.368	1.029	1.029	100.0%
Germany	0.153	0.457	0.610	0.196	0.466	0.662	0.662	100.0%
Lithuania	0.368	0.144	0.512	0.413	0.149	0.562	0.562	100.0%
Poland	0.100	0.345	0.446	0.148	0.352	0.500	0.500	100.0%
Latvia	0.172	0.163	0.335	0.230	0.172	0.402	0.402	100.0%
Netherlands	0.095	0.227	0.321	0.120	0.267	0.386	0.247	63.8%
Italy	0.096	0.409	0.506	0.089	0.295	0.385	0.385	100.0%
Estonia	0.106	0.225	0.331	0.099	0.237	0.335	0.335	100.0%
Czechia	0.040	0.174	0.214	0.051	0.200	0.251	0.251	100.0%
Bulgaria	0.009	0.132	0.141	0.013	0.185	0.198	0.012	6.3%
Slovakia	0.041	0.088	0.129	0.053	0.099	0.152	0.152	100.0%
Luxembourg	0.004	0.092	0.096	0.005	0.099	0.104	0.104	100.0%
Croatia	0.000	0.080	0.080	0.000	0.095	0.096	0.096	100.0%
Hungary	0.032	0.054	0.086	0.036	0.059	0.094	0.082	87.5%
Romania	0.021	0.061	0.081	0.018	0.067	0.085	0.085	100.0%
Slovenia	0.012	0.028	0.039	0.013	0.030	0.044	0.044	100.0%
Belgium	0.000	0.011	0.011	0.000	0.021	0.021	0.021	100.0%
Total EU 27	4.266	7.016	11.282	5.147	7.992	13.140	11.924	90.7%

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

4

Final energy consumption from solid biofuels in the European Union in 2020 and in 2021 (in Mtoe)*

	2020	2021	Compliant** 2021	Compliant 2021 %
Germany	9.274	10.737	10.737	100.0%
France	7.644	8.498	8.498	100.0%
Poland	7.447	7.287	7.287	100.0%
Italy	6.463	7.079	7.079	100.0%
Finland	5.175	5.494	4.791	87.2%
Sweden	5.567	5.476	5.476	100.0%
Spain	3.643	3.709	3.648	98.4%
Romania	3.350	3.551	3.551	100.0%
Austria	3.013	3.350	3.350	100.0%
Czechia	2.582	2.830	2.830	100.0%
Portugal	1.802	1.766	1.766	100.0%
Hungary	1.528	1.629	1.617	99.3%
Belgium	1.146	1.320	1.320	100.0%
Croatia	1.062	1.146	1.146	100.0%
Bulgaria	1.152	1.049	0.841	80.2%
Slovakia	0.897	1.024	1.024	100.0%
Denmark	0.982	1.011	1.011	100.0%
Latvia	0.905	0.922	0.922	100.0%
Greece	0.760	0.789	0.789	100.0%
Netherlands	0.696	0.714	0.681	95.3%
Lithuania	0.631	0.637	0.637	100.0%
Slovenia	0.479	0.533	0.533	100.0%
Estonia	0.432	0.422	0.422	100.0%
Ireland	0.180	0.192	0.113	58.9%
Luxembourg	0.027	0.029	0.029	100.0%
Cyprus	0.026	0.026	0.026	100.0%
Malta	0.001	0.002	0.002	100.0%
Total EU 27	**66.861**	**71.220**	**70.124**	**98.5%**

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

5

Heat consumption from solid biofuels** in the countries of the European Union in 2020 and 2021 (in Mtoe)*

	2020	2021	Compliant*** 2021	Compliant 2021 %
Germany	9.883	11.399	11.399	100.0%
France	8.759	9.793	9.793	100.0%
Sweden	7.731	8.218	8.218	100.0%
Poland	7.892	7.787	7.787	100.0%
Finland	6.808	7.574	6.605	87.2%
Italy	6.969	7.464	7.464	100.0%
Austria	3.960	4.378	4.378	100.0%
Spain	3.643	3.709	3.648	98.4%
Romania	3.432	3.636	3.636	100.0%
Czechia	2.796	3.080	3.080	100.0%
Denmark	2.465	2.728	2.115	77.6%
Portugal	1.802	1.766	1.766	100.0%
Hungary	1.614	1.723	1.700	98.6%
Belgium	1.156	1.341	1.341	100.0%
Latvia	1.240	1.324	1.324	100.0%
Bulgaria	1.293	1.248	0.854	68.4%
Croatia	1.142	1.242	1.242	100.0%
Lithuania	1.143	1.199	1.199	100.0%
Slovakia	1.026	1.176	1.176	100.0%
Netherlands	1.017	1.100	0.927	84.3%
Greece	0.760	0.789	0.789	100.0%
Estonia	0.763	0.757	0.757	100.0%
Slovenia	0.518	0.577	0.577	100.0%
Ireland	0.180	0.192	0.113	58.9%
Luxembourg	0.123	0.133	0.133	100.0%
Cyprus	0.026	0.026	0.026	100.0%
Malta	0.001	0.002	0.002	100.0%
Total EU 27	**78.143**	**84.360**	**82.048**	**97.3%**

Gross heat production in the transformation sector and final energy consumption. **Excluding charcoal. ***Compliant with the criteria of Article 29 of Directive (EU) 2018/2001.* ***Source: Eurostat*

due, other than farming, aquaculture, fishing and forestry residue, only have to meet the GHG emission reduction criteria laid down in §10 to be eligible for inclusion. Eurostat's 2021 SHARES tool that measures the share of energy produced from renewable sources compliant with the Directive's requirements, puts the amount of electricity produced from "compliant" solid biomass at 80.4 TWh and the amount of heat produced from solid biomass at 82 Mtoe (i.e., 11.9 Mtoe of heat from the processing sector and 70.1 Mtoe directly consumed by end users). Thus, according to Eurostat, 86.6% of the European Union's 2021 solid biomass electricity output and 97.3% of its solid biomass heat output met the Directive's requirements. This initial count suggests that RED II has only had an impact on a minority of European Union countries so far, and in particular the Netherlands and Denmark, which are major importers of biomass fuels and use them in large production facilities.

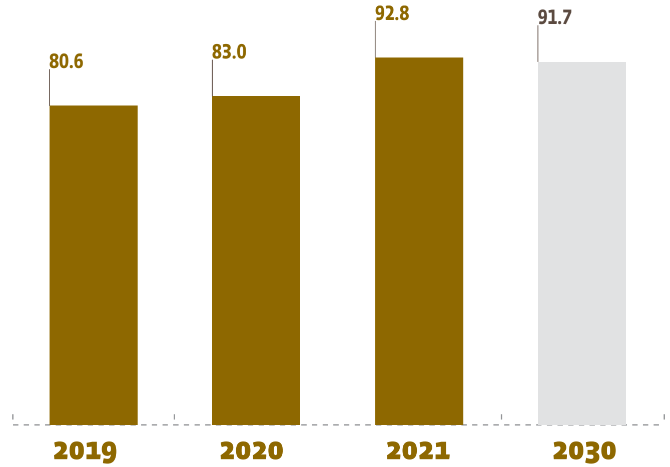
IS THE FUTURE OF SOLID BIOMASS REALLY SUSTAINABLE?

The growing appetite for biomass fuel raises the issues of the sustainability and effects of using these fuels on climate change. They parallel the situation of liquid biofuels for transport which have been at the centre of the European institutions' legal controversies and debates. The European Parliament's 14 September 2022 vote on a set of amendments related to biomass as part of the proposed revision to the European Renewable Energies Directive (RED II) clearly discourages Member States from subsidizing the biomass used in power plants and enjoins them to decrease the use of primary wood as renewable energy. The amendments' stated aim is to curb the amount of biomass that can be burnt and reaffirm the cascading principle. These amendments, which the European Council has yet to discuss, dismayed the sector players.

The abstract of a lengthy scientific report "The use of woody biomass for energy production in the EU" published in 2021 by the JRC Science (Joint Research Centre) for policy report, reminds us that forests are often perceived as being at the nexus of the solutions to the two main environmental crises that plague our planet today – climate change and biodiversity loss. The EU has envisioned the European Green Deal with the specific purpose of mitigating both phenomena. Choices will have to be made between the various energy and non-energy uses and biodiversity protection. Solid biomass, and biomass in general, cannot be substitutes for all fossil energy uses, so priorities will have to be defined. ■

6

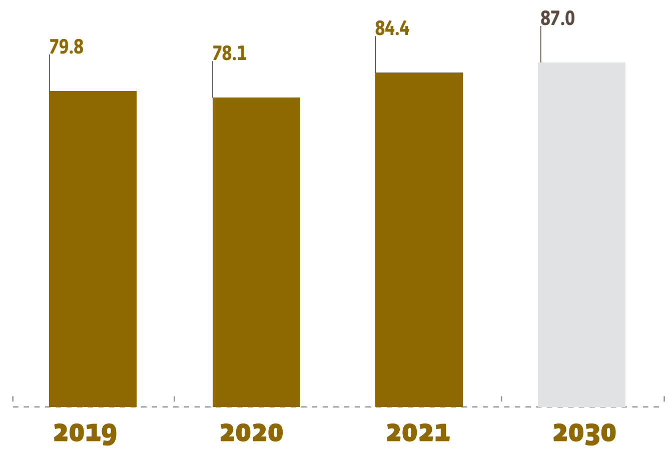
EurObserv'ER projection of electricity production from solid biofuels in the EU-27 (in TWh)



Source: EurObserv'ER

7

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



Source: EurObserv'ER

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CONCENTRATED SOLAR POWER

Concentrated solar power (CSP) plants cover all the technologies devised to transform solar radiation energy into very high temperature heat for onward conversion into electricity. There are tower plants, whose heliostat fields (devices fitted with reflectors to track the sun) concentrate sunlight onto a receiver at the top of a tower, parabolic trough plants comprising parallel line-ups of long half-cylindrical reflectors that revolve around a horizontal axis to track the sun and concentrate its rays on a horizontal tube. There are also Fresnel plants comprising rows of flat reflectors that pivot, tracking the sun to redirect and concentrate the sun's rays permanently on an absorbing tube. A fourth, less widespread category, consists of parabolic plants with a parabolic reflector that reflects the sun's rays onto a convergence point, as the reflector's base is automatically orientated opposite the sun to track it. One CSP technology feature is the plants' ability to smooth out electricity production using a thermal storage buffer. This storage is usually achieved by heating molten salts in a tank to keep them at high temperature.

Although initially CSP technologies were exclusively used for producing electricity, new outlets for them have been sought in recent years: producing steam and heat for industry and district heating networks.

GLOBAL CSP CAPACITY STOOD AT 6 570.9 MW AT THE END OF 2021

EurObserv'ER counts at least two high-capacity CSP plants that were commissioned during 2021, which takes global CSP capacity to at least 6 570.9 MW at the end of 2021. The highest capacity CSP plant is the Chilean Atacama 1 tower plant, called Cerro Dominador ("the dominating hill"), inaugurated on 8 June 2021 by a consortium formed by Abengoa, Acciona and EIG Global Energy Partners. This 110-MW tower plant has 10 600 reflectors that concentrate the sun's rays on the top of a 252-metre-high tower where a tank is sited containing molten salts that will be heated to over 560°C. This tower plant breaks new ground with its 17.5-hour storage system that enables it to operate 24 hours round the clock, with enough capacity to supply 380 000 city dwellers. The second project, whose construction started in 2017 and was completed in 2021, is China's Yumen Xinneng/Xinchen (50-MW) Beam-down tower plant.

A NEW CSP PLANT WENT ON GRID IN ITALY WHILE SPAIN MISSED AN OPPORTUNITY

The capacity of the European Union's stock of CSP plants remained static at 2 328.8 MW including demonstration plants in 2021, as the last plant was connected in 2019 (the 9-MW capacity Fresnel demonstration plant for the eLLO project in the Pyrénées-Orientales). The net maximum capacity data released by Eurostat point to 2 306 MW at the end of 2021 (2 304 MW in Spain and 2 MW in Germany). The discrepancy arises from the fact that a few countries have chosen not to publish figures for their demonstration plants. This capacity is highly concentrated in Spain whose official installed concentrated solar power capacity stands at 2 304 MW (i.e., 99% of all EU CSP capacity). Red Eléctrica de España quanti-


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Concentrated solar power plant in operation in the European Union at the end of 2021*

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
Total Italy		**8.15**	
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		**2 328.8**	

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

Continues overleaf

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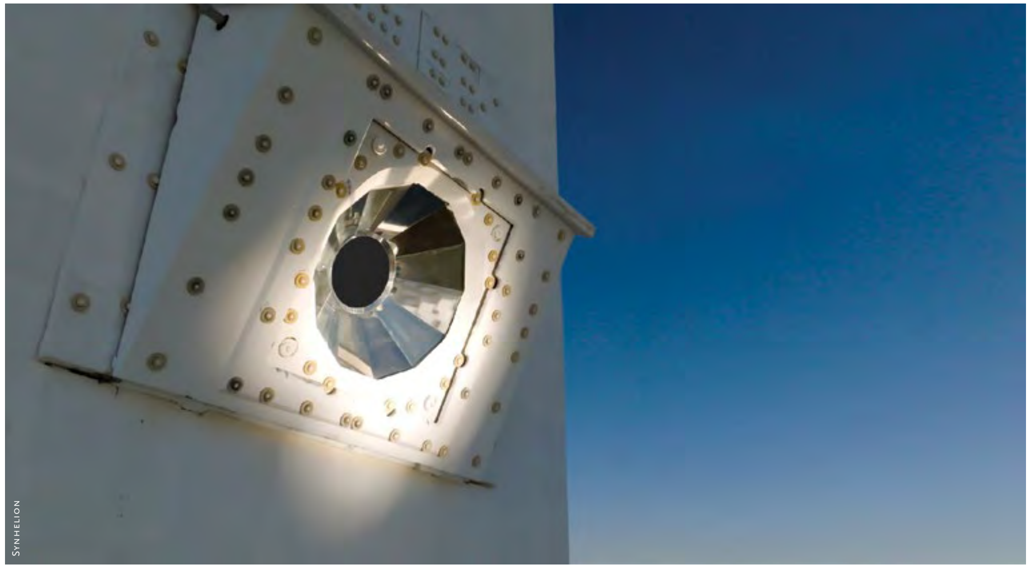
fied the net output of Spain's CSP plants at 4 705 GWh compared to 4 538 GWh in 2020 (a 3.7% rise). This performance is 88% of the best ever year for output, 2017, when 5 347 GWh was produced. Gross electricity output, which allows for the plants' own electricity consumption, is a little higher at 5 176 GWh compared to 4 992 GWh in 2020. In 2017, the record year, 5 883 GWh was delivered, according to Eurostat.

The European Union standstill finally ended in 2022 when the SOLINPAR CSP went on stream at Partanna (Sicily), owned by the Italian company SOL.IN.PAR srl. This 4.26-MW capacity Fresnel type CSP plant, was constructed by the Danieli group's FATA spa company. The total solar field area is 83 000 m² (equivalent to about 10 football pitches), where 126 Fresnel type linear solar collectors have been installed, arranged as 9 loops. The plant has a 180-MWh thermal molten salts storage system that equates to about 15 hours of operation at full load, even in the absence of solar radiation. The plant can produce electricity for more than 1 400 families (about 30% of the municipal area's population). It is planned to couple this plant with a 5.6-MW capacity solar photovoltaic panel field to achieve combined electrical capacity of 9.86 MW. On 18 February 2020, FATA signed another EPC contract with the Stromboli Solar "project company" to construct another Fresnel type CSP plant at Trapani (Sicily), with total capacity of 4 MWe that will have a 16-hour storage system. The theoretical commissioning date has yet to be disclosed.

On 25 October 2022, the Spanish government organized its third renewable energy auction for 520 MW of electricity, that for the first time included CSP power with a minimum reserve of 220 MW. To be eligible for bidding the CSP projects had to include at least six hours of energy storage. The CSP could also be hybridized with biomass, biogas, bioliquids and even solar photovoltaic provided that the PV component does not exceed 10% of the CSP capacity. Unfortunately, no successful bid for CSP technology was made as the prices proposed by the qualified bidders were all higher than the reserve price. This is sadly a missed opportunity for the Spanish sector, particularly as, according to Protermosolar, the Spanish solar thermal industry association, there were other bids in addition to the qualified bids, that amounted to over 500 MW of capacity that were ultimately not submitted to the auction because of uncertainties surrounding the grid connection eligibility dates. If we consider the sum of the qualified capacity in the auction and the offer that would have been made had there been greater certainty of obtaining grid capacity, CSP project capacity in excess of 700 MW would probably have been ready to compete. This volume, according to Protermosolar, demonstrates the real interest and commitment to CSP technology in Spain. David Trebolle, Protermosolar's secretary general, emphasized the major challenge of future auctions is "to work on a new auction design that enables the reserve prices to be adjusted better to the technology's real costs. As these auctions offer a tremendous opportunity for substituting fossil energies and should be interpreted this way. The market, alone, does not offer incentives for investment, or stable revenues that would cover the renewable technology costs to be covered with storage capable of providing the back-up that the electricity system needs, particularly at night".

Hence, the rollout of new tenders to help implement new CSP projects in Spain is consigned to the future. In the interim, Spain is concentrating on CSP projects for industrial heat. More than twenty projects were launched in 2022, and this number could double in 2023. As a result of the energy price hike and sharp fluctuations, the industrial sector is showing increasing interest in these projects that offer diminishing return on investment times. For instance, Heineken España and the company CSIN have announced the construction of a 6 000-m² CSP plant on the Quart de Poblet site. The plant will produce about 3 504 MWh of thermal energy as heat and steam per annum, to be used in the water heating and packing processes of the various products that Heineken España manufactures in that brewery. The whole project amounts to an investment of 2.2 million euros with commissioning scheduled for June 2023. Heineken España, in addition to giving up the land, will purchase the solar thermal energy produced over the next 15 years from CSIN, on which date it will be able to acquire the installations. It is the second CSP plant to supply solar thermal energy to the Heineken group. In October 2022, Engie España started the construction of an initial 43 000-m² CSP plant that will supply heat



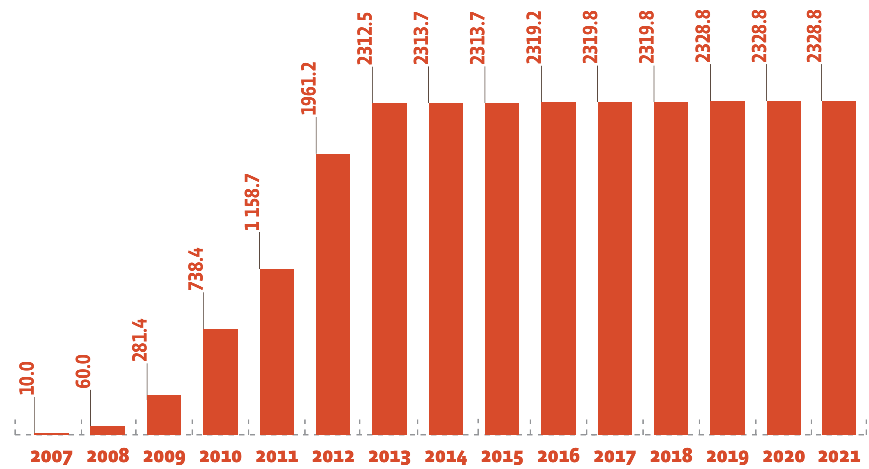
to the brewery at Seville. This 30-MW plant is designed to generate 28 700 MWh per annum at an investment cost of 20 million euros. Engie will operate the plant for 20 years and sell the heat, which will reduce the brewery's gas consumption by 60%. The system will have eight 100-m³ storage tanks to allow for heat production for five to six hours when there is no solar radiation. In Spain, 51 renewable solar heat projects, amounting to a combined total of 62 MW, have benefitted from the Thermal Energy Production funding programme (of 27.6 million euros), co-financed by ERDF (European Regional Development Fund). Of this total 23 CSP projects for thermal use have been selected for 42.6 MWth of capacity (19.1 million euros of funding). The largest project selected is the 30-MW project for the Heineken brewery at Seville, presented above. The remaining projects are for the chemicals industry (3 projects) and various agribusinesses such as agricultural operations, meat processing, dairy and cheese product manufacturers, as well as several service sector projects.

CSP IS PART AND PARCEL OF THE EU'S SOLAR ENERGY STRATEGY

While the European CSP sector attempts to rise from the ashes, it has had to plead its case in Brussels as the latter appeared to have side-lined it in its strategy for combatting climate change and its response to the energy security crisis. In a letter addressed to the Commission last April, the Spanish Association for the Promotion of the Solar Thermal Industry alerted it to the danger of the dearth of concentrated solar energy in the new European strategy. For Protermosolar, the Public Consultation process for contributing to the new European Union solar energy strategy was too narrowly focused on photovoltaic and did not address the real functional capacities offered by today's solar thermal technology. Protermosolar regretted that concentrated solar power energy's potential was insufficiently addressed in terms of storage and its capacity to supply large amounts of energy by day and by night. The association also invited the Commission to better assess the possibility of hybridizing the two solar technologies, photovoltaic and solar thermal, as a competitive solution to provide electricity systems with flexibility. The sector also complained about the lack of incentives proposed to promote research into complementary renewable technologies, nor the renovation of existing solar thermal plants by adding storage systems to those that have none, and the absence of defined national aims. These grievances have been partly addressed. In its communication that presents its strategy for solar energy, the Commission points out that given that the variable renewable energy share is increasing in the electricity system, tenders should also support technologies founded on renewable energies that can reduce grid stability and system integration costs. Concentrated solar power (CSP) with heat storage and solar photovoltaic with batteries are examples of technologies that can provide these benefits. It also states that CSP could supply heat for industrial processes from 100° to >500°C. The EU will continue its support for research and innovation through Horizon Europe and will provide financial support for innovation in solar thermal and concentrated solar power technologies. Thus, concentrated solar power has its part to play in solving Europe's crises. Renewable energies are never stronger or more relevant than when they are playing as a team. ■

2

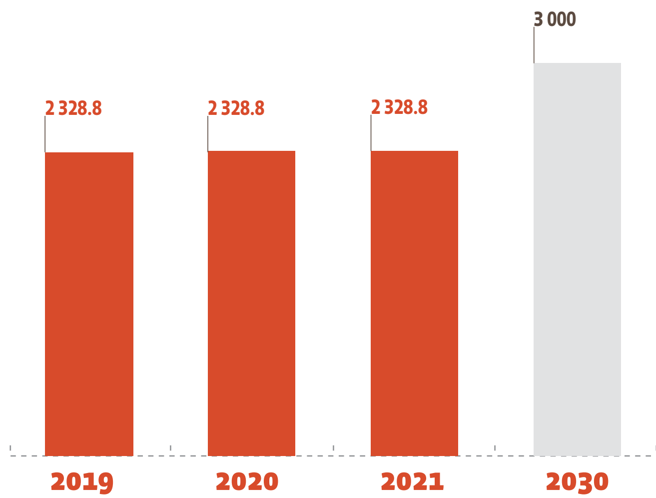
European Union concentrated solar power capacity trend (MW)



Source: EurObserv'ER

3

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



Source: EurObserv'ER

OCEAN ENERGY

Marine energy, also known as ocean energy, offers coastal countries significant diversification potential for their electricity mixes. Competition in the European sector is rife with companies trying to outdo each other and impose their marine turbine or wave energy converter 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 (WEC) 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 that each has 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.

ALMOST 250 MW OF PROJECTS IN SERVICE AT THE END OF 2021 AROUND THE EU

Because of the number of projects currently being tested, drawing up an inventory of the capacity of marine energy projects in service is no mean task. The official organizations do not systematically monitor the prototypes, be they on- or off-grid, and the incessant turnover of prototypes (immersion, improvement, maintenance decommissioning phases), sometimes tested over relatively short periods (about one to two years), does nothing to simplify the production of an accurate project count. Eurostat and the International Energy Agency carry out official statistical monitoring of the net capacity of projects using wave, tide and sea current energy, as defined by the international "tide, wave and ocean" classification. As it stands, only two EU-27 countries – France and Spain – monitor net marine energy capacity and the resulting gross electricity output. The data released by the SDES (Monitoring and Statistics Directorate) of the French ministries of the environment, energy, construction, housing and transport is restricted to the La Rance tidal range power plant's capacity and electricity output. In 2021, its capacity was recorded at 211.4 MW for 483.8 GWh of output. The power plant has a pumped storage unit that added 66 GWh to this total in 2021 (65 GWh in 2020).

Spain's Ministry for Ecological Transition similarly quantified the capacity and electricity output of the Enagas ocean thermal plant and the 296-kW capacity of the Mitriku wave energy plant, giving total capacity of 4.8 MW and output of 19 GWh at the end of 2021. The other EU countries with demonstrators and prototypes that were approached for the purpose of this barometer, have so far decided against

1

List of projects using ocean energies having been active during the year 2021 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
Wavegame - Test at SEM REV	GEPS Techno	Wavegame (prototype)	Wave energy	SEM REV	2019	0.12
Paimpol Brehat	Hydroquest	HydroQuest	Tidal current	Brittany - Paimpol Brehat	2019	1
Total France						241.12
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
WavePiston - Plocan test center	Wavepiston	Wavepiston	Wave energy	Plocan. Gran Canaria	2020	0.2
Biscay - BiMEP Platform	Wello Oy	Penguin 2	Wave energy	Bay of Biscay	2021	0.6
Total Spain						5.60
Netherlands	Tocardo	T2	Tidal_Stream	Oosterscheldedam	2015	1.25
Oosterscheldedam	Tocardo	T2	Tidal current	Oosterscheldedam	2015	1.25
Port of Den Helden	Slow Mill	Slow Mill	Wave energy	Port of Helden	2021	0.04
100 kW VAWT for Vlissingen	Water2Energy	VAWT	Tidal current	Vlissingen	2021	0.1
Total Netherlands						1.39
Denmark						
Pilot plant at the Afsluitdijk	Redstack	TRL7	Salinity Gradient	Breezanddijk on the Afsluitdijk	2014	0.05
Port of Fredrikshaven	Crestwing	Tordenskiold	Wave energy	Port of Fredrikshaven	2018	0.3
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						0.55

Continues overleaf

EUROBSERV'ER – THE STATE OF RENEWABLE ENERGIES IN EUROPE – 2022 EDITION

Portugal						
Swell Project	AW-Energy	WaveRoller	Wave energy	Peniche	2019	0.35
Total Portugal						**0.35**
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
PC80 Platform (Eni)	Wave for Energy	ISWEC	Wave energy	Ravenna	2019	0.05
Total Italy						**0.12**
Greece						
Port of Heraklion test project	SINN Power	SP WEC 3rd Gen	Wave energy	Heraklion	2017	0.036
Port of Heraklion test project	SINN Power	SP WEC 4rd Gen	Wave energy	Heraklion	2018	0.072
Total Greece						**0.11**
Cyprus						
Larnaca Bay project	SWEL	WLM	Wave energy	Larnaca Bay	2021	0.001
Total Cyprus						**0.001**
Total EU 27						**249.2**

** including demonstrators and prototypes during the test phase. ** The Huelva project exploits the temperature difference between the ocean and liquefied fossil gas. *** Ocean Thermal Energy Conversion.* ***Source: EurObserv'ER***

monitoring, because of the low output levels and statistical confidentiality rules.
Table 1 shows another installed marine energy capacity monitoring indicator, that includes prototypes and pre-commercial demonstrators that were in service in 2021. The EurObserv'ER marine energy capacity figure for the EU-27, including the 240 MW capacity of the La Rance tidal range plant in France and the 4.5 MW of the Enagas LNG terminal's ocean thermal plant, rose to 249.2 MW. Furthermore, EurObserv'ER puts the EU and Faroe Islands' tidal stream project capacity running in 2021 at more than 2.6 MW and the capacity of wave energy converters at 2.1 MW. The UK, whose test centres accommodate many projects funded by European programmes, add a further 10 MW of capacity, including 9.9 MW of projects using tidal stream energy.
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 their low visual impact which is limited for completely submerged or low height models, while turbines placed or anchored on the seabed that are not exposed above the surface level present fewer navigational constraints. According to Ocean Energy Europe, in its Ocean Energy, Key trend and statistics 2021 publication, published in March 2022, Europe has amassed 30.2 MW of marine turbine capacity since 2010 using tidal streams, 11.5 MW of which are currently submerged in European waters (European Union, the UK and Norway).
A further three new turbines with combined capacity of 2.2 MW were submerged in European waters in 2021 and another 1.5-MW turbine returned to the water following maintenance and modification to improve its performance
One of them, the horizontal-axis 2-MW marine turbine called O2, developed by Scottish engineering firm Orbital Marine Power, was anchored off Orkney

2

Capacity and electricity production from ocean energy in European Union in 2020 et 2021 (GWh)*

	2020		2021	
	MW	GWh	MW	GWh
France**	211.8	481.8	211.4	483.8
Espagne	4.8	27.0	4.8	19.0
Total EU 27	**216.6**	**508.8**	**216.2**	**502.8**

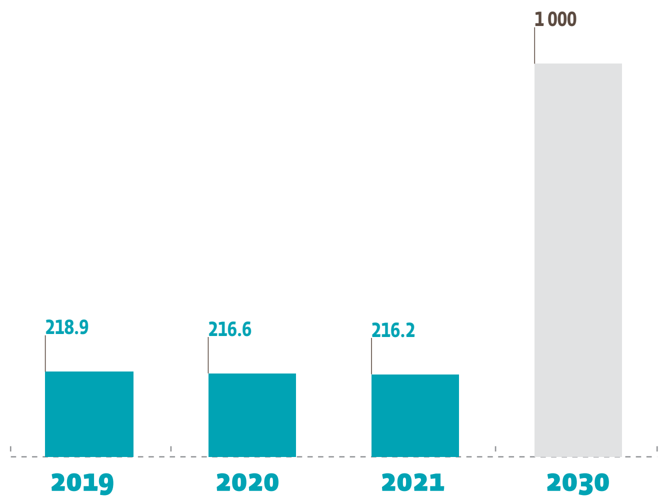
Net maximum electrical capacity. ** Electricity production excluding pumped storage. For information, production from pumping of the Rance tidal power plant was 65 GWh in 2020, 66 GWh in 2021.. **Source: Eurostat.*

on the European Marine Energy Centre's (EMEC) Fall of Warness site, a test and research centre specializing in the development of wave and tidal energy based on the Orkney Islands, north of Scotland. This model is currently the world's most powerful tidal turbine. It comprises two rotors 20 metres in diameter, that each develop 1 MW, connected to a 72-metre floating platform by two 18-meter long articulated arms, capable of sweeping up 600 m² of water. Another turbine, this time in European Union waters (the Netherlands) is a 100-kW vertical axis water turbine VAWT, developed by the Dutch start-up Water2Energy. This turbine was installed in the recesses of an outfall channel by the sea locks of the Flushing marina in Zeeland, the Netherlands' most westerly province. The vertical axis water turbines are of the Darrieus type. The design, construction and installation of this prototype were developed under the framework of the INTERREG 2 SEAS European ENCORE project, for Zeeland province. Swedish developer Minesto has added a second 100-kW DG 100 (Deep Green 100) marine turbine of the "underwater tidal kite" type at Vestmannasund on the site of its first commercial project on the Faroe Islands. In addition to these three new machines, the Spanish tidal turbine developer Magallanes Renovables refloated its second-generation double-rotor ATIR floating platform with a combined capacity of 1.5 MW on the EMEC test site on Orkney, Scotland in April 2021. More recently, in April 2022, the French turbine designer Sabella resubmerged its D10 water turbine and reconnected it to the Ushant Island power grid in June 2022, starting a third test and production campaign for the water turbine model. The D10 wind turbine is a gravity-based water turbine with maximum capacity of 1 MW, a rotor diameter of 10 m, it is 17 m high and weighs 450 tonnes. Many technologies convert wave energy into electricity by using point or linear floaters, swell systems and even oscillating columns of water. The Ocean Energy Europe association data for 2021 records that a total capacity of 12.7 MW of wave energy converter projects have been tested in Europe since 2010, and that at the end of 2021, 1.4 MW of projects were being tested in European waters. The year 2021 was particularly active with 681 kW new projects – three in the European Union (for a total of 641.4 kW), one in Scotland on the EMEC test site and another in Norway. They include Europe's most powerful project, that was submerged in August 2021 – and the second generation of the 600-kW, commercially sized Penguin WEC 2 wave energy converter, developed by the Finnish firm Wello Oy, a decade after it launched its first full-scale prototype that it tested in 2012 on the Orkney test site (Scotland). This 44 metre-long wave energy converter with off-centre rotating mass and direct drive has been deployed on the Biscay Marine Energy Platform (BiMEP), Spain on the Basque coast. The Penguin is designed to capture the rotation energy generated by the movement of its asymmetrical hull that rises and rolls as each wave passes and can operate with full storm height waves of over 18 metres.

A wave energy converter (WEC) of the "point absorber" type was installed in August 2021 in the Dutch North Sea Port of Helden. It uses the Slow Mill concept developed by the Dutch firm Slow Mill Sustainable Project bv. The prototype, on a tenth scale, has 40 kW of installed capacity. The Slow Mill WEC comprises a floater with blades linked variably to an anchor on the seabed. The WEC sector should be busier in 2022 than in 2021 with, according to Ocean Energy Europe forecasts, up to 2.8 MW of wave energy capacity deployed, including at least four commercially sized machines manufactured by CorPower Ocean, Eni SpA, Bombora and Wavepiston. These deployments will be sited around the UK, Spain and Portugal. The most eagerly awaited prototype is the Bombora MWave wave converter of the Pembrokeshire Demonstration project in Wales – a € 23.5 million project, which is funded by the European Regional Development Fund (ERDF) via the Welsh government. Boasting 1.5 MW of capacity, the MWave will be the world's most powerful wave energy converter. It weighs 900 tonnes, its dimensions are 75 metres long, 15 metres wide and 6 metres high. Also awaited is the CorPower C4, with 300 kW of capacity which should be launched as part of the HiWave-5 Project off Portugal's northern coast at the end of the year.

3

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



Source: EurObserv'ER

COULD THIS BE THE LULL BEFORE THE STORM IN EU WATERS?

The commercial phase is in the offing after years of testing and the proliferation of full-scale prototypes in Europe. The UK, which has taken and is still taking full advantage of the European Union's policies, has shown the way by guaranteeing revenues for electricity production likely to deploy more than forty MW. However, the Ocean Energy Europe association observes that project deployment in European Union waters seems to be losing speed and falling short of its Offshore Renewable Energy Strategy targets published on 19 November 2020. The strategy's medium- and long-term targets for ocean energy are to achieve total capacity of 100 MW in the EU by 2025 (on top of the La Rance Tidal Power Plant's capacity) then about 1 GW by 2030 and finally 40 GW by 2050. Progress has been made but has not yet resulted in decisions guaranteeing fast development of ongoing projects. The European Commission anticipates that it will play its role with the Horizon Europe 2023-24 work project that includes four auction rounds for marine energy with a proposed envelope of € 94 m. Ocean Energy Europe fears that the European Union runs a high risk of missing its 2025 deadline. However, it considers that a significant number of commercial projects could be launched before 2025 and that many more will get to the "Final Investment Decision" (FID) stage by the same timeline. ■

RENEWABLE ENERGY IN TRANSPORT

Renewable energy consumption in transport is now covered by a new legal framework – that of the Renewable Energies Directive 2018/2001 (known as RED II) – most of whose provisions came into force on 1 January 2021. The directive marks a new policy direction that aims to abolish high Indirect Land Use Change (ILUC) risk biofuels by the end of the decade. They will be gradually substituted by consumption of "advanced" biofuels, that are not sourced from food crops or from synthetic Renewable Fuels of Non-Biological Origin (RFNBOs), by producing "green" hydrogen with the possibility of combining it with sequestered carbon. New measures were also introduced to accelerate the electrification of transport. The main provisions of the RED II 2018 Directive's transport target are presented in the inset.

BIOFUELS

THE CONTEXT OF CONSUMPTION RECOVERY

The gradual lifting of lockdown measures at the end of the 2021 winter stimulated energy consumption in all modes of European Union transport – road, rail and others. Biofuel consumption obviously benefitted from this return to normal because it is directly linked to the incorporation mandates defined in each Member State. Data provided by the Eurostat SHARES tool that harmonizes the calculations of energy produced from renewable sources, shows that 17 136.1 ktoe of liquid and gaseous biofuel were used in transport in 2021 that amounts to a 5% increase over the 2020 figure of about 16 322.5 ktoe. The SHARES tool shows that 99.5% (i.e., 17 051.4 ktoe) of the liquid and gaseous biofuel used in transport in 2021, complied with the requirements of the Directive (EU) 2018/2001 and thus were included in the European Union target calculations. This compares with the 99.6% compliance result in 2020, when the compliance criteria of the previous Directive 2009/28/EC applied. The SHARES tool does not give an accurate breakdown of the various biofuel types. EurObserv'ER reckons that biodiesel accounted for about 79.9% of total biofuel consumption in 2021 (compliant and non-compliant), ahead of bioethanol (16.6%) and biogas fuel (2.5%). Bioethanol consumption grew (by 13.6% year-on-year, or 3 Mtoe), outstripping that of biodiesel (2.6%, or 13.7 Mtoe). Biogas fuel consumption in transport also increased (by 30.2%) at 426.9 ktoe (including biomethane injected into the fossil gas grid allocated to the transport sector with appropriate traceability requirements).

Incidentally, the increase in biofuel consumption was sharper in "advanced" biofuels, namely those produced from the raw materials listed in Annex IX, Part A, of the Directive (EU) 2018/2001. According to Eurostat, advanced biofuel consumption increased from 1.2 Mtoe in 2020 to 2.1 Mtoe in 2021 (by 868.2 ktoe), amounting to 70.9% growth. It should be pointed out that in the light of the premiums, the Member States were allowed to count double (i.e., 4.2 Mtoe) towards their transport goals. Consumption of biofuel produced with used cooking oil and animal fats (feedstocks listed in Part B, Annex IX) increased over the year, but to a lesser extent, from 3.1 to 3.4 Mtoe in 2021 (10.2%).

AustroCel Hallein GmbH

1

Biofuels consumption for transport in the European Union in 2020 (in ktoe) according Directive 2009/28/EC

	Biodiesel*	Biogasoline	Biogas**	Total	Compliant biofuels***
Germany	2 613.0	702.3	76.0	3 391.3	3 388.4
France	2 089.5	554.6	0.6	2 644.8	2 639.9
Spain	1 439.9	98.0	0.0	1 538.0	1 535.7
Sweden	1 212.4	93.2	100.5	1 406.2	1 406.2
Italy	1 245.1	19.6	82.1	1 346.8	1 345.9
Poland	856.5	183.0	0.0	1 039.5	1 039.5
Belgium	568.7	97.3	0.0	666.0	666.0
Netherlands	301.8	226.4	34.6	562.9	562.9
Romania	391.6	91.6	0.0	483.3	483.3
Austria	353.6	55.0	0.4	409.0	406.8
Finland	301.3	93.5	9.5	404.3	390.6
Czechia	306.6	65.8	1.2	373.6	373.6
Hungary	194.1	83.9	0.0	278.0	278.0
Portugal	255.7	6.4	0.0	262.1	262.1
Denmark	172.6	79.8	8.5	260.9	260.9
Greece	150.0	68.3	0.0	218.2	190.0
Ireland	155.1	19.4	0.0	174.5	174.5
Bulgaria	143.4	26.5	0.0	169.9	159.6
Slovakia	127.1	25.9	0.0	153.1	153.1
Luxembourg	126.6	13.8	0.0	140.4	140.4
Lithuania	87.2	15.8	0.0	103.0	103.0
Slovenia	84.9	8.0	0.0	93.0	93.0
Croatia	64.8	0.8	0.0	65.6	65.6
Estonia	32.8	6.2	14.5	53.5	53.4
Latvia	31.5	12.8	0.0	44.2	44.2
Cyprus	26.0	0.7	0.0	26.6	26.6
Malta	13.8	0.0	0.0	13.8	13.3
Total EU 27	**13 345.9**	**2 648.6**	**328.0**	**16 322.5**	**16 256.5**

** including a marginal consumption of other liquid biofuels. ** Possibility to allocate domestically produced biomethane blended in the natural gas grid to the transport sector with appropriate traceability requirements. *** Compliant biofuels according articles 17 and 18 of Directive 2009/28/EC. Note: Breakdown between types of biofuel has been estimated by EurObserv'ER.*
Source: Eurostat (Total and compliant biofuels).

2

Biofuels consumption for transport in the European Union in 2021 (in ktoe) according Directive (EU) 2018/2001

	Biodiesel*	Biogasoline	Biogas**	Total	Compliant biofuels***
Germany	2 166.6	734.7	82.8	2 984.0	2 961.4
France	2 185.9	710.2	1.6	2 897.8	2 897.8
Italy	1 388.4	27.1	136.5	1 552.0	1 551.9
Spain	1 410.1	140.6	0.0	1 550.6	1 549.9
Sweden	1 221.8	117.3	112.6	1 451.8	1 451.8
Poland	911.7	208.0	0.0	1 119.7	1 119.7
Belgium	606.8	118.7	0.0	725.5	725.5
Finland	557.2	113.5	12.1	682.8	663.9
Netherlands	356.7	233.2	40.8	630.8	630.2
Romania	374.8	120.9	0.0	495.8	495.8
Austria	410.3	49.3	0.4	460.0	460.0
Czechia	305.8	55.5	19.0	380.2	380.2
Portugal	323.1	17.1	0.0	340.2	340.2
Hungary	196.7	87.0	0.0	283.7	283.7
Denmark	179.0	81.8	8.8	269.7	269.7
Greece	131.4	68.1	0.0	199.5	160.8
Ireland	163.7	20.3	0.4	184.4	184.4
Bulgaria	148.8	20.8	0.0	169.6	166.8
Slovakia	134.4	26.1	0.0	160.5	160.5
Luxembourg	118.6	17.9	0.0	136.5	136.5
Lithuania	110.4	16.5	0.0	126.9	126.9
Slovenia	94.0	8.6	0.0	102.6	102.5
Croatia	90.4	0.8	0.0	91.2	91.2
Estonia	41.4	4.2	11.8	57.5	57.5
Latvia	34.0	11.7	0.0	45.8	45.8
Cyprus	26.2	0.0	0.0	26.2	26.2
Malta	10.9	0.0	0.0	10.9	10.8
Total EU 27	**13 699.1**	**3 010.1**	**426.9**	**17 136.1**	**17 051.4**

** including a marginal consumption of other liquid biofuels. ** Possibility to allocate domestically produced biomethane blended in the natural gas grid to the transport sector with appropriate traceability requirements. *** Compliant biofuels according articles 17 and 18 of Directive 2009/28/EC. Note: Breakdown between types of biofuel has been estimated by EurObserv'ER.*
Source: Eurostat (Total and compliant biofuels).

3

Biofuel consumption whose raw materials used are considered to be equivalent to twice their energy content in 2020 and 2021 (in ktoe)

	2020			2021		
	Advanced biofuel[1]	Used cooking oil and animal fats[2]	Total	Advanced biofuel[1]	Used cooking oil and animal fats[2]	Total
Italy	407.6	536.5	944.0	538.3	800.1	1 338.4
Spain	66.9	484.7	551.6	471.3	396.0	867.3
Sweden	240.5	58.0	298.4	332.2	300.6	632.7
Germany	113.6	591.7	705.3	183.7	442.4	626.1
Netherlands	98.1	301.3	399.4	144.4	358.3	502.6
Portugal	7.0	153.1	160.1	83.8	172.4	256.2
France	46.1	186.5	232.6	71.2	111.8	183.0
Hungary	0.1	144.0	144.1	0.2	163.8	164.0
Ireland	10.9	154.1	165.0	0.4	160.4	160.8
Finland	87.1	0.0	87.1	83.2	6.1	89.3
Slovenia	16.2	49.1	65.3	30.9	56.3	87.2
Czechia	6.5	81.2	87.7	19.2	67.8	87.1
Bulgaria	16.6	39.2	55.8	9.1	62.3	71.3
Belgium	16.7	38.8	55.5	27.6	39.8	67.4
Denmark	13.0	25.7	38.7	17.4	38.0	55.5
Luxembourg	0.0	60.3	60.3	0.0	55.3	55.3
Slovakia	0.0	36.2	36.2	8.0	37.7	45.7
Estonia	22.5	14.5	37.0	34.1	4.2	38.3
Croatia	0.0	35.2	35.2	0.0	35.5	35.5
Greece	0.0	41.2	41.2	0.0	34.9	34.9
Cyprus	0.0	18.5	18.5	2.1	20.1	22.2
Poland	34.8	0.0	34.8	20.8	0.0	20.8
Latvia	9.9	0.2	10.1	12.3	0.0	12.3
Malta	0.1	7.5	7.6	1.8	8.9	10.8
Austria	9.8	3.3	13.0	0.0	0.5	0.5
Lithuania	0.0	0.2	0.2	0.0	0.0	0.0
Romania	0.0	0.0	0.0	0.0	0.0	0.0
Total EU 27	1 224.0	3 060.8	4 284.7	2 092.2	3 373.1	5 465.2

1. Advanced biofuels means biofuels that are produced from the feedstock listed in Part A of Annex IX of the Directive (EU) 2009/28/EC. 2. Biofuels that are produced from the feedstocks listed in Part B of Annex IX of the Directive (EU) 2009/28/EC.
Source: Eurostat.

These biofuels also benefit from double accounting for their energy content, however, their use is now restricted by RED II which has set a 1.7% cap on the consumption eligible for transport target accounting purposes.
In 2021, this rule hit at least the Netherlands' transport target, as it was precluded from including all of its consumption of biodiesel produced from used cooking oil. Article 29 of the RED II Directive laid down stricter environmental criteria for GHG emissions of production installations. The article specifies that the amounts of biofuel (and biogas) contributing to the reduction in GHG emissions must be at least 65% produced in installations that have entered operation since 1 January 2021, at least 70% for those starting up before 31 December 2025 and at least 80% for installations starting up from 1 January 2026 onwards. This legislation directly benefits the expansion of the lowest-emitting advanced biofuels, led by HVO biodiesel, as well as cellulose ethanol, biomethanol, biomethane (bio-CNG/LNG) and biokerosene (and other biofuels – SAF). This is particularly beneficial to new Swedish and Finnish plants, producing biofuel based on refining tall oil, a wood-to-paper pulp conversion waste product, and also bioethanol produced from food waste flows and cellulose ethanol.

RENEWABLE ELECTRICITY IN TRANSPORT

A NEW COMMON RULE... A NEW START

The increased renewable electricity share coupled with the surge in EV sales, should have led to sharp rises in EU renewable electricity consumption for transport. However, a new statistical feature inherent to RED II caused a break in some countries' statistical series between 2020 and 2021. As it happens, the accounting rules for this indicator defined by the Directive 2009/28/EC applied until 2020 and have been replaced by the new Directive 2018/2001 Directive rules since 2021. The new rules state that the renewable electricity consumption figure for the transport sector must be calculated on the basis of the countries' electricity production mixes. Previously Member States could choose between their domestic mix and the average EU mix. So, countries that previously used the average EU renewable electricity production mix as their reference figure, which was higher than their own, must now recalculate this indicator. Renewable electricity consumption input has declined through this computing change rather than increasing in some countries' transport sectors. This phenomenon applies to France, the Netherlands and Eastern European countries such as Poland and the Czech Republic. We will have to wait for the 2022 data, namely two indicators constructed in the same way, to produce more accurate data on the increase in renewable electricity consumption in their transport sectors. The data for 2021 released by the Eurostat SHARES tool, puts

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Renewable electricity used in transport (road, rail, other transport modes) in 2020 and 2021 (in ktoe)

	2020				2021			
	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	21.5	351.3	0.0	372.8	48.9	405.4	0.0	454.4
Italy	5.6	135.5	154.1	295.1	13.2	155.9	158.3	327.4
Sweden	28.2	128.8	0.0	157.0	87.8	156.7	0.0	244.5
Austria	0.9	117.5	78.9	197.3	0.9	120.9	86.1	207.8
France	11.7	192.0	27.1	230.9	15.3	150.8	17.1	183.1
Spain	6.1	88.5	6.4	101.0	11.3	99.4	7.2	117.9
Romania	1.5	36.0	1.5	39.0	6.9	42.2	1.8	50.9
Netherlands	18.6	41.3	0.0	60.0	17.0	25.7	0.0	42.7
Poland	2.1	80.1	5.7	87.9	0.8	39.7	1.3	41.9
Denmark	5.1	22.7	0.0	27.9	13.3	25.7	0.0	39.0
Belgium	3.7	40.5	0.5	44.7	4.6	27.6	0.7	32.9
Finland	4.0	21.7	0.0	25.6	7.7	22.6	0.0	30.3
Portugal	0.5	18.6	0.3	19.3	0.8	20.8	0.2	21.8
Czechia	2.0	41.7	1.8	45.5	0.9	19.0	0.9	20.8
Croatia	0.1	9.3	1.5	10.8	0.3	10.2	1.6	12.2
Slovakia	0.7	11.6	1.7	14.0	0.5	8.9	1.8	11.1
Hungary	1.7	31.6	0.3	33.6	0.7	9.9	0.1	10.7
Bulgaria	1.0	10.2	0.3	11.5	0.8	8.3	0.2	9.3
Slovenia	0.1	5.6	0.2	5.8	0.1	6.3	0.2	6.6
Greece	0.6	5.0	0.0	5.6	0.3	4.5	0.0	4.7
Latvia	1.3	2.9	0.2	4.3	1.3	3.0	0.1	4.5
Ireland	1.2	1.4	0.0	2.5	2.0	1.5	0.0	3.5
Luxembourg	0.5	3.6	0.0	4.1	0.2	1.3	0.0	1.6
Lithuania	1.1	0.4	0.5	2.0	0.8	0.2	0.3	1.3
Estonia	0.4	0.3	1.2	1.9	0.3	0.2	0.0	0.6
Malta	0.1	0.0	0.0	0.1	0.0	0.0	0.0	0.0
Cyprus	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total EU 27	**119.9**	**1398.2**	**282.1**	**1800.3**	**236.7**	**1366.7**	**278.0**	**1881.4**

Note: A new method of calculation inherent in RED II has led to a break in the statistical series between the 2020 values and the 2021 values. In fact, until 2020, the accounting rules for this indicator were defined by the Directive 2009/28/EC. But since 2021, the applicable accounting rules are those defined by Directive (EU) 2018/2001 (RED II). From now on, the consumption of renewable electricity used in transport must imperatively be calculated from the national electricity production mix, whereas previously the member countries had the choice between their national mix or the average mix of the European Union. For this reason , countries that had previously chosen to use the European Union's generation mix as a reference, because the share of renewable electricity was higher there, are required to recalculate this indicator from the year 2021. ***Source: Eurostat.***

New target, new rules

The new Renewable Energy Directive (2018/2001) raised the target for renewable energies in transport to 14% in 2030 (compared to 10% in 2020 in the previous repealed RED directive). This threshold is classed as the "minimum share" to reach, after reformulating and adding new sustainability and greenhouse gas reduction criteria. The RED II Directive provides for the energy content of the biofuel (and biogas) share used in transport and produced from specific feedstocks to be counted as double in the energy balance of the countries using them, in order to achieve this target. This double accounting applies to the "advanced biofuels", defined in article 2, produced from the feedstocks listed in Part A of the Directive's Annex IX (algae, forestry and forest-based industry waste and residue, straw, animal manure, sewage sludge, crude glycerine, bagasse, etc.). It also includes biofuels (and biogas) produced from other feedstocks listed in Part B of the annex, primarily, used cooking oil and animal fats. Yet, biofuels produced from these feedstocks are not deemed to be advanced and so are excluded from the specific calculations for minimum shares assigned to advanced biofuels. The RED II Directive has specified targets of 0.2% for 2022, at least 1% for 2025 and at least 3.5% for 2030 for each Member State, to encourage the industrial development of "advanced biofuels". However, it enables Member States to waive these limits if they can prove that they have problems sourcing these feedstocks.

Other incentives have been set up to promote the modes of transport with the lowest greenhouse gas emissions. Thus, the renewable electricity share is counted as equal to four times its energy content when used for road transport and to 1.5 times its energy content when used in rail transport. The contribution of biofuels supplied to air and maritime transport equates to 1.2 times their energy content except for fuels produced from crops destined for human food and animal fodder. Thus, these incentives reduce the physical incorporation volumes of biofuels required to achieve the minimum 14% share in 2030.

RED II also set a cap on biofuels produced from crops traditionally used for human and animal consumption. Their share will be subject to a double constraint until 2030. Their penetration must not exceed 7% in final energy consumption in the transport sector and furthermore, may be no more than one percentage point higher than their 2020 rate. Member States wishing so can also set a lower limit and apply distinctions between biofuels. RED II also introduced a 1.7% limit on the contribution of biofuels or biogases produced from used oils or animal fats (Part B of annex IX) (except for Cyprus and Malta).

Another major aspect of the RED II directive is to be found in its Article 29, which strengthens its sustainability criteria and has implications for the use of palm oil. The article sets the minimum requirements for GHG savings, protection from high carbon stock conversion and biodiversity protection. It introduces specific criteria for high Indirect Land Use Change risk biofuels (ILUC effect) and whose expanding growing area is making clear inroads into high carbon stock soils. The use of high-risk biofuels will be capped at the 2019 level until 2023 and eliminated by 2030. These criteria were spelt out by delegated act 2019/807 published in May 2019. The European Commission thereby defined the high ILUC effect risk feedstocks as those whose growing penetration into high carbon land share is over 10% with more than 1% average annual expansion in growing area since 2008. Only palm oil is affected by this provision (with soy narrowly escaping it) using the European Commission's calculations (annexed to the delegated act). Nonetheless, palm oil producers will be able to certify that their feedstock is low risk provided that they can demonstrate that their production meets general RED II sustainability criteria.

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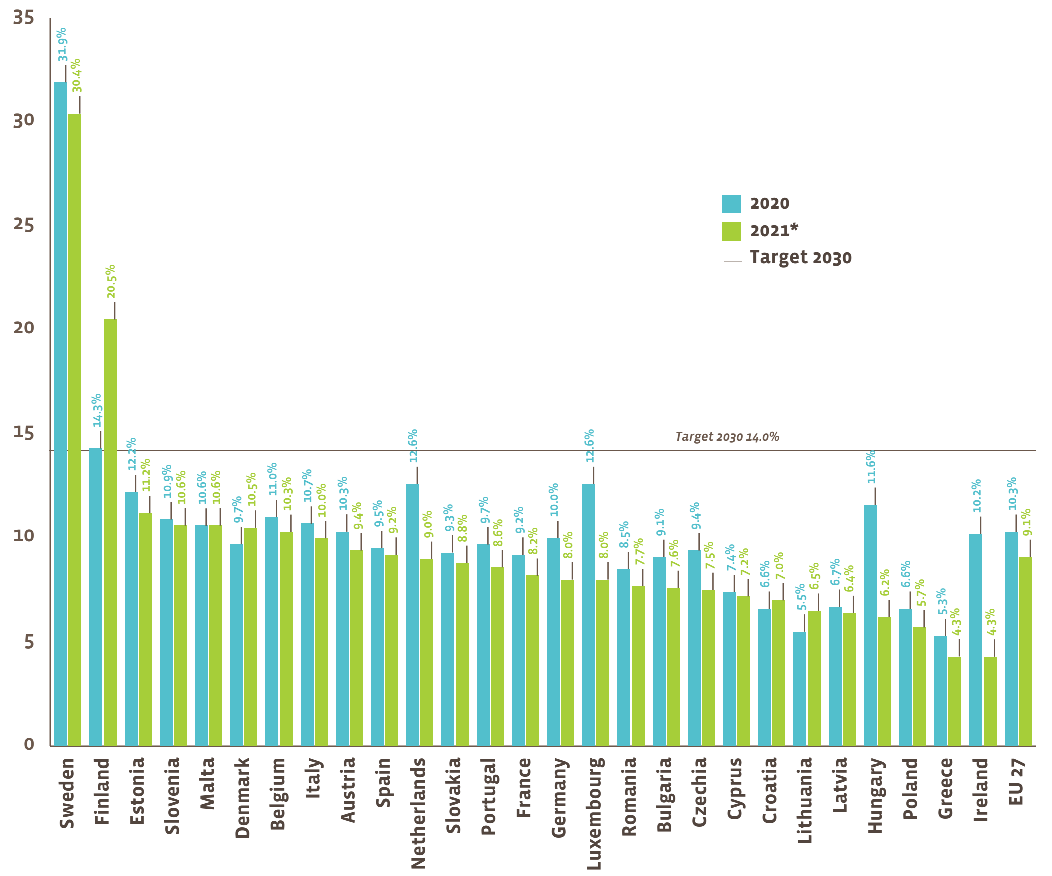
Share of energy from renewable sources in transport (in %) - Directive 2009/28/EC for 2020 and Directive (EU) 2018/2001 for 2021



** Data for 2020 are calculated on the basis of Directive 2009/28/EC, while data for 2021 follow Directive (EU) 2018/2001.*
Source: Eurostat

this consumption at 1 881.4 ktoe (including 236.7 ktoe used in road transport). Now in some countries, a large proportion of renewable electricity consumption in transport is not clearly monitored and is assigned, by default, to the "other transport" category. Despite some countries' poor data, 2021 posts a year-on-year increase of about 4.5% of EU-wide renewable electricity consumption across all forms of transport. Most of this rise can be attributed to renewable electricity consumption in road transport, through burgeoning rechargeable EV sales.

THE RENEWABLE ENERGY SHARE IN TRANSPORT QUANTIFIED AT 9.1% IN 2021

Eurostat claims that in applying the new Directive 2018/2001 renewable energy rules, the 2021 EU-wide renewable energy share in transport stands at 9.1%, down from the previous year's share of 10.3% under the former directive's rules. The accounting method revamp has heavily penalized some countries and widened the gap from the 14% renewable energy share target in transport for 2030, as their renewable energy share of transport has dropped several percentage points. The worst annual losses hit

Ireland (5.9 pp), Hungary (5.4 pp), Luxembourg (4.6 pp), the Netherlands (3.6 pp), Germany (2 pp) and the Czech Republic (1.9 pp). All in all, 22 EU countries posted lower renewable energy shares than in 2020.

The new reference year for projecting towards the renewable energy target in transport for 2030 with its calculated share is now 2021. The intervening years will be calculated using the same methodology. Member States' progress will be compared on the basis of one rule, unless the legislation is revised again… and a reform of the RED II is underway. The European Commission published its "Fit for 55" legislative package in July 2021, that plans to raise the Renewable Energy Directive's 2030 targets to achieve the climate neutrality goal by 2050 defined in the European Green Deal and reduce net GHG emissions by 55% compared to 1990 levels by 2030. It sets a new global renewable energy target of 40% and a new binding target of 13% to reduce GHG intensity in transports compared to the reference fossil fuel emissions level, to replace the 14% renewable energy consumption target in transport. Thus, a GHG emission reduction targets system for fuels is already implemented in Germany, as a decarbonizing tool in transports, that also aims to promote the use of low CO_2-emitting biofuels. However, there is no change in the proposed overhaul of the 2018 RED II Directive for the "agrofuel" ceiling which is 1% above the consumption levels of each Member State in 2020, up to a global seven percent ceiling of their final road and rail transport consumption. Now, the European Commission plans to set a new 2.2% target for the use of advanced biofuels by 2030, and also to abolish the multipliers (on advanced biofuels, used oils, etc.). At the end of the day, the new subtarget will be more ambitious than the current RED II 3.5% target. The Commission also intends to set a 2.6% sub-target for RFNBOs, which demonstrates its interest in promoting these fuels produced from renewable hydrogen. These higher-target proposals were discussed and approved at the European Council meeting of 27 June 2022. Turning to the transport sub-targets, the Council paved the way for Member States to choose between a binding 13% reduction target in GHG intensity in transports by 2030 or a binding renewable energy target of at least 29% in final energy consumption in the transport sector by the same deadline. The Council set a binding 0.2% sub-target for advanced biofuels in the renewable energy share supplied to the transport sector 2022, increasing to 1% in 2025 and 4.4% in 2030, while integrating the addition of double accounting for these fuels. Thus, this formulation is similar to the indicative 2.2% sub-target in 2030 minus the multipliers proposed by the European Commission. The Council agreed on an indicative 2.6% sub-target for RFNBOs (primarily renewable hydrogen and hydrogen-based synthetic fuels), which matches the European Commission's proposed sub-target, and effectively amounts to a 5.2% share when double accounting is applied. A strong commitment has already been made through these negotiations on the new legislative package. The European Council and European Parliament came to an initial pact on 27 October 2022, when they decreed the end of diesel- and petrol-driven combustion engine vehicle sales in the EU in 2035. The text approved by the Member States, based on the Commission's "Fit for 55" proposal, plans to reduce the CO_2 emissions of new cars in Europe to zero from 2035 onwards. This historic decision, is tantamount to curtailing sales of new petrol- and diesel-driven private cars (M1), light utility vehicles (N1) as well as hybrid vehicles in the EU on that date, in favour of 100% electric vehicles. The agreement also plans for CO_2 emissions from new private cars in the European Union to drop by 55% by 2030 from their 2021 level, while utility vehicles will have to reduce these emissions by 50%. This decision clearly sets out the strategic trajectory for transport… namely the programmed abolition of combustion engines in favour of the generalised 100% decarbonised renewable or nuclear electrification of transports. ■


NordFuel Oy

A NEW DEPARTURE AND A NEW DEFINITION FOR THE 2030 TIMELINE

Renewable energies are on the front line as never before, combatting climate change, where they offer so many fossil fuel substitutes and hence solutions for reducing greenhouse gas emissions. They are also paramount in defending the European Union's economic and energy sovereignty, fighting gas and oil price volatility that is weakening the European Union economy. They are one of our best weapons for weaning the EU off its reliance on Russian fossil fuels.

Europe's ambition and recognition of the geopolitical and climate significance of deploying renewable energies comes as no news. The European Union has made progress since the European Commission adopted the Green Paper on 20 November 1996, by setting clear benchmarks for developing renewable technologies. Its implementation marked the first step towards a renewable energy sources-friendly strategy. Publication of the White Paper on renewable energies on 26 November 1997 set a pioneering European Union-wide global target (for 15 countries at the time)[1]. Besides that, deployment of this White Paper's target monitoring indicators helped Observ'ER to create the EurObserv'ER project in 1999.
Many changes have been made to European renewable energy legislation and they have gradually increased its targets over the years. In 2009, the EU set itself the target of raising its gross final energy consumption renewable energy share to 20% by the 2020 timeline. In 2018, this target was raised to 32% by 2030. In July 2021, the European Commission advised the Member States to raise it again to 40% by 2030 because of the EU's new climate ambitions. In May 2022, following Russia's attack on Ukraine, the European Commission rushed through the REPowerER Plan, with its proposal to raise the 2030 renewable energy target to 45%.

THE RED II DIRECTIVE ADOPTS 2021 AS ITS NEW REFERENCE YEAR

The specific calculation provisions of the Renewable Energy Directive (EU) 2018/2001 (known as RED II) first applied in 2021. Therefore, the 2021 results cannot be directly compared with the 2020 results, which applied the calculation provisions of the previous 2009/28/EC Directive (known as RED I). Eurostat, which monitors the new renewable energy directive targets using its SHARES statistical tool, points out that the change to the legal basis between the former and current directives forced a break in series between 2020 and 2021. Eurostat also warns that several issues may force other breaks in the chronological series, primarily the late transposition of directives and changes in statistical methodology. So, Eurostat encourages readers to analyse the differences between the two directives (RED I and RED II), the energy sector and all the individual national specifics before drawing conclusions from the new renewable energy directive's initial monitoring indicators.
EurObserv'ER emphasises that the main statistical breaks between the two directives stem from the new sustainability criteria for solid and gaseous biofuels, which disqualified a fraction of biomass energy from inclusion in the new directive's renewable energy targets from 2021 onwards. This is compounded by the new renewable electricity calculation method for transport that several countries feel is much less generous. Additionally, starting in 2021, the applicable accounting rules state that countries' renewable electricity consumption for transports must always be calculated on the basis of their national electricity production mix, whereas in the past, Member States could choose between their domestic mix and the average European Union mix (cf. data on renewable energies in transport).
This conclusion aims to make an initial assessment of the real state of renewable electricity output in 2021, namely, the non-normalized hydroelectricity output, including all biomass electricity output (from solid, liquid, and gaseous biofuels), regardless of whether or not it complies with the RED II requirements, before we embark on a more thorough inventory of the first RED II monitoring indicators. The same applies to our reporting on the EU-27 countries' various renewable heat and cold shares. They include all biomass energy output regardless of its RED II compliance status. These "established" indicators have been obtained from the Eurostat database with reference to the Member States' complete energy balance, updated on 22 January 2023. They serve to weigh up the differences from the "eligible" indicators that comply with the RED II legal specifications.

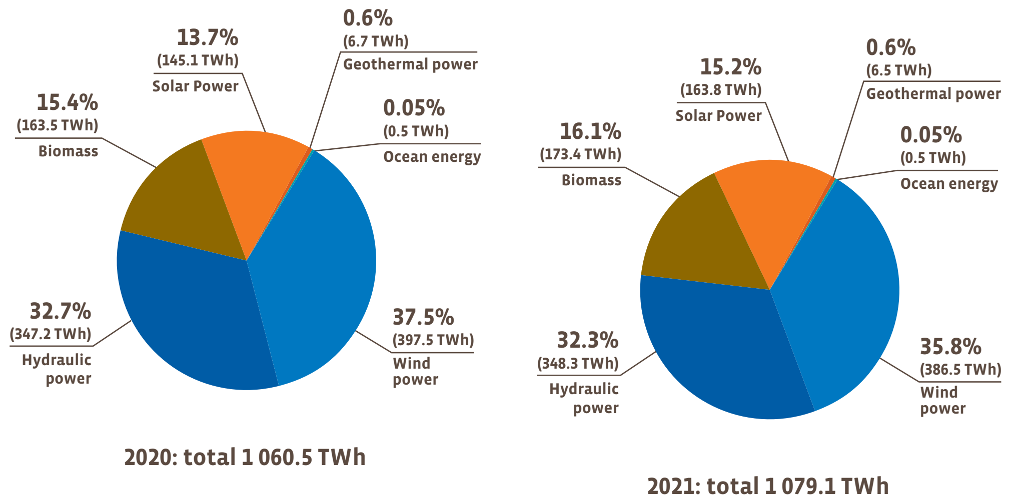
A DIVERSIFIED, COMPLEMENTARY RES MIX

When compared with 2020, 2021 was a bad year for EU renewable electricity output, largely because of the wind deficit that hit the main production areas (Germany, France, Belgium, Ireland and Sweden). Eurostat data for gross non-normalized European renewable electricity output in 2021, excluding pumped storage output, was 1 079.1 TWh, which equates to growth of 1.7% over the year (1 060.5 TWh). The figure is only 18.5 TWh higher than in 2020, and a far cry from the additional 81.8 TWh measured between 2019 and 2020. Even so, the increase in renewable electricity output over the past two years has exceeded 100 TWh (100.3 TWh), which shows the resilience of these sectors' momentum.
Now in 2021, renewable energies covered 37.1% of the gross total electricity output in the EU-27 (quantified by Eurostat at 2 906.2 TWh). The renewable share has fallen from 38.1% since 2020 (with total electricity output of 2 784.6 TWh). Thus 2021 favoured the production of conventional electricity, which increased faster during the post-Covid economic recovery.
Renewable energies' main strength is their diversity and complementarity. The 10.9 TWh drop in wind energy output across the European Union, was more than offset by the other renewable sectors' output (18.6 TWh for solar, 9.9 TWh for biomass, 1.1 TWh for hydropower excluding pumped storage). Wind energy confirmed its supremacy in the European Union renewable electricity production stakes with actual output of 386.5 TWh, ahead of hydropower excluding pumped storage (348.3 TWh in 2021). However, its share in total renewable electricity output slipped to 35.8% in 2021 (from 37.5% in 2020).
Wind energy thus accounted for 13.3% of the European Union's total gross electricity output in 2021 quantified at 2 781.4 TWh (14.3% share

1. *The renewable energy sources share was doubled to 12% (primary energy) in 2010.*

1

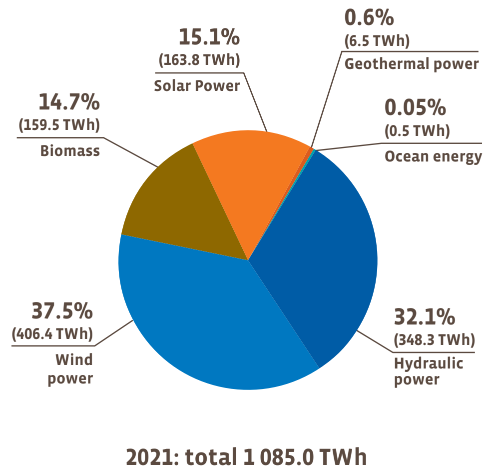
Share of each energy source in renewable electricity generation in the EU-27 (in %)



Notes for calculation: Hydro is actual (not normalised) and excluding pumping. Wind is actual (not normalised). Solar includes solar photovoltaics and concentrated solar power generation. 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***

2

Share of each energy source in renewable electricity generation in 2021 in the EU 27 (in %) according to the Directive (EU) 2018/2001 specifications.



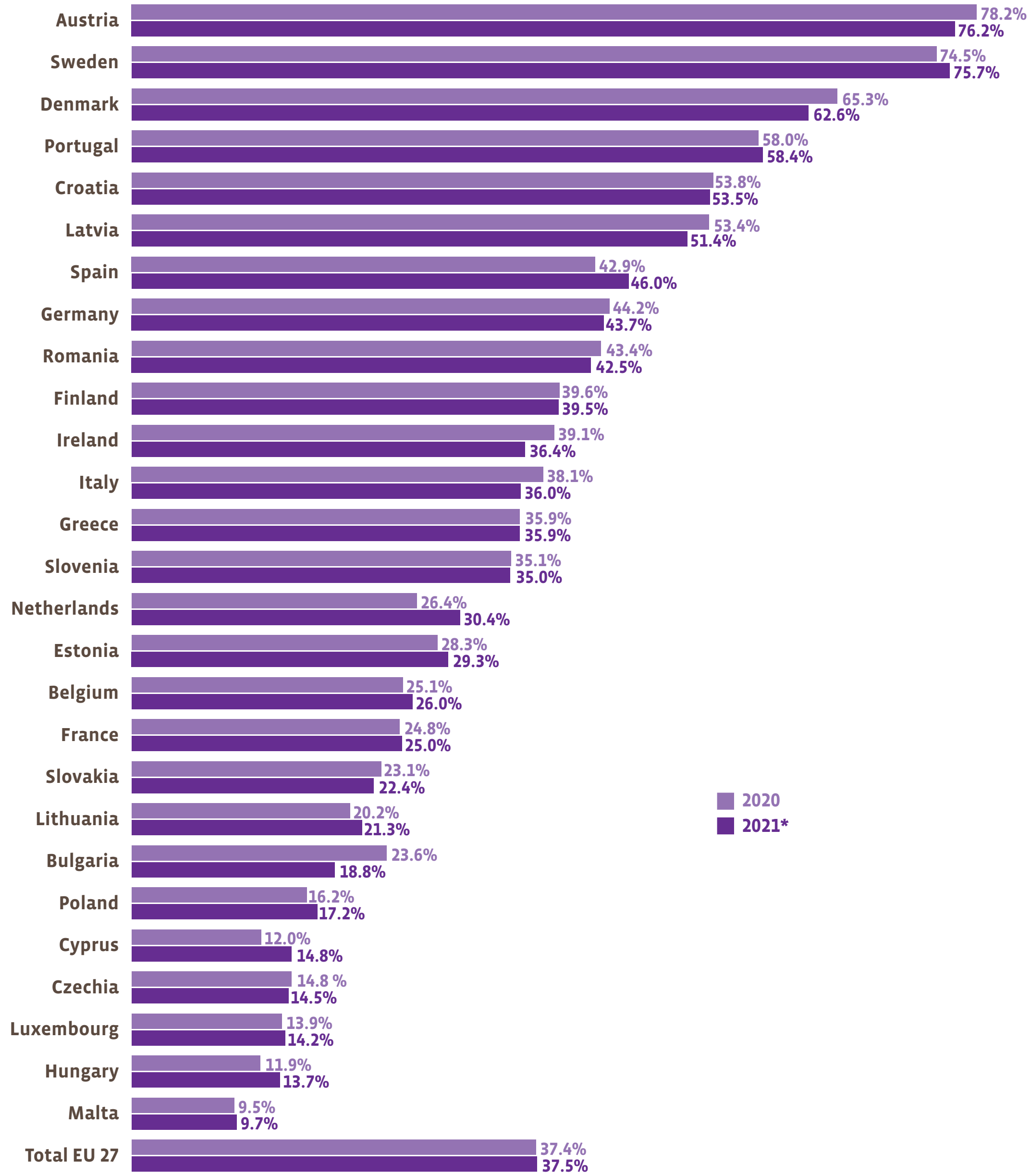
Notes for calculation: Hydro is normalised and excluding pumping. Wind is normalised. Solar includes solar photovoltaics and concentrated solar power generation. Biomass includes electricity generation from solid biofuels, liquid biofuels and biogas (pure and blended in the fossil gas grid) calculated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

in 2020). Note that offshore wind power output increased slightly by 0.8% rising from 47.4 TWh in 2020 to 47.7 TWh in 2021, making it more robust than onshore output. Incidentally, Belgium is an outlier in that its offshore wind energy share dominates its wind power output (57.7% in 2021). It should shortly be joined by Denmark (47.3%) and the Netherlands (44.2%) given the investments that these two countries are making in offshore wind turbines.

Hydropower is the European Union renewable electricity production's second mainstay. the sector (excluding pumping and non-normalized output) enjoyed a good year overall across the European Union in 2021, as it did in 2020. The amount of energy generated increased by 1.1 TWh. This increase was too small to maintain its share of Europe's renewable electricity output. It decreased to 32.3% in 2021 (32.7% in 2020). The minor increase in hydropower output excluding pumping in the European Union, masks great disparity between the Member States. Only Sweden, out of the top 5 producer countries (Sweden, France, Italy, Austria, and Spain), increased its output (2.1%, with an additional 1.5 TWh). The biggest falls in output were recorded in France (4.7%, 3 TWh), Italy (4.6%, 2.2 TWh) and Austria (7.7%, 3.2 TWh). At the scale of the European Union, these drops were offset by

3

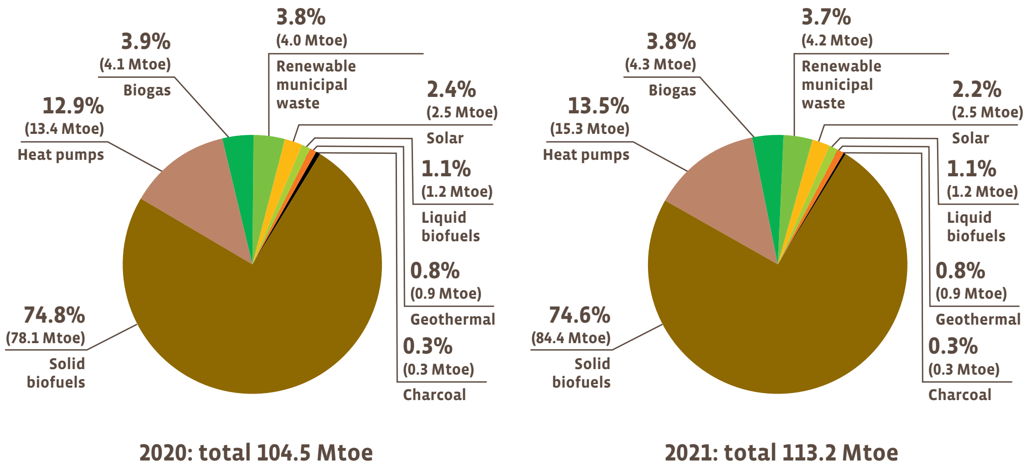
Share of energy from renewable sources in gross electricity consumption (%) - Directive 2009/28/EC for 2020 and Directive (EU) 2018/2001 for 2021



** Data until 2020 are calculated on the basis of Directive 2009/28/EC, while data for 2021 follow 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. For 2020, all other renewables includes electricity generation from solid biofuels, biogas (pure and blended in the fossil gas grid), compliant liquid biofuels with criteria from the directive 2009/28, renewable municipal waste, geothermal, and tide, wave & ocean. For 2021 the accounting of electricity generation from solid biofuels, liquid biofuels and biogas (pure and blended in the fossil gas grid) is calculated according to their compliance with the criteria of Directive (EU) 2018/2001).* ***Source: Eurostat (updated 24th January 2023)***

4

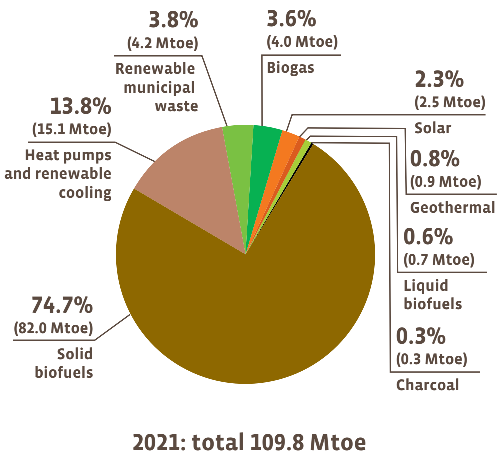
Share of each energy source in renewable heat and cooling consumption in the EU 27 (in %)



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 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***

5

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

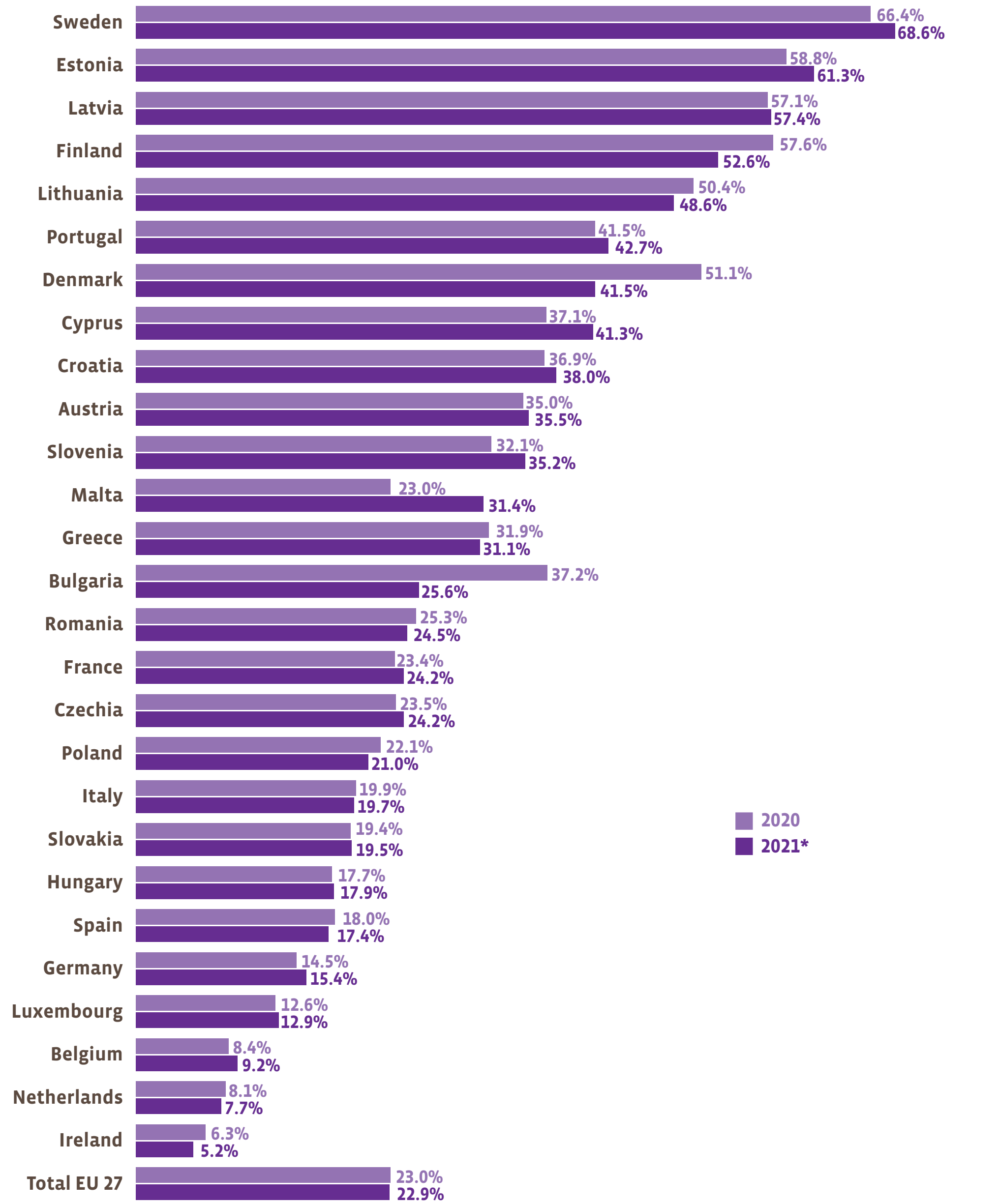


Note for calculation: Renewable sources for heating and cooling correspond to the sum of final energy consumption of renewables fuels in Industry and Others Sectors, of production of derived heat from renewable fuels, heat pumps for heating and renewable cooling. For final energy consumption and derived 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***

the sharp increases in hydropower output enjoyed by Greece (76.6%, 2.6 TWh), Romania (13.2%, 2 TWh), Bulgaria (70.9%, 2 TWh) and Croatia (25.9%, 1.5 TWh). Solar energy finally changed status in 2021 as not only did the sector's output surge faster than any other in the European Union but it also contributed the most to renewable electricity production. According to Eurostat, European Union solar power output added 18.6 TWh between 2020 and 2021 to reach 163.8 TWh in 2021 (158.6 TWh of solar photovoltaic and 5.2 TWh of CSP), which represents 12.9% growth. The solar power share of total renewable electricity output rose from 13.7% in 2020 to 15.2% in 2021. Solar power is now hot on the heels of biomass energy for electricity production, and given their respective dynamics, solar should overtake biomass as early as 2022, while they have already exchanged places in terms of their contributions to the RED II targets. Effectively, the implementation of the solid and gaseous biomass sustainability criteria, in addition to those applicable to liquid biomass, have already disqualified a fraction of biomass electricity output (13.9 TWh in 2021) from inclusion in the renewable energy target calculations (see further on). Solar power had a 5.6% share of the European Union's total electricity output in 2021 (5.2% in 2020). It has finally emerged from the backwoods. What is ↘

6

Share of energy from renewable sources for heating and cooling (%) - Directive 2009/28/EC for 2020 and Directive (EU) 2018/2001 for 2021



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 2009/28/EC for 2020 and with the requirements of Directive (EU) 2018/2001 for 2021 are included.
** Data until 2020 are calculated on the basis of Directive 2009/28/EC, while data for 2021 follow Directive (EU) 2018/2001.*
Source: Eurostat (updated 24th January 2023)

7

Overall share of energy from renewable sources (%) - Directive 2009/28/EC for 2020 and Directive (EU) 2018/2001 for 2021

** Data until 2020 are calculated on the basis of Directive 2009/28/EC, while data for 2021 follow Directive (EU) 2018/2001.*
Source: Eurostat (updated 24th January 2023)

more, solar power delivered more than 8% of total electricity production in nine European Union countries: 11.6% in Malta, 10.6% in Hungary, 9.9% in Spain, 9.6% in Greece, 9.5% in the Netherlands, 9.1% in Cyprus; 8.7% in Italy, 8.4% in Germany and 8.1% in Luxembourg).
When we take biomass energy as a whole (solid biomass, biogas, renewable municipal waste, and liquid biomass), EU electricity output reached 173.4 TWh in 2021, equating to 6% annual growth (or 9.9 TWh). Almost all of this increase was provided by solid biomass (9.8 TWh) whose output was 92.8 TWh in 2021 (11.8% more than in 2020). Biogas (used pure in biogas plants and injected into the fossil gas grid) stagnated (0.0% growth over the 12 months), at 56.6 TWh (4 TWh of which was from biomethane injected into the fossil gas grid). Renewable municipal waste recovered in waste-to-energy plants contributed 0.7 TWh between 2020 and 2021 (a 3.7% increase, for a total of 19.6 TWh). Lastly, at 4.4 TWh in 2021, the highly developed sector of liquid biomass output recovered as electricity in Italy declined by 12% (falling 0.6 TWh between 2020 and 2021).
European Union electricity production from the geothermal energy (essentially Italian) and marine energies (essentially French) sectors hardly evolved between 2020 and 2021 with respective 2021 outputs of 6.5 TWh (a 0.2 TWh loss) and 0.5 TWh (a 0.0 TWh change).

THE LONGER WINTER REKINDLED BIOMASS HEAT

The Eurostat data from the Member States' full energy balance updated on 22 January 2022 shows that renewable energy consumption used for heating and cooling increased sharply (by 8.2%)between 2020 and 2021, rising from 104.5 to 113.2 Mtoe. This indicator covers the energy consumed directly by final users (final energy consumption) in industry and "other sectors" (such as residential, commercial, farming, forestry and fishing), as well as heat output from the processing sector (derived heat) and renewable production delivered by heat pumps. EurObserv'ER has opted to add an estimate of final energy consumption to the total (industries and "other sectors") and the heat derived from biomethane injected and mixed into the fossil gas grid. This sometimes sizeable consumption in several countries (Denmark, Germany, France), is omitted from the full energy balance biogas indicators, that only cover the energy use of "pure" biogas. The Eurostat SHARES tool gives estimates of the final energy and derived heat consumption from biomethane injected into the fossil gas grid in the country files, by identifying the fraction that complies with RED II.
The Member States' energy balance data should not be used as is for the RED II target calculations, as the latter have their own calculation specifications and modes with, for example, specific biomass indicators that factor in the compliance criteria. EurObserv'ER holds that about 3.2 Mtoe of biomass renewable heat (all forms) for 2021, were disqualified for the RED II target calculations on the grounds of non-compliance. This is trivial compared to the overall biomass heat consumption, as the bulk of the solid biomass used in the European Union was taken from EU soil where the RED II criteria for forestry operations and energy recovery were met.
Solid biomass, compliant or otherwise, was the main contributor to the renewable heat surge. Its input rose by 6.2 Mtoe over its 2020 figure to 84.4 Mtoe and the surge can be largely attributed to the winter that was generally colder and longer than in recent years. Much of this increase derives from the residential sector's strong demand for heat, which was particularly marked in Germany, France and also Belgium, Italy, and Austria. The amount of solid biomass heat sold to heating networks (from the processing sector) increased even more. The highest rises were recorded in Sweden and Finland. Solid biomass still covers almost three-quarters (74.6% in 2021) of the European Union's renewable heat and cold consumption. However, the 2021 share contracted slightly, encroached on by renewable heat and cold delivered by heat pumps. HPs contributed less energy to renewable heat (and cold) in 2021 than solid biomass (an increase of 1.9 Mtoe between 2020 and 2021) for a total of

15.3 Mtoe. Yet the sector's underlying growth is much higher (14.1% for HPs versus 8% for solid biomass). Hence, the HP share of renewable heat (and cold) is rising… from 12.9% in 2020 to 13.5% in 2021. In 2021, HPs gained from the longer heating season and highly conducive market dynamics, resulting in sales of more than 5.2 million HPs (all technologies), compared to 4.5 million units in 2020. The contribution made over the 12 months by HPs thus increased by 1.9 Mtoe to a total of 15.3 Mtoe in 2021. The boost came from countries' policies to promote the electrification of their heat requirements by legislation (France, Finland, Sweden, Denmark, and the Netherlands) and the increase in summer cooling needs (another consequence of climate warming) provided by the reversible heat pump segment. The stage is set for heat pumps to accelerate their contribution to the climate targets this decade, aided by much more proactive building energy refurbishment policies.

Other sectors besides HPs contributed positively to the increase in total renewable heat consumption in 2021, albeit to a lesser extent: biogas (pure or mixed into the grid) gained 0.22 Mtoe, i.e., 4.3 Mtoe), renewable municipal waste (0.17 Mtoe, totalling 4.2 Mtoe), liquid biomass (0.09 Mtoe, totalling 1.2 Mtoe) and geothermal energy (0.04 Mtoe, totalling 0.9 Mtoe. Solar thermal's contribution across the European Union was zero between 2020 and 2021 (a total of 2.5 Mtoe), because of less sunshine in Germany, Denmark and Austria which concealed better momentum in Greece, Italy, Poland, and Spain.

THE SPECIFIC TARGETS OF THE RED II DIRECTIVE

A 37.5% RENEWABLE TARGET OF GROSS ELECTRICITY CONSUMPTION

The renewable electricity output monitoring indicator used to calculate the Renewable Energy Directive (EU) 2018/2001 target is distinct in that it factors in normalized hydroelectric and wind energy output to ignore climatic variations and offer a truer representation of the individual Member States' efforts. What is more, it only includes the electricity output generated from RED II criteria-compliant liquid, solid and gaseous biomass.

The 2021 normalized output figures adopted for the EU-27 were 348.3 TWh for hydropower (345.2 TWh in 2020), and 406.4 TWh for wind power (376.4 TWh in 2020). Eurostat publishes the RED II criteria-compliant solid, liquid and gaseous biomass electricity output figures (pure and mixed into the fossil gas grid) in the SHARES tool's detailed country fact sheets. EurObserv'ER has collated all the sub-indicators and quantifies the compliant biomass electricity output at 159.5 TWh, which means that 13.9 TWh of biomass electricity was omitted.

Total renewable electricity output, namely the numerator used to calculate the renewable share of gross electricity consumption, is thus put at 1 085 TWh in 2021, while total electricity output (the denominator) is put at 892.9 TWh. Thus, the renewable share of gross electricity consumption is estimated at 37.5% in 2021 applying the RED II ((EU) 2018/2001) calculation specifications and terms.

It is hard to compare these figures with the 2020 situation (when a 37.4% share was established), because the calculations were made on the basis of the RED I (2009/28/EC) Directive. In fact, as Eurostat points out in the SHARES tool set up for the purpose of Directive target monitoring calculations, a break in series was introduced between 2020 and 2021 by the change to the legal basis. In the case of electricity output, the main statistical break can be put down to the new solid and gaseous biomass electricity production compliance criteria, in addition to the fact that 13.9 TWh of liquid biomass electricity has been excluded from the calculations. EurObserv'ER reckons that this missing output equates to a difference of about 0.3 of a percentage point in the renewable share of gross electricity consumption. Thus, this share would have been higher if the former calculation rules had applied. Notwithstanding the change to the calculation method, huge country variations in the renewable electricity share are observed. Between 2020 and 2021, the Netherlands' renewable electricity share surged. Although it is one of the countries to have been severely affected by the rollout of RED II, because of its use of imported wood pellets in its major power plants, the Netherlands posted a 4 percentage point renewable electricity share increase between 2020 and 2021 to achieve 30.4%. This increase can be accredited to its heavy solar and wind power sector investment programme. Likewise, Spain has gained 3 percentage points, which takes its renewable electricity share to 46%. Its performance can be put down firstly to a much windier year for wind power generation, which resulted in an extra 1 GW of output and secondly to a significant increase in the country's solar photovoltaic capacity (it added 3.6 GW between 2020 and 2021). On the downside, a dozen countries' renewable electricity shares contracted between 2020 and 2021. Bulgaria's statistics, for example were heavily penalized by the implementation of solid biomass sustainability criteria (it lost 4.8 percentage points), with only 0.3% of its solid biomass electricity deemed to be compliant. We will have to wait twelve months to discover whether or not the differential in indicators can be attributed to the late implementation of the indicator calculation method or whether the electricity produced was ineligible. Only 4.5% of Ireland's solid biomass electricity was deemed to be RED II compliant, which may be explained by the high level of non-compliant pellet imports. This low compliance level is largely responsible for the 2.1 pp drop in its renewable electricity share. The same holds true for Denmark, where only 51.1% of the biomass electricity was deemed compliant, and again, precipitated the 2.7 pp shrinkage of its renewable electricity share.

Graph 3 shows how wildly the Member States' renewable electricity shares vary with their renewable energies potential, primarily hydropower and wind power, and the support policies in place. Austria has the highest renewable electricity share of the EU (76.2% in 2021), ahead of Sweden (75.7%) and Denmark (62.6%). Renewable electricity shares stand at over 50% in Portugal (58.4%), Croatia (53.5%) and Latvia (51.4%). Only five countries had renewable electricity shares of less than 15% in 2021 – Malta (9.7%), Hungary (13.7%), Luxembourg (14.2%), Czechia (14.5%) and Cyprus (14.8%)

A NEW REFERENCE YEAR FOR RENEWABLE HEAT AND COLD

The renewable heat and cold share calculations were also affected for the first time in 2021 by the application of the RED II sustainability criteria for solid and gaseous biomass. However, at 0.1 of a percentage point, the reduction of this share between 2020, when calculations were based on RED I, and 2021 when the RED II specifications were applied is insignificant. As the calculation bases are different, the two indicators cannot be directly compared, unless the fraction deemed non-compliant is reintegrated or subtracted depending on which reference year is used. Because of the extent to which biomass energy is used to produce heat, with the resulting much sharper drop in the biomass energy share of electricity output, the methodology change has a sharper impact on electricity output. The Eurostat SHARES tool quantifies renewable heat and cold at 110.4 Mtoe in 2021, which is 6 Mtoe higher than in 2020, when all the solid biomass and biogas heat was factored in. The denominator, namely all fuels (including heat) used for heating and cooling was quantified at 482.5 Mtoe in 2021, resulting in a renewable share of 22.9%. EurObserv'ER has examined the SHARES tool country fact sheets in detail and reckons that the renewable heat and cold consumption considered should have been very slightly lower (about 109.8 Mtoe), because a few hundred ktoe of liquid biomass and biogas should have been subtracted because of their non-compliance. Eurostat, which is aware of these minor differences caused by an old version of its SHARES tool, has decided against republishing updated version immediately, as it views the impact on the calculation results to be minimal. As 2021 was a year when the RED II specifications were introduced, corrections will be made in the 2022 version of the SHARES tool.

The first-ever specific calculation for renewable cold (put at 463.8 ktoe in 2021) that is now singled out from the heat indicators, also created a break in the renewable energy statistics for heat pumps and other systems capable of producing cold. This distinction enables estimates of the renewable energy contribution to be made for heat pumps that only cater for heating needs (put at 14.7 Mtoe in 2021).

The use of the new solid biomass eligibility criteria through RED II has penalized the renewable heat and cold shares of those countries that declared a non-compliant share just as it did for their electricity outputs. The same countries are the most heavily penalized, namely Bulgaria which lost 11.6 percentage points from its indicator figure between 2020 and 2021 (from 37.2 to 25.6%), Denmark, which lost 9.5 pp (from 51.1 to 41.5%) and Finland (5 pp lost, from 57.6 to 52.6%). Smaller drops were registered by Lithuania, Poland, Ireland, Spain, and the Netherlands. Once again, 2021 should be viewed as the new reference year and we will have to wait another 12 months before we can compare identical methodology indicators.

The application of compliance criteria for solid and gaseous biomass made 2.6 Mtoe of renewable heat ineligible in 2021 (2.3 Mtoe for solid biomass and 0.3 Mtoe for biogas), according to the EurObserv'ER calculations. This shortfall equates to roughly a 0.5 percentage point difference in the renewable

heat and cold share. Hence, had the same calculation methodologies been applied to 2020 and 2021, renewable energies would have made positive growth in heat and cold consumption.
The renewable heat and cold share is naturally higher in the forest Member States, as biomass is far and away the main source of renewable heat. Sweden fully exploits its forestry potential (industries and heating networks) and has generalized the use of domestic heat pumps. Share of energy from renewable sources for heating and cooling according to the specification of the (EU) Directive 20018/2001 was thus measured at 68.6% in 2021 in Sweden. In the countries where it is the majority, there are also Estonia (63.1% in 2021), Latvia (57.4%) and Finland (52.6%), but is a minority player in the Benelux countries (12.9% in Luxembourg, 9.2% in Belgium and 7.7% in the Netherlands) and in Ireland (5.2%).

CAN THE RENEWABLE SHARE BE DOUBLED BY 2030?

So, 2021 marks a new departure, a new reference year. It puts the global energy share supplied by renewable sources at 21.8%. This share will have to be more or less doubled if the European Union is to realize its climate goals depending on the new target chosen when RED II is recast.
For the reasons stated above, the overall renewable share for 2021 compared to that of 2020 calculated against the yardstick of the previous directive should not be interpreted as a 0.2 percentage point decline, but by the legislator's resolve to make renewable energy growth as sustainable as possible with minimal impact on biodiversity and maximum GHG reduction efficiency. Incidentally, EurObserv'ER reckons that if the same rules had been applied retroactively in 2020, the renewable share of gross total final energy consumption would have grown by 0.1 to 0.2 percentage points between 2020 and 2021.
In a divergence from the previous directive, the European Union countries no longer have to set formal national targets but are obliged to suggest their own targets and draw up their own national development plans under Horizon 2030. It will be up to the European Commission to assess these plans and take EU-wide measures to ensure they match the European Union's global targets. Thus, the progress made by each Member State using an indicative trajectory, as prescribed by the previous directive no longer needs to be monitored. The only benchmark will be the progress made by each Member State's renewable share and the common pace that will enable the community's 2030 target to be met. Consequently, in 2021, the transfer and solidarity mechanisms that enable the "laggard" countries to meet their national targets were used very frugally. The amounts dropped from 1 909.9 ktoe (received by the requesting countries) to 305.6 ktoe in 2021. The Netherlands and Ireland stopped using these transfer mechanisms, which contributed to the drops in their renewable shares between 2020 and 2021. On the other hand, Belgium (209.5 ktoe received), Luxembourg (68.8 ktoe received), Slovenia (17.9 ktoe received) and Malta (5.2 ktoe received) used the mechanisms in 2021 to improve their renewable share totals. Germany received 4.3 ktoe from Denmark stemming from a cross-border tender for a solar photovoltaic plant. The European Commission continues to encourage use of these transfer mechanisms and they are still used for joint ventures, such as investments made in common infrastructures that facilitate the integration of renewable energies, as well as common resources being made available for developing innovative technologies or working on storage initiatives. The Directive also provides for these transfer mechanisms and joint ventures to benefit third countries outside the European Union through green hydrogen or biomethane imports. Examples of joint ventures are the agreement between Belgium and Denmark for common investments in submarine grids so that Belgium can benefit from future Danish offshore wind farm output. Furthermore, some countries plan to achieve their national targets for 2030 via transfer mechanisms with other countries because of lack of space in their own country. An illustration of this is the Luxembourg accord with Denmark. New cross-border renewable energy projects were approved by the European Commission in August 2022 such as the "Alliance for a European, cross-border green hydrogen value chain" CEO project undertaken by Germany, Italy, the Netherlands and Spain and the Elwind project, a joint, hybrid offshore wind energy project in the Baltic Sea between Estonia and Latvia.
As soon as the 2018/2001 Directive was adopted in December 2018, it was coupled with a clause to raise its main global renewable energy share target by 2023. A year later, on 11 December 2019, the Commission presented its Green Deal that aims to turn Europe into a climate neutral continent by 2050 by supplying clean, affordable and secure energy. In an effort to achieve this, the 27 European Union Member States have undertaken to reduce their emissions by at least 55% compared to 1990 levels by 2030. This ambition, which is capable of combatting climate change, prompted the Commission to put forward a new legislative package in July 2021 to recast the RED II Directive, harmonize its renewable energy targets with its new climate goals and enable this Green Deal to be rolled out. As briefly mentioned in the foreword to this conclusion, the European Commission suggested raising the binding target of renewable sources in the EU's energy mix to 40% by 2030 and promoting the use of low-emission fuels, such as green hydrogen produced from renewable energy, primarily in industry. In May 2022, the Commission rushed through the REPowerEU Plan, that plans to raise the renewable energy target to 45% for 2030 to accelerate transition and gradually minimise the EU's energy reliance on Russia, by accelerating the development of heat pumps, biomethane and green hydrogen and by rolling out an ambitious Solar Plan. At the end of February 2023, the Member States were still negotiating the update of the renewable energy policy framework and terms for achieving the new 40 or 45% target for 2030. It is expected that the recast Renewable Energies Directive will be adopted in the coming months, hoping that the European Council and the European Parliament will quickly overcome their latest differences, in particular on the place to be given to primary woody biomass in the new renewable objectives. As time has passed, the Member States have less than 8 years to collectively and jointly achieve their 2030 target. ■

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

The share of RES in the building stock has already grown strongly in recent years in Europe. In general, RES are particularly successful in the area of electricity generation. In the heating and cooling sector, RES consumption is still lagging somewhat behind. 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). 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 the main focus on self-consumption of electricity from photovoltaics.

INTEGRATION OF RES HEATING AND COOLING

Heating and cooling demands are satisfied using a high variety of different decentralised technologies that are integrated into the respective building, or centralised heating via district heating. Decentralised heating technologies in buildings include heat pumps, electric boilers, biomass boilers, and solar thermal collectors. In light of the ambition to further decarbonise the heating and cooling sector, especially in highly populated urban areas, urban infrastructures are gaining importance. Relevant urban infrastructure and generation plants for the integration of RES in buildings comprise mainly district heating networks including biomass CHP and heat-only plants, geothermal plants as well as solar thermal collector fields and large-scale heat pumps.

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 heterogenous building stock and the long life cycle 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 display the degree of usage of the respective RES in the building sector, as well as its use. 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 of 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 data on sales were not available for all technologies or countries, the number of exchanged systems is assessed based on the change in market stock share. Although solar thermal energy is mainly used in combination with other systems, it is separately listed here to show its significance and dynamics.

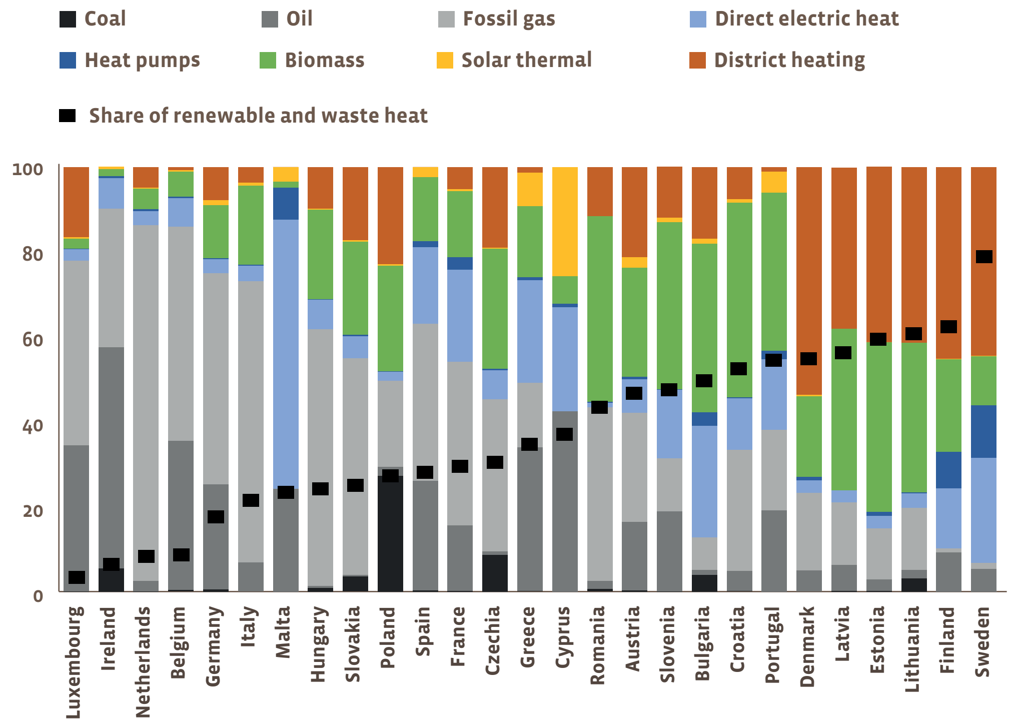
The **shares of RES electricity for heating** in the building stock are shown to display the increasing importance of electricity in the heating sector. By dividing the electricity consumption from RES for direct electric heating as well as for heat pumps by the final heat demand in buildings, this indicator 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 decentralised technologies in buildings. For this purpose, the total of the 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 2020



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, fossil gas, oil, renewables (biofuels) and wastes, 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

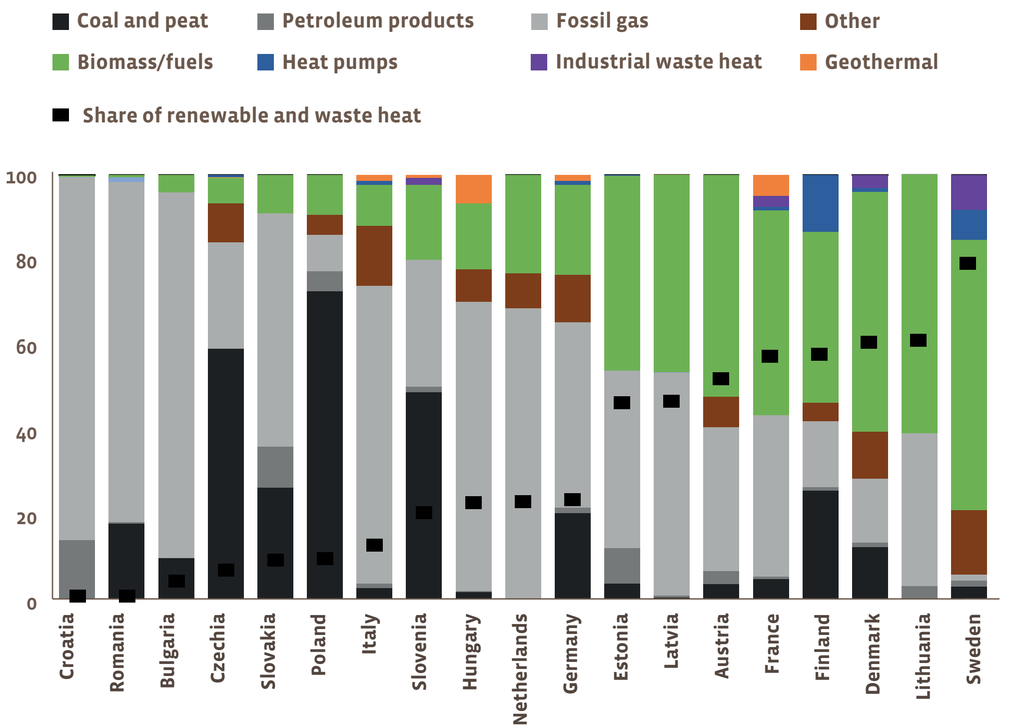
Figure 1 presents the consumption shares of RES heating and cooling in 2020 for residential buildings and services. This share is a combined indicator for the integration of RES in buildings and urban infrastructure. It depicts the share of RES in the total final energy demand for heating and cooling. 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, and to a smaller extent in Hungary, Slovakia and Belgium, gas is still dominating the heating system. Oil boilers are an important heating source in Cyprus, Ireland, Luxembourg and Greece. Even though the heating market experiences a constant decrease in oil boilers, other countries such as Ireland, Cyprus, Belgium, Luxembourg, Greece, Spain and Germany and Malta still have a decent share of this technology in their heating mix. In Poland, a large share of coal is used for heating while direct electric heating plays a role in Malta, Bulgaria, Sweden, Cyprus, Greece and France. District heating is especially strong in the Scandinavian countries as well as in the Baltic and other east European countries. In the latter countries, district heating has a long history and relies on existing networks.

The share of renewable and industrial waste heat in Figure 1 depicts the total of RES shares in decentral heating and central district heating including RES shares in electricity used to generate heat. RES and waste heat dominate in Sweden (80%), Finland (63%), Lithuania (61%) and Estonia (60%), Latvia (57%) and Denmark (55%). In these countries, a large part of the consumption is provided by district heating based on RES (mainly biomass) and industrial waste heat. In several other countries, a high RES share is mainly driven by the decentral use of biomass. Portugal (55%), Croatia (53%) and Bulgaria (50%) reach high shares due 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 Slovenia (41%), Estonia (39%), Latvia (38%) and Portugal (34%). Decentral heat pumps are growing in importance every year. However, higher shares are still only reached in Scandinavian countries such as Sweden (12%) and Finland (9%). 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 (26%) or Greece (8%).

2

District heating supply mix in 2020



***Source:** Own assessment based on diverse sources: Eurostat, DHC Trend project and data from national statistic institutes of the MS.* *Notes: Based on 2020 data for: BG, DE, AT, FI; 2019 data for: SE; 2018 data for: HR, RO, NL, PO, CZ, SK, SI, HU, IT, EE, FR, DK, LT. Other includes renewable and non-renewable forms of energy such as 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).*

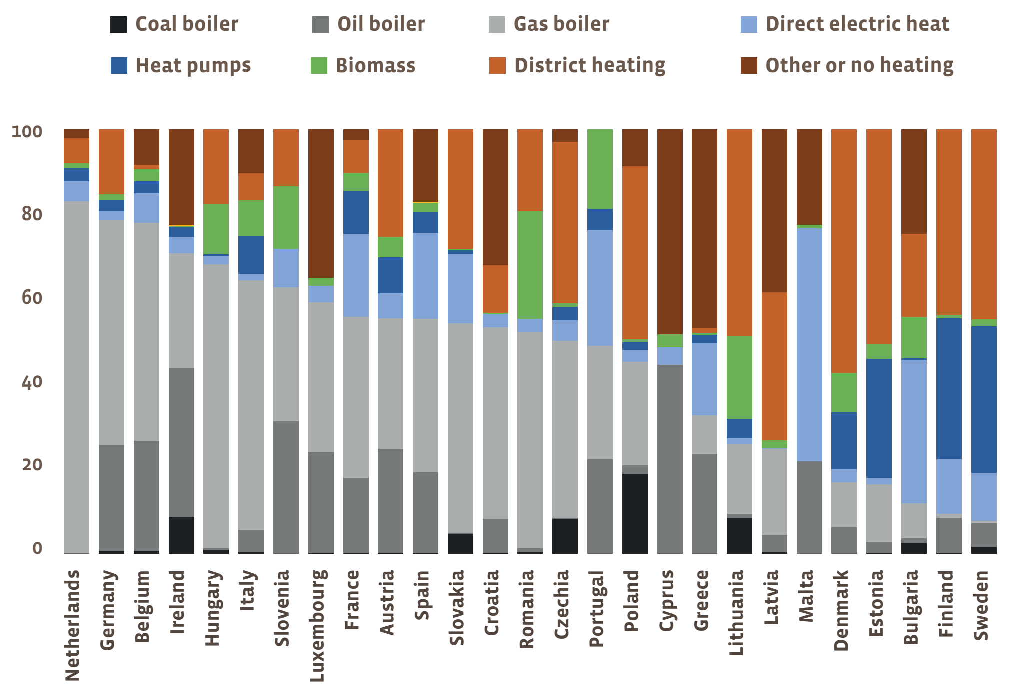
SHARE OF RES IN DISTRICT HEATING

Figure 2 depicts the district heating supply mix in the countries where district heating covers at least 2% or more of the heating and hot water demand in 2020. In most countries, the existing district heating networks still rely on fossil fuels with fossil gas and coal as the dominant sources. Coal and peat are mostly used in Poland (73%), Czechia (59%) and Slovenia (49%). Oil as a source for DH consumption still plays a relevant role in the supply mix of Croatia (14%), Slovakia (10%) and Estonia (8%).

The most dominant RES in district heating are biofuels such as biomass, biogas and renewable waste. Especially in Sweden (63%), Lithuania (61%), Denmark (57%), Austria (52%), France (48%), Latvia (47%), Estonia (46%) and Finland (40%) biofuels are the most important source in district heating. Large-scale heat pumps are mostly used in Finland (14%), Sweden (7%) and Denmark (1%). Waste heat from industrial processes decreases in most countries compared to the previous year, especially in Bulgaria and Poland. This decline could be reasoned by shutdowns of industrial processes due to the Covid crisis. The highest share of industrial waste heat can be observed in Sweden (9%). 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 therefore is included in "Other". Denmark is the only exception, having a relatively high share of solar thermal energy of up to 2%.

3

Market stock shares of RES in heating in 2020



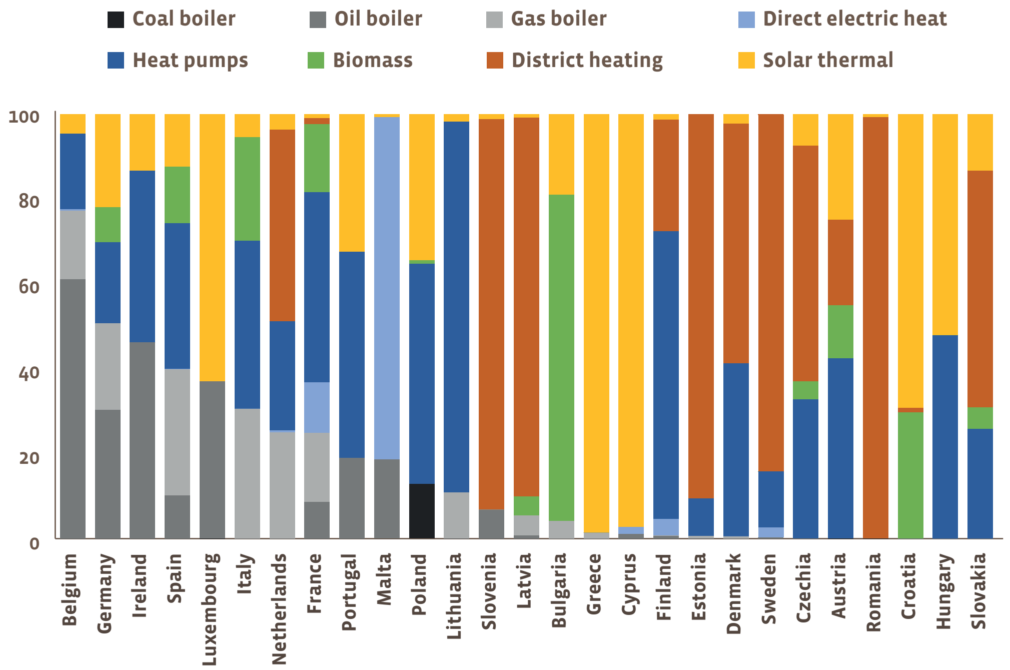
***Source:** Own assessment based on diverse sources: Eurostat, EHPA Market and Statistic Report, Bioenergy Europe Statistical Report and Solar Heat Europe Market Statistics.* *Notes: Solar is not counted as an alone standing system as it is used mainly in combination with other systems. District heating is calculated based on the number of served citizens divided by the average household size. Market stock data of coal, oil and gas boilers are based on data from 2019 adjusted with change in consumption (adjusted with HDD).*

MARKET STOCK AND MARKET SALES SHARES OF RES IN HEATING

Figure 3 depicts the technology shares in the building stock, i.e. technology shares of dwellings. In contrast to figure 1 above, it shows the share of households 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 very high for Cyprus and Greece. It is also considerably high for Latvia, Luxemburg, Ireland and Malta. 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, in most countries this share is decreasing compared to the previous year, indicating that data availability is increasing.

4

Market sales shares of RES in heating in 2020



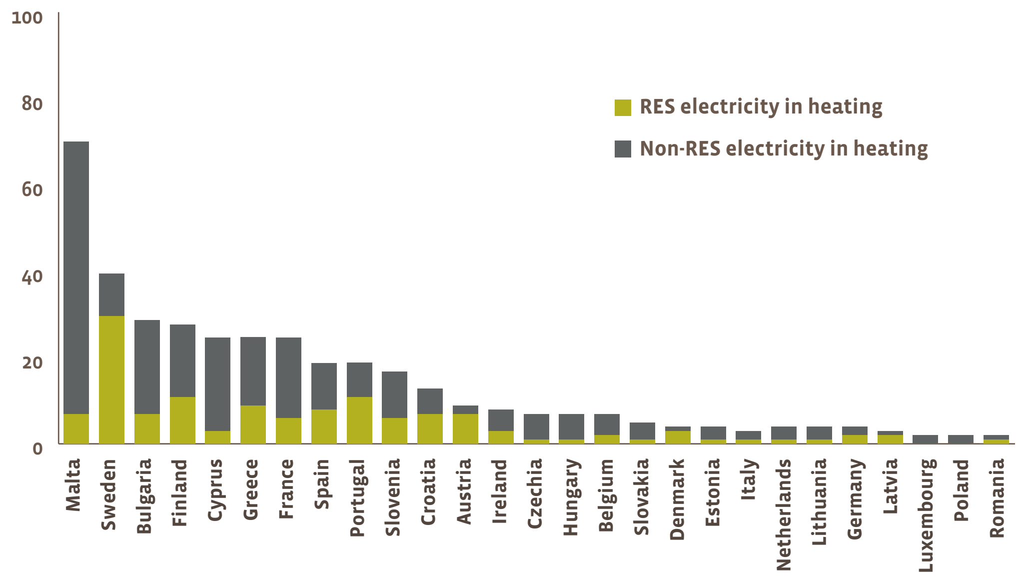
Source: Own assessment based on diverse sources: Eurostat, EHPA Market and Statistic Report, Bioenergy Europe Statistical Report and Solar Heat Europe Market Statistics. *Notes: Fossil fuel boilers, electric boilers and district heating are calculated based on the change in market stock share. One unit of solar thermal contains 4 m² per household.*

Figure 4 shows the market sales share of RES technologies used for heating and cooling. 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. Thus, it shows the dynamic in the market, i.e. the RES technology expansion in this sector.

District heating shows very high dynamics in most countries, especially in Romania, Slovenia, Estonia and Latvia. Decentral heat pumps show a high dynamic in the markets of Lithuania, Finland, Portugal, Hungary, Poland, Austria, France and Denmark. Direct electric heating technologies, which had significant sales shares in 2019, are pushed out by heat pumps and only have a high share of sales in Malta. Solar thermal energy shows very high sales rates in countries where it has already a high share, such as Cyprus and Greece. However, also in Croatia, Luxembourg and Hungary, there are significant sales shares. Biomass boilers display a high dynamic in Bulgaria, Croatia, Italy and France. Sales of fossil-based heating systems are still at a high level in countries like Belgium, Germany, Ireland, Spain, Luxembourg and Italy. Overall, the RES market sales share shows a higher dynamic compared to the previous year in most MS, and thus, RES in heating is taking off and increasingly contributing to the GHG emission targets.

5

Share of RES and fossil-based electricity used in heating in 2020



Source: Own assessment based on other indicators and Eurostat.

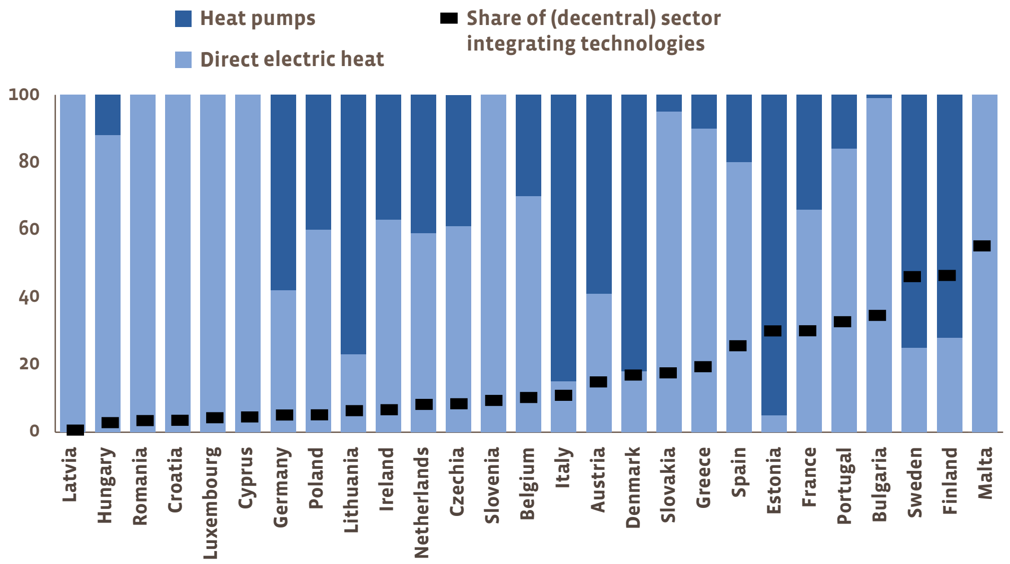
SHARES OF RES ELECTRICITY FOR HEATING

With respect to rising RES shares in the power sector, electric heating gains significance. Figure 5 shows the share of RES electricity used for heating residential buildings and services, including the share of electricity in district heating. This indicator, thus, shows the share of RES electricity used in small and large-scale direct electric heaters as well as in small and large-scale heat pumps.

Even though electricity as a source of heating is gaining importance, the EU average of RES electricity for heating purposes is still below 5%. Leading countries in using RES electricity in their heating mix are Malta, Sweden, Bulgaria, Finland, Cyprus and Greece. France, Spain and Portugal have also a high share of electricity in their heating mix. However, in Malta, Bulgaria and Cyprus electricity is to a large extent still generated from fossil fuels. The heat demand in Malta and Cyprus is quite low, thus, the high fossil share in electricity is not significant in absolute terms, while in Bulgaria it is the opposite case.

6

Market stock share of (decentral) sector integrating technologies in 2020



Source: Based on the market stock indicator. *Note: "Share of (decentral) sector integrating technologies" is the market share of heat pumps (HP) and direct electric heating (DEH) systems, i.e. number of HP+DEH of total number of heating systems.*

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 sector integrating technologies in buildings, such as (decentral) direct electric heaters and heat pumps. In Malta, Finland and Sweden market stock shares are above 40% and in Bulgaria, Portugal, France and Estonia market stock shares of 30% or more can be observed. However, in half of the countries, decentral direct electric heaters and heat pumps still play a minor role with shares of less than 10%.

CONCLUSION RES HEATING AND COOLING INTEGRATION IN BUILDINGS

Overall, fossil gas boilers remain the most commonly used heating technology, followed by district heating. In recent years district heating gained importance in decarbonising the heating and cooling sector, especially in highly populated urban areas. Coal boilers, as well as oil boilers, are slowly disappearing as the consumption shares as well as the market sale shares reveal. Nevertheless, due to the long life cycle of these boilers and the ongoing sales of fossil-based boilers, it can be assumed that they will play a significant role in heating even in the future, and thus counteracting the decarbonisation efforts in the heating and cooling sector. This is especially the case for gas boilers, which still receive financial funding in several countries. Reasons for this state support are the prospect of using synthetic fuels or green hydrogen in such boilers.

Albeit the relatively high dynamic of heat pumps in some countries, the consumption shares remain low, compared to fossil fuel-based heating. Nevertheless, RES electricity, used in direct electric heaters and heat pumps, has the potential of becoming a dominant option as a renewable source for heating and cooling applications in the residential and service sector. Similarly, solar thermal plants have quite some potential and their dynamics are quite high in some countries.

In summary, in some countries RES consumption, as well as the dynamic in sales of RES systems, is high. In particular, heat pumps are increasingly employed in Scandinavian countries while biomass (still) plays a significant role in several eastern European countries. Overall, there is more dynamic in renewable (and waste) heating, than in the previous years. However, more action is needed to reach the energy and climate targets.

INTEGRATION OF RES ELECTRICITY (SELF-CONSUMPTION)

As already pointed out, RES are particularly widespread in the area of electricity generation. In addition to utility-scale installations, decentralised agents such as households, business owners or cooperatives have become active in this area, producing and consuming their own electricity as either individual or collective self-consumers, depending on the ownership of the assets that are used for electricity production. Collective self-consumption can for instance take place at the flat, building, neighbourhood or village level.

The following chapter looks into the integration of RES electricity at the building level, focusing on self-consumption of photovoltaics (PV) as the most mature and affordable technology available. Other technologies, such as small wind turbines, are less common to date. Small-scale thermal power stations or hydropower can play a role for certain industrial self-consumers, but are equally not in the focus of analysis.

In general, it can be said that despite being a widespread and growing phenomenon in the EU energy landscape, self-consumption is still not well monitored and systematically evaluated, hence difficult to assess in its entirety. Therefore, the objective of the present analysis is to assess self-consumption of photovoltaic-based electricity within the EU from various angles. This is done by combining empirical data collection and technical-economic approaches. Analysing trends in self-consumption is important because RES electricity self-consumption does not only contribute to increasing RES penetration in the EU, but also plays a key role in engaging citizens and spreading awareness regarding renewable energy in general and thus can help to "democratise" the energy transition.

Over the last decade, the cumulative installed capacity of solar PV systems has increased significantly across EU Member States (MS). This development goes along with incentive mechanisms provided by MS to overcome financing gaps of solar RES electricity systems. In general, it is important that MS act in accordance with EU Directive 2018/2001 on the promotion of the use of energy from renewable sources, ensuring that electricity generated for self-consumption or fed into the grid is not subject to "discriminatory or disproportionate procedures and charges, and to network charges that are not cost-reflective". Charges and fees can only be levied if certain conditions are met. MS also have to ensure that excess electricity can be traded between market participants. That said, self-consumption regulatory schemes vary considerably among MS and countries provide different incentives regarding the potential injection into the grid of surplus energy. One also needs to distinguish between building applied (BAPV) and building integrated (BIPV) systems as these are sometimes supported in a different manner, e.g. in France. BAPV systems fulfil only one function – electricity generation – and are attached or added to building surfaces, whereas BIPV systems, which are less widespread to date, offer a dual functionality as they are able to produce energy while also serving as a construction element.

In general, building owners or owners of PV-based electricity generation systems have to decide on the allocation of the self-generated electricity. They decide between either self-consumption or grid injection of the produced power depending on economic factors and preferences. In general, it can be said that the allocation of self-generated electricity is depending on policy as well as market factors. In addition to the revenues from feeding in self-generated electricity influencing 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 storage technologies 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

The PV self-consumption share is defined as the share of the total PV production directly consumed by the PV system owner and assessed for a selection of countries, namely Italy, France, Germany, Spain, Lithuania, Malta, Portugal and Sweden. This selection of countries is based on the rationale to include countries with high shares and low shares of PV in their overall electricity generation as well as Member States from different parts and regions of Europe. In forthcoming reports, additional countries will be included in the analysis to ultimately cover all EU MS.

To assess RES self-consumption in buildings and thus attain a holistic view, three different approaches are combined.

First, an **empirical assessment** is conducted, using different data sources (e.g. national statistic reports and websites, studies and information compiled by different Ministries, etc.). The empirical data delivers information about the self-consumption shares in different countries as well as cumulated PV capacities, but without particular focus on small-scale residential PV systems.

Second, the **technical assessment** assesses the technical self-consumption share defined as the overlap of the generation profile (solar 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 is due to limited data availability regarding storage and balancing for home energy use. Residential PV systems are also not further distinguished by their deployment location and building integrated (BIPV) inside the roof or facade as well as building adapted (BAPV) installations on top of the roof or ground-mounted located directly next to the building are added up and only grid connected systems considered. The calculation relies on residential PV installations with an estimated capacity of up to 10 kWp. If available data is such that it groups the small-scale capacity range of PV residential installations in different system sizes (e.g. smaller than 5 kW or up to 20 kW) those are also considered.
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. "Load" is 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 a standard load profile. 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 amounts 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 and includes the production of all installed PV systems in a country, regardless of their capacity.

As for the **economic assessment**, it is assumed that households are rationale economic actors seeking to minimise their electricity costs. 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 tariff changes during a given year, e.g. in Germany, 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

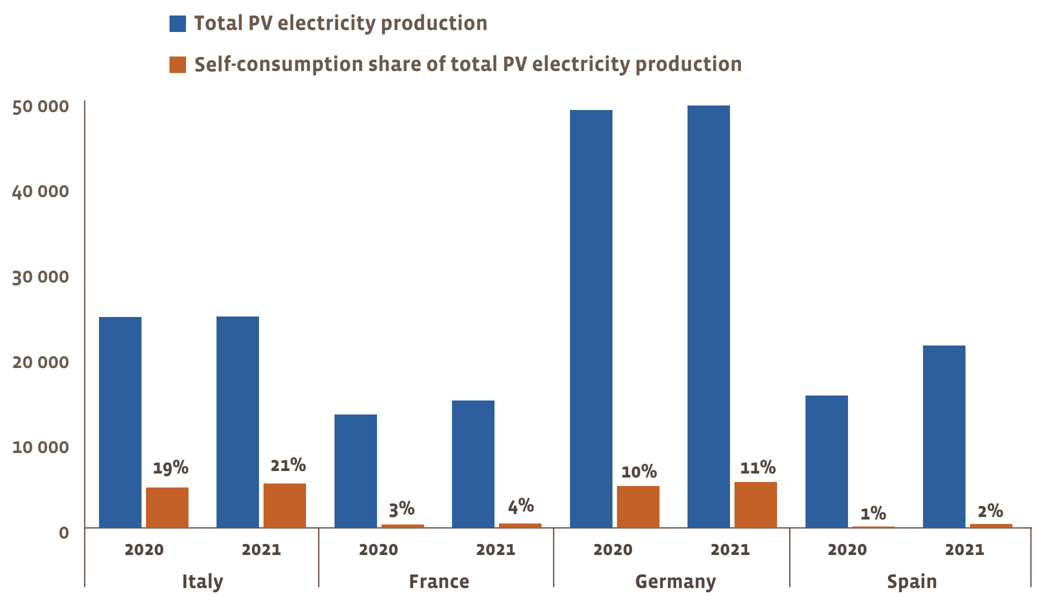
RESULTS OF THE EMPIRICAL APPROACH

In a first step, the deployment of PV on buildings as well as the share of self-consumed PV is assessed empirically, using different data sources. In the literature, a distinction is made between decentralised and centralised PV installations, as well as between BAPV and BIPV. However, official statistical data collected by national entities usually does not offer this level of granularity and assigns self-consumption of all types of PV installations to one group.

For presentation reasons, PV based electricity production and self-consumption is illustrated in two figures, Figure 7 and Figure 8. 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 eight 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 2,500 GWh per year (Lithua-

7

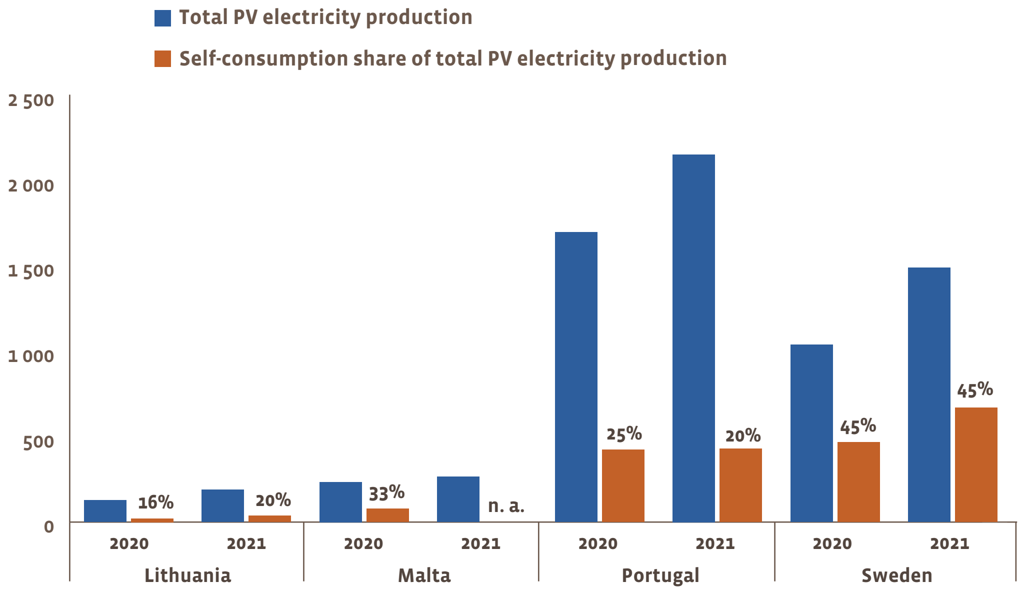
Electricity production from photovoltaics in 2020 and 2021



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)

8

Electricity production from photovoltaics in 2020 and 2021



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)

nia, Malta, Portugal, Sweden).

As can be seen, self-consumption shares vary considerably among the investigated MS, ranging from close to 0% to 45%. In the sub-set of countries analysed, shares are highest in Sweden, remaining constant at 45% between 2020 and 2021 despite a significant increase in total PV electricity production. As for Malta, the 2020 self-consumption share reported was 33%, but with no data available for 2021. Also, Portugal and Italy reported high self-consumption shares, but with an opposite trend. While the Italian data shows growth in self-consumption from 19% in 2020 to 21% in 2021, the self-consumption share in Portugal has fallen from 25% to 20% within the same period of time. While Portugal experienced an expansion in total electricity production from PV, production remained relatively constant in Italy. Lithuania experienced growth in both total PV electricity production and the self-consumption share, increasing from 16% in 2020 to 20% in 2021. As for Germany, numbers suggest that the (modest) increase in total PV electricity production from 2020 to 2021 was proportional to the increase in self-consumption from PV. From the sub-set of countries analysed, reported self-consumption shares are lowest in France and Spain, staying below 5% in both years.

Since there exist no uniform definition and standards on how to meter and calculate self-consumption, the accounted figures in national statistics are only partially comparable. Over the coming years improvements of data availability, accessibility and quality of data on self-consumption can be expected.

RESULTS OF THE TECHNICAL APPROACH

The technical assessment takes into account technical aspects, most notably the generation and load profile of households. It assesses a potential, technical self-consumption share of PV based electricity. It is defined as the overlap of the generation profile (PV energy production) and load profile (home energy use). Thus, it represents a theoretical, maximum self-consumption potential.

Table 2 depicts this theoretical maximal self-consumption share in 2020 for selected countries.

2

Technical maximum self-consumption shares per year per country

	2020
Germany	58%
Spain	61%
France	59%
Italy	58%
Lithuania	53%
Malta	n/a
Portugal	55%
Sweden	n/a

Source: Own assessment and calculation based ENTSO-E, Eurostat, Odyssee indicators database

In times when the production is higher than the load, self-consumption is equal to the load because the total electricity demand can be covered by the PV production. The excess electricity can be fed into the grid. In the trivial case, if the production is zero, the self-consumption is also zero. During times when the PV system is producing less electricity than demanded, for example in the morning hours, all of the produced electricity is self-consumed and the remaining demand is withdrawn from the grid.

The approach does not include storage systems or demand side management, i.e. electricity consumption cannot be shifted. As the technical self-consumption share is based on different assumptions and approaches, the calculations deviates from the empirical grounded self-consumption shares. However, it becomes clear that there still seems to be significant potential left for a better exploitation of the self-consumption potential in most countries. The considerable gap between empirical self-consumption and technical maximum shares suggests that self-consumption is far from being fully exploited from a technical perspective. The calculated optimal shares are in line with values found in the literature for different types of consumers, such as households or offices. In general, the presence of battery systems can boost demand coverage considerably.

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 empirical self-consumption shares might also be of 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, i.e. when it comes to electricity investment decisions in context to self-consumption they decide between 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 assessment displays for each country the most profitable "self-consumption scenario", which indicates the most likely investment decision.

Table 3 depicts the results for eight selected countries over time.

3

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

	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Germany	Feed-in	Feed-in	Feed-in	Self-consumption	Self-consumption	Self-consumption	Self-consumption	Self-consumption	Self-consumption	Self-consumption	Self-consumption
Spain	Feed-in	Feed-in	Self-consumption	Self-consumption	Self-consumption	Self-consumption	Self-consumption	Self-consumption	Self-consumption	Self-consumption	Self-consumption
France	No invest	No invest	No invest	No invest	No invest	No invest	No invest	Feed-in	Feed-in	Feed-in	Feed-in
Italy	Feed-in	Feed-in	No invest	No invest	Self-consumption	Self-consumption	Self-consumption	Self-consumption	Self-consumption	Self-consumption	Self-consumption
Lithuania										Self-consumption	Self-consumption
Malta										Feed-in	Feed-in
Portugal	Feed-in	Feed-in	Feed-in	Feed-in	Feed-in	Self-consumption	Self-consumption	Self-consumption	Self-consumption	Self-consumption	Self-consumption
Sweden										Self-consumption	Self-consumption

Feed-in — No invest — Self-consumption

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

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

This is also 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 six out of the eight analysed countries in 2020. This suggests that in a large number of countries incentives are put in place to stimulate self-consumption. In France 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 self-consumption less attractive.

It is important to bear in mind that the decision to self-consume or not will vary from consumer to consumer and 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. Thus, the results should be considered under the respective conditions. Outcomes of course also depend on (non-economic) preferences, e.g. a preference for sufficiency, the exact reference electricity price or additional support mechanisms. However, the results depicted above offer a first orientation on the most likely decision taken by households in a given country in a given year, hence providing an indication on whether self-consumption is profitable or not.

CONCLUSION RES ELECTRICITY INTEGRATION IN BUILDINGS

The present chapter analyses RES electricity integration in buildings and self-consumption combining different approaches. While the economic approach highlights the countries in which self-consumption is economically feasible and makes good economic sense, the technical approach outlines the theoretical share of self-consumption without considering storage options. The empirical results show the actual situation per year and country and include impacts of storage options (mainly batteries), non-economically based consumption decisions and data quality issues.

Overall, it can be concluded that the technical potential for self-consumption of electricity is large. This also holds true for the economic potential in most countries where self-consumption is the dominant scenario. From the empirical analysis, we can see that there are likely still large discrepancies between actual level of self-consumption and technical optimum, especially in France and Spain. The economic analysis suggests that self-consumption is an attractive option in most countries.

FOCUS: MARKET SHARES OF THE POWER GENERATING CAPACITIES INSTALLED IN 2021 BY TECHNOLOGY

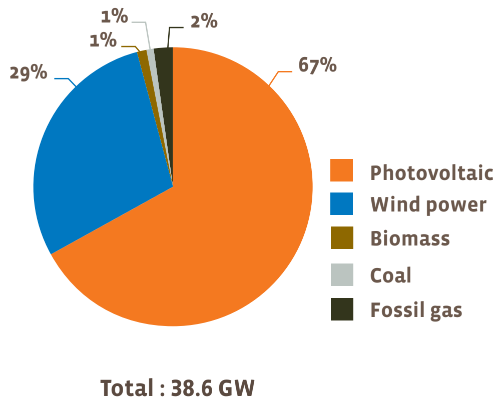
In 2021, 97% of newly connected electricity capacity within the European Union was related to renewable technologies. Photovoltaics remains by far the leading technology ahead of wind power.

Graph 1 shows that in 2021, 97% of newly connected electricity capacity in European Union countries came from renewable technologies (compared to 91% in 2020), i.e. 37.3 MW out of a total of 38.6 MW. Photovoltaic is the most representative sector with 25.7 MW installed, i.e. 67% of additional electrical capacity in 2021. Driven by a very active European market, this technology establishes its predominance a little more because in 2020 its share had been 55 %. Wind power remains around 30% (29% in 2021 against 32% in 2020) despite a year 2021 marked by low installed capacity at sea. As for fossil fuels, coal and gas together represented 3% and no new nuclear capabilities have been identified.

Graph n°2 presents the details of each of the Member States in descending order of the additional electrical power connected in 2021 and only four countries commissioned fossil power plants in 2021. Firstly Poland, which has 496 MW at from coal and 190 MW from gas. These powers represented 1.87% of the total additional electrical capacity connected in the country. Another Member State to have added fossil fuel units to its electricity fleet: Germany. The country has connected 186 MW of electrical power to fossil gas, i.e. only 2.4% of the total additional electrical capacity connected in 2021. Finally, Slovenia and Romania have also expanded their electrical production facilities with new capacities operating from of fossil gas (respectively 62 and 41 MW). It should be noted that Romania was the only member country of the European Union where the capacities from fossil technologies connected in 2021 were higher than those from renewable energy. ■

1

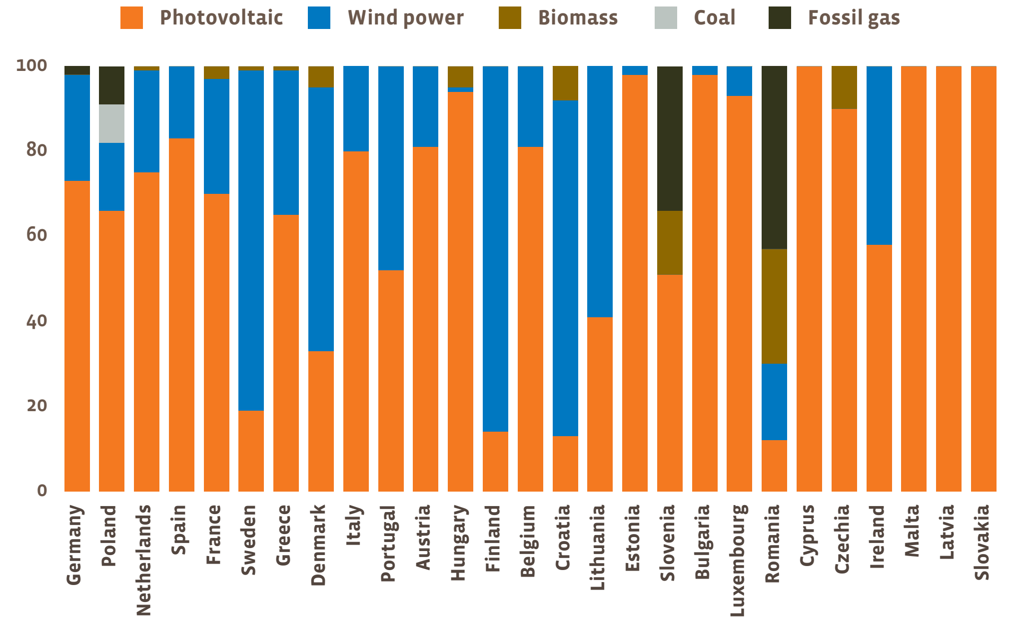
Distribution of additional electrical capacities connected to EU-27 grids in 2021 by technology



Source: EurObserv'ER - Enerdata

2

Distribution of additional electrical capacities connected to EU-27 grids in 2021 by technology



Source: EurObserv'ER - Enerdata

FOCUS: ELECTRICITY STORAGE CAPACITIES

THE CHALLENGES OF ELECTRICITY STORAGE

As the share of renewably-sourced electricity consumption continues to grow in Europe, the challenges posed by this energy's storage have become a core issue. The energy landscapes of the European Union Member States are currently being transformed through the electrification of uses, reduction in fossil energy consumption, and the development of renewable energies on electricity grids. Problems can arise when electricity outputs from variable cycle renewable technologies (e.g., photovoltaic or wind energy) are at odds with consumers' demands of power grids. This is when electricity storage acts as a lever to facilitate RES integration into the grids and markets.

Renewable energies have much to gain by increasing their ability to be harnessed to safeguard against certain situations, such as sales price collapse episodes on the wholesale markets partly induced by a surplus in production capacity to consumption. In addition, the reduction in Russian gas imports and the increase in its price, generally covering consumption peaks, encourages us to strongly develop other solutions for stabilizing the electricity network. Power grids, over and above their transmission role linking producers to consumers, are responsible for properly running the electricity market. This implies they must supply a number of services to players, producers, aggregators, suppliers, and consumers. The responsiveness offered at certain key points of the grid by storage facilities can optimise load and frequency fluctuations, with the aim of protecting against the risks of local outages, or worse still, generalised blackouts.

The available storage equipment technologies are listed in Table 1, grouped by family. Currently, the most commonly used electricity storage solution in Europe in terms of available capacity is mechanical, specifically in the form of pumped hydro storage (PHS) facilities with two water reservoirs. During low-electricity demand periods, the plant pumps water from the lower to the upper reservoir to capture it, so that when the grid is faced with peak electricity demand, the water can be released through the turbines. This then sends it back to the lower reservoir. They offer the power grid most of its flexibility in conjunction with other hydroelectricity infrastructures. However, not all countries have suitable natural geographical reliefs to develop this type of hydropower facility.

The other mature electricity storage solution is the use of batteries harnessing electrochemical reaction. The most widespread technology is lithium-ion battery technology that uses an electrolytic lithium-ion solution and usually cobalt (positive terminal) and graphite (negative terminal) electrodes.

There are also electricity storage technologies in the form of heat that raise the temperature of a fluid or solid, change the physical state of a material, or produce endothermic (heat-absorbing) chemical reactions. Steam turbines use this restored heat by reversing the state change to generate electricity. The main development in Europe has been in molten salts sub-technology, but in a fairly restricted context: that of electricity storage on concentrated solar power sites. The last type of technology involving chemical reactions is known as "power-to-gas" (P2G) which offers potential even if the ↘

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
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 2022 based on the Database of the European energy storage technologies and facilities.

2

Electricity storage capacities installed in the EU-27 at the end of 2022 (in MW)

	Mechanical		Thermal		Electro-Chemical			Chemical	
	Pumped hydro storage	Other technologies	Molten salt	Other technologies	Li-ion	Other technologies	Unknown electro-chemical technologies	Power to gas	Total
Germany	6 719.2	321.0	0.0	1.5	572.3	4.4	0.0	15.2	7 633.6
Italy	7 330.6	0.0	4.7	0.4	17.4	39.1	0.0	1.2	7 393.3
Spain	4 703.8	0.0	1 069.2	61.0	7.0	0.0	0.0	0.0	5 841.0
Austria	5 015.8	0.0	0.0	0.0	2.5	0.0	0.0	0.0	5 018.3
France	4 207.3	0.0	9.0	12.0	38.3	1.0	94.6	0.0	4 362.2
Portugal	2 991.8	0.0	0.0	0.0	6.0	0.0	0.0	0.0	2 997.8
Poland	1 746.2	0.0	0.0	0.0	1.3	0.0	0.0	0.0	1 747.5
Belgium	1 304.0	0.0	0.0	0.0	107.1	1.4	0.0	0.0	1 412.5
Bulgaria	1 399.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1 399.0
Luxembourg	1 294.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1 294.0
Czechia	1 175.0	0.0	0.0	0.0	3.0	0.0	0.0	0.0	1 178.0
Slovakia	1 017.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1 017.3
Lithuania	900.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	900.0
Greece	699.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	699.0
Croatia	619.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	619.3
Ireland	292.0	0.0	0.0	4.6	111.0	0.0	19.0	0.0	426.6
Slovenia	185.0	0.0	0.0	0.0	12.6	0.0	0.0	0.0	197.6
Sweden	91.0	0.0	0.0	10.0	5.0	0.0	0.0	0.0	106.0
Romania	91.5	0.0	0.0	0.0	1.0	0.0	0.0	0.0	92.5
Netherlands	0.0	0.0	0.0	0.0	34.4	3.0	0.0	0.0	37.4
Hungary	0.0	0.0	0.0	0.0	6.5	0.0	0.0	0.0	6.5
Finland	0.0	0.0	0.0	0.0	3.5	2.0	0.0	0.0	5.5
Denmark	0.0	0.0	0.0	0.0	1.6	0.0	0.0	1.3	2.9
Estonia	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cyprus	0.0	0.0	0.0	0.0	0.0	0.0		0.0	0.0
Latvia*	n.c	n.c	n.c	n.c	n.c	n.c	n.c	n.c	n.c
Malta*	n.c	n.c	n.c	n.c	n.c	n.c	n.c	n.c	n.c
Total EU 27	41 781.7	321.0	1 082.9	89.5	930.5	50.8	113.6	17.6	44 387.6

** Our database does not include data for the facility projects of Latvia or Malta, as neither country was able to supply any data.*
Source: EurObserv'ER 2022 based on the Database of the European energy storage technologies and facilities.

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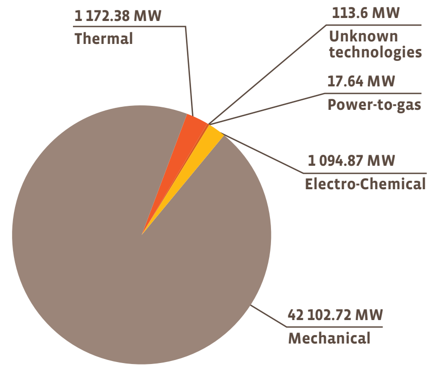
capacities used for electricity storage are low. These chemical reactions use electricity to produce synthetic gases (e.g., dihydrogen), which can be combined with different molecules and stored in gaseous form, such as methane that can also be injected into the gas grid, liquid (ammonium), or to a lesser extent, in solid form used to generate electricity on demand. Currently, using the syngas produced directly for industrial uses is generally more expedient than storing it and regenerating the electricity in gas-fired power plants because the electrical yield of power-to-gas-to-power conversion cannot exceed 35%. Globally it should be noted that directly using renewable electricity is in most cases more effective in reducing our green house gases emissions than producing syngas. There are of course many other techniques to store electricity, but they are not economically viable yet and therefore underdeveloped.

COST IS THE MAIN ISSUE

Economic cost is the main reason why electrochemical storage is so underdeveloped today, despite the relatively mature state of the technologies. Other technologies (e.g., thermal or compressed air storage) offer yields that are too low for crucial sub-seasonal uses. Reducing the energy production cost would offset the yield losses. The profitability of such a solution is directly affected by the value of the stored electron. Storage must also overcome many regulatory obstacles, in addition to technical obstacles, to find the place it deserves in the energy market. Some of the most recent initiatives are more like pilot or research projects, or stem from public auctions. However, those that have found an economic model that can be reproduced on a large scale are few and far between. Thus, regulation mechanisms in several countries are trying to create a suitable framework for energy storage, so that energy storage can operate as a grid-balancing tool, primarily based on the capacity mechanisms that put less value on the quantity of stored energy than on the installations' quality (namely, the power and responsiveness). Yet, the gas crisis could help the development of electricity storage system in a market where gas power plants under development today represent one of the main alternatives for flexibility, as peak production capacities. The idea is to create a profitable model for infrastructures that generate only a little energy, yet do so at crucial times, while only operating a few hundred hours per annum. This

1

Installed capacities by technology in the EU-27 at the end of 2021



Source: EurObserv'ER based on the Database of the European energy storage technologies and facilities

is the first time since the second oil crisis (1979), that an energy crisis has had such an impact by affecting the whole of Europe, to the point that households are threatened with shortages. This could lead to significant equipment of expensive individual installations by people who no longer have confidence in the electricity network to overcome this type of problem.

MORE THAN 44 GW ALREADY IMPLEMENTED IN EU-27

Our reporting is based on the Database of the European energy storage technologies and facilities, a European Commission database produced in 2020 that identifies more than 800 storage facilities across Europe. They are known as "front of the meter" facilities, namely storage equipment connected to the generation grid or transmission grid. These generally large facilities are placed before the electricity meter. They differ from "behind the meter" facilities found in the internal networks in the residential, commercial, and industrial sectors; and are thus external to the public electricity grids. For example, electric vehicle battery storage is classified as "behind the meter," and thus falls outside the scope of this study. EurObserv'ER has collected data in 2021 and 2022 to update that database with new projects and consolidate information of existing facilities.

At the end of 2022, 44.4 GW of storage capacity total was connected to either the generation or the transmission grids of the EU-27. Pumped hydro storage technology dominates this capacity with 41.8 GW, and is particularly well developed in Italy, Germany, Austria, Spain, and France as each of the latter has more than 4 GW of storage. Thermal molten salts storage accounts for 1.1 GW, and almost all of it is installed in Spain, primarily due to Spain being the location of most EU concentrated solar power (CSP) plants, using this type of storage. Li-ion battery storage accounts for 930 MW, mainly developed in Germany (572 MW). Then there are some pilot electrolyser sites geared to grid balancing (17.6 MW).

Table 3 gives details of the planned projects in the European Union (licensed, under construction, etc.). The total capacity identified amounts to 26.5 GW. While mechanical storage dominates this capacity (24.3 GW), an additional 1.6 GW is expected from electro-chemical storage in the next few years.

3

Planned capacities by country at the end of 2022 (in MW)

	Mechanical		Thermal		Electro-Chemical			Chemical	
	Pumped hydro storage	Other technologies	Molten salt	Other technologies	Li-ion	Other technologies	Unknown electro-chemical technologies	Power-to-gas	Total
Spain	9 146.7	0.0	0.0	0.0	338.6	0.0	0.0	0.0	9 485.3
Germany	5 746.0	0.0	0.0	0.0	92.5	0.0	0.0	250.1	6 088.6
Ireland	1 260.0	0.0	0.0	0.0	0.0	0.0	869.7	0.0	2 129.7
Austria	1 440.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1 440.0
Greece	1 182.0	0.0	52.0	0.0	0.0	0.8	15.2	0.0	1 250.0
Croatia	1 243.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1 243.7
Romania	1 028.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1 028.8
Bulgaria	864.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	864.0
Portugal	668.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	669.0
Belgium	550.0	0.0	0.0	0.0	25.0	0.0	0.0	0.0	575.0
Estonia	550.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	550.0
Slovenia	420.0	0.0	0.0	0.0	15.0	0.0	0.0	0.0	435.0
Netherland	0.0	320.0	0.0	0.0	0.0	0.0	3.8	0.0	323.8
Lithuania	225.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	226.0
France	12.0	0.0	0.0	0.0	48.1	10.0	100.0	5.0	175.1
Italy	0.0	0.0	0.0	0.0	20.0	4.0	0.7	0.0	24.7
Finland	0.0	0.0	0.0	0.0	10.6	0.0	0.0	0.0	10.6
Czechia	0.0	0.0	0.0	0.0	10.0	0.0	0.0	0.0	10.0
Cyprus	0.0	0.0	0.0	0.0	5.0	0.0	0.0	0.0	5.0
Denmark	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	1.0
Slovakia	0.0	0.0	0.0	0.0	0.6	0.0	0.0	0.0	0.6
Hungary	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Luxembourg	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Poland	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sweden	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Latvia*	n.c	n.c	n.c	n.c	n.c	n.c	n.c	n.c	n.c
Malta*	n.c	n.c	n.c	n.c	n.c	n.c	n.c	n.c	n.c
Total	24 336.2	320.0	52.0	0.0	566.4	14.8	990.3	256.1	26 535.8

** Our database does not include data for the facility projects of Latvia or Malta, as neither country was able to supply any data .*
Source: EurObserv'ER 2022 based on the Database of the European energy storage technologies and facilities.

SPOTLIGHT ON THE MAJOR COUNTRY PLAYERS

In light of its new climate law, which was passed in May 2021, ***Spain*** introduced new incentives to promote the expansion of its energy storage capacities. According to the legislation, the national storage capacities are to increase to 20 GW in 2030 and 30 GW in 2050. This increase in capacity refers to large-scale, grid-connected storage units as well as smaller units, mostly used for residential or commercial self-consumption. Looking at the latest EurObserv'ER data, Spain hosts over 17.2 GW of energy storage capacity to date, largely based on pumped hydro systems. While the National Integrated Energy and Climate Plan 2021-2030 («PNIEC») commits to the commissioning of at least 3.5 GW of pumped storage capacity, another 2.5 GW of battery storage capacity is to be added by 2030. Therefore, one of the largest announced battery projects in the EU-27 is located in Spain as well. In three phases, Spanish utility Endesa is developing Spain's largest BESS (Battery Energy Storage System) in Andorra, named Teruel, with about 318 MW of total capacity. The first phase of about 160 MW is to be commissioned in 2022, while the next phases will boast capacities of 54 and 105 MW, to be commissioned in 2023 and 2026, respectively. In addition, at Spanish utility Endesa's headquarters, the Second Life project has been launched, using electric vehicle batteries as an energy source, interconnecting them and storing them at the Endesa plant in Melilla. The Second Life project has 4 MW of capacity and can produce up to 1.7 MWh.

As one of the largest users of energy storage solutions in the EU, ***Germany*** currently hosts 13.8 GW of energy storage capacity in operation or planning stages. Similar to other EU Member States, the largest part of it consists of pumped hydro storage plants. However, a shift towards battery-based solutions can be observed. According to the scenario calculations of the Fraunhofer Institute for Solar Energy Systems ISE, about 100 GWhe of electrical storage capacity will be needed in Germany by 2030, and about 180 GWhe by 2045, in order to reach the German target of 80 per cent renewable electricity by 2030 and 100 per cent by 2045, respectively. The largest electrochemical battery system in operation is BigBattery Lausitz with 66 MW of useful capacity, which was commissioned in November 2020. However, German utility RWE is planning a battery system of 117 MW at the power plant sites in Lingen and Werne to be commissioned by the end of 2022. The batteries will be virtually coupled with RWE's run-of-river hydroelectric power plants along the Moselle river. By up-regulating or down-regulating the flow rate at these plants, RWE can provide additional power as balancing energy as well. The coupling allows the total output of the batteries to be increased by about 15 percent. In this way, batteries and hydropower plants work virtually hand in hand to contribute to grid stability. The planned system comprises of 420 lithium-ion battery racks, enclosed in 47 shipping containers, spread across two RWE power plant sites. The plant in Werne will have 72 MW of capacity, the one in Lingen will come to 45 MW. At Berlin's EUREF Campus, the car manufacturer AUDI has installed an energy storage system for research purposes with 1 MW of capacity. The research aims to develop existing storage capacities of electric cars for new practical applications using intelligent charging strategies. The storage unit batteries are taken from test vehicles of the car manufacturer, thereby giving the batteries a second life. Additionally, Germany is home to novel types of energy storage in experimental stage: in Hamburg, Siemens and Gamesa have opened a 30-MW Electro—Thermal Energy Storage (ETES) unit. ETES uses electricity to heat volcanic stones to temperatures of 600°C and higher. This heat can be converted back into electricity using a conventional steam turbine according to the company. Power to Gas (P2G) is another technology thought to be widely used in the future. The gas industry body DVGW in 2020 counted 35 P2G projects in Germany. The systemic advantages of using P2G (physical-technical storability, existing gas grid and storage infrastructure) relieve the traditional electricity sector through more flexibility and may potentially lead to cost reductions. DVGW estimates that theoretically up to 200 TWh of energy could be stored in underground gas caverns in Germany - this is roughly equivalent to 23,000 times the capacity of a state-of-the-art pumped storage power plant. The massive upscaling of fossil gas infrastructures, however, is challenged in the face of decarbonization efforts and the government's pledge of climate neutrality by 2045.

Although ***Portugal*** is relatively small compared to Italy, Spain, Germany or France, it is very well endowed with mechanical storage capacity. Indeed, with almost 3 000 MW, it has the sixth largest capacity of the European Union of. Moreover, Portugal is cur-

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rently carrying out a number of projects to increase its installed capacity to eventually reach the 3,400 MW threshold. Construction of the Gouvaes (880 MW) and Daivoes (160 MW) projects was completed in 2022. These two pumped storage stations are part of the Tâmaga hydroelectric complex, the largest currently under construction in the European Union, and will provide an important means of flexibility for the country, which produces almost 60% of its electricity (58.03% in 2020) from renewable sources. The last unit, the Alto Tâmaga (118 MW) is still under construction.

Another country could well become an important player in the storage market. This is ***Croatia***, which, although equipped with only 620 MW of STEP, is planning to develop more than 1 200 MW through four projects of several hundred MW. VRDOVO is the most powerful of these, with two giant turbines for a total capacity of 540 MW (and 490 MW in pumped storage mode). It is part of the Vis Viva consortium, which aims to develop several other low-carbon energy infrastructures in Croatia. This huge plant will be built in an area with particularly suitable topography for hydroelectricity, not far from the Peruća hydroelectric power plant, whose basin will serve as a low reservoir, while a high reservoir will be built in the Ravno Vrdovo valley, 600 m higher.

Due to the ***Netherlands***' topography, the installation of pumped storage plants can be ruled out. Therefore, the country focusses on the development of electrochemical storage capaci-

ties, mainly based on Li-ion batteries. At the time of writing, about 118.5 MW of Li-ion batteries were either deployed or under construction. The largest battery projects in operation are the Rhino (12 MW) and Buffalo (25 MW) storage facilities, both located in proximity of the Mammoettocht and Neushoorntocht wind farms in Lelystad. However, Project Castor, to be commissioned in spring 2023, will surpass the Buffalo storage with 30 MW/63 MWh of capacity to be the largest electrochemical storage system in the Netherlands. Next to electrochemical storage systems, the Netherlands is developing an innovative 320-MW compressed air energy storage (CAES) project, which is planned in the former salt caves at Zuidwending. The air will be compressed by enormous compressors and should store up to 2 GWh of electricity every day using a 100% renewably-sourced electricity supply. The compressed air, with an estimated yield of less than 50%, could be decompressed in turbines to provide electrical current. The commissioning of the CAES project has been delayed by a year and is planned for 2026.

Similar to the Netherlands, ***Denmark*** does not have the topographic opportunity to deploy pumped storage solutions. However, with its huge on- and off-shore wind capacities, the country is developing alternative means to store electricity, mainly in form of batteries and other, new technologies. Funded by the EU Horizon 2020 program, the 2LiPP (2nd Life for Power Plants) project is an example for such innovation. Planned for commissioning in 2024, the project aims to demonstrate a scalable hybrid storage system which is designed to support CHP plants in their transition from fossil-based operations to key providers of grid stability and security of supply in a renewable grid. The 10-15 MWh demonstration plant will use a combination of three different energy storage technologies: flywheel, recycled Li-ion batteries and molten salts storage. The largest energy storage project in Denmark, however, will be the Green Hydrogen Hub CAES in Northern Jutland with 320 MW of capacity to be commissioned in 2026. Using hydrogen-fuelled compressed air energy storage (CAES) technology, the project will act as a facilitator for increased integration of onshore and offshore wind by providing balancing services and system services.

Ireland is extremely ambitious about developing electrical storage capacity despite its population of barely 5 million. It wishes to develop both its mechanical storage capacity, which is relatively discreet today with less than 300 MW, and its electrochemical storage capacity. The objective is to reach more than 1 200 MW of mechanical storage, in particular through the innovative MAREX project of 900 MW. This is a STEP solution based on a coastal reservoir in County Mayo in the north of Ireland which will be able to store marine salt water. It is part of a wider objective of cooperation with the United Kingdom to build a 750-MW high voltage line between the two states in order to flow renewable energy production in this region with very high potential. Indeed, the deployment of off-shore wind farms in this area is particularly relevant due to wind speeds of up to 10 m/s at 100 m altitude. Meanwhile, although few technical details have been officially released, Ireland is by far the most ambitious country in terms of electrochemical storage capacity. With more than 1 350 MW announced, the country has aroused the curiosity of many players in a technology that currently represents less than 200 MW installed in the entire European Union. In all, more than 50 electrochemical storage projects are expected, some in the tendering process, others in the authorisation process. One of them, the Lumcloon BESS (Battery Energy Storage System), went into operation at the end of 2020. With 100 MW of capacity, it was led by the young project company Lumcloon Energy in partnership with the Koreans from Hanwha Energy Corporation. It provides high power and high reactivity battery capacity to support the Irish grid operator. The Aghada BESS, a 19-MW project in County Cork, came on stream in 2022. In view of the country's very ambitious announcements, barriers such as acceptability are likely to conflict with the development of large-scale electrochemical storage stations in Ireland. One of the main fears of opponents is the fire hazard associated with the batteries. ■

FOCUS: RENEWABLE ENERGY COMMUNITIES

The current international context raises the question of energy sovereignty and the need to move away from dependence on fossil fuels, for both geopolitical and climatic reasons. This is a major challenge and meeting it requires the unprecedented mobilisation of the economy and society. Renewable energies make a significant contribution to this, in particular by placing energy production in the hands of individuals or communities, which is what is known as citizen energy. Here, citizens not only participate in 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 are intended to create a regulatory framework conducive to citizen-led renewable energy projects.

Many may have thought at first that the citizen energy movement was just a fad of a few dreamy activists. However, it is a concrete movement, rooted in the territories, which mobilises millions of citizens in Europe through economically sound projects that strengthen social cohesion and project acceptability. Citizen energy is not only – and this is an understatement – a key lever for the success and acceleration of energy transition and the essential deployment of renewable energies, it is also a vector for the democratisation of energy and its appropriation by the citizens. It brings energy production closer to home and makes it possible 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. Hence, this chapter will not focus solely on one precise and inflexible concept that would correspond to what a true renewable energy community should be. This section will attempt to capture the different national and even regional approaches in their multiplicity and the progress made by the different states in transposing the European directives into their own legislation. In its work, the EurObserv'ER team relied in particular on the RESCoop.eu federation, which brings together many European actors active in the promotion of citizen energy, as well as on the Collective Action Models for the Energy Transition and Social Innovation (COMETS) project supported by the European Commission, which aimed to establish the contribution of Collective Action Initiatives to the energy transition.

Thus, the COMETS project has identified collective action initiatives for most EU countries, which themselves include projects contributing to the energy transition of the territories. Overall, nearly 10 000 operations have been identified (see table 1).

__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.

REGULATORY TEXTS THAT ARE LONG OVERDUE

In France, citizen energy entered the political landscape for good in 2010 with the creation of the Énergie Partagée (« Shared Energy ») association, whose charter introduces the term for the first time in the definition of «citizen project». But it was in March 2021, two years after the 100th project labelled by *Énergie partagée*, that an ordinance officially introduced the notion of energy community into French law, as provided for in the European Directives 2018/2001 of December 2018 and 2019/944 of June 2019. *Énergie Partagée*

The COMETS project
The objective of the COMETS project is to study collective action initiatives (CAIs) as the main driver of social innovation in the energy sector. The role of citizen-led CAIs (e.g. energy communities, cooperatives, purchasing groups) and their contribution to energy transition has not been quantified at a global level, nor has their potential contribution been estimated or understood in sufficient depth. The COMETS project aims to fill these gaps by quantifying the overall contribution of CAIs to the energy transition at national and European level, by studying their evolution and scaling up in depth in six selected countries. The definition of CAIs has some differences with those of the REC and the CEC, but they share some important features:
- *Members participate voluntarily and have full control over their projects (one member, one vote).*
- *Projects must benefit the local community.*
- *Like the REC, a CAIs can cover renewable energy, energy saving or sustainable energy advice and services.*

1

Number of Collective Action Initiatives (CAIs) identified through the COMETS project

Member States	Number of CAIs	Number of projects	Number of citizen involved
Germany	>3 012	4 530	300 000
Netherlands	1 001	1 442	120 000
Denmark	130	1 109	5 000-500 000
France	347	760	130 000
Belgium	90	576	120 000
Sweden	312	311	80 000-100 000
Austria	282	>282	>564
Finland	77	150	112 000
Estonia	131	137	393-1 300
Poland	112	>112	784
Italy	82	64	n.a
Czechia	35	35	17 000
Croatia	10	8 – 10	1 300
Lithuania	8	8	160
Luxembourg	4	7	n.a
Slovenia	7	7	n.a

Source: COMETS

is organised around two entities. On the one hand, there is the association which acts as the spokesperson for the actors of citizen energy, and which carries out lobbying actions with the public authorities. On the other hand, there is the cooperative which directly finances and supports local citizen initiatives in the implementation of their renewable energy projects thanks to the citizen savings of its members. Énergie partagée and Centrales Villageoises, the other association whose model consists of developing small citizen solar roof installations, are the pioneering structures of citizen energy in France. At the end of 2022, there were more than 580 citizen projects in operation (and about a hundred in development) on the territory. In addition, there are projects mainly supported by local authorities without necessarily direct citizen governance, but which are part of the same dynamic, that of the reappropriation of production issues by the territories.

In total, more than 35 500 citizens have invested part of their savings in this type of project. In fact, almost all the operations carried out relate to electricity production. Very few projects concern the production of renewable heat. In terms of technology, photovoltaics is the most represented in number but wind power has the highest electrical output.

In 2021, the French government introduced, via the ordinance of 4 March, the notions of renewable energy communities (RECs) and citizen energy communities (CECs). A decree implementing this ordinance was expected in spring 2022 but was still awaited at the end of the year. The objective of this future decree is to create a framework conducive to citizen projects. In addition to formalising the concept, it will, for example, provide financial incentives for project leaders to go through a citizen-type development.

2

Citizen projects in France

Technologies for renewable electricity	Number of projects	Capacity (MW)	Energy generated (GWh)
Photovoltaic	547	86.06	107.40
Wind power	15	109.2	228.1
Hydropower	5	1.5	5.994
Total	567	196.76	341.49
Technologies for renewable heat	**Number of projects**	**Capacity (MWth)**	**Heat output (GWh)**
Solid biomass	13	16.4	30.5
Technologies for renewable biogas	**Number of projects**	**Capacity (MWth)**	**Biogas output (GWh)**
Biogas plants	2	2.3	20.6

Source: Eurobserv'ER based on Énergie Partagée and Centrales Villageoises data

GERMANY, THE FORERUNNER

In Germany, RECs and CECs have already been in existence for several decades, although there is no official regulatory framework. However, by the end of 2022, transposition of the EU directive will have taken place at least partially. Prior to this, a legal definition of so-called citizen energy companies (Bürgerenergiegesellschaften, BEG) was first formulated in the Renewable Energy Act 2017 (EEG 2017). With the EEG 2023 amendment passed by the Parliament in July 2022, the legal definition of BEGs has been updated to be in line with EU legislation. Thus, these citizen companies are exempted from the need to participate in tenders, between 1 and 6 MW for PV projects and between 1 and 18 MW for wind projects. In addition, a BEG must consist of at least 50 natural persons as voting members or shareholders, while at least 75 per cent of the voting rights must be held by natural persons residing in a postcode area that is wholly or partly within a 50 kilometres radius of the project. The remaining 25 per cent of the voting rights can be held by small and medium-sized enterprises with fewer than 250 employees and less than € 50 million in turnover or by local authorities.

According to the Deutscher Genossenschafts- und Raiffeisenverband (DGRV), the federation of German cooperatives, 914 energy cooperatives have been founded in Germany since 2006. Of these, 847 cooperatives are still in operation. 3.3 billion Euros were invested by those communities, providing 8 TWh of renewable electricity, or about 3.5% of the country's total renewable electricity production. For example, the village of Feldheim in Brandenburg is an example of a long-standing citizen energy community. All households in the village are supplied with heat and electricity from renewable energy plants via self-sufficient local networks. Connected to a 123 MW wind farm and a 10 MW storage battery, the village has its own biogas plant (526 kWe & 560 kWth) as well as a wood chip heating plant, which is used during peak periods. The local district heating network is owned by Feldheim Energie GmbH & Co KG, a limited partnership formed by the connected households and businesses and the neighbouring municipality of Treuenbrietzen.

THE LAW IS CHANGING IN AUSTRIA

In July 2021, the Austrian parliament passed the Renewable Energy Expansion Act (EAG), which aims to convert the country's electricity supply to 100% electricity from renewable energy sources by 2030 and to achieve climate neutrality by 2040. The possibility of creating energy communities is part of this new legislation. Prior to July 2021, shared power plants were used to consume and produce electricity in several households, for example in a block of flats. Since the legislation was passed by Parliament, this is also possible across property boundaries in the context of energy communities. Participants in an energy community can thus share the production and supply of energy - whether electricity, heat or gas - with wider populations. This should bring economic benefits, but more importantly it should offer the opportunity for citizens to actively participate and have a say in local energy policies. According to the Renewable Energy Expansion Act, the main objective of an energy community must explicitly be «not financial gain», but «to provide ecological, economic or social benefits to the community». In the legislation, a distinction is made between citizen energy communities (Bürgerenergiegemeinschaft, BEG) and locally limited renewable energy communities (erneuerbare Energiegemeinschaft, EEG). Depending on the number of participants and the connection to the electricity grid, a local or regional EEG can be established. The participants of a local EEG are interconnected at the low-voltage network levels. If the medium-voltage network levels are involved, this is referred to as a regional BEG.

So far, a limited number of projects have been successfully commissioned. Most are still in the planning or implementation phase. According to a survey of grid operators conducted in March 2022 by Österreichs Energie, the representative body of the Austrian electricity industry, 14 EEGs are in operation, 34 are under implementation and 88 are in the planning phase. OurPower is one of the first nationwide citizen energy communities in Austria. For participants, BEG also offers the opportunity to participate directly in the expansion of renewable energy and to consume the electricity generated. This approach is particularly interesting for individuals living in apartment buildings (where renewable operations are more difficult than in single-family homes) or with limited financial means. However, EEGs can only produce, consume, store or sell electricity and not heat. Moreover, while small EEGs benefit because they do not use the entire public grid, BEGs do not. About 200 green power plants are currently participating in OurPower, producing about 40% of their electricity from solar, 30% from wind, 20% from hydro and 10% from biomass.

3

Citizen projects in Wallonia

Technologies for renewable electricity	Number of projects	Capacity (MW)	Energy generated (GWh)
Photovoltaic	16	1.84	1.6
Wind power	19	38	65
Hydropower	4	1.7	4.101
Biogas plants	2	1.01	5.379
Total	41	43.35	76.08

Source: REScoop Wallonia

CITIZENS' PROJECTS IN WALLONIA

There are about 42 citizen cooperatives in Belgium that are members of the REScoop network. However, the competence for renewable energy is shared between the different regions. In Wallonia, the Walloon Federation of Renewable Energy Citizens' Cooperatives, REScoop Wallonia, follows the development of and invests in citizens' projects through its network of 19 cooperatives with some 15,000 members. They have created the Comptoir Citoyen des Énergies (COCITER), a cooperative green electricity supplier. This has resulted in the development of over 43 MW of renewable electricity projects (including 38 MW of wind power). Some 16 biomass heating projects have also been carried out by the federation. One member cooperative, Courant d'Air, has also developed a tool called «Photovoltaics for all» to simulate the performance and costs of rooftop solar installations and to find local professionals. A legislative decree of 5 May 2022 formalised the concepts of renewable energy communities and citizen energy communities by translating the RED II Directive. However, this text has yet to specify what a citizen renewable energy project is. A governmental decree should be published in 2023 to clarify this. The Walloon government has also adopted the Pax Aeolienica II to promote the development of wind energy in the region. It proposes the beginning of a definition of the concept of citizen project, but only in the case of wind power projects. Developers are now obliged to open the capital of their project to citizens and local authorities up to a threshold of 24.99% for each of these entities.

For their part, the regions of Flanders and Brussels have also transposed the European Directive. At the federal level, REScoop Wallonia and REScoop Vlaanderen (federation of cooperatives in Flanders) have created a cooperative common to all Belgium for the development of citizen projects at sea: Seacoop.

A CONCEPT THAT IS STRUGGLING TO TAKE SHAPE IN EUROPE

As we can see from the various European examples, citizen energy is reflected in different approaches or concepts in different countries. Although some countries have enjoyed an interesting dynamic for several years and a growing number of Member States have transposed the European Directives on the subject, most of them do not explicitly support or follow the development of citizen renewable initiatives. 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. ■

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 2020 and 2021. 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.

Further important model features are briefly highlighted below:

- *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 in more detail. This paper can be downloaded from the EurObserv'ER project website.

WIND POWER

In 2021, the net additional wind power capacity connected in the European Union remained below the 11 GW threshold (10 796.5 MW). However, the main highlight of the past year was the low level of offshore activity. With only 604.8 MW of new offshore capacity installed, 2021 was four times less than the 2 452.8 MW installed. Annual added power and total installed capacity numbers are fundamental to the total employment numbers that arise from the employment model. The sharp downturn in the offshore segment has resulted in a decline in employment for the sector as a whole. With 211 500 total jobs identified for 2021, EurObserv'ER estimates a significant employment decrease for the EU-27 in 2021, (68 900 jobs over 2020). This is coupled with a decrease in turnover (€9.6 billion) and gross value added (€3.8 billion). While wind energy was the largest sector in terms of turnover in our 2020 estimates, the employment decrease in turnover in 2021 the wind sector puts the technology in fourth third place, behind solid biomass and, heat pumps and PV.

In terms of individual country results, the Netherlands, Spain and Germany are among those with the largest declines in employment and activity in 2021. Germany, the European wind industry leader, has gone from an estimated 83 500 jobs to 69 200 in 2021. The fact that no sites will be connected in 2021 explains this decline. The same phenomenon was observed in Spain or in the Netherlands. The big loss in jobs in Spain resulted from very low newly installed capacity in 2021 (0.3 GW) compared to the previous year. Accordingly, the total number of jobs in the wind sector in Spain returns to earlier levels of employment. Netherlands has experienced a significant 31 600 jobs decrease mainly related to the poor level of annual activity registered for 2021 where only 1 GW of added capacity were connected instead of 2.1 GW in 2020.

The decline in activity fits with the situation sketched by industry. The CEOs of the five largest wind turbine manufacturers in Europe have sent a letter to the President of the European Commission alerting her to the very difficult situation in the European wind energy supply chain. The letter states that in the past two years the industry has had to close turbine and component manufacturing plants in Germany, Spain and Denmark, traditional strongholds of the wind industry in Europe

In contrast, Denmark has seen a significant increase in employment in its wind energy sector (from 22 800 to 31 900 full-time equivalents) and in its turnover (€2 760 million in 2021, i.e. +38% compared to 2020). The country was the only one to connect an offshore wind farm in 2021 at the Kriegers Flak site. Similarly, Sweden has seen an increase in employment in 2021 mainly due to the fact that the country has been Europe's largest wind energy market. In 2021, 2104 MW were installed and the forecast for 2022 is 2.2 GW. ■

Employment and turnover

	Employment (direct and indirect jobs)		Turnover (in M€)		Direct GVA (in M€)	
	2020	2021	2020	2021	2020	2021
Germany	83 500	69 200	13 960	11 710	6 090	5 110
Denmark	22 800	31 900	5 080	6 670	2 000	2 760
Spain	44 300	23 000	5 860	3 320	2 430	1 440
France	15 800	14 500	2 640	2 460	1 050	970
Sweden	9 600	14 100	1 880	2 700	950	1 360
Netherlands	42 100	10 500	6 350	1 670	2 700	680
Poland	10 900	8 600	840	690	370	300
Portugal	10 300	7 200	750	570	300	230
Greece	6 300	6 600	590	630	260	280
Italy	6 000	6 100	1 040	1 050	440	450
Finland	2 300	4 400	430	780	190	340
Croatia	2 100	2 600	140	160	60	70
Lithuania	600	2 200	40	110	20	50
Austria	1 100	2 000	230	380	90	160
Belgium	12 700	2 000	2 700	440	1 080	170
Romania	2 500	2 000	210	170	90	80
Ireland	3 100	1 600	520	310	220	130
Bulgaria	600	700	40	50	20	20
Hungary	1 200	700	80	40	30	20
Czechia	1 100	600	100	60	30	20
Estonia	800	300	60	30	20	10
Latvia	100	200	10	10	<10	<10
Cyprus	100	100	10	10	<10	<10
Luxembourg	200	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	**280 400**	**211 500**	**43 630**	**34 060**	**18 500**	**14 710**

Source: EurObserv'ER

PHOTOVOLTAIC

The European Union solar photovoltaic market remained very active in 2021 despite disruptions in component supply chains and increases in module prices. EurObserv'ER evaluated that the maximum net capacity of the EU-27 increased by at least 22.8 GW in 2021. This 24.9% year-on-year rise pushed up the European Union's annual cumulative capacity by 16.7% for the year to 158.9 GW. Regarding the socioeconomic impacts, EurObserv'ER estimates photovoltaic turnover at €27.6 billion in 2021 (against €20.9 billion in 2020), gross value added at €11 480 million (against €8 760 million in 2020) and employment at 223 100 FTE – a similar increase as the turnover.

With 56 000 jobs (up from 55 600 in 2020), Germany remains the leader in number of jobs in the PV sector in the EU-27. This follows from 5.0 GWp of new installed capacity in 2021, more than the 4.7 GWp installed in 2020. A market that remained stable between the two years, which resulted in very similar employment figures. The employment estimates for PV in Spain increased for 2021 as compared to 2020. The country installed 2.8 GW of net photovoltaic capacity in 2021, which is more than in 2020 (1.5 GW) and the main part of this total was installed through electricity purchase contracts. That makes the Spanish markets one of the biggest solar markets to operate without subsidies or state-guaranteed prices. Many other countries also show an increase in jobs estimates due to an increase in new capacity installed. For instance, The Netherlands and Italy have shown increases in employment in 2021 (3 100 jobs and 3 700 jobs respectively), and remain in the top 6 countries with the largest number of jobs in the PV sector. Similarly, their respective turnover also increased with 17% (€460 million increase) and 32% (€520 million increase).

EurObserv'ER monitors a quite remarkable PV and related socioeconomic growth in most EU-27 countries for 2021. A substantial increase of 2.8 GWp in installed PV capacity in France resulted in a large additional number of jobs in the PV sector (19 700 new jobs compared to 2020). Accordingly, the employment model yields a significant increase in turnover (€2.8 billion) and gross value added (€1.2 billion) as well in 2021. The increase is amplified by an underestimate of the 2020 figures for France due to a limited increase in installed capacity seen in early estimates. Furthermore, Poland has emerged as the second largest PV market in 2021 (with 3.7 GWp of new installed capacity), showing a positive trend that is also reflected in a €2.5 billion sector turnover – almost doubled compared to 2020 – and 35 200 jobs. Two other countries, Portugal and Austria, have shown relatively high increases in employment results from high new installed capacity numbers (548 MWp and 766 MWp respectively). With 4 800 new jobs and 260 million higher turnover, Portugal tripled their employment numbers. Austria has shown a more than doubling in employment (2 800 new jobs), turnover (€480 million increase) and GVA (€210 million increase). On the other hand, some countries experienced market decline such as Hungary where significantly less PV systems were installed in 2021 than in 2020 and the country observed a decrease of 4 000 jobs in 2021 compared to our 2020 estimate. ■

Employment and turnover

	Employment (direct and indirect jobs)		Turnover (in M€)		Direct GVA (in M€)	
	2020	2021	2020	2021	2020	2021
Germany	55 600	56 000	8 310	8 440	3 700	3 750
Poland	20 200	35 200	1 410	2 470	570	1 000
Spain	19 100	25 400	2 040	2 680	890	1 170
France	3 600	23 300	520	3 350	210	1 380
Netherlands	18 600	21 700	2 690	3 150	1 020	1 190
Italy	11 400	15 100	1 650	2 170	630	830
Portugal	2 400	7 200	130	390	50	150
Greece	5 500	7 000	450	570	180	230
Austria	2 200	5 000	400	880	170	380
Belgium	4 300	4 300	830	840	300	300
Denmark	2 500	3 500	500	700	200	280
Sweden	4 000	3 100	700	530	330	250
Estonia	400	2 500	30	180	10	70
Hungary	6 300	2 300	360	140	150	50
Czechia	2 900	2 200	220	180	80	60
Finland	1 300	2 000	260	410	100	160
Romania	1 500	1 900	110	130	40	50
Bulgaria	1 800	1 800	90	100	30	30
Lithuania	800	1 500	30	70	20	30
Cyprus	<100	600	10	50	<10	20
Luxembourg	200	500	40	70	10	30
Ireland	200	300	20	50	10	20
Malta	300	200	20	10	10	10
Slovakia	200	200	20	20	10	10
Latvia	100	100	10	<10	<10	<10
Slovenia	100	100	10	10	<10	<10
Croatia	<100	<100	<10	<10	<10	<10
Total EU 27	**165 700**	**223 100**	**20 870**	**27 610**	**8 760**	**11 480**

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 €5.2 billion and 38 300 jobs for 2021. These figures show an important increase in sector turnover which more than double the 2020 result. Employment levels also did very well with 18 200 jobs, almost doubling the 2020 figure.

The greater part of the large increase in employment arises from the 13 900 jobs increase in Germany, placing Germany high at the top for most jobs in the solar thermal sector of the EU-27. This big increase in employment can be explained due to a high growth of installed capacity of solar thermal systems (1.6 GWth). Similarly, these large increases can also be seen in the turnover (€2.2 billion increase) and gross value added (€940 million increase). Denmark has also made good progress in 2021. In terms of solar thermal energy, the country specialises above all in the niche of heating networks integrating this energy, since Denmark had 125 such networks by the end of 2021. The number of jobs is estimated at nearly 32 000 (31 900) with a turnover of €6.7 billion (+31% compared to 2020).

On the other hand, the Spanish results were not good. Driven by a national solar thermal market that has shrunk by almost 20% in 2021, socio-economic indicators have followed this trend. It is estimated that the country will have a total of 23 000 jobs and a turnover of €3.3 billion, well below the 2020 levels. In this country, it is not only the continuous installation activity of solar thermal collectors for hot water provision but also the operation and maintenance (O&M) services in the CSP sector that positively affect employment. However, Spain is home to the largest CSP power plant fleet in the EU. 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. Solar thermal activity in the rest of the Union was limited but slowly growing in 2021, leading to relatively stable estimates in the remaining Member States. ■

Employment and turnover

	Employment (direct and indirect jobs)		Turnover (in M€)		Direct GVA (in M€)	
	2020	2021	2020	2021	2020	2021
Germany	3 100	17 000	430	2 590	190	1 130
Spain	6 400	5 400	950	840	450	410
Poland	1 500	2 800	110	200	40	70
Greece	1 800	2 300	150	210	50	80
Austria	1 400	1 900	260	360	110	150
Denmark	300	1 500	50	290	20	110
France	1 000	1 500	140	220	60	90
Italy	1 000	1 500	130	200	50	80
Bulgaria	1 000	1 300	50	60	20	20
Portugal	600	800	30	40	10	10
Hungary	200	400	10	20	<10	10
Cyprus	200	300	10	20	<10	10
Czechia	100	200	10	10	<10	<10
Belgium	100	100	20	10	10	<10
Finland	<100	100	10	10	<10	<10
Croatia	200	100	10	<10	<10	<10
Ireland	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
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	**20 100**	**38 300**	**2 480**	**5 200**	**1 170**	**2 320**

Source: EurObserv'ER

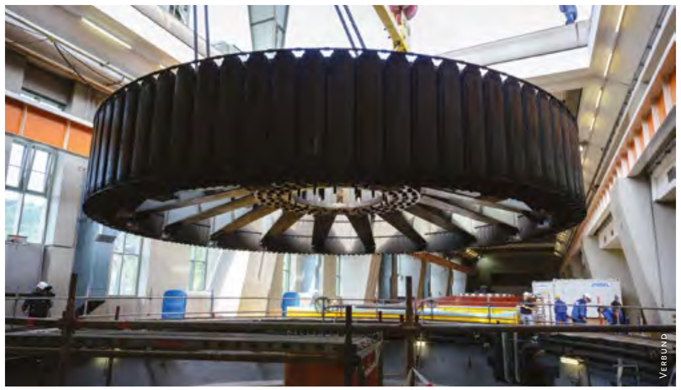
HYDROPOWER

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. Moreover, the annual change of the installed capacity depends both on the connection of new units but also on the increase in the average power commissioned according to climatic conditions or the energy needs of a country. Since data relating only to new capacities is not available, it is possible that over-estimates may be made for certain countries.

France saw the largest increase in installed capacity in 2021 (+580 MW). Correspondingly, the employment estimates increased significantly as well by 11 700. Other countries with an increase in capacity and jobs estimates are Germany, Austria, Spain, Portugal and Czechia. On the other hand, there was no increase in capacity in Italy, while it showed the largest growth in capacity in 2020. The jobs estimate for Italy shows the largest decline out of all of the EU-27 countries (-5 300 jobs compared to 2020). We consider the appearance of the observed peaks for hydropower a consequence of the modelling approach.

The overall employment level increased by 12 900 FTE to 48 800 hydropower jobs in the EU-27. And a similar increase is observed for the turnover part that is estimated at €6.4 billion. The highest hydro power turnover can be observed in the Member States with large hydro power capacities: France (26.2 GW), Italy (22.8 GW), Austria (14.7) and Spain (20.1 GW).

In the countries where no new capacity was added in 2021, 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€)	
	2020	2021	2020	2021	2020	2021
France	3 800	15 500	560	2 220	220	920
Italy	11 600	6 300	1 630	910	660	350
Germany	3 100	4 700	480	720	210	320
Austria	2 100	4 500	400	810	150	340
Spain	3 600	4 000	430	460	190	210
Portugal	2 000	2 700	120	160	40	60
Sweden	2 000	2 100	370	380	170	180
Czechia	600	1 400	50	100	20	40
Romania	1 100	1 400	90	110	30	40
Greece	800	900	70	80	30	30
Bulgaria	800	800	50	50	20	20
Croatia	700	600	40	40	20	10
Finland	400	500	70	90	30	40
Latvia	500	500	30	30	10	10
Poland	500	500	40	40	20	20
Slovakia	500	500	40	40	20	20
Slovenia	400	400	30	30	10	10
Lithuania	300	300	10	10	10	10
Belgium	200	200	40	40	10	10
Hungary	<100	200	<10	10	<10	<10
Luxembourg	200	200	30	30	10	10
Ireland	100	100	10	10	<10	<10
Cyprus	<100	<100	<10	<10	<10	<10
Denmark	<100	<100	<10	<10	<10	<10
Estonia	100	<100	<10	<10	<10	<10
Malta	<100	<100	<10	<10	<10	<10
Netherlands	<100	<100	<10	<10	<10	<10
Total EU 27	**35 900**	**48 800**	**4 650**	**6 420**	**1 950**	**2 720**

Source: EurObserv'ER

GEOTHERMAL ENERGY

Geothermal energy consists of extracting the heat contained in the ground, in order to use it to heat buildings, cool them or produce electricity. The main use is the heating of homes and commercial premises, but other applications are possible in agriculture (heating of greenhouses, drying of agricultural products, etc.), fish farming, heating of swimming pools, cooling, among others. 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 increased by €100 million to €910 million. And employment increased to 7 300 in 2021 (from a previous level of 6 100 jobs).


Atlas

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 2021, the largest increase in geothermal capacity for heating occurred in the Poland: from 61 MWth to 137 MWth installed capacity. With a turnover of €90 million and 1 200 jobs, Poland is the largest in terms of employment in the geothermal sector. The Netherlands maintained its high level of activity in 2021 with the addition of 71 MWth of geothermal for heating and cooling. This is reflected in the 1 000 jobs and €170 million turnover estimate. Italy follows as a historically dominant player with 1 000 jobs and a turnover of €160 million, owing to its large existing geothermal power and heating capacity. With a turnover of €130 million and 800 jobs in the geothermal sector, the geothermal sector in France remains the fourth largest in the EU after the Netherlands, Italy and Poland. Germany and Hungary follow with 700 and 500 jobs respectively. ■

Employment and turnover

	Employment (direct and indirect jobs)		Turnover (in M€)		Direct GVA (in M€)	
	2020	2021	2020	2021	2020	2021
Poland	100	1 200	10	90	<10	30
Italy	1 000	1 000	150	160	60	60
Netherlands	1 100	1 000	180	170	70	60
France	700	800	120	130	40	50
Germany	500	700	80	110	30	50
Hungary	500	500	30	30	10	10
Austria	200	100	40	20	20	10
Romania	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
Portugal	100	<100	<10	<10	<10	<10
Sweden	<100	<100	10	10	<10	<10
Slovenia	100	<100	10	<10	<10	<10
Slovakia	<100	<100	<10	<10	<10	<10
Total EU 27	**6 100**	**7 300**	**810**	**910**	**440**	**470**

Source: EurObserv'ER

HEAT PUMPS

For heat pumps we see another large increase in terms of industry turnover and EU wide employment in 2021, following a large increase in 2020. The increase in 2021 is caused by a change in the processing of input data in our model. The input now more accurately represents the estimated number of heat pumps installed in countries where there is also a significant amount of decommissioning of older heat pumps taking place. The estimates for Italy have increased significantly as a result of this change, moving it up into the first place in terms of turnover (over €20 billion) and employment (141 300 FTE). On the other hand we see a significant decline in France, caused by an overestimate in the 2020 values. Despite the correction, France still has the second largest heat pump sector in the EU – thanks to a large and active heat pump market. For Greece we see a similar decline due to an overestimation of the estimates in 2020. Other countries with a notable decline in the estimated employment and turnover are Slovenia (-€1.1 billion and 13 600 jobs) and Portugal (-€470 million and 9 700 jobs). For Slovenia and Portugal the decline is caused by fewer new heat pumps being installed in 2021 compared to 2020.

The modelling resulted in an estimated overall turnover of €52 billion (up over €11 billion) and a heat pump employment level of 377 300 workers. The increase is largely driven by the effect of the changed methodology on the estimates for Italy. Spain, Portugal and Germany remain large players with over 20 000 persons employed in the sector. In the Netherlands we see a large increase in terms of employment (+ 6 400 FTE) and turnover (+1 billion). Heat pumps remains the largest renewable energy sector in the EU in terms of employment.

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.

While a large part of the heat pumps sold and installed in Europe are also still manufactured and "Made in the EU", the demand for heat pumps seems to have grown more quickly in 2021 than the production capacity – leading to more imports of heat pumps and heat pump parts from outside the EU. The heat pump value chain and creation remain positive examples of how renewables contribute not only to lower emissions and reduced dependence on imported fossil fuels (see chapter on avoided fossil fuel use), but also how they promote economic prosperity in Member States. ■

Employment and turnover

	Employment (direct and indirect jobs)		Turnover (in M€)		Direct GVA (in M€)	
	2020	2021	2020	2021	2020	2021
Italy	35 900	141 300	5 320	20 650	1 970	7 900
France	89 000	64 600	13 500	9 760	5 480	3 950
Spain	30 900	33 600	3 560	3 860	1 470	1 600
Germany	24 400	27 400	3 930	4 370	1 690	1 890
Portugal	31 700	22 500	1 800	1 290	680	480
Netherlands	13 700	20 100	2 200	3 230	800	1 180
Sweden	12 300	15 000	2 360	2 850	1 040	1 260
Poland	5 900	8 200	410	580	160	220
Finland	6 400	7 700	1 150	1 380	460	560
Greece	24 100	5 500	2 240	570	870	220
Belgium	3 900	4 200	800	870	290	310
Denmark	3 500	3 700	670	710	270	290
Malta	2 600	3 100	210	250	80	100
Slovakia	3 500	3 100	290	240	100	90
Slovenia	15 500	2 800	1 300	230	500	90
Austria	1 800	2 600	340	480	140	200
Lithuania	5 500	2 500	240	110	120	60
Estonia	1 900	2 300	140	170	50	60
Czechia	2 000	1 900	170	160	60	50
Hungary	1 500	1 800	90	110	30	40
Ireland	800	1 200	110	170	40	70
Romania	900	1 100	60	70	20	30
Bulgaria	700	700	40	40	10	10
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	318 800	377 300	40 970	52 190	16 370	20 700

Source: EurObserv'ER

BIOGAS

Anaerobic digestion is a natural process of biological degradation of organic matter in an oxygen-free environment due to the action of multiple microorganisms. Methanisation biogas from anaerobic fermentation is broken down into several segments segmented according to the origin and treatment of the waste: landfill, wastewater treatment or non-hazardous waste and raw plant matter. Biogas is used to produce heat and/or electricity but can also be injected directly into gas transport and distribution networks.
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 2021, primary energy output from biogas in the European Union remained relatively stable compared to 2020 around 14 600 ktoe. The number of jobs in the biogas sector marginally contracted to 47 100 in 2021 – 1 800 full time jobs less than in 2020. The sector produced a turnover of €5.5 billion a slight decline from €5.75 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 Germany, Italy, Czechia and France all decreased by 500-600 FTE compared to 2020, but the workforces in these countries remain the largest for the biogas sector. Sector turnover also shows decreases in these four countries. Poland has the fifth highest sector turnover according to our estimates and a sectoral workforce comparable to France. They are followed by Spain where the employment estimate increased by 500 FTE in 2021 compared to 2020. The increase follows an increase in electricity produced from biogas in Spain compared to the previous year (928 GWh compared to 881 GWh in 2020). ■

Employment and turnover

	Employment (direct and indirect jobs)		Turnover (in M€)		Direct GVA (in M€)	
	2020	2021	2020	2021	2020	2021
Germany	24 800	24 200	3 400	3 320	1 540	1 500
Italy	6 900	6 300	750	690	390	360
Czechia	3 900	3 400	260	230	110	90
France	3 100	2 600	410	350	170	140
Poland	2 600	2 600	140	140	50	50
Spain	800	1 300	80	130	40	60
Croatia	800	800	50	50	20	20
Greece	500	700	30	40	10	20
Latvia	500	500	30	20	10	10
Netherlands	500	500	80	90	40	40
Portugal	400	500	20	30	10	10
Slovakia	500	500	40	40	20	20
Austria	500	400	70	60	30	30
Belgium	400	400	110	100	40	30
Hungary	500	400	30	20	10	10
Bulgaria	300	300	20	20	10	10
Denmark	500	300	90	60	40	20
Finland	300	300	30	30	10	10
Lithuania	200	300	10	20	10	10
Cyprus	100	100	10	10	<10	<10
Ireland	100	100	20	20	10	10
Luxembourg	100	100	10	10	<10	<10
Sweden	100	100	<10	10	<10	10
Slovenia	200	100	20	10	10	<10
Estonia	<100	<100	<10	<10	<10	<10
Malta	<100	<100	<10	<10	<10	<10
Romania	<100	<100	<10	<10	<10	<10
Total EU 27	48 900	47 100	5 750	5 530	2 640	2 520

Source: EurObserv'ER

BIOFUELS

The European biofuels sector (EurObserv'ER subsumes biodiesel, bioethanol and biogas for transport in the biofuels technologies) saw a small increase in 2021. Overall biofuel consumption increased by 7.8% between 2020 and 2021 to 17 022 ktoe (+ 1 229 ktoe). Substantial biofuel production capacities remain idle in the EU. According to EurObserv'ER calculations, the entire European Union biofuel induced industry turnover increased slightly to €12.1 billion, whereas the employment level increased from 141 600 to 148 300 jobs in 2021. The methodology used to evaluate the biomass industry covers biomass supply activities, i.e. supply in the agricultural sector. Biofuels remains the fifth largest renewable energy job creator in the EU, following solid biomass, heat pumps, solar PV, and wind energy.

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, Poland (21 400 jobs and €970 million) is the largest in terms of biofuel employment. Romania (17 800 persons employed with a turnover of €740 million) and Hungary (17 000 persons employed and €980 million turnover) follow closely behind France the biofuels job head count in the EU in 2021.

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 with €2.3 billion). In 2021, France was the second consumer of biofuel in Europe, behind Germany. It is the second largest market in terms of biofuel jobs with 18 800 jobs. It 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 €1.3 billion, while the employment level slightly decreased to 13 500 persons. Biofuel induced turnover increased in Germany (€1.8 billion, up from €1.6 billion in 2020) and correspondingly also saw an increase in job figures with 12 400 persons employed in 2021. ■

Employment and turnover

	Employment (direct and indirect jobs)		Turnover (in M€)		Direct GVA (in M€)	
	2020	2021	2020	2021	2020	2021
Poland	17 900	21 400	820	970	310	370
France	21 900	18 800	2 600	2 250	1 100	950
Romania	20 100	17 800	830	740	380	340
Hungary	15 800	17 000	920	980	440	470
Spain	13 900	13 500	1 380	1 340	720	700
Germany	10 900	12 400	1 570	1 770	700	790
Sweden	6 500	7 300	400	450	170	190
Lithuania	4 800	7 200	240	350	100	150
Italy	5 700	5 700	600	590	300	300
Slovakia	4 100	4 400	340	360	150	160
Czechia	4 300	4 300	280	280	110	110
Latvia	2 600	3 300	130	170	40	50
Bulgaria	2 400	3 100	150	200	60	70
Austria	2 100	2 600	320	390	140	180
Greece	2 700	2 600	140	130	70	60
Belgium	1 700	1 600	460	430	170	160
Croatia	1 200	1 600	80	100	40	50
Netherlands	1 200	1 200	260	270	110	110
Finland	600	1 000	80	150	30	60
Estonia	200	400	10	20	<10	10
Ireland	100	300	20	40	10	20
Portugal	400	300	40	40	10	10
Cyprus	<100	<100	<10	<10	<10	<10
Denmark	<100	<100	<10	10	<10	<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	**141 600**	**148 300**	**11 720**	**12 070**	**5 220**	**5 360**

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 Renewable municipal waste (RMW) 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 renewable sectors in the European Union. EurObserv'ER estimates the RMW sector is worth €2.5 billion in 2021, with €1.1 billion in gross added value. With 14 500 direct and indirect fulltime equivalent jobs, an increase by 1 700 jobs compared to 2020 can be observed. The increase is driven by an apparent increase in capacity of Waste-to-Energy plants in 2021 compared to 2020. The most notable increases are observed in Poland (+€110 million and 1 600 jobs) and Austria (+€180 million and 1 000 jobs). Meanwhile a significant reduction can be observed for the estimates for Sweden (-€110 million and 600 jobs).
EurObserv'ER estimates that roughly two thirds of the estimated turnover and employment are based on investment in new capacity (CAPEX) and around one third of turnover and jobs can be attributed to the operation and maintenance of Waste-to-Energy plants. According to the EurObserv'ER modelling, Germany is the largest MSW member state in terms of socioeconomic impacts, with €750 million turnover and 3 900 jobs in the sector. Poland ranks next with an estimated workforce of 1 900 workers and an industry turnover of €130 million in 2021. Italy (1 700 full time jobs) follows next. ■


DALKIA WASTENERGY

Employment and turnover

	Employment (direct and indirect jobs)		Turnover (in M€)		Direct GVA (in M€)	
	2020	2021	2020	2021	2020	2021
Germany	3 200	3 900	660	750	290	330
Poland	300	1 900	20	130	10	60
Italy	1 200	1 700	220	300	80	120
Austria	300	1 300	60	240	20	100
France	1 200	1 300	230	240	90	90
Netherlands	800	800	180	160	70	70
Sweden	1 400	800	310	200	150	90
Belgium	300	300	80	70	30	30
Denmark	800	300	190	90	80	40
Spain	500	300	70	50	30	20
Finland	300	200	70	50	30	20
Portugal	500	200	40	20	10	10
Czechia	<100	100	<10	<10	<10	<10
Hungary	100	100	10	10	<10	<10
Ireland	100	100	30	20	10	10
Lithuania	<100	100	<10	<10	<10	<10
Luxembourg	<100	100	<10	30	<10	10
Bulgaria	500	<100	30	<10	10	<10
Cyprus	<100	<100	<10	<10	<10	<10
Estonia	200	<100	20	10	10	<10
Greece	<100	<100	<10	<10	<10	<10
Croatia	<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	12 800	14 500	2 330	2 480	1 040	1 130

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 is 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 basically channeled into producing heat.

The consumption of solid biofuels energy reached record levels in the European Union in 2021. This significant increase, which corresponds to an increase in consumption of 7.8 Mtoe (from 96.4 to 104.2 Mtoe), is explained both by a harsher winter in 2021 and by the rise in fossil fuel prices in the second half of the year, which increased the competitiveness of biomass fuels. Following the same logic, electricity and heat production from solid biofuels increased in 2021 from 83 to 90 GWh (+ 8.4%) and from 11.4 to 13.1 Mtoe (+ 15%) respectively. These increases have had an impact on the socio-economic results of the sector, with an estimated 353 800 jobs in 2021 (+70 800 compared to 2020) and an estimated turnover of €38.5 billion (+€8.7 billion compared to 2020). Solid biofuel is the once again the largest renewable energy source in 2021, ahead of heat pumps, solar PV and wind power. In terms of turnover, biomass is also the largest sector ahead of heat pumps and wind power. 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, especially as more than 95% of the biomass fuels used in the sector come from EU countries. In 2021, imports from outside the EU accounted for only 3.5% of total consumption.

Regarding the countries, Germany has the highest solid biofuels turnover (€6 billion) and with 41 300 jobs is also home to the second largest biomass work force. Poland, one of the most important agricultural country in EU, represents 46 900 jobs, although the sector turnover is significantly lower at €2.2 billion. The different ratios between employment and turnover are caused by how different types of activity are modelled. Finland, Sweden and France rank next in terms of turnover (respectively €4.6 billion, €4.6 billion and €3.8 billion). France remains the third largest solid biofuels workforce at 24 900 jobs. ■

Employment and turnover

	Employment (direct and indirect jobs)		Turnover (in M€)		Direct GVA (in M€)	
	2020	2021	2020	2021	2020	2021
Poland	32 700	46 900	1 360	2 160	590	910
Germany	33 000	41 300	4 650	5 990	2 500	3 100
France	24 300	24 900	3 730	3 840	1 740	1 810
Netherlands	7 600	23 300	1 090	3 610	500	1 440
Sweden	21 500	22 900	4 320	4 590	1 820	1 940
Italy	19 200	21 100	1 370	1 670	800	910
Finland	12 600	19 200	3 260	4 560	2 090	2 750
Latvia	10 800	17 700	550	890	210	340
Spain	20 900	17 400	1 550	1 060	710	520
Czechia	12 400	15 900	710	940	260	340
Denmark	4 700	12 900	740	2 180	310	900
Bulgaria	9 700	12 200	410	530	160	210
Hungary	9 200	12 100	320	480	130	190
Croatia	8 600	10 400	310	380	160	190
Austria	8 000	9 800	1 730	2 070	800	950
Lithuania	9 500	9 200	350	320	170	150
Portugal	12 400	8 700	970	790	510	460
Romania	6 100	8 700	290	420	120	180
Estonia	10 300	8 300	920	780	340	300
Slovakia	4 700	5 400	300	340	150	170
Ireland	1 500	2 100	130	200	60	90
Slovenia	800	1 100	70	90	40	50
Belgium	1 300	1 000	460	400	140	120
Greece	400	800	40	90	20	30
Luxembourg	600	300	100	50	40	20
Cyprus	100	100	<10	<10	<10	<10
Malta	<100	<100	<10	<10	<10	<10
Total EU 27	283 000	353 800	29 750	38 450	14 390	18 090

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 1.47 million persons are directly or indirectly employed in the European Union renewable energy sector. This represents a gross increase of 156 700 jobs (12%) from 2020 to 2021. It must be noted that a change in the calculations for heat pumps has a large effect on the total increase. Excluding heat pumps we see an increase of almost 100 000 FTE across the remaining RES sectors.
- 18 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 (256 800 jobs, 17% of all EU renewable employment), Italy (206 100 jobs, 14%), France (167 800 jobs, 11%), Poland (129 300 jobs, 9%), and Spain (124 000 jobs, 8%).
- The largest growth in employment estimates were found in the Italy due to a change in the calculation for heat pumps. Other large increases are found in Poland (+36 700 new jobs, equal to +40%), Denmark (+19 000, equal to +54%), and Austria (+10 500 jobs, equal to +53%). The greatest decreases were observed in Spain (-16 500 jobs, equal to -12%), Greece (-15 700, -37%) and Slovenia (-12 500 jobs, equal to -71%).
- Heat pumps (377 300 jobs, 26% of the total EU) remained the largest sector in terms of renewable energy induced employment, followed by solid biomass (353 800 jobs, 24%) and solar PV (223 100 jobs, 15%). The most significant upward jump in employment per technology was in the solid biomass sector with an additional 70 800 jobs (+25%), followed by heat pumps and solar PV that saw an addition of 58 500 and 57 400 new jobs respectively. Increases were also observed in the biofuels, hydropower, geothermal and MSW sectors. Declines are seen in the wind energy and biogas sectors.

TURNOVER

- In total the renewable energy related industry turnover in EU 27 Member States in 2021 amounted to around €185 billion, representing a gross growth of around €22 billion against 2020 (+13%). Also here it must be noted that a change in the calculations for heat pumps has a large effect on the total increase. Excluding heat pumps we see an increase in turnover of almost €11 billion across the remaining RES sectors.
- 17 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 (€39.8 billion), Italy (€28.4 billion), France (€24.8 billion), Spain (€13.8 billion), and the Netherlands with €12.4 billion. The first four are also the countries where the gross value added is largest, followed by Sweden.
- The largest growth in turnover according to the EurObserv'ER modelling was observed in Italy (€15.5 billion) due to a change in the calculation for heat pumps. Other large increases are found in Denmark (+€3.4 billion), Poland (+€2.3 billion), Germany (+€2.3 billion) and Finland (+€2.1 billion). The largest dips in turnover occurred in Belgium (-€2.3 billion) and Spain (-€2.2 billion).
- The largest renewable energy technologies in terms of industry sector turnover were heat pumps with €52 billion, followed by solid biomass (€38.5 billion) and wind energy at €34 billion. The gross value added was also largest for these sectors: €20.1 billion for heat pumps, €18.1 billion for solid biomass and €14.7 billion for wind energy. ■

2020 EMPLOYMENT DISTRIBUTION BY SECTOR

	Total	Heat pumps	Solid biofuels	Wind	PV	Biofuels	Biogas	Hydro	Solar thermal	MSW	Geothermal
Germany	242 100	24 400	33 000	83 500	55 600	10 900	24 800	3 100	3 100	3 200	500
France	164 400	89 000	24 300	15 800	3 600	21 900	3 100	3 800	1 000	1 200	700
Spain	140 500	30 900	20 900	44 300	19 100	13 900	800	3 600	6 400	500	100
Italy	99 900	35 900	19 200	6 000	11 400	5 700	6 900	11 600	1 000	1 200	1 000
Poland	92 600	5 900	32 700	10 900	20 200	17 900	2 600	500	1 500	300	100
Netherlands	85 800	13 700	7 600	42 100	18 600	1 200	500	<100	100	800	1 100
Portugal	60 800	31 700	12 400	10 300	2 400	400	400	2 000	600	500	100
Sweden	57 600	12 300	21 500	9 600	4 000	6 500	100	2 000	100	1 400	<100
Greece	42 300	24 100	400	6 300	5 500	2 700	500	800	1 800	<100	<100
Denmark	35 400	3 500	4 700	22 800	2 500	<100	500	<100	300	800	<100
Hungary	35 400	1 500	9 200	1 200	6 300	15 800	500	<100	200	100	500
Romania	32 600	900	6 100	2 500	1 500	20 100	<100	1 100	100	<100	100
Czechia	27 500	2 000	12 400	1 100	2 900	4 300	3 900	600	100	100	<100
Belgium	25 000	3 900	1 300	12 700	4 300	1 700	400	200	100	300	<100
Finland	24 400	6 400	12 600	2 300	1 300	600	300	400	<100	300	<100
Lithuania	22 000	5 500	9 500	600	800	4 800	200	300	<100	<100	<100
Austria	19 700	1 800	8 000	1 100	2 200	2 100	500	2 100	1 400	300	200
Bulgaria	17 900	700	9 700	600	1 800	2 400	300	800	1 000	500	<100
Slovenia	17 500	15 500	800	<100	100	<100	200	400	<100	<100	100
Latvia	15 000	<100	10 800	100	100	2 600	500	500	<100	<100	<100
Estonia	14 200	1 900	10 300	800	400	200	<100	100	<100	200	<100
Croatia	14 000	<100	8 600	2 100	<100	1 200	800	700	200	<100	100
Slovakia	13 900	3 500	4 700	<100	200	4 100	500	500	100	100	<100
Ireland	6 200	800	1 500	3 100	200	100	100	100	100	100	<100
Malta	3 700	2 600	<100	<100	300	<100	<100	<100	<100	<100	<100
Luxembourg	1 800	<100	600	200	200	<100	100	200	<100	<100	<100
Cyprus	1 100	<100	100	100	<100	<100	100	<100	200	<100	<100
Total EU 27	1 313 300	318 800	283 000	280 400	165 700	141 600	48 900	35 900	20 100	12 800	6 100

Source: EurObserv'ER

2021 EMPLOYMENT DISTRIBUTION BY SECTOR

	Total	Heat pumps	Solid biofuels	PV	Wind	Biofuels	Hydro	Biogas	Solar thermal	MSW	Geothermal
Germany	256 800	27 400	41 300	56 000	69 200	12 400	4 700	24 200	17 000	3 900	700
Italy	206 100	141 300	21 100	15 100	6 100	5 700	6 300	6 300	1 500	1 700	1 000
France	167 800	64 600	24 900	23 300	14 500	18 800	15 500	2 600	1 500	1 300	800
Poland	129 300	8 200	46 900	35 200	8 600	21 400	500	2 600	2 800	1 900	1 200
Spain	124 000	33 600	17 400	25 400	23 000	13 500	4 000	1 300	5 400	300	<100
Netherlands	79 300	20 100	23 300	21 700	10 500	1 200	<100	500	100	800	1 000
Sweden	65 600	15 000	22 900	3 100	14 100	7 300	2 100	100	100	800	<100
Denmark	54 400	3 700	12 900	3 500	31 900	<100	<100	300	1 500	300	<100
Portugal	50 200	22 500	8 700	7 200	7 200	300	2 700	500	800	200	<100
Finland	35 500	7 700	19 200	2 000	4 400	1 000	500	300	100	200	<100
Hungary	35 500	1 800	12 100	2 300	700	17 000	200	400	400	100	500
Romania	33 300	1 100	8 700	1 900	2 000	17 800	1 400	<100	100	<100	100
Austria	30 200	2 600	9 800	5 000	2 000	2 600	4 500	400	1 900	1 300	100
Czechia	30 100	1 900	15 900	2 200	600	4 300	1 400	3 400	200	100	<100
Greece	26 600	5 500	800	7 000	6 600	2 600	900	700	2 300	<100	<100
Lithuania	23 500	2 500	9 200	1 500	2 200	7 200	300	300	<100	100	<100
Latvia	22 700	<100	17 700	100	200	3 300	500	500	<100	<100	<100
Bulgaria	21 100	700	12 200	1 800	700	3 100	800	300	1 300	<100	<100
Croatia	16 500	<100	10 400	<100	2 600	1 600	600	800	100	<100	<100
Slovakia	14 500	3 100	5 400	200	<100	4 400	500	500	100	<100	<100
Estonia	14 300	2 300	8 300	2 500	300	400	<100	<100	<100	<100	<100
Belgium	14 200	4 200	1 000	4 300	2 000	1 600	200	400	100	300	<100
Ireland	6 000	1 200	2 100	300	1 600	300	100	100	100	100	<100
Slovenia	5 000	2 800	1 100	100	<100	<100	400	100	<100	<100	<100
Malta	4 100	3 100	<100	200	<100	<100	<100	<100	<100	<100	<100
Cyprus	1 700	<100	100	600	100	<100	<100	100	300	<100	<100
Luxembourg	1 700	<100	300	500	100	<100	200	100	<100	100	<100
Total EU 27	1 470 000	377 300	353 800	223 100	211 500	148 300	48 800	47 100	38 300	14 500	7 300

Source: EurObserv'ER

2020 TURNOVER BY SECTOR (€M)

	Total	Wind	Heat pumps	Solid biofuels	PV	Biofuels	Biogas	Hydro	Solar thermal	MSW	Geothermal
Germany	37 470	13 960	3 930	4 650	8 310	1 570	3 400	480	430	660	80
France	24 450	2 640	13 500	3 730	520	2 600	410	560	140	230	120
Spain	15 930	5 860	3 560	1 550	2 040	1 380	80	430	950	70	10
Netherlands	13 050	6 350	2 200	1 090	2 690	260	80	<10	10	180	180
Italy	12 860	1 040	5 320	1 370	1 650	600	750	1 630	130	220	150
Sweden	10 370	1 880	2 360	4 320	700	400	<10	370	10	310	10
Denmark	7 350	5 080	670	740	500	<10	90	<10	50	190	10
Belgium	5 510	2 700	800	460	830	460	110	40	20	80	<10
Finland	5 370	430	1 150	3 260	260	80	30	70	10	70	<10
Poland	5 160	840	410	1 360	1 410	820	140	40	110	20	10
Portugal	3 910	750	1 800	970	130	40	20	120	30	40	<10
Austria	3 850	230	340	1 730	400	320	70	400	260	60	40
Greece	3 730	590	2 240	40	450	140	30	70	150	<10	<10
Hungary	1 860	80	90	320	360	920	30	<10	10	10	30
Czechia	1 820	100	170	710	220	280	260	50	10	<10	<10
Romania	1 630	210	60	290	110	830	<10	90	10	<10	10
Slovenia	1 480	<10	1 300	70	10	<10	20	30	<10	<10	10
Estonia	1 220	60	140	920	30	10	<10	<10	<10	20	<10
Slovakia	1 070	<10	290	300	20	340	40	40	<10	10	<10
Lithuania	950	40	240	350	30	240	10	10	<10	<10	<10
Bulgaria	890	40	40	410	90	150	20	50	50	30	<10
Ireland	880	520	110	130	20	20	20	10	10	30	<10
Latvia	800	10	<10	550	10	130	30	30	<10	<10	<10
Croatia	670	140	<10	310	<10	80	50	40	10	<10	<10
Malta	310	<10	210	<10	20	<10	<10	<10	<10	<10	<10
Luxembourg	270	40	<10	100	40	<10	10	30	<10	<10	<10
Cyprus	100	10	<10	<10	10	<10	10	<10	10	<10	<10
Total EU 27	162 960	43 630	40 970	29 750	20 870	11 720	5 750	4 650	2 480	2 330	810

Source: EurObserv'ER

2021 TURNOVER BY SECTOR (€M)

	Total	Heat pumps	Solid biofuels	Wind	PV	Biofuels	Hydro	Biogas	Solar thermal	MSW	Geothermal
Germany	39 770	4 370	5 990	11 710	8 440	1 770	720	3 320	2 590	750	110
Italy	28 390	20 650	1 670	1 050	2 170	590	910	690	200	300	160
France	24 820	9 760	3 840	2 460	3 350	2 250	2 220	350	220	240	130
Spain	13 750	3 860	1 060	3 320	2 680	1 340	460	130	840	50	<10
Netherlands	12 370	3 230	3 610	1 670	3 150	270	<10	90	10	160	170
Sweden	11 730	2 850	4 590	2 700	530	450	380	10	10	200	10
Denmark	10 730	710	2 180	6 670	700	10	<10	60	290	90	10
Finland	7 470	1 380	4 560	780	410	150	90	30	10	50	<10
Poland	7 470	580	2 160	690	2 470	970	40	140	200	130	90
Austria	5 690	480	2 070	380	880	390	810	60	360	240	20
Portugal	3 340	1 290	790	570	390	40	160	30	40	20	<10
Belgium	3 210	870	400	440	840	430	40	100	10	70	<10
Greece	2 340	570	90	630	570	130	80	40	210	<10	<10
Czechia	1 980	160	940	60	180	280	100	230	10	<10	<10
Hungary	1 840	110	480	40	140	980	10	20	20	10	30
Romania	1 680	70	420	170	130	740	110	<10	10	<10	10
Estonia	1 230	170	780	30	180	20	<10	<10	<10	10	<10
Latvia	1 170	<10	890	10	<10	170	30	20	<10	<10	<10
Slovakia	1 080	240	340	<10	20	360	40	40	10	<10	<10
Bulgaria	1 070	40	530	50	100	200	50	20	60	<10	<10
Lithuania	1 020	110	320	110	70	350	10	20	<10	<10	<10
Ireland	840	170	200	310	50	40	10	20	10	20	<10
Croatia	780	<10	380	160	<10	100	40	50	<10	<10	<10
Slovenia	420	230	90	<10	10	<10	30	10	<10	<10	<10
Malta	340	250	<10	<10	10	<10	<10	<10	<10	<10	<10
Luxembourg	240	<10	50	10	70	<10	30	10	<10	30	<10
Cyprus	150	<10	<10	10	50	<10	<10	10	20	<10	<10
Total EU 27	184 920	52 190	38 450	34 060	27 610	12 070	6 420	5 530	5 200	2 480	910

Source: EurObserv'ER

2020 GROSS VALUE ADDED BY SECTOR (€M)

	Total	Wind	Heat pumpss	Solid biofuels	PV	Biofuels	Biogas	Hydro	Solar thermal	MSW	Geothermal
Germany	16 940	6 090	1 690	2 500	3 700	700	1 540	210	190	290	30
France	10 160	1 050	5 480	1 740	210	1 100	170	220	60	90	40
Spain	6 940	2 430	1 470	710	890	720	40	190	450	30	<10
Italy	5 380	440	1 970	800	630	300	390	660	50	80	60
Netherlands	5 330	2 700	800	500	1 020	110	40	<10	<10	70	70
Sweden	4 660	950	1 040	1 820	330	170	<10	170	<10	150	<10
Finland	2 960	190	460	2 090	100	30	10	30	<10	30	<10
Denmark	2 950	2 000	270	310	200	<10	40	<10	20	80	<10
Poland	2 130	370	160	590	570	310	50	20	40	10	<10
Belgium	2 080	1 080	290	140	300	170	40	10	10	30	<10
Austria	1 670	90	140	800	170	140	30	150	110	20	20
Portugal	1 630	300	680	510	50	10	10	40	10	10	<10
Greece	1 510	260	870	20	180	70	10	30	50	<10	<10
Hungary	830	30	30	130	150	440	10	<10	<10	<10	10
Romania	720	90	20	120	40	380	<10	30	<10	<10	<10
Czechia	700	30	60	260	80	110	110	20	<10	<10	<10
Slovenia	620	<10	500	40	<10	<10	10	10	<10	<10	<10
Slovakia	490	<10	100	150	10	150	20	20	<10	<10	<10
Estonia	480	20	50	340	10	<10	<10	<10	<10	10	<10
Lithuania	480	20	120	170	20	100	10	10	<10	<10	<10
Ireland	390	220	40	60	10	10	10	<10	<10	10	<10
Bulgaria	350	20	10	160	30	60	10	20	20	10	<10
Croatia	350	60	<10	160	<10	40	20	20	<10	<10	<10
Latvia	330	<10	<10	210	<10	40	10	10	<10	<10	<10
Malta	170	<10	80	<10	10	<10	<10	<10	<10	<10	<10
Luxembourg	130	10	<10	40	10	<10	<10	10	<10	<10	<10
Cyprus	100	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Total EU 27	70 480	18 500	16 370	14 390	8 760	5 220	2 640	1 950	1 170	1 040	440

Source: EurObserv'ER

EUROBSERV'ER – THE STATE OF RENEWABLE ENERGIES IN EUROPE – 2022 EDITION

2021 GROSS VALUE ADDED BY SECTOR (€M)

	Total	Heat pumps	Solid biofuels	Wind	PV	Biofuels	Hydro	Biogas	Solar thermal	MSW	Geothermal
Germany	17 970	1 890	3 100	5 110	3 750	790	320	1 500	1 130	330	50
Italy	11 360	7 900	910	450	830	300	350	360	80	120	60
France	10 350	3 950	1 810	970	1 380	950	920	140	90	90	50
Spain	6 140	1 600	520	1 440	1 170	700	210	60	410	20	<10
Sweden	5 300	1 260	1 940	1 360	250	190	180	10	10	90	<10
Netherlands	4 790	1 180	1 440	680	1 190	110	<10	40	<10	70	60
Denmark	4 430	290	900	2 760	280	<10	<10	20	110	40	<10
Finland	3 960	560	2 750	340	160	60	40	10	<10	20	<10
Poland	3 030	220	910	300	1 000	370	20	50	70	60	30
Austria	2 500	200	950	160	380	180	340	30	150	100	10
Portugal	1 430	480	460	230	150	10	60	10	10	10	<10
Belgium	1 150	310	120	170	300	160	10	30	<10	30	<10
Greece	970	220	30	280	230	60	30	20	80	<10	<10
Hungary	820	40	190	20	50	470	<10	10	10	<10	10
Romania	760	30	180	80	50	340	40	<10	<10	<10	<10
Czechia	740	50	340	20	60	110	40	90	<10	<10	<10
Slovakia	510	90	170	<10	10	160	20	20	<10	<10	<10
Estonia	500	60	300	10	70	10	<10	<10	<10	<10	<10
Lithuania	490	60	150	50	30	150	10	10	<10	<10	<10
Latvia	470	<10	340	<10	<10	50	10	10	<10	<10	<10
Bulgaria	410	10	210	20	30	70	20	10	20	<10	<10
Croatia	390	<10	190	70	<10	50	10	20	<10	<10	<10
Ireland	380	70	90	130	20	20	<10	10	<10	10	<10
Slovenia	220	90	50	<10	<10	<10	10	<10	<10	<10	<10
Malta	190	100	<10	<10	10	<10	<10	<10	<10	<10	<10
Luxembourg	130	<10	20	<10	30	<10	10	<10	<10	10	<10
Cyprus	110	<10	<10	<10	20	<10	<10	<10	10	<10	<10
Total EU 27	79 500	20 700	18 090	14 710	11 480	5 360	2 720	2 520	2 320	1 130	470

Source: EurObserv'ER

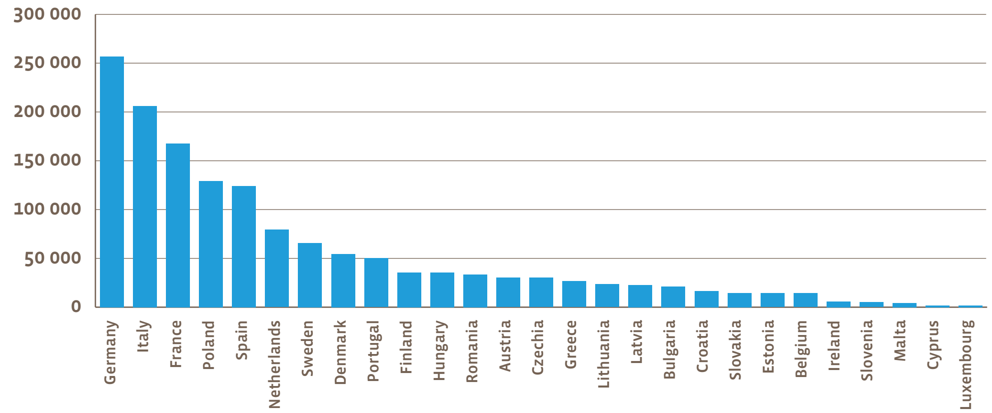
RENEWABLE ENERGY DEVELOPMENT AND ITS INFLUENCE ON FOSSIL FUEL SECTORS

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 2022 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 2021. 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

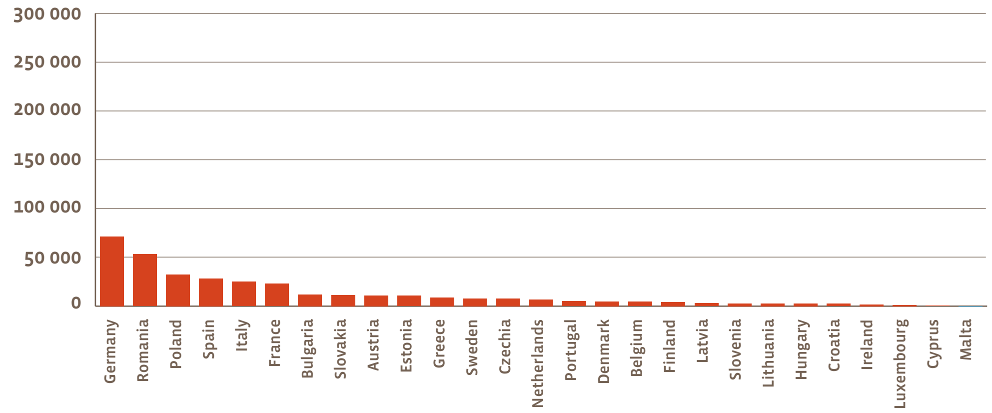
Gross renewable employment as reported in the previous sections (data for 2021)



Source: EurObserv'ER

2

Indicator for equivalent replaced fossil employment, looking at operation, maintenance and fuel production activities only (data for 2021)



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 report. 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. The data sources used in this barometer cover investment information of renewable energy plants from residential to utility-scale, while 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.

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 annual publication Financing and Investment Trends *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 the following years.

Investment in Renewable Energy

Bloomberg Energy Transition Investment Trends 2022 reports an investment in the energy transition of $154 billion in EU member states in 2021, second place behind China and followed by the U.S. The energy transition investment includes investment in renewable energy, energy storage, electrified transport, electric heat, nuclear energy, hydrogen, CCS and sustainable materials. Among all EU member states, Germany, France and Spain invested $47 billion, $27 billion and $11 billion respectively in these low-carbon fields. More than half of the investment volume in Germany and France was spent on electrified transport (followed by renewable energy and electric heat), while Spain spent slightly more than half of the investment 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 2020 and 2021.

WIND POWER

Since 2017, a notable increase in wind onshore investments is observed. Investments in new wind offshore capacity increased vastly in 2020 and went down slightly in 2021. Total investments in wind capacity went up from €25.4 billion in 2020 by 10% to €27.8 billion in 2021. The associated capacity added increased even stronger, namely by 43% from 13 GW to 18 GW. This indicates that investment costs in the wind sector declined between both years. This is analysed in more detail for onshore and offshore wind investments in the following sections.

In 2020, the Netherlands led among all EU 27 Member States in investment in wind capacity with around €7.9 billion (mostly in offshore windpower), while Germany took over the first place in 2021 with € 8 billion. France stayed in second place in both years, although the asset finance volume in the wind power sector decreased from €6.5 billion in 2020 to €4.6 billion in 2021. Spain, Poland, Greece, Italy, Finland and Sweden have invested in the wind sector in both years and all, except for Poland, have at least doubled their investments in 2021.

1

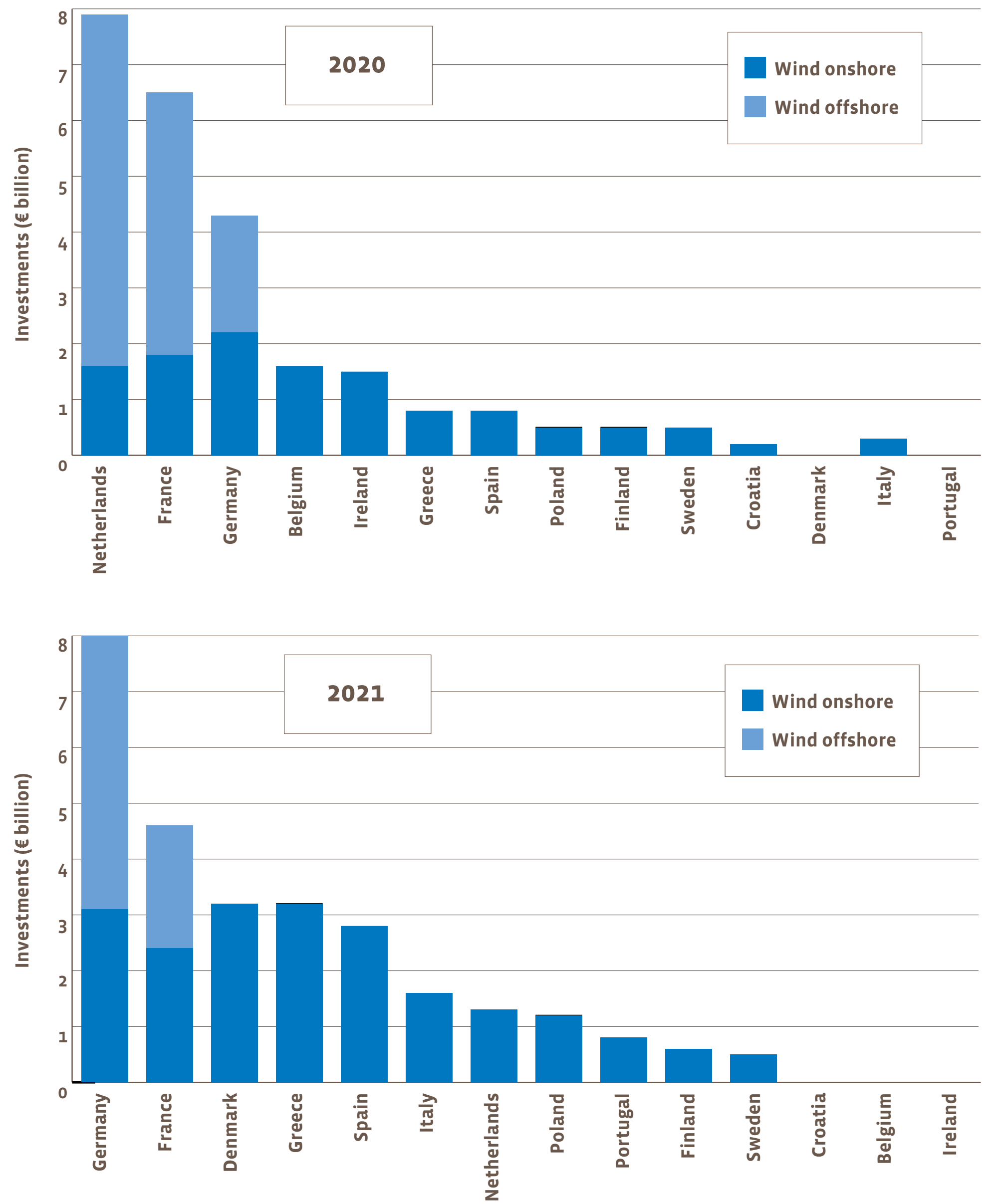
Overview of asset finance in the wind power sector (onshore + offshore) in the EU Member States in 2020 and 2021

	2020		2021	
	Asset finance - newly built (€ bn)	Associated capacity added (GW)	Asset finance - newly built (€ bn)	Associated capacity added (GW)[1]
Germany	4.3	1.7	8.0	3.5
France	6.5	2.2	4.6	2.2
Spain	1.5	1.5	3.2	2.9
Sweden	0.8	0.8	3.2	2.6
Finland	0.5	0.4	2.8	2.5
Poland	1.6	1.3	1.6	1.3
Netherlands	7.9	3.2	1.3	1.2
Greece	0.5	0.2	1.2	0.7
Denmark	0.0	0.2	0.8	0.2
Italy	0.3	0.2	0.6	0.5
Portugal	0.0	0.0	0.5	0.4
Belgium	0.5	0.4	0.0	0.0
Ireland	0.8	0.5	0.0	0.3
Croatia	0.2	0.2	0.0	0.0
Total EU 27	**25.4**	**12.8**	**27.8**	**18.3**

1. These capacity data may differ from the one reported in the energy indicator chapter which are the most recent and accurate figures. ***Source: EurObserv'ER own assessment based on WindEurope and Eurostat.***

1

Asset finance in the wind power sector in the EU Member States in 2020 and 2021



Source: EurObserv'ER own assessment based on WindEurope and Eurostat

WIND INVESTMENTS SHIFT FROM OFFSHORE TO ONSHORE

In 2020, the total wind investments in the EU 27 Member States were distributed almost evenly between onshore wind (48 %) and offshore wind (52%) investments. This distribution has shifted strongly from offshore to onshore wind investments in 2021. Onshore wind investments increased from €12 billion in 2020 by 63 % to €20 billion in 2021. As a result, onshore wind investments made up 72% of the total wind investment in 2021. In contrast, investments in offshore wind plants decreased by 40% from €13.1 billion in 2020 to €7.8 billion in 2021. The share of offshore wind in overall wind investments in 2021 reduced therefore to 28%.

The associated capacity added of onshore wind investments increased from 9.25 GW in 2020 by 74% to 16.05 GW in 2021. As for offshore wind, the associated capacity added decreased slightly along with the lower investment volumes from 3.5 GW in 2020 to 2.2 GW in 2021. In contrast to wind onshore, this indicates a slight increase in the investment costs of offshore wind plants. In the case of onshore, investment costs are as expected substantially lower, namely €1.3 million per MW of onshore capacity in 2020 as well as in 2021.

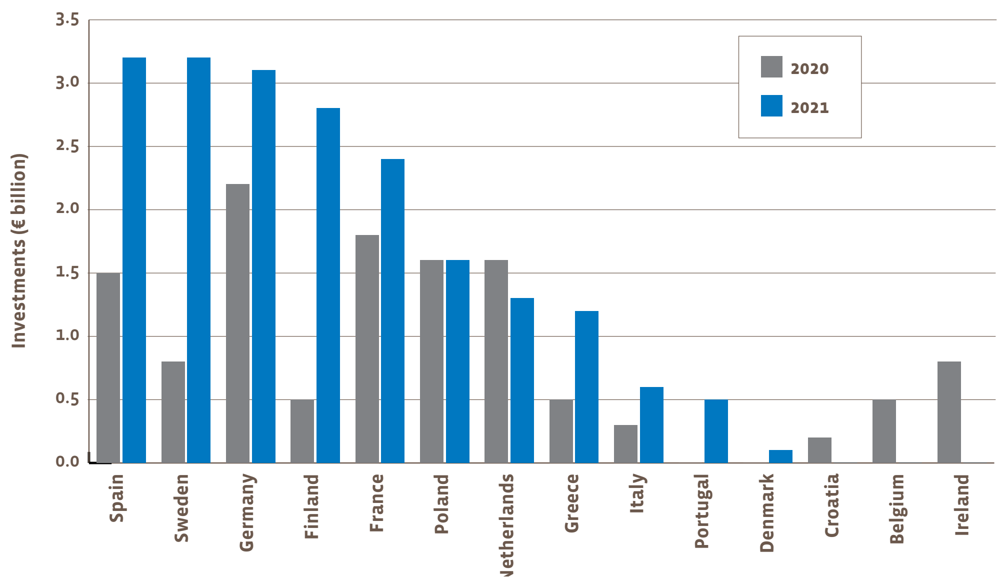
SPAIN AND SWEDEN SURPASS GERMANY IN ONSHORE WIND

In 2020, Germany led among all EU 27 Member States in onshore wind investments with around €2.2 billion, which increased by 41% to €3.1 billion in 2021. Meanwhile, Spain doubled its investments in onshore wind plants and Sweden increased its investment volumes even fourfold in 2021 compared to 2020. Consequently, Spain and Sweden slightly surpassed Germany in 2021 with investment volumes of €3.2 billion each. Finland showed an even stronger increase in onshore wind investments from €0.5 billion in 2020 to €2.8 billion in 2021. This made Finland the 4th highest Member State investing in the onshore wind sector in 2021, followed by France with €2.4 billion, which was the second highest in 2020.

As for associated capacity added, Spain led in both years with 1.5 GW in 2020 and 2.9 GW in 2021. Germany and Poland achieved 1.3 GW each in 2020 as the second highest, while Sweden and Finland surpassed in 2021 with 2.6 GW and 2.5 GW respectively. In 2021, Germany contributed 2.1 GW added capacity as the 4th highest Member State. The strongest growth in associated capacity added is observed in Finland, namely over 6 times from 0.4 GW in 2020 to 2.5 GW in 2021. The higher increase in associated capacity added than in investment volumes indicates a decrease in investment costs in onshore wind plants. A similar trend could also be observed in the overall EU 27 level, especially in Greece, the Netherlands, and Germany.

2

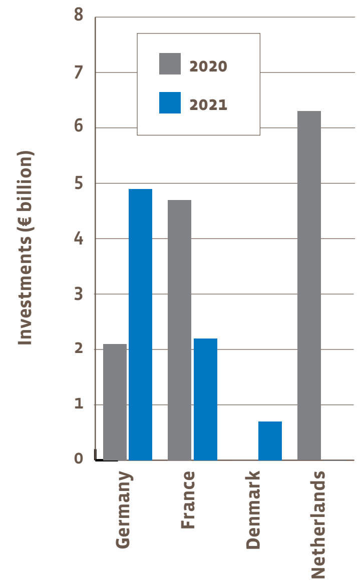
Asset finance in the onshore wind sector in the EU Member States in 2020 and 2021



Source: EurObserv'ER own assessment based on WindEurope and Eurostat

3

Asset finance in the offshore wind sector in the EU Member States in 2020 and 2021



Source: EurObserv'ER own assessment based on WindEurope and Eurostat

THE NETHERLANDS STEPS DOWN IN OFFSHORE WIND, WHILE GERMANY SPEEDS UP

Among the limited players in the offshore wind sector, the Netherlands made enormous investments of €6.3 billion in this sector in 2020 and stepped back in 2021. Meanwhile, Germany invested more than twice as high in offshore wind plants. With investment volumes of €4.9 billion in 2021, Germany led in offshore wind investments in the EU, although it was the third largest player in 2020 with investments of €2.1 billion. The dramatic change observed in the Netherlands should be interpreted bearing in mind the particularly high investments in 2020. Additionally, several GW of offshore wind is currently being planned and constructed and these investments will be counted in the next years. Hence, this is not necessarily an indication of a downturn, but 2021 could rather be an exceptional year for the Netherlands as well as for other Member States.

France remained the second largest player in offshore wind investments, although it slowed down its investments from €4.7 billion in 2020 to €2.2 billion in 2021. Moreover, Denmark also invested €0.7 billion in offshore wind plants.

Analog to the decrease in investment volumes, the associated capacity added in the offshore wind sector has dropped from 3.5 GW in 2020 by 37% to 2.2 GW in 2021. Almost

2

Overview of asset finance in the onshore wind sector in the EU Member States in 2020 and 2021

	2020		2021	
	Asset finance - newly built (€ bn)	Associated capacity added (GW)	Asset finance - newly built (€ bn)	Associated capacity added (GW)
Spain	1.5	1.5	3.2	2.9
Sweden	0.8	0.8	3.2	2.6
Germany	2.2	1.3	3.1	2.1
Finland	0.5	0.4	2.8	2.5
France	1.8	1.2	2.4	1.6
Poland	1.6	1.3	1.6	1.3
Netherlands	1.6	1.1	1.3	1.2
Greece	0.5	0.2	1.2	0.7
Italy	0.3	0.2	0.6	0.5
Portugal	-	-	0.5	0.4
Denmark	-	0.2	0.1	-
Croatia	0.2	0.2	NA	NA
Belgium	0.5	0.4	-	-
Ireland	0.8	0.5	-	0.3
Total EU 27	**12.3**	**9.2**	**20.0**	**16.1**

Source: EurObserv'ER own assessment based on WindEurope and Eurostat.

half of the capacity added in 2020 was contributed by the Netherlands, while Germany achieved over half of the capacity added in EU 27. Overall, a drop in investment costs could be observed according to the data on asset finance and associated capacity added in offshore wind sectors. However, WindEurope reported average expenditures per MW of offshore capacity of €3.4 million and €3.5 million in 2020 and 2021 respectively. This could be caused by missing investment information for Member States or plants with relatively small contributions, which normally have higher specific capital expenditures. ■

3

Overview of asset finance in the offshore wind sector in the EU Member States in 2020 and 2021

	2020		2021	
	Asset finance - newly built (€ bn)	Associated capacity added (GW)	Asset finance - newly built (€ bn)	Associated capacity added (GW)
Germany	2.1	0.4	4.9	1.4
France	4.7	1.0	2.2	0.6
Denmark	-	-	0.7	0.2
Netherlands	6.3	2.1	0.0	-
Total EU 27	**13.1**	**3.5**	**7.8**	**2.2**

Source: EurObserv'ER own assessment based on WindEurope and Eurostat.

PHOTOVOLTAIC

When analysing investments in solar PV, two points are particularly important to be kept in mind. First of all, asset financing in the previous editions of the EurObser'ER report only con-tains utility-scale investments. In the current report, in addition to utility-scale PV investments by the EU Member States, 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, are included in the estimated investment data.

Overall, the total investment in solar PV in the EU 27 Member States was estimated to reach €18 billion associated with a capacity added of 20 GW. Slightly over one-third of the investments resulted in plant size between 20 kW and 1 MW, followed by investments in utility-scale installations over 1 MW and small-scale residential installations less than 20 kW. Due to the limited availability of investment information for the year 2021, no estimation for the total investment in all Member States is made. Nevertheless, a detailed analysis of Member States with available information in 2021 is shown in the following sections.

1

Overviwew of estimated investment in the solar photovoltaic sector in the EU Member States in 2020

	2020	
	Estimated investment (€m)	Associated capacity added (MW)
Germany	4 220	4 807
Netherlands	3 798	3 724
Poland	2 103	2 416
Spain	2 048	3 528
Belgium	1 139	938
France	1 018	997
Italy	807	749
Hungary	664	731
Sweden	454	400
Greece	436	454
Denmark	260	224
Austria	260	341
Portugal	170	199
Finland	111	96
Cyprus	90	78
Estonia	90	87
Ireland	86	34
Slovenia	81	92
Bulgaria	57	49
Czechia	37	36
Malta	33	33
Luxembourg	31	27
Croatia	24	24
Lithuania	7	61
Latvia	2	2
Romania	0	0
Slovakia	0	0
Total EU 27	**18029**	**20127**

Source: own assessment based on IEA, BMWK and Eurostat

GERMANY KEEPS POLE POSITION

Germany showed the highest investments in solar PV as well as the highest associated capacity added in both 2020 and 2021. The investment volumes of Germany reached €4.2 billion in 2020 and increased by 23% to €5.2 billion in 2021. The second highest investment in solar PV occurred in the Netherlands for both 2020 and 2021, although the investment volumes slightly decreased from €3.8 billion in 2020 to €3.7 billion in 2021. Spain and France showed also strong and increasing investments in both years and reached investment volumes of €3.5 billion and €3.3 billion respectively in 2021.

In contrast to the observation in the previous barometer, the associated capacity added increased not as strongly as the overall asset finance for PV power plants between the two years. This indicates that the investment costs of PV increased between the two years. This could be ex-plained by the special macroeconomic circumstances, elevating shipping costs and the supply disruption caused by the pandemic. Germany, among all Member States, also led the associated capacity added, which increased by 19% from 4.8 GW in 2020 to 5.7 GW in 2021. The invest-ment distribution in Germany in 2020 was similar to the picture on the EU level, with a higher investment share in installations between 20 kW and 1 MW of around half of capacity added. Spain and the Netherlands were also part of the top three Member States with the most capacity added. Spain raised from third to second place by increasing capacity added from 3.5 GW in 2020 to 4.9 GW in 2021. In contrast, the Netherlands stepped down to third place due to the decreased capacity added of 3.7 GW in 2020 to 3.6 GW in 2021.

2

Overview of estimated investment in the solar photovoltaic sector in the EU Member States in 2021

	2021	
	Estimated investment (€ m)	Associated capacity added (MW)
Germany	5 210	5 702
Netherlands	3 705	3 632
Spain	3 466	4 900
France	3 280	3 351
Italy	1 052	938
Denmark	833	718
Sweden	613	500
Portugal	489	571
Austria	281	740
Finland	116	100

Source: EurObserv'ER own assessment based on IEA, BMWK and Eurostat

PV INVESTMENT DISTRIBUTION VARIES AMONG MEMBER STATES

The distribution of EU PV investments varies considerably across Member States. Spain, as an example, invested 76 % in grid-connected centralised power plants in 2020. On the contrary, Sweden showed a completely different picture. 92 % of the investment volumes in Sweden contributed to decentralised power plants in 2020, with 50 % in small-scale installations in the residential sector and 42 % in medium-scale installations in the commercial sector. In 2021, the share of investment volumes in Poland in small PV plants in the residential sector increased further up to 67 %. Similarly, Sweden invested more than half of its assets in small installations that are less than 20 kW and decentralised grid-connected PV installation for residential houses, while investments in commercial buildings contributed only 26.5 % of the total installed capacity in the year 2021.

Depending on the demand, the investment distribution shifts among sectors as well. For instance, France distributed its investments in 2020 evenly, with 44 % in distributed installations in the commercial sector, 32% in centralized PV power plants and 23% in the residential sector. In 2021, the shares in the commercial sector and residential sector decreased to 29 % and 16 % respectively, while investments in the industrial sector took up a share of 26 %. Italy, on the other side, focused its investments more on relatively small PV projects with an average capacity of 11.8 kW and only 10% of the invested plants were larger than 1 MW. ■

RENEWABLE ENERGY COSTS AND ENERGY PRICES

Competitiveness is one of the important aspects in renewables becoming mainstream energy technology. In 2021 and 2022 prices for energy for conventional energy carriers (fossil fuels and electricity generated from fossil fuels) increased, having a strong effect on the attractiveness of renewable energy. The effect of the conventional energy price increase in the current situation can be compared to what is happening to the cost development of renewable energy. Although through deployment and technology learning the costs of renewable energy may go down, under the current (2022) macroeconomic circumstances however renewable costs may also increase, because of increased world-wide demand and disturbed markets.

This section focuses on renewable energy costs and conventional energy prices, but uncertainty makes that we can only partly update the renewable costs.
For calculating the levelized cost of energy (LCoE) for renewables we present the following: renewable technology investment costs based on literature, an approach to estimate the weighted average cost of capital (WACC) and then the resulting LCoE values.
Moreover, 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 versus actual energy prices (including taxes and levies) in the closing section.

Investment costs data for Europe

INVESTMENT COSTS

Over the past decades, the trends in renewable energy have been relatively stable. They show decreasing specific investment costs and increasing energy yields, resulting in lower levelised cost of energy (LCoE) every year. In certain periods, investment costs have increased, yet always temporarily. In previous EurObserv'ER Barometers the decrease in costs compared to the year 2005 were reported, highlighting strong investment cost reductions for solar PV and wind power. Similar conclusions are reported in the two papers discussed in this section.

The volatile and uncertain economic circumstances in the years 2021 and 2022 make it difficult to generalise the situation to a continuing cost reduction or, on the contrary, a cost increase. In this section, the results of 2021 reports are discussed from IRENA and IEA, two organisations monitoring renewable energy developments. IRENA[1] states that the longer term trend of reduced costs for renewable energy investment costs is still continuing a similar path. IRENA has its own project cost database, from which cost reductions can be observed for a number of European countries. For the two consecutive years 2020 and 2021, investment cost reductions are observed for onshore wind (Croatia, Germany, Greece, Italy, Spain and Sweden). On the other hand, onshore wind investment costs showed increases for other countries (Finland, France, the Netherlands, Poland and the United Kingdom) while the costs in for example Denmark remained equal. For solar PV, according to IRENA, supply chain disruptions during 2021 led to higher material costs and scarcity. As a result, the prices for crystalline modules increased between 4% and 7% for 2020 to 2021, for all module types. Contrarily, when evaluating the utility scale systems, it was found that total installed PV system costs reduced from 2020 to 2021. This was confirmed for a few European countries (France and the Netherlands), whereas other countries show unchanged costs in 2021 compared to 2020 (Italy, Spain, United Kingdom). IRENA also points out that for solar PV, regional differences still show a wide range in observed costs. For example, the 2021 utility scale PV costs in the Netherlands are 50% above those observed in Austria. For offshore wind IRENA report an overall decline in total installed costs, up to and including the year 2021.

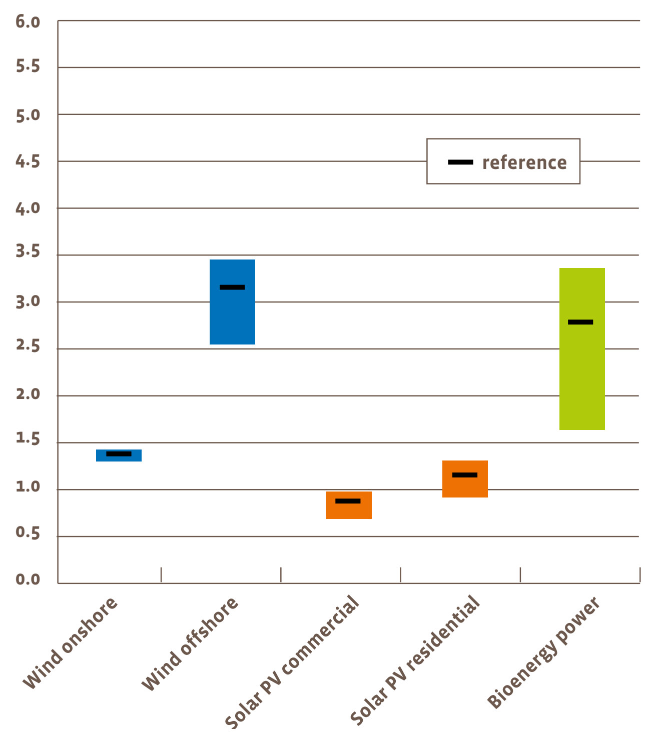
IEA reports price increases for commodities, energy and shipping prices, yielding increases in the cost of producing and transporting solar PV modules, wind turbines and biofuels worldwide. Compared to commodity prices in 2019, IEA estimates that investment costs for utility-scale solar PV and onshore wind are 25% higher. Equipment manufacturers, installers and developers are absorbing cost increases in different ways, where smaller companies are more exposed to this risk. Moreover, increases in commodity prices do not immediately affect investment costs, as developers, manufacturers and other parts of the supply chain usually maintain stocks of materials and have contracts based on previous prices. However, the increase in raw material and logistics costs will ultimately affect the whole value chain. The higher costs have resulted in a reduction of renewable projects, which also has an upward effect on prices. Furthermore, auctions for renewable projects report higher prices in 2021 compared to 2020, which is difficult to translate directly into investment cost increases. If commodity prices remain high through 2022, IEA estimates that three years of costs reductions for solar and five years for wind would be cancelled out. Similar for biofuels, where prices increased an estimated 70% to 150% in various parts of the world.

The attractiveness and competitive strength of renewable energy carriers also depends on the prices of the conventional energy carriers (electricity, heat, transport fuels). Consequently, increasing investment and financing costs will result in higher values for LCoE, but not necessarily in reduced competitiveness.

1. Source: Renewable Power Generation Costs in 2021 (July 2022), https://www.irena.org/Publications/2022/Jul/Renewable-Power-Generation-Costs-in-2021

1

Renewable energy investments costs for the year 2020 according to JRC as used in LCoE section (M€/MW)



Source: JRC

Pronouncing on the investment costs for renewables in 2021 is challenging. The year is partially characterised by continuing reduced investment costs, a trend which might come to a halt by 2022, where the economic situation is getting more insecure and inflation increases, under continuing material scarcity and labour force shortage. On the other hand, there are indications that the 2021 costs were already increasing.

As a result of these uncertain and volatile trends showing various investment cost developments, the investment costs in 2021 are assumed to be equal to those of the previous EurObserv'ER 2020 report. Anticipating price increases in 2022, the investment costs are for the purpose of the analysis unaltered. For O&M costs it is difficult to obtain developments, although the economic situation might have an upward effect on these costs. Here we follow the assumptions of IRENA, where O&M costs in 2021 are the same as in 2020. The WACC estimates, however, are updated with new data for 2021 values. Therefore. the resulting LCoE values will differ from the values estimated for the year 2020.

An overview of the investment-costs that are used for the calculation of the levelized costs of energy (LCoE) is depicted in Figure 1. It can be seen that also in this report, all technologies are characterised by data ranges. These ranges refer to the technology in general and do not exclusively target technologies in the European Union. It can be observed that the investment costs vary significantly across technologies.

Besides the investment costs, O&M costs and the energy yield, 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 expenditure, 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 renewable 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 across different technologies in different member states. However, since the WACC also changes over time due to various factors, such as prevailing economic conditions, policy consistency, and technological developments, our selected approach allows for consistency in the results over time.

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 to equity ratio[3] are multiplied as percentages to build up 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. 2021. Euro area statistics. Averaged bank lending rates over small and large loans*
2. *PWC. 2022. Worldwide Tax Summaries. https://taxsummaries.pwc.com.*
3. *Source: Eindadvies basisbedragen SDE++ 2021, PBL, 2021, https://www.pbl.nl/publicaties/eindadvies-basisbedragen-sde-plus-plus-2021. Debt to equity ratio of low, medium and high risk technologies.*
4. *Source: Netherlands Enterprise Agency (RVO), Stimulation of sustainable energy production and climate transition (SDE++). Cost of equity of low, medium and high risk technologies.*
5. *Source: Eindadvies basisbedragen SDE++ 2021, PBL, 2021, https://www.pbl.nl/publicaties/eindadvies-basisbedragen-sde-plus-plus-2021*
6. *Body of European Regulators for Electronic Communications (BEREC), 2021. BEREC Report on WACC parameter calculations according to the European Commission's WACC Notice of 6th November 2019 (WACC parameters report 2021). 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 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, biomass fermentation and CCS 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 an* ***average 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.*

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

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	Average	Average	High
Cost of equity	6%	6%	8%	8%	12%
Debt to equity ratio					
minimum	*70/30*	*85/15*	*65/35*	*60/40*	*50/50*
average	*80/20*	*90/10*	*75/25*	*70/30*	*60/40*
maximum	*90/10*	*95/5*	*85/15*	*80/20*	*70/30*

Source: EurObserv'ER

LIMITATIONS OF METHODOLOGY

The current methodology 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 current approach involve similar technology risks across different member states. For future research, these simplifying assumptions should be addressed.

UPDATES ON WACC PARAMETERS

Due to further evolution of solar PV and wind offshore technologies, the debt to equity ratios for these technologies have been updated. According to the Dutch Subsidy scheme[1], the solar PV D/E ratio increased to 90/10 in 2021 as project developers increased the gearing level of their investments. This enables them to finance more projects with the same amount of equity (less equity is needed per investment), and thus can increase their revenues. With this ratio, solar PV projects still complied with Debt Service Coverage Ratios (DSCR) requirements of financial institutions which govern the debt sizing of projects. The maximum D/E ratio for solar PV has been estimated at 95/5 and a minimum ratio of 85/15, resulting in a small range of minima and maxima for the D/E ratio compared to the ratio's of 2020. Furthermore, the level of leverage (the percentage of debt financing) in project finance of wind onshore projects has increased from 60% to 75% in recent years, according to a study by PWC[2]. Capital costs are therefore lower, as debt is generally cheaper than equity.

RESULTS

An overview of the calculated WACC values by technology and member state is presented in Table 2.

We observe that for the low-risk technologies, such as wind onshore and solar PV, the WACC values range from as low as between 2-3% in some member states (e.g., Germany, Netherlands, Denmark) to above 4% in other member states (e.g., Greece, Romania, Poland). For the higher risk technologies, such as bioenergy, the WACC estimates range from between 4-7% in some member states (e.g., Austria, Belgium, Germany) to 6-9% 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 Germany, Denmark, Belgium and the Netherlands. At the other side of the spectrum, less favourable financing conditions appear to be available for all technologies in Central and Eastern European member states, in particular in Greece, Poland and Romania, and especially for technologies that are considered riskier to deploy.

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.

Currently, there is significant global macroeconomic uncertainty, which is leading to volatility in indicators that are typically used to interpret current and future investment opportunities. Inflation levels are causing concern and central banks are responding by raising interests to control inflation. Rising interest rates are increasing the cost of debt and equity, and thus the cost of capital. The results in this report are generated from data from the year 2021, and thus do not take into account the current (2022) macroeconomic situation. We anticipate the results in next year's report, generated from 2022 data, to fully reflect the current economic climate, and thus show much higher WACC values across all technologies and EU member states. ■

1. *Source: Eindadvies basisbedragen SDE++ 2021, PBL, 2021, https://www.pbl.nl/publicaties/eindadvies-basisbedragen-sde-plus-plus-2021*
2. *Financing offshore wind; A study commissioned by Invest-NL. August 2020.*

2

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

	Wind onshore			Wind offshore			Solar PV			Hydropower			Bioenergy and other technologies*		
	Low estimate	Averate estimate	High estimate	Low estimate	Averate estimate	High estimate	Low estimate	Averate estimate	High estimate	Low estimate	Averate estimate	High estimate	Low estimate	Averate estimate	High estimate
Austria	1.7%	2.2%	2.7%	NA	NA	NA	1.5%	1.7%	2.2%	2.6%	3.3%	4.0%	4.5%	5.6%	6.7%
Belgium	1.6%	2.1%	2.6%	2.1%	2.9%	3.6%	1.3%	1.6%	2.1%	2.5%	3.2%	3.9%	4.4%	5.5%	6.6%
Bulgaria	2.9%	3.3%	3.8%	NA	NA	NA	2.7%	2.9%	3.3%	3.7%	4.4%	5.0%	5.6%	6.6%	7.6%
Croatia	2.2%	2.8%	3.5%	NA	NA	NA	1.9%	2.2%	2.8%	3.2%	4.1%	4.9%	5.3%	6.5%	7.7%
Cyprus	3.4%	3.8%	4.3%	NA	NA	NA	3.1%	3.4%	3.8%	4.2%	4.9%	5.6%	6.1%	7.2%	8.3%
Czechia	2.7%	3.2%	3.7%	NA	NA	NA	2.4%	2.7%	3.2%	3.6%	4.3%	5.0%	5.5%	6.6%	7.7%
Denmark	1.8%	2.3%	2.7%	2.3%	3.0%	3.7%	1.6%	1.8%	2.3%	2.7%	3.3%	4.0%	4.5%	5.6%	6.7%
Estonia	3.0%	3.4%	3.9%	NA	NA	NA	2.8%	3.0%	3.4%	3.8%	4.5%	5.1%	5.7%	6.7%	7.7%
Finland	1.9%	2.4%	2.9%	2.5%	3.1%	3.8%	1.7%	1.9%	2.4%	2.8%	3.5%	4.1%	4.7%	5.7%	6.8%
France	1.6%	2.1%	2.6%	2.1%	2.8%	3.5%	1.3%	1.6%	2.1%	2.5%	3.2%	3.9%	4.4%	5.5%	6.6%
Germany	1.7%	2.1%	2.6%	2.2%	2.9%	3.5%	1.5%	1.7%	2.1%	2.5%	3.2%	3.9%	4.4%	5.5%	6.5%
Greec	3.6%	4.3%	5.0%	NA	NA	NA	3.2%	3.6%	4.3%	4.7%	5.6%	6.5%	6.8%	8.1%	9.4%
Hungary	3.1%	3.7%	4.3%	NA	NA	NA	2.8%	3.1%	3.7%	4.1%	4.9%	5.7%	6.1%	7.3%	8.5%
Irland	3.8%	4.1%	4.3%	4.2%	4.7%	5.2%	3.6%	3.8%	4.1%	4.5%	4.9%	5.4%	6.1%	7.0%	7.9%
Italy	1.9%	2.5%	3.2%	NA	NA	NA	1.6%	1.9%	2.5%	2.9%	3.8%	4.6%	5.0%	6.2%	7.5%
Latvia	4.1%	4.3%	4.6%	NA	NA	NA	4.0%	4.1%	4.3%	4.7%	5.2%	5.6%	6.4%	7.2%	8.1%
Lithuania	2.5%	2.9%	3.3%	NA	NA	NA	2.3%	2.5%	2.9%	3.3%	3.9%	4.5%	5.1%	6.1%	7.2%
Luxembourg	1.6%	2.1%	2.6%	NA	NA	NA	1.4%	1.6%	2.1%	2.5%	3.2%	3.9%	4.4%	5.5%	6.6%
Malta	2.0%	2.5%	3.0%	NA	NA	NA	1.7%	2.0%	2.5%	2.9%	3.6%	4.4%	4.8%	6.0%	7.1%
Netherlands	1.7%	2.1%	2.6%	1.9%	2.4%	2.9%	1.4%	1.7%	2.1%	2.5%	3.2%	3.9%	4.4%	5.5%	6.6%
Poland	2.8%	3.5%	4.1%	NA	NA	NA	2.5%	2.8%	3.5%	3.9%	4.7%	5.5%	5.9%	7.1%	8.3%
Portugal	2.4%	3.0%	3.6%	3.0%	3.8%	4.5%	2.1%	2.4%	3.0%	3.4%	4.2%	4.9%	5.4%	6.5%	7.7%
Romania	2.5%	3.3%	4.1%	NA	NA	NA	2.1%	2.5%	3.3%	3.7%	4.7%	5.7%	5.9%	7.3%	8.8%
Slovakia	2.6%	3.0%	3.4%	NA	NA	NA	2.4%	2.6%	3.0%	3.4%	4.0%	4.6%	5.2%	6.2%	7.2%
Slovania	2.1%	2.6%	3.0%	NA	NA	NA	1.8%	2.1%	2.6%	3.0%	3.6%	4.3%	4.8%	5.9%	7.0%
Spain	1.8%	2.4%	3.0%	2.4%	3.2%	3.9%	1.6%	1.8%	2.4%	2.8%	3.6%	4.3%	4.8%	5.9%	7.1%
Sweden	1.9%	2.4%	2.9%	2.5%	3.2%	3.8%	1.7%	1.9%	2.4%	2.8%	3.5%	4.2%	4.7%	5.8%	6.8%

Other technologies include geothermal, biogas and solid biomass.* ***Source: EurObserv'ER*

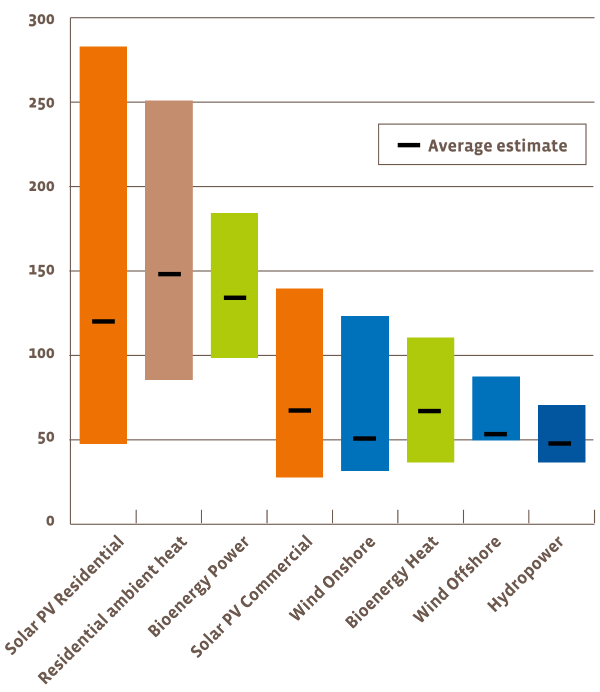
Levelised cost of energy

In this section, levelised costs of energy (LCoE, in €/kWh or €/MWh) are estimated for various renewable energy technologies, based on the investment costs (which haven't been adapted compared to the previous report 'The state of Renewable Energies', Edition 2021, see dedicated section) and WACC estimates presented in the previous section. 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 (5000 MC draws per LCoE value), resulting in LCoE ranges. Whereas technology costs were taken from JRC reports (JRC 2014 and 2018), fuel price assumptions were borrowed from (Elbersen et al, 2016) and interpolated from modelled data. Similar to the investment costs, in this edition the biomass prices haven't been updated because of the uncertain macroeconomic situation. All LCoE values are reported in euros of the year 2020. Furthermore, locational and operational aspects, but also design choices and energy yields vary across member states, and therefore 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 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.

1

Estimated levelised cost of renewable energy in the European Union (€/MWh) for the year 2021.



Note: the investment costs refer to the situation from 2020 and that only WACC estimates have been brought up to date .
Source : EurObserv'ER

RENEWABLE ELECTRICITY

Looking at the trend, the LCoE from solar PV has continued to decrease over the past few years, which has also been demonstrated in previous versions of 'The State of Renewable Energies in Europe'. Solar PV in the residential sector is small in system size (it should fit on rooftops) and therefore is relatively expensive. Residential PV has 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 the most expensive renewable technology, although that varies strongly from country to country. On the EurObserv'ER website the calculated LCoE for solar PV is presented, from which it follows that residential PV is cheapest in Spain and Portugal, producing power at very competitive prices compared to household electricity prices (see next section). Based on the current analysis, which partly refers to the year 2020, the average estimated cost level for residential PV is 120 EUR/MWh. From the calculations it follows that bioenergy power generation is roughly between 100 and 180 EUR/MWh across Europe (assumed fuel prices similar to 2020). Commercial solar PV does benefit from economies of scale and at the lower range is very competitive, at prices that occur in Spain, Portugal, Italy and Greece. According to the calculations, commercial solar PV should be possible to generate electricity at costs below 132 EUR/MWh in all EU member states. The average costs for onshore wind power are slightly lower than for commercial PV, with a similar cost bandwidth. Offshore wind has a smaller range because not all 27 member states have projects in place. The lowest LCoE values for offshore wind occur in Denmark, the Netherlands and Spain, while the highest LCoE values are in Germany, Belgium and Finland. Hydropower traditionally has been a cost competitive technology for many years in many countries. It is capital intensive, but due to the usually high number of running hours, the produced electricity can be found at the lower LCoE levels, in our estimates between 36 and 66 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. The country specific LCoE estimates are available for multiple technologies from the EurObserv'ER website. The graph depicted here shows aggregate values for the European Union as a whole.

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. Scaling up to collective systems, possibly in combination with district heating, may decrease the costs further.

As already indicated in the sections on investment costs and weighted average cost of capital, the macroeconomic uncertainty makes reporting on renewable energy costs difficult. For the levelised costs of energy we opted for keeping investment costs constant, an assumption that was based on observations in reports by IRENA and IEA. Biomass fuel prices are assumed equal to prices in 2020. The weighted average cost of capital has been adapted to the situation in 2021, which makes that the LCoE values change slightly. Looking ahead towards 2022 the macroeconomic uncertainty further increases, which will be reported upon in the upcoming edition of 'The State of Renewable Energies in Europe'. ■

Prices of energy

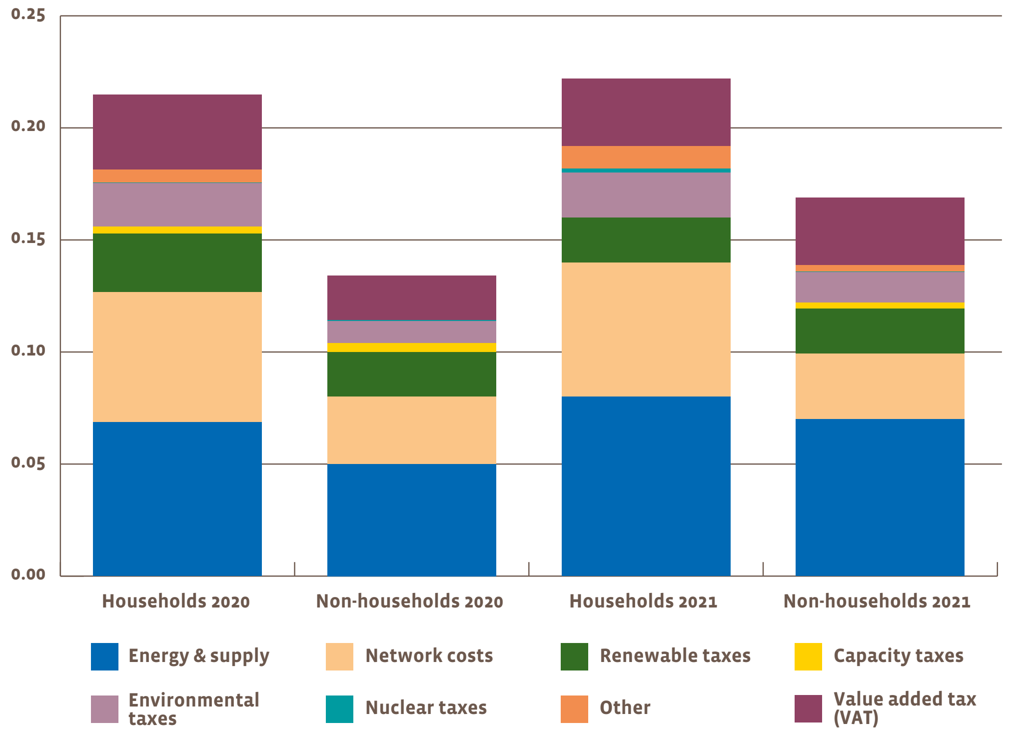
Energy prices for electricity and fossil gas are monitored by Eurostat. These prices are listed in Figures 1 and 2 here for the years 2020 and 2021. Energy prices consist of multiple cost components: the cost of the energy carrier itself (energy and supply), network charges and various taxes, fees, charges and levies.

MULTIPLE COMPONENTS IN ENERGY PRICES

For both electricity and fossil 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 fossil 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 instruments aimed at changing consumer energy use patterns and they mostly flow into the general budget. 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 a few countries: Belgium, Italy and 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, and comparable to the average value of the value added tax (VAT), which is imposed on all cost components. The ranges of electricity and fossil gas prices observed in the European Member States in 2019 and 2020 are depicted in Figures 1 and 2 respectively. It can be observed that from 2020 to 2021 prices for energy and supply increased for both gas and electricity. For non-household consumers the increase was more pronounced than for households. For electricity, renewable taxes came down for both households and non-households consumers. Overall, both total gas and total electricity prices increased. For households electricity increased 5% and gas 3%. For non-households consumers electricity increased 13% and gas 39%. ■

1

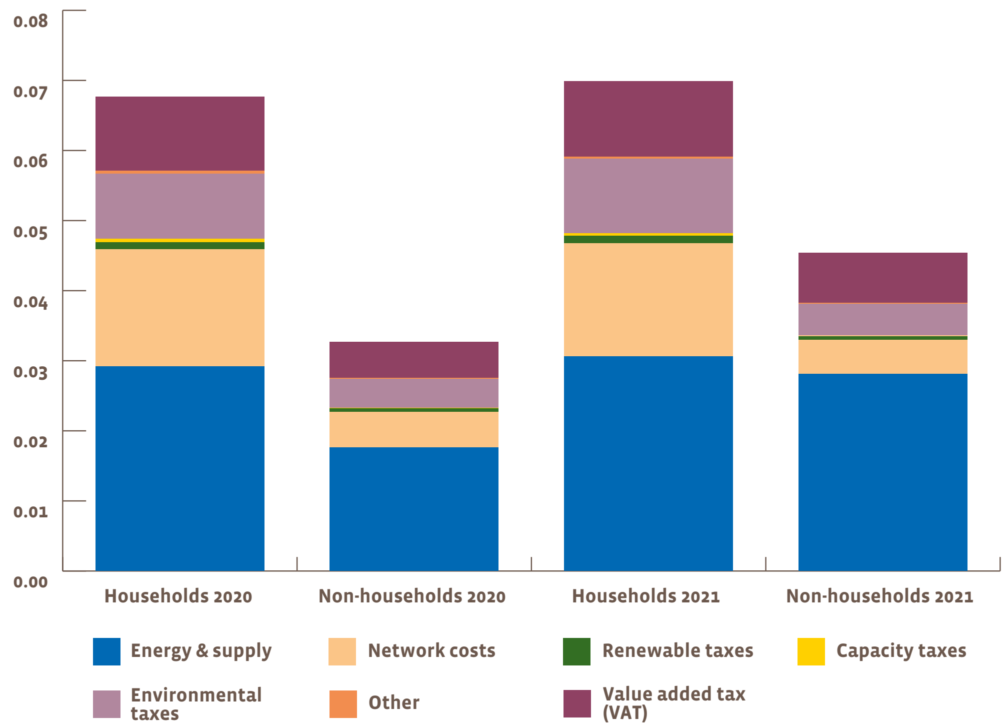
Average electricity price observed in the European Union in 2020 and 2021 (€/kWh)



Note: the electricity price components [EUR/kWh] are based of an average of all electricity consumption bands.
Source: Eurostat, 2022.

2

Average fossil gas prices observed in the European Union in 2020 and 2021 (€/kWh)



Note: the gas price components [EUR/kWh] are based of an average of all gas consumption bands.
Source: Eurostat, 2022.

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 for 2020, first set under the Renewable Energy Directive, or RED (Directive 2009/28/EC) which has been recast under the 'Clean Energy for all Europeans' package: REDII (Directive 2018/2001/EU), entered into force in December 2018. 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.

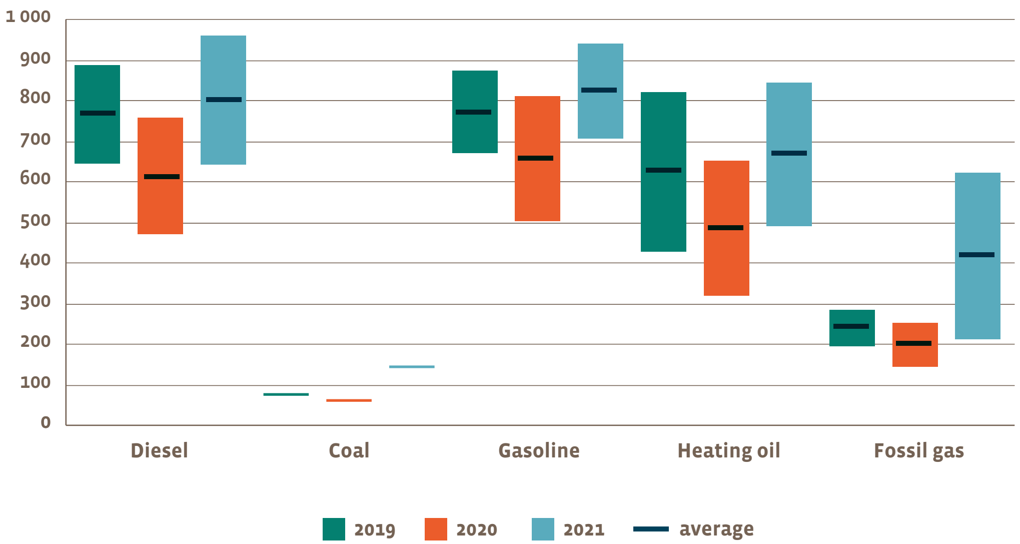
Looking further, towards 2030, the RED II does set a binding EU-wide target of 32 % RES in gross final energy consumption. Member States had to propose an indicative level of effort contributing to the EU binding target for renewables in their NECPs[1], due by the end of 2019. However, mid 2021 the European 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. The proposals are not yet in final legislation. Trilogue negotiations between the Parliament, the Council and the Commission are currently ongoing.

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.

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)



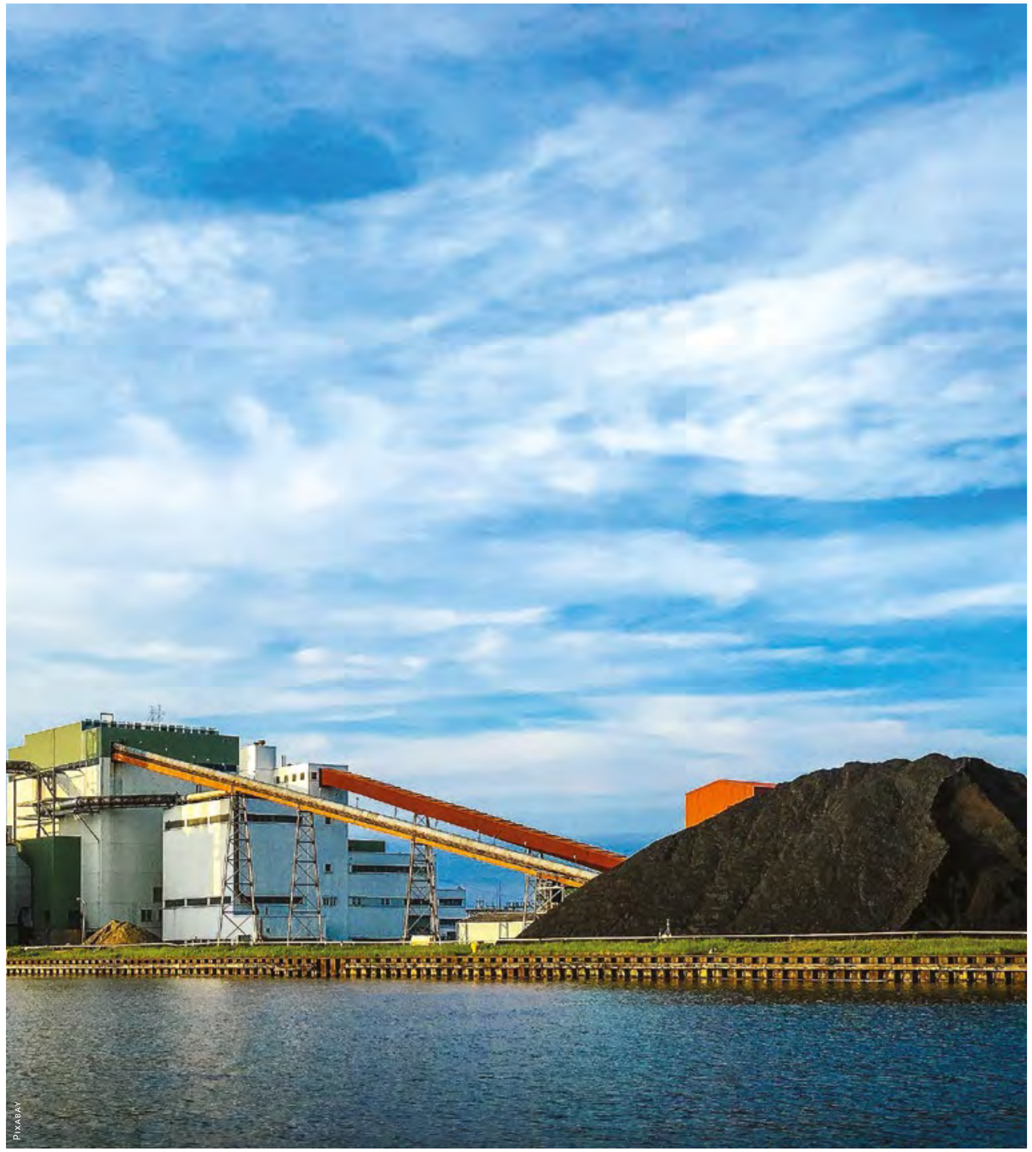
Source: Eurostat, European Commission, Nasdaq

Avoided costs refer to the expenses that do not occur as a result of avoided fossil fuels. These are estimated as follows: cumulative amounts of avoided fossil fuels multiplied by the corresponding fuel price levels observed in the various countries.
The amount of avoided fossil fuels are annually analysed by the European Environment Agency ('*Renewable energy in Europe 2022 - Recent growth and knock-on effects*', (EEA 2022)). 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). Figure 1 highlights the fuel price ranges observed in the 27 EU Member States for 2019, 2020 and 2021 for five energy carriers: coal, diesel, gasoline, fossil 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, 2022). 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.

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

Looking at the individual energy carriers and their ratios, it can be seen that all fossil fuel prices in 2020 decreased compared to 2019 due to the COVID crisis. In 2021 all prices increased significantly due to the economic recovery in 2021 which has tightened commodity markets and put upward pressure on prices across the board. Observed fuel prices for diesel, gasoline and fuel oil differ widely across member states and along the year. For gas prices the spread across countries was traditionally lower but has increased significantly in 2021[3].

3. World Energy Outlook 2021, IEA, https://www.iea.org/reports/world-energy-outlook-2021/prices-and-affordability



Methodological note

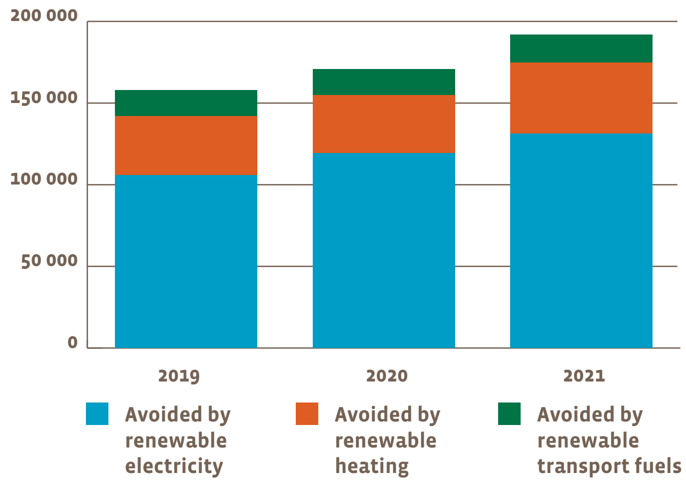
- The focus of the analysis is on the national level, quantifying the avoided costs in the case where all fossil energy carriers are being purchased abroad. As a consequence, all fuel prices considered exclude taxes and levies. Moreover, we do not differentiate caloric values of the fuels to their origin 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. This is in line with progress reported by the European Environment Agency (EEA 2022)
- The avoided in line with the ones from the European Environment Agency (EEA 2021).
- The avoided costs through the substitution of fossil gas by synthetic fossil gas (SFG) 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 28/EC/2009 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 2021 estimates are proxies, borrowed from EEA (2022).
- Gross effects of renewable energy consumption on GHG emissions are based on data available from Eurostat for primary energy consumption and on CO_2 emission factors per fuel type (t CO_2/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 on the basis of 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, CO_2 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 2021 and 2020 the use of renewable energy substituted respectively around 192 Mtoe and 171 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 35 billion for EU27 collectively in 2020, increasing to EUR 48 billion in 2021. In 2021 the largest financial contributions derive from renewable electricity (53% of the total), followed by renewable transport (28% of the total). Finally, renewable heat has a contribution of 19% to the total avoided expenses. Because the fuel prices for transport fuels are high compared to the fuel prices for heating, the avoided expenses are relatively higher than the avoided fossil fuels.

2

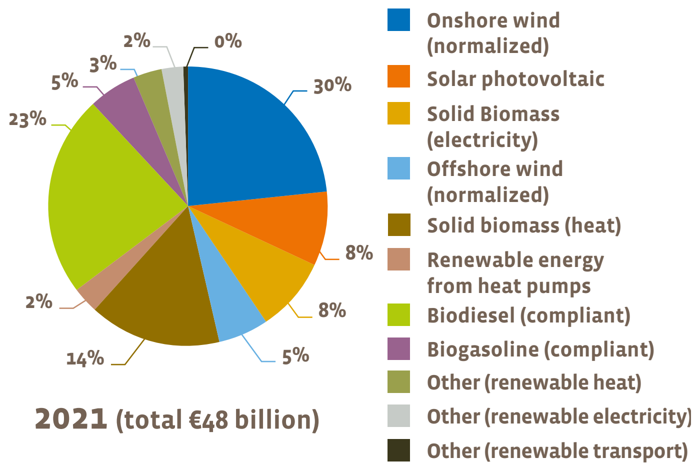
EU-27 avoided fossils fuels per sector (ktoe)



Note: Reference year 2005. Note: for 2021 proxy data are used.
Source: EurObserv'ER based on EEA data.

3

EU-27 avoided expenses through renewables



Note : Reference year 2005. Note: for 2021 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 68% of the total avoided fossil fuels in 2021 (in terms of energy). This is followed by renewables in the heating and cooling sector contributing to 23% of the total avoided fossil fuels and the remaining share was substituted through renewable transport fuels (around 9%, only fuels compliant with Directive 2009/28/EC are included). In monetary terms, the avoided costs were EUR 17.7 billion in 2020 and EUR 25.5 billion in 2021 in the electricity sector. Second, renewable transport contributed to avoided costs reaching to EUR 9.2 billion in 2020 while in 2021 this increased to EUR 13.6 billion. Third is renewable heat which contributed to avoided costs of EUR 8.1 billion in 2020 and EUR 9.2 billion in 2021. For correctly interpreting these results it is important to take into account a number of methodological notes, see the text box in this chapter.

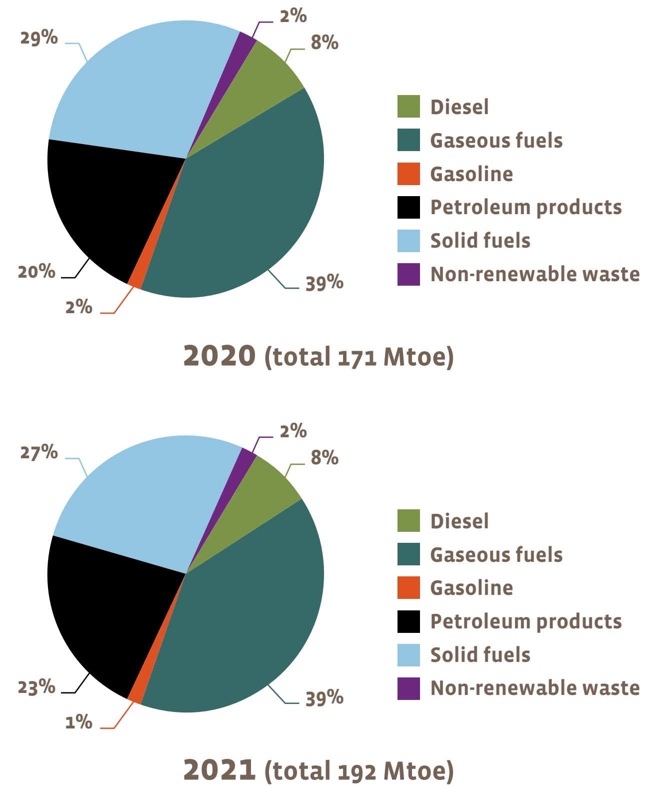
While the penetration of renewable energy (expressed in avoided fossil fuels) expanded by approximately 13% from 2020 to 2021, the effect of the avoided fossil fuel expenses is, with a 38% increase (from EUR 35 billion to EUR 48 billion) more pronounced than the growth in renewable energy. Reason for this is the strong increase in fossil fuel prices in 2021 compared to 2020.
Among the RES technologies, onshore wind avoided the purchase of fossil fuels at an amount of EUR 14.6 billion in 2021 (EUR 10.0 billion in 2020, both for normalised production) compared to the level in 2005. Next biodiesels in transport has been responsible for EUR 11.0 billion in 2021 (EUR 7.4 billion in 2020, both for compliant fuels). Solid biomass for heat purposes is third in the row with EUR 6.6 billion in 2021 (EUR 4.8 billion in 2020).

Chart 3 shows how each technology contributes to the total avoided expenses in 2021.

The largest share of avoided fossil fuels comes from fossil gas (39% for both 2020 and 2021), followed by solid fuels (mainly coal, respectively 29% and 27% for 2020 and 2021). Next are oil products, with a contribution of respectively 20% and 23% in 2020 and 2021. The remaining fuels (transport fuels and non-renewable waste) cover the remaining share (12% in 2020 and 11% in 2021).

4

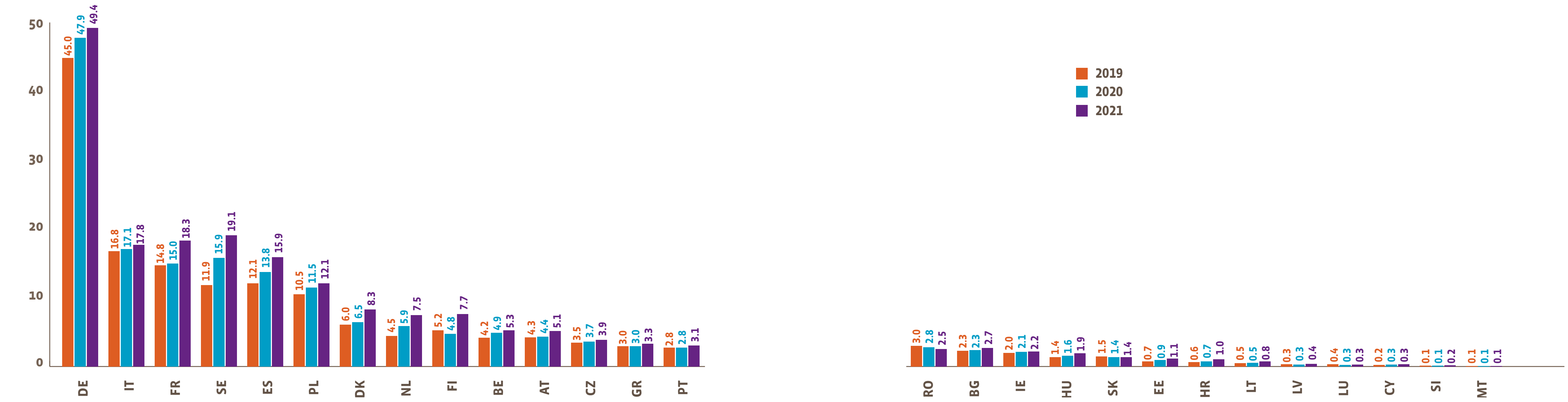
EU-27 substituted fossil fuels during 2020 and 2021



Note : reference year 2005. Note: for 2021 proxy data are used.
Source: EurObserv'ER based on EEA data.

5

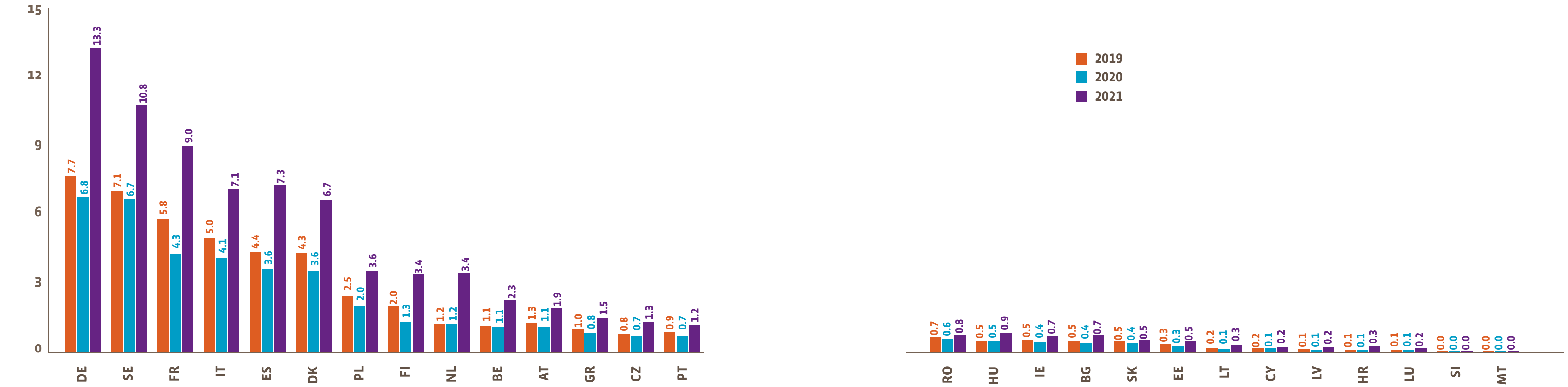
Avoided fossil fuels per country (Mtoe)



Note : Reference year 2005. Note: for 2020 proxy data are used. ***Source: EurObserv'ER based on EEA data.***

6

Avoided expenses per country (€ billion)



Note : Reference year 2005. Note: for 2020 proxy data are used. ***Source: EurObserv'ER based on EEA data.***

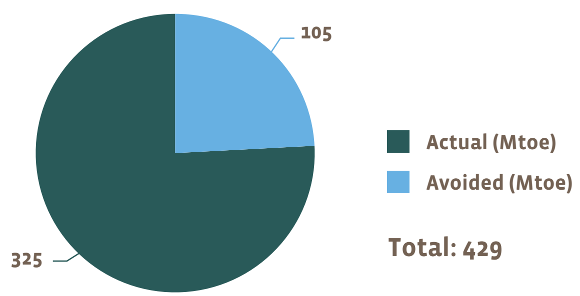
AVOIDED FOSSIL FUELS & EXPENSES PER MEMBER STATE

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 higher in 2021 compared to 2020.
It can be observed from the results that countries with higher avoided fossil fuels figures do 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.

Figures 7 and 8 indicate how the amounts of estimated avoided fuel due to increased RES consumption since 2005 relate to the total EU27 fuel use. 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. fossil gas used not for combustion but for producing chemicals). For the transport fuels a comparison is not possible because these are not primary fuels (but instead secondary fuels). Reference year depicted is 2021.

7

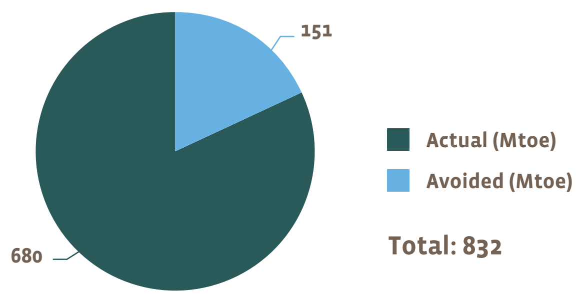
Effect on solid fuels in EU-27 in 2021 (Mtoe)



Note: reference year 2005. Note: for 2021 proxy data are used.
Source: Eurostat, EurObserv'ER based on EEA data.

8

Effect on gaseous fuels in EU-27 in 2021 (Mtoe)



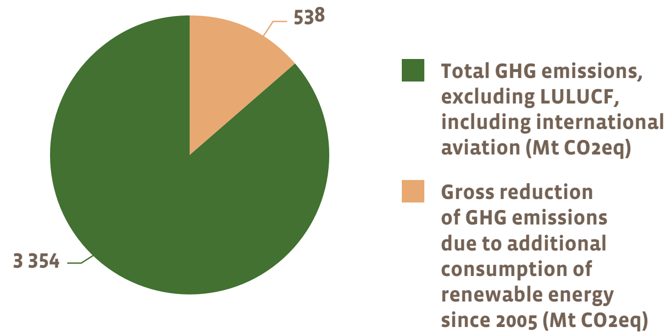
Note: reference year 2005. Note: for 2021 proxy data are used.
Source: Eurostat, EurObserv'ER based on EEA data.

AVOIDED GHG EMISSIONS IN EU27 AND PER MEMBER STATE

Finally, the figures 9 and 10 indicate the estimated savings in GHG emissions in 2020 and 2021 due to increased RES consumption since 2005, for the EU as a whole and per Member State.
In 2021, for the EU27 a gross reduction of 601 Mt CO_2eq of GHG emissions has been realised due to the additional consumption of renewable energy. While total EU27 GHG emissions were approximately 3526 Mt CO_2eq in 2021, the additional uptake of renewable energy has led to a gross reduction of GHG emissions of 14.6% in 2021, compared to the reference year 2005.
The gross reduction of GHG emissions due to the additional consumption of renewable energy has increased from 538 Mt CO_2eq in 2020 to approximately 601 Mt CO_2eq in 2021.

9

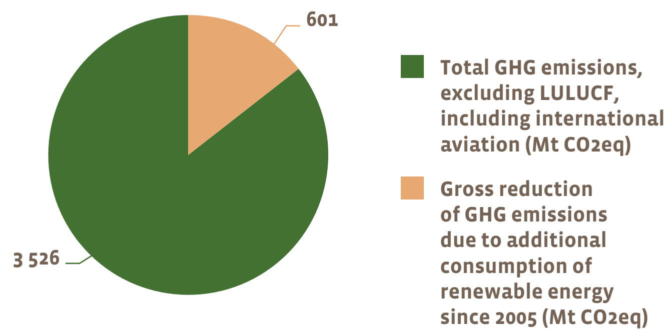
Effect on GHG emissions in EU-27 in 2020



Note: Reference year 2005. Note: for 2021 proxy data are used.
Source: Eurostat, EurObserv'ER based on EEA data.

10

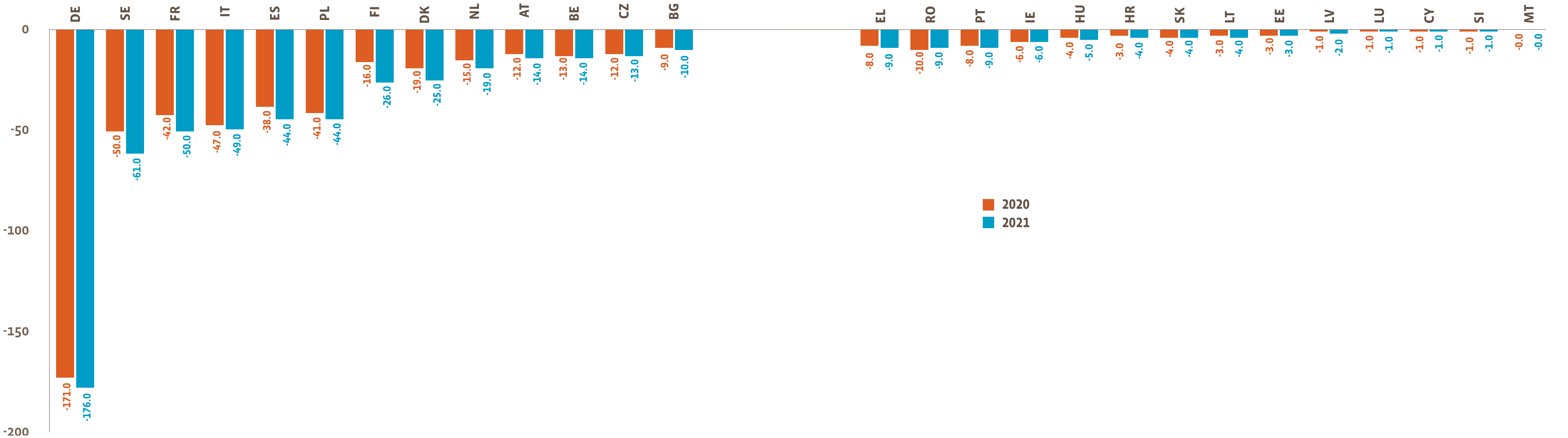
Effect on GHG emissions in EU-27 in 2021



Note: Reference year 2005. Note: for 2021 proxy data are used.
Source: Eurostat, EurObserv'ER based on EEA data.

11

Estimated gross reduction of GHG emissions, due to RES uptake since 2005, per country (Mt CO_2)



Note: Reference year 2005. Note: for 2021 proxy data are used. ***Source: Eurostat, EurObserv'ER based on EEA data.***

In terms of gross avoided GHG emissions in 2021, the countries with the largest estimated gross reductions were Germany (176 Mt CO2), Sweden (61 Mt CO2), France and Italy (50 and 49 Mt CO2 respectively). ■

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 (grey 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 grey area in Figure 1) as well as from the private sector are taken into account (see dark grey 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 , 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 2-year time delay in reporting for most Member States, thus data for 2020 is by large complete, while the data for 2021 contain gaps and is (still) incomplete. For the data on private R&D, the time delay is even longer (2018 and 2019) 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 SET Plan Steering Group or through targeted data mining. Note that, because of the incomplete data set for 2021, the text in this chapter refers to the most complete data, being 2019 for Private R&D and patents and 2020 for Public R&D. In case the data points for public expenditure in 2020 may not be completely up to date, the text refers to 2019 values. 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.

1

Sectors by financing and performing of R&D

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

1. *IEA. International Energy Agency RD&D Online Data Service. Available from: http://www.iea.org/statistics/RDDonlinedataservice/*

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://setis.ec.europa.eu/related-jrc-activities/jrc-setis-reports/monitoring-ri-low-carbon-energy-technologies

PUBLIC R&D INVESTMENTS

Public R&D investments are depicted by RE technologies.

PRIVATE R&D INVESTMENTS

Private R&D investments are depicted by RE technologies. Data are only available for the countries of the EU-27 in 2018 and 2019.

PUBLIC R&D INVESTMENTS

SOLAR ENERGY

		Public R&D Exp. (in € m)		Share of Public R&D Exp. by GDP	
		2019	2020	2019	2020
EU-27	Germany	118.50	101.56	0.0034%	0.0030%
	France	66.46	78.00	0.0027%	0.0034%
	Netherlands	16.09	18.40	0.0020%	0.0023%
	Spain	15.98	12.11	0.0013%	0.0011%
	Belgium	11.08	9.71	0.0023%	0.0021%
	Sweden	4.84	8.77	0.0010%	0.0018%
	Poland	7.58	6.47	0.0014%	0.0012%
	Austria	8.25	6.18	0.0021%	0.0016%
	Finland	6.46	5.21	0.0027%	0.0022%
	Denmark	2.86	1.90	0.0009%	0.0006%
	Czechia	1.77	1.22	0.0008%	0.0006%
	Ireland	0.40	0.40	0.0001%	0.0001%
	Lithuania	0.43	0.36	0.0009%	0.0007%
	Hungary	n.a.	0.23	n.a.	0.0002%
	Slovakia	0.19	0.22	0.0002%	0.0002%
	Estonia	0.32	0.05	0.0012%	0.0002%
	Total EU-27	289.55	250.78	0.0021%	0.0019%
	EU Commission	120.05	63.81	0.0009%	0.0005%
Other Countries	United States	381.65	297.24	0.0020%	0.0016%
	Korea	60.91	56.69	0.0042%	0.0039%
	United Kingdom	37.85	43.59	0.0015%	0.0018%
	Switzerland	40.25	38.75	0.0064%	0.0060%
	Japan	33.12	30.33	0.0007%	0.0007%
	Australia	12.59	23.71	0.0010%	0.0020%
	Canada	15.12	20.93	0.0010%	0.0014%
	Norway	8.26	7.54	0.0023%	0.0024%
	Turkey	12.85	1.98	0.0019%	0.0003%
	New Zealand	0.31	0.51	0.0002%	0.0003%

Source: JRC SETIS, Eurostat, WDI Database

In the field of solar energy, the US is the largest player in terms of public R&D investment in both 2019 and 2020, followed by EU27. Countries that follow next on the list for 2019 are Korea, with Switzerland, UK and Japan as runners-up. The figure displays a significant decrease in public R&D investments in the US. Figures for China as well as some other countries are not available.

Within the EU-27, the European Commission provides €64 million of public R&D investments in 2020, behind the two dominant countries; Germany (€102 million) and France (€78 million). Even though Germany showed a 17% decrease in public investments, together with France they realized 72% of the EU-27 public investments (in 2020). Next are the Netherlands, Spain and Belgium (values for 2020).

When looking at the normalization of the R&D figures by GDP, the share of the EU-27 is on a similar level in both years, although slightly lower in 2020, while the US and the European Commission showed bigger decreases in public investments. Furthermore, it is worthwhile to point out the high relative level of engagement of public spending on R&D in Switzerland; 0.006% of the GDP. Korea and Norway also have a higher relative share of their GDP invested than the EU-27. Within the EU-27, Germany and France have the largest budget share for solar energy, followed by the Netherlands and Finland. ■

PUBLIC R&D INVESTMENTS

GEOTHERMAL ENERGY

		Public R&D Exp. (in € m)		Share of Public R&D Exp. by GDP	
		2019	2020	2019	2020
EU-27	Germany	14.36	15.69	0.0004%	0.0005%
	France	9.72	13.23	0.0004%	0.0006%
	Netherlands	11.32	3.64	0.0014%	0.0005%
	Sweden	0.09	2.44	0.0000%	0.0005%
	Hungary	n.a.	1.18	n.a.	0.0009%
	Austria	0.02	0.53	0.0000%	0.0001%
	Belgium	0.72	0.39	0.0002%	0.0001%
	Ireland	0.46	0.38	0.0001%	0.0001%
	Poland	0.09	0.32	0.0000%	0.0001%
	Spain	n.a.	0.29	n.a.	0.0000%
	Slovakia	0.45	0.22	0.0005%	0.0002%
	Czechia	0.64	0.16	0.0003%	0.0001%
	Total EU-27	44.73	38.47	0.0003%	0.0003%
	EU Commission	18.25	16.49	0.0001%	0.0001%
Other Countries	United States	78.68	99.78	0.0004%	0.0005%
	Switzerland	21.06	17.96	0.0033%	0.0028%
	Japan	14.89	17.48	0.0003%	0.0004%
	Canada	12.68	5.81	0.0008%	0.0004%
	New Zealand	6.81	3.70	0.0036%	0.0020%
	United Kingdom	1.10	1.76	0.0000%	0.0001%
	Korea	1.70	1.61	0.0001%	0.0001%
	Norway	1.74	1.30	0.0005%	0.0004%
	Australia	0.09	0.06	0.0000%	0.0000%

Source: JRC SETIS, Eurostat, WDI Database

With regard to geothermal energy, the U.S. is found to have by far the largest public R&D investments of all assessed countries. With €99.8 million in 2020 this is more than double the value of the entire EU-27 (€38.5 million). Within the EU-27, the European Commission is the largest single provider of R&D funding. On the level of individual countries two of them dominate the public investments; Germany and France. Other countries with significant investments are Switzerland and Japan. Compared to solar energy, the public R&D expenditures are rather low. In terms of GDP normalization, Switzerland and the US show a larger engagement than the EU-27.

Switzerland and New Zealand stand out with the largest shares of public R&D investment by GDP in 2020. Within the EU-27, Hungary shows the highest share of public R&D investment by GDP, followed by the France. ■

PUBLIC R&D INVESTMENTS
HYDRO ENERGY

		Public R&D Exp. (in € m)		Share of Public R&D Exp. by GDP	
		2019	2020	2019	2020
EU-27	France	2.03	3.40	0.0001%	0.0001%
	Austria	2.87	3.25	0.0007%	0.0009%
	Sweden	2.72	2.32	0.0006%	0.0005%
	Germany	1.78	2.31	0.0001%	0.0001%
	Spain	1.81	0.42	0.0001%	0.0000%
	Poland	0.33	0.24	0.0001%	0.0000%
	Czechia	0.19	0.07	0.0001%	0.0000%
	Finland	0.09	0.05	0.0000%	0.0000%
	Total EU-27	12.84	12.06	0.0001%	0.0001%
	EU Commission	23.95	10.18	0.0002%	0.0001%
Other Countries	United States	98.35	134.24	0.0005%	0.0007%
	Switzerland	15.35	15.08	0.0024%	0.0023%
	Canada	14.53	13.72	0.0010%	0.0009%
	Turkey	0.11	6.30	0.0000%	0.0010%
	Norway	7.71	5.77	0.0022%	0.0018%
	Korea	2.09	0.60	0.0001%	0.0000%
	United Kingdom	n.a.	0.26	n.a.	0.0000%
	Australia	0.12	0.07	0.0000%	0.0000%
	New Zealand	0.01	0.01	0.0000%	0.0000%

Source: JRC SETIS, Eurostat, WDI Database

Hydro energy is a small field with regard to public R&D investment when compared, for example, to solar energy. Among the assessed countries, the US has the largest public R&D investment (€134.24 million in 2020, see table 3). Remarkable engagements (though much lower than that of the US) are noted for Switzerland and Canada. Within the EU-27, the European Commission provides €10.2 million of the funding, while national commitments of the EU-27 in this area are slightly higher; €12.1 million in 2020), with the largest respective contributions from France, Austria, Sweden and Germany. Also the GDP shares show that the engagement by the US is significantly higher than by the EU-27. Switzerland and Norway stand out with the largest GDP shares, while Turkey also showed increased public R&D investments, as a relatively high percentage of its GDP. ■

PUBLIC R&D INVESTMENTS
BIOFUELS

		Public R&D Exp. (in € m)		Share of Public R&D Exp. by GDP	
		2019	2020	2019	2020
EU-27	France	67.36	65.24	0.0028%	0.0028%
	Germany	42.09	50.40	0.0012%	0.0015%
	Sweden	18.23	18.46	0.0038%	0.0038%
	Denmark	14.34	12.72	0.0046%	0.0041%
	Finland	13.58	11.19	0.0057%	0.0047%
	Austria	10.61	10.49	0.0027%	0.0028%
	Czechia	6.51	7.31	0.0029%	0.0034%
	Netherlands	8.55	7.30	0.0011%	0.0009%
	Spain	5.38	6.98	0.0004%	0.0006%
	Belgium	0.87	3.53	0.0002%	0.0008%
	Ireland	2.37	2.38	0.0007%	0.0006%
	Lithuania	1.54	1.70	0.0032%	0.0034%
	Poland	2.52	1.68	0.0005%	0.0003%
	Hungary	n.a.	0.31	n.a.	0.0002%
	Estonia	0.12	0.12	0.0004%	0.0004%
	Slovakia	0.04	0.01	0.0000%	0.0000%
	Total EU-27	202.65	199.81	0.0014%	0.0015%
	EU Commission	69.25	90.07	0.0005%	0.0007%
Other Countries	United States	224.79	248.08	0.0012%	0.0013%
	Japan	56.87	83.63	0.0013%	0.0019%
	Canada	37.28	55.10	0.0024%	0.0038%
	Korea	20.19	28.41	0.0014%	0.0020%
	Norway	17.04	26.22	0.0048%	0.0082%
	Switzerland	20.04	23.72	0.0032%	0.0037%
	United Kingdom	15.70	13.22	0.0006%	0.0006%
	Australia	3.83	4.91	0.0003%	0.0004%
	New Zealand	1.57	1.57	0.0008%	0.0008%
	Turkey	0.75	0.29	0.0001%	0.0000%

Source: JRC SETIS, Eurostat, WDI Database

In terms of public R&D investment, biofuels remain a large field within renewables of the EU-27. With €200 million spent on public R&D funding in 2020, the biofuels sector follows the solar sector (€250 million) and leaves the wind sector behind (€163 million). The US provides the most absolute expenditure on public R&D of the world; €248 million in 2020. Within the EU-27, additional funding is provided by the European Commission (€90 million), after which the largest national contributions in the EU-27 come from France and Germany. Other listed countries with significant investments are Japan (€84 million) and Canada (€55 million). With regard to the GDP shares, the EU-27 is slightly ahead of the US, where Finland, Denmark and Sweden show particularly high GDP shares. ■

PUBLIC R&D INVESTMENTS

WIND ENERGY

		Public R&D Exp. (in € m)		Share of Public R&D Exp. by GDP	
		2019	2020	2019	2020
EU-27	Germany	77.88	77.62	0.0022%	0.0023%
	Denmark	19.90	21.10	0.0064%	0.0068%
	France	20.67	17.95	0.0008%	0.0008%
	Netherlands	48.37	15.77	0.0059%	0.0020%
	Spain	25.04	15.04	0.0020%	0.0013%
	Belgium	8.33	5.81	0.0017%	0.0013%
	Sweden	2.75	5.04	0.0006%	0.0010%
	Finland	1.40	1.76	0.0006%	0.0007%
	Ireland	0.96	1.07	0.0003%	0.0003%
	Austria	1.19	0.99	0.0003%	0.0003%
	Czechia	0.60	0.25	0.0003%	0.0001%
	Poland	0.35	0.24	0.0001%	0.0000%
	Lithuania	0.14	0.10	0.0003%	0.0002%
	Total EU-27	208.45	162.73	0.0015%	0.0012%
	EU Commission	44.06	47.84	0.0003%	0.0004%
Other Countries	Japan	137.51	161.98	0.0031%	0.0037%
	United States	86.17	94.33	0.0005%	0.0005%
	Korea	48.48	66.12	0.0033%	0.0046%
	United Kingdom	25.68	14.72	0.0010%	0.0006%
	Switzerland	5.91	6.13	0.0009%	0.0009%
	Norway	254.97	5.69	0.0717%	0.0018%
	Canada	5.82	5.35	0.0004%	0.0004%
	Turkey	0.70	0.57	0.0001%	0.0001%
	Australia	0.29	0.53	0.0000%	0.0000%

Source: JRC SETIS, Eurostat, WDI Database

Wind energy is one of the three biggest public investment areas (next to solar energy and biofuels). The largest investments in 2019 are committed by Norway (2020 value may not be up to date). For 2020, the following countries show the largest public investments in wind energy R&D: the EU-27, Japan, US and Korea (in that order). Within the EU-27, the most significant public investments occur in Germany, Denmark and France. On top of that the European Commission contributes with an additional €48 million of funding. In terms of GDP shares, Korea and Japan stand out in 2020 with the largest value. The EU-27 share of GDP is larger than the share of Switzerland, the United States and Canada. ■

PUBLIC R&D INVESTMENTS

OCEAN ENERGY

		Public R&D Exp. (in € m)		Share of Public R&D Exp. by GDP	
		2019	2020	2019	2020
EU-27	France	10.62	8.01	0.0004%	0.0003%
	Denmark	0.69	5.87	0.0002%	0.0019%
	Sweden	4.37	5.54	0.0009%	0.0012%
	Ireland	4.98	3.06	0.0014%	0.0008%
	Spain	1.06	0.91	0.0001%	0.0001%
	Belgium	0.27	0.22	0.0001%	0.0000%
	Poland	0.04	0.07	0.0000%	0.0000%
	Total EU-27	22.05	23.68	0.0002%	0.0002%
	EU Commission	24.36	36.13	0.0002%	0.0003%
Other Countries	United Kingdom	20.33	17.32	0.0008%	0.0007%
	Japan	8.49	6.20	0.0002%	0.0001%
	Canada	1.50	3.47	0.0001%	0.0002%
	Korea	1.96	1.25	0.0001%	0.0001%
	Australia	0.14	0.14	0.0000%	0.0000%
	Norway	0.11	0.10	0.0000%	0.0000%
	Turkey	n.a.	0.05	n.a.	0.0000%

Source: JRC SETIS, Eurostat, WDI Database

Ocean energy is a comparably small field in terms of public R&D investment. Whereas the European Commission shows the largest public R&D investments in ocean energy, the next most significant investments (2020) are made in the EU-27 and the UK. On the national level, France, Denmark and Sweden are investing the largest amounts in 2020. GDP shares are dominated by Denmark in 2020, reaching 0.0019% of its investments in R&D per trillion euros of GDP. The next highest GDP shares on public R&D came from Sweden (0,0012%) and Ireland (0.0008%). In general, the EU-27 have invested a mere 0.0002% of their GDP to public R&D. ■

PUBLIC R&D INVESTMENTS

RENEWABLE ENERGY TECHNOLOGIES IN TOTAL

		Public R&D Exp. (in € m)		Share of Public R&D Exp. by GDP	
		2019	2020	2019	2020
EU-27	Germany	254.61	247.58	0.0073%	0.0073%
	France	176.86	185.85	0.0073%	0.0080%
	Netherlands	84.35	45.10	0.0104%	0.0057%
	Sweden	33.00	42.58	0.0069%	0.0089%
	Denmark	37.86	41.59	0.0122%	0.0133%
	Spain	49.27	35.74	0.0040%	0.0032%
	Austria	22.93	21.44	0.0058%	0.0056%
	Belgium	22.21	19.66	0.0046%	0.0043%
	Finland	21.52	18.21	0.0090%	0.0077%
	Poland	10.90	9.02	0.0020%	0.0017%
	Czechia	9.71	9.00	0.0043%	0.0042%
	Ireland	9.16	7.29	0.0026%	0.0020%
	Lithuania	2.12	2.16	0.0043%	0.0043%
	Hungary	0.01	1.72	0.0000%	0.0012%
	Slovakia	0.67	0.45	0.0007%	0.0005%
	Estonia	0.46	0.16	0.0016%	0.0006%
	Total EU-27	780.26	687.52	0.0056%	0.0051%
	EU Commission	299.91	264.52	n.a.	n.a.
Other Countries	United States	869.63	873.67	0.0046%	0.0047%
	Japan	250.88	299.62	0.0056%	0.0068%
	Korea	135.33	154.69	n.a.	n.a.
	Canada	86.94	104.38	0.0057%	0.0072%
	Switzerland	102.60	101.65	0.0162%	0.0156%
	United Kingdom	100.65	90.87	0.0040%	0.0038%
	Norway	289.81	46.63	0.0815%	0.0147%
	Australia	17.06	29.43	0.0014%	0.0025%
	Turkey	14.42	9.19	0.0022%	0.0015%
	New Zealand	8.71	5.78	0.0046%	0.0031%

Note: the sum across technologies is only given, if data of all RET in one country are available, i.e. as soon as one RET is missing, the data are indicated as n.a.
Source: JRC SETIS, Eurostat, WDI Database.

The aggregated results of public R&D investments for all renewable energy technologies in the EU-27 reveals a strong position in 2020 with almost €1 billion when accounting for both the national contributions (€687.5 million) and those of the European Commission (€264.5 million) together. The second largest contribution of public R&D investments in renewable energy technologies came from the United States, with €873.7 million. In general, the EU-27 has invested 0.0051% of the GDP in public R&D in 2020. Furthermore, Switzerland, Norway, and Denmark stand out with the highest GDP shares. ■

PRIVATE R&D INVESTMENTS

SOLAR ENERGY

		Private R&D Exp. (in € m)		Share of Private R&D Exp. by GDP	
		2018	2019	2018	2019
EU-27	Germany	488.98	383.46	0.0145%	0.0110%
	France	148.76	121.29	0.0063%	0.0050%
	Netherlands	60.45	51.29	0.0078%	0.0063%
	Spain	53.71	40.24	0.0045%	0.0032%
	Italy	94.53	39.62	0.0053%	0.0022%
	Portugal	1.22	28.43	0.0006%	0.0133%
	Austria	32.82	23.79	0.0085%	0.0060%
	Sweden	46.32	16.13	0.0098%	0.0034%
	Denmark	14.25	13.20	0.0047%	0.0043%
	Belgium	12.37	12.58	0.0027%	0.0026%
	Poland	17.63	7.80	0.0035%	0.0015%
	Finland	11.89	7.25	0.0051%	0.0030%
	Cyprus	n.a.	6.69	n.a.	0.0289%
	Ireland	3.22	4.19	0.0010%	0.0012%
	Czechia	n.a.	3.90	n.a.	0.0017%
	Croatia	n.a.	1.67	n.a.	0.0030%
	Hungary	5.47	1.67	0.0040%	0.0011%
	Luxembourg	0.84	1.67	0.0014%	0.0027%
	Romania	3.65	1.67	0.0018%	0.0007%
	Slovenia	n.a.	0.46	n.a.	0.0009%
	Total EU-27	997.93	767.00	0.0074%	0.0055%

Source: JRC SETIS, Eurostat, WDI Database

In the field of solar energy within the EU-27, Germany is by far the largest player in terms of private R&D investment, accounting for 50% of the total EU-27 investments. With a large gap to Germany, the following countries ranking next on the list in 2019 are France, Italy, the Netherlands and Spain (in that order).
Among the GDP normalized investments in private R&D, Germany, unsurprisingly, has the largest share (0.0110% in 2019). The private sectors of Cyprus and Portugal have invested a relatively large share of their GDP in solar energy (0.0289% and 0.0133% respectively),. The rest of the EU-27 countries have a private GDP expenditure share of under 0.01%. The total GDP share of the EU-27 showed a drop to 0.0055% in 2019. ■

PRIVATE R&D INVESTMENTS

GEOTHERMAL ENERGY

		Private R&D Exp. (in € m)		Share of Private R&D Exp. by GDP	
		2018	2019	2018	2019
EU-27	Austria	n.a.	4.17	n.a.	0.0010%
	Hungary	n.a.	4.17	n.a.	0.0028%
	Germany	23.82	3.92	0.0007%	0.0001%
	Finland	6.02	3.13	0.0026%	0.0013%
	France	n.a.	2.30	n.a.	0.0001%
	Italy	15.24	2.08	0.0009%	0.0001%
	Slovakia	n.a.	2.08	n.a.	0.0022%
	Netherlands	5.83	1.16	0.0008%	0.0001%
	Sweden	0.51	0.80	0.0001%	0.0002%
	Total EU-27	57.27	23.82	0.0004%	0.0002%

Source: JRC SETIS, Eurostat, WDI Database

In geothermal energy, the private (as well as the public) R&D expenditures are around two orders of magnitude lower than in solar energy. The largest investments are due to Austria and Hungary followed by germany, Finland and France. R&D investments in geothermal in EU-27 more than halved in 2019, mainly due to a critical drop of investments in Germany. Hungary leads the share of GDP invested in private R&D in 2019, not by far, before Slovakia. ■

PRIVATE R&D INVESTMENTS

HYDRO ENERGY

		Private R&D Exp. (in € m)		Share of Private R&D Exp. by GDP	
		2018	2019	2018	2019
EU-27	Germany	9.06	30.29	0.0003%	0.0009%
	France	24.74	11.35	0.0010%	0.0005%
	Poland	n.a.	2.65	n.a.	0.0005%
	Austria	4.15	1.47	0.0011%	0.0004%
	Sweden	5.32	1.33	0.0011%	0.0003%
	Spain	0.87	0.88	0.0001%	0.0001%
	Finland	6.02	0.88	0.0026%	0.0004%
	Netherlands	0.99	0.88	0.0001%	0.0001%
	Slovenia	3.16	0.88	0.0069%	0.0018%
	Italy	0.99	0.59	0.0001%	0.0000%
	Total EU-27	63.20	51.23	0.0005%	0.0004%

Source: JRC SETIS, Eurostat, WDI Database

Like geothermal energy, hydro energy is also a rather small field with regard to private R&D investments. As in earlier reporting periods private R&D investments remain fairly larger than public ones. France committed by far the largest investments (2018) followed by Germany, Finland, Sweden and Austria. In 2019, a remarkably high investment volume by Germany is registered, which makes it the biggest private investor in this year. The total share of GDP investments in private R&D for the EU-27 have slightly reduced from 2018 to 2019, reaching 0.0004%. In spite of the drop in R&D investments in 2019, Slovenia remains the country in EU-27 with higher GDP share directed to hydro energy with 0,0018%. All other countries had GDP shares lower than 0,001% in 2019. ■

PRIVATE R&D INVESTMENTS

BIOFUELS

		Private R&D Exp. (in € m)		Share of Private R&D Exp. by GDP	
		2018	2019	2018	2019
EU-27	Denmark	102.39	92.87	0.0339%	0.0300%
	Finland	46.60	37.10	0.0200%	0.0155%
	Netherlands	42.45	35.13	0.0055%	0.0043%
	France	20.07	24.73	0.0008%	0.0010%
	Italy	18.15	23.44	0.0010%	0.0013%
	Sweden	6.60	20.35	0.0014%	0.0043%
	Austria	6.99	19.16	0.0018%	0.0048%
	Germany	44.01	18.64	0.0013%	0.0005%
	Luxembourg	n.a.	9.86	n.a.	0.0158%
	Belgium	7.94	7.56	0.0017%	0.0016%
	Latvia	n.a.	5.23	n.a.	0.0170%
	Portugal	1.75	5.23	0.0009%	0.0024%
	Romania	n.a.	5.23	n.a.	0.0023%
	Hungary	39.63	4.18	0.0291%	0.0029%
	Spain	5.59	3.45	0.0005%	0.0003%
	Czechia	2.33	0.65	0.0011%	0.0003%
	Total EU-27	355.57	312.81	0.0026%	0.0022%

Source: JRC SETIS, Eurostat, WDI Database

Biofuels remains the third largest field in terms of private R&D investments after wind energy and solar energy. The highest private investments (2019) within the EU-27 were made by Denmark, Finland, the Netherlands, France and Italy (in that order). Hungary has made a significant investment in private R&D of almost €40 million in 2018, but showed a significant drop to €4 million in 2019. Similarly, Germany showed a large decrease in investments (€18.6 million in 2019). Other countries increased their investments relative to 2018, such as Austria, France or Italy. Still, the EU-27 total R&D investment dropped by 12% from 2018 to 2019. One country has spent a significant amount (0.03%) of their GDP on private R&D in 2019; Denmark. ■

PRIVATE R&D INVESTMENTS

WIND ENERGY

		Private R&D Exp. (in € m)		Share of Private R&D Exp. by GDP	
		2018	2019	2018	2019
EU-27	Denmark	599.32	735.20	0.1982%	0.2375%
	Germany	632.99	343.96	0.0188%	0.0099%
	Spain	52.64	76.41	0.0044%	0.0061%
	France	14.02	39.22	0.0006%	0.0016%
	Austria	29.72	28.45	0.0077%	0.0072%
	Netherlands	37.71	27.19	0.0049%	0.0033%
	Sweden	20.10	14.87	0.0043%	0.0031%
	Italy	3.13	9.13	0.0002%	0.0005%
	Finland	3.99	5.57	0.0017%	0.0023%
	Belgium	34.24	2.80	0.0074%	0.0006%
	Cyprus	n.a.	2.55	n.a.	0.0110%
	Latvia	n.a.	1.27	n.a.	0.0042%
	Poland	2.50	1.27	0.0005%	0.0002%
	Portugal	n.a.	0.85	n.a.	0.0004%
	Total EU-27	1 438.72	1 288.75	0.0106%	0.0092%

Source: JRC SETIS, Eurostat, WDI Database

Since 2017, wind energy attracts the largest private R&D investment volumes (€1.4 billion in 2018) in the EU-27 (followed by solar energy). Germany and Denmark are responsible for over 80% of the EU-27 investments (in both 2018 and 2019). All other EU-27 countries spend a bit more than €200 million on wind energy, with Spain having the largest investments. In 2019, it was followed by France, Austria and the Netherlands. In total, a significant drop of investments is noted for 2019, mainly due to a lower commitments by Germany. In terms of GDP shares, Denmark stands out with by far the largest value (0.24% in 2019), compared to the total GDP expenditure share of the EU-27 of 0.0092%. ■

PRIVATE R&D INVESTMENTS

OCEAN ENERGY

		Private R&D Exp. (in € m)		Share of Private R&D Exp. by GDP	
		2018	2019	2018	2019
EU-27	France	8.47	12.20	0.0004%	0.0005%
	Italy	n.a.	8.87	n.a.	0.0005%
	Sweden	6.08	3.14	0.0013%	0.0007%
	Netherlands	3.20	2.40	0.0004%	0.0003%
	Germany	5.69	1.80	0.0002%	0.0001%
	Finland	2.13	1.20	0.0009%	0.0005%
	Ireland	n.a.	1.20	n.a.	0.0003%
	Slovenia	n.a.	1.20	n.a.	0.0025%
	Spain	0.53	0.53	0.0000%	0.0000%
	Total EU-27	29.34	32.53	0.0002%	0.0002%

Source: JRC SETIS, Eurostat, WDI Database

Ocean energy is again one of the smaller fields in terms of private R&D investment. France, Sweden and Germany were most committed in this technology in 2018. These countries accounted for more than two thirds of the total EU-27 investments in that year. In 2019, a 10% increase in private R&D investments in EU-27 was noted, leading to more than €30 million of investments. The largest shares of GDP spent on ocean energy in the private R&D sector in 2018 were from Sweden and Finland. Similarly to geothermal energy, the total normalized GDP expenditure of the EU-27 was 0.0002% for private R&D ocean energy in both 2018 and 2019. ■

PRIVATE R&D INVESTMENTS

RENEWABLE ENERGY TECHNOLOGIES IN TOTAL

	Private R&D Exp. (in € m)		Share of Private R&D Exp. by GDP	
	2018	2019	2018	2019
Denmark	723.97	841.28	0.2395%	0.2718%
Germany	1 204.54	782.08	0.0358%	0.0225%
France	216.05	211.08	0.0091%	0.0087%
Spain	113.34	121.51	0.0094%	0.0098%
Netherlands	150.64	118.06	0.0195%	0.0145%
Italy	132.04	83.73	0.0075%	0.0047%
Austria	73.68	77.04	0.0191%	0.0194%
Sweden	84.94	56.62	0.0180%	0.0119%
Finland	76.66	55.13	0.0328%	0.0230%
Portugal	2.96	34.51	0.0014%	0.0161%
Belgium	56.52	22.94	0.0123%	0.0048%
Poland	24.80	11.73	0.0050%	0.0022%
Luxembourg	6.70	11.53	0.0112%	0.0185%
Hungary	45.10	10.02	0.0331%	0.0068%
Cyprus	n.a.	9.24	n.a.	0.0399%
Romania	8.20	6.90	0.0040%	0.0031%
Latvia	n.a.	6.50	n.a.	0.0212%
Ireland	11.60	5.39	0.0036%	0.0015%
Czechia	5.30	4.56	0.0025%	0.0020%
Slovenia	3.16	2.54	0.0069%	0.0052%
Slovakia	n.a.	2.08	n.a.	0.0022%
Croatia	n.a.	1.67	n.a.	0.0030%
Total EU-27	2 942.03	2 476.15	0.0217%	0.0177%

Note: the sum across technologies is only given, if data of all RET in one country are available, i.e. as soon as one RET is missing, the data are indicated as n.a.
Source: JRC SETIS, Eurostat, WDI Database

A final look at the private R&D investment in all renewable energy technologies in 2018 shows a strongly dominant position of Germany, which is surpassed by Denmark in 2019. In this year, Germany becomes second in R&D investments, followed by France, Spain and the Netherlands. The wind energy sector received more than 50% of the total private R&D investments in the EU-27, whereas the solar energy sector is placed second with 31% of total private R&D. The GDP share in 2019 is by far the highest in Denmark (0.27%). Among the other countries with significant investments, Germany, Finland, Latvia, Luxembourg and Portugal display the highest values. The total GDP share of the EU-27 has decreased from 0.022% in 2018 to 0.018% in 2019, which is in line with the total decrease in private R&D investments. 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 with regard to 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 U.S.. 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 of 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 (2019/2020) and the US are the frontrunners in public R&D spending, followed by Korea (data for China is not available). Within the EU-27, the largest investments in 2020 are due to Germany, France and the European Commission. For private R&D investments within the EU-27, Germany, France and the Netherlands are the leading countries (2019).
- With regard to geothermal energy, the U.S. ranks first with a substantial difference from the subsequent EU-27 countries; Germany, France and the Netherlands. Private R&D expenditures in the EU-27 are highest in Austria, Hungary and Germany.
- In hydro energy, the U.S. dominates in public R&D investments, followed by Switzerland, Canada and the EU-27. Within the EU-27, the European Commission is in the lead, followed by France, Germany and Sweden. As for the private R&D investments in the EU-27, the largest values are noted for Germany and France.
- Within biofuels, the U.S. is in the head position regarding public R&D investments, followed by the European Commission and Japan (2020). Within the EU-27, the largest contributions are due to France and Germany. As for the private R&D investments within the EU-27, Denmark, Finland and the Netherlands are in the lead (2019).
- In wind energy, the EU-27 shows the largest public R&D spending in 2020, followed by Japan and the US. Within the EU-27, the largest contributions come mainly from Germany, followed by Denmark and France. With regard to private R&D spending in the EU-27 (2019), Denmark and Germany are by far on the top of the list.
- In ocean energy – also a rather small field in terms of public R&D – the European Commission and the UK show the largest public R&D expenditures. Within the EU-27, the largest contributions are provided by Denmark and Sweden. Concerning private R&D investments within the EU-27, France, Italy and Sweden are the most committed countries in 2019.
- Regarding the total public R&D expenditures the EU-27 and the US are clearly the two most significant among the assessed regions worldwide. With some distance behind, Japan, Norway, and Korea follow outside of the EU-27. Denmark and France 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 France, Spain and the Netherlands (2019). ■


Voith

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 the area of 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	
	2018	2019	2018	2019	2018	2019
EU-27						
Germany	187.3	158.0	0.4	0.4	55.6	45.5
France	107.7	95.6	0.7	0.7	45.6	39.2
Netherlands	31.0	39.5	0.8	1.2	40.1	48.6
Spain	33.7	33.9	1.9	2.1	28.0	27.3
Poland	27.4	28.0	1.3	1.8	54.9	52.6
Italy	32.7	26.3	1.0	0.9	18.5	14.6
Austria	12.2	13.1	0.5	0.6	31.7	33.0
Portugal	1.0	8.5	0.6	3.3	4.9	39.7
Sweden	15.2	7.8	0.5	0.3	32.4	16.3
Belgium	9.8	7.5	0.6	0.7	21.3	15.7
Denmark	5.7	5.7	0.2	0.2	18.7	18.3
Finland	5.7	5.7	0.3	0.4	24.6	23.6
Romania	8.7	4.5	2.0	1.2	42.1	20.1
Czechia	2.2	2.0	0.6	0.5	10.4	8.9
Cyprus	0	2.0	0	4.4	0	86.3
Ireland	2.3	1.4	0.4	0.2	7.1	3.8
Slovakia	2.0	1.3	1.3	1.7	22.3	14.1
Greece	1.3	0.9	2.0	1.5	7.4	5.0
Croatia	0	0.5	0	1.9	0	9.0
Hungary	1.5	0.5	1.0	0.4	11.0	3.4
Luxembourg	1.5	0.5	0.7	0.2	24.9	8.0
Lithuania	1.4	0.4	3.9	0.7	31.1	8.5
Slovenia	0	0.3	0	0.3	0	5.6
Bulgaria	0.5	0	0.6	0	8.9	0
Estonia	0	0	0	0	0	0
Latvia	1.0	0	3.1	0	34.3	0
Malta	0	0	0	0	0	0
Total EU-27	491.9	443.9	0.6	0.6	36.4	31.7

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Other Countries						
China	6 679.4	5 420.2	1.1	1.1	547.5	432.3
Korea	1 485.0	1 409.2	1.4	1.5	980.6	971.9
Japan	743.2	630.4	0.6	0.6	168.0	140.1
United States	428.2	374.1	0.6	0.6	282.7	19.9
Rest of the world*	430.8	375.0	1.0	1.0	7.3	6.0
out of which United Kingdom	*40.5*	*25.3*	*0.5*	*0.4*	*16.0*	*10.1*

** 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, Eurostat, WDI Database.***

In the field of solar energy, China is the uncontested frontrunner in terms of patents (filed domestically or internationally), although Korea has the higher levels of patents per trillion of GDP. China is followed in number of patents by Korea and Japan and then the EU-27 and the US. Within the EU-27, Germany has filed the largest number of patents, followed by France, the Netherlands, Spain and Poland (2019). Among the more significant patent filing countries, Poland, the Netherlands, Germany, Portugal and France are scoring highest in terms of patents per GDP within the EU-27.

In comparison to 2018, the EU-27 showed a similar amount of patent specialization, with Portugal, Spain and Poland showing the highest specialization indices among the coutries with highest number of patents. Outside the EU-27 in 2019, only Korea showed a small increased specialization in solar energy patent filings relative to 2018, while remaining countries kept their specialization levels. ■

GEOTHERMAL ENERGY

	Number of patent families		Patent specialization		Patents per € trillion GDP	
	2018	2019	2018	2019	2018	2019
EU-27						
Germany	5.1	6.8	0.6	0.6	1.5	2.0
Austria	0.2	2.0	0.4	3.6	0.4	5.0
Finland	1.1	2.0	3.5	4.9	4.5	8.3
Hungary	0	2.0	0	57.8	0	13.6
France	0.3	1.1	0.1	0.3	0.1	0.5
Italy	2.5	1.0	4.5	1.3	1.4	0.6
Poland	6.0	1.0	17.0	2.4	12.0	1.9
Slovakia	0	1.0	0	47.9	0	10.6
Netherlands	1.5	0.6	2.4	0.7	1.9	0.8
Sweden	1.2	0.3	2.1	0.5	2.5	0.7
Belgium	0	0	0	0	0	0
Bulgaria	0	0	1.0	1.0	0	0
Cyprus	0	0	1.0	1.0	0	0
Czechia	0	0	1.0	1.0	0	0
Denmark	1.0	0	1.6	0	3.3	0
Estonia	0	0	1.0	1.0	0	0
Greece	0	0	1.0	1.0	0	0
Spain	1.0	0	3.2	0	0.8	0
Croatia	0	0	1.0	1.0	0	0
Ireland	0	0	1.0	1.0	0	0
Lithuania	0	0	1.0	1.0	0	0
Luxembourg	0	0	1.0	1.0	0	0
Latvia	0	0	1.0	1.0	0	0
Malta	0	0	1.0	1.0	0	0
Portugal	0	0	1.0	1.0	0	0
Romania	0	0	1.0	1.0	0	0
Slovenia	0	0	0	0	0	0
EU27	19.8	17.9	1.3	0.9	1.5	1.3

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Other Countries						
China	83.3	137.7	0.8	1.0	6.8	11.0
Korea	34.0	41.6	1.9	1.7	22.4	28.7
Japan	11.8	14.1	0.5	0.5	2.7	3.1
United States	9.4	6.5	0.7	0.4	6.2	0.3
Rest of the world*	18.1	14.0	2.5	1.4	0.3	0.2
out of which United Kingdom	*0.7*	*1.0*	*0.5*	*0.6*	*0.3*	*0.4*

** 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. Eurostat. WDI Database.***

In terms of the number of patent filings, geothermal energy is a far less significant field than solar energy. Within the EU-27 countries less than 20 patents were filed in 2018 (as well as in 2019). Germany, Austria, Finland, Hungary, France, and Italy are the most active countries in terms of patents within the EU-27. Outside the EU-27, China is the clear frontrunner with 138 patents in 2019. Korea and Japan follow with double digit patent filings, with Korea filing more patens than the EU-27 combined. Furthermore, the number of patents filed per GDP expenditure was highest for Korea, surpassing by far China and Hungary. The next highest GDP expenditure on patent filings in the EU-27 in 2019 were in Slovakia, Finland and Austria.

Among the most significant patent filing countries, Slovakia and Hungary show a high level of specialization. Outside the EU-27, specialization levels remain relatively low. ■


Groupe ES

HYDROENERGY

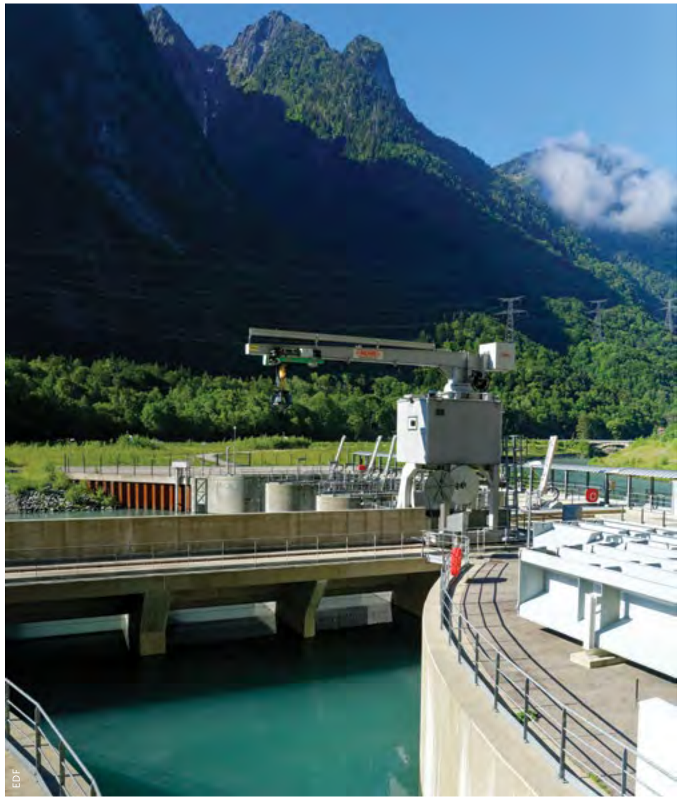
	Number of patent families		Patent specialization		Patents per € trillion GDP	
	2018	2019	2018	2019	2018	2019
EU-27						
Germany	6.5	19.1	0.2	0.7	1.9	5.5
France	16.2	8.7	1.8	0.9	6.9	3.6
Poland	4.5	6.3	3.6	5.8	9.0	11.9
Italy	1.0	1.6	0.5	0.8	0.6	0.9
Romania	1.0	1.5	3.8	5.7	4.9	6.7
Greece	0	1.0	0	22.8	0	5.5
Spain	0.6	1.0	0.5	0.9	0.5	0.8
Austria	3.0	0.8	2.1	0.6	7.8	2.1
Sweden	3.0	0.7	1.5	0.3	6.4	1.4
Finland	3.8	0.5	3.6	0.5	16.4	2.1
Netherlands	0.5	0.5	0.2	0.2	0.6	0.6
Slovenia	1.6	0.5	23.0	7.0	34.9	10.3
Lithuania	0.5	0.3	22.4	5.8	11.0	5.1
Belgium	1.0	0	1.0	0	2.2	0
Bulgaria	0	0	0	0	0	0
Cyprus	0	0	0	0	0	0
Czechia	1.5	0	6.9	0	7.1	0
Denmark	0	0	0	0	0	0
Estonia	0	0	0	0	0	0
Croatia	0	0	0	0	0	0
Hungary	0	0	0	0	0	0
Ireland	1.0	0	2.6	0	3.1	0
Luxembourg	0	0	1.0	1.0	0	0
Latvia	0	0	1.0	1.0	0	0
Malta	0	0	0	0	0	0
Portugal	0.5	0	5.0	0	2.4	0
Slovakia	2.3	0	24.8	0	25.0	0
EU27	**48.4**	**42.5**	**0.9**	**0.8**	**3.6**	**3.0**

Continues overleaf

	Number of patent families		Patent specialization		Patents per € trillion GDP	
Other Countries						
China	426.1	412.4	1.2	1.2	34.9	32.9
Japan	60.2	51.2	0.7	0.7	13.6	11.4
Korea	43.5	49.1	0.7	0.8	28.7	33.8
United States	12.8	8.0	0.3	0.2	8.5	0.4
Rest of the world*	35.4	50.3	1.4	1.9	0.6	0.8
out of which United Kingdom	*2.8*	*2.7*	*0.6*	*0.6*	*1.1*	*1.1*

** 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. Eurostat. WDI Database.***

In hydro energy, the patent filings are higher than in geothermal energy. Again, China is the clear frontrunner, followed by Japan, Korea and the EU-27. Within the EU-27, Germany and France are in the head position followed by Poland and Italy (2019). No significant specialization can be observed among these most active countries.
In relation to its economic size, China and Korea reveal the highest patent filing figures per GDP. Within the EU-27, from the significant patent filing countries, Poland and Germany show the highest GDP expenditure on patent filings. ■



BIOFUELS

	Number of patent families		Patent specialization		Patents per € trillion GDP	
	2018	2019	2018	2019	2018	2019
EU-27						
France	28.6	33.7	1.2	1.7	12.1	13.8
Germany	22.8	20.2	0.3	0.3	6.8	5.8
Netherlands	16.1	11.1	2.7	2.3	20.8	13.7
Finland	13.3	9.9	4.7	4.3	56.8	41.3
Denmark	12.8	9.8	2.2	1.8	42.4	31.7
Italy	8.0	7.5	1.6	1.7	4.5	4.2
Poland	19.0	7.3	5.8	3.2	38.1	13.8
Sweden	1.7	5.5	0.3	1.3	3.5	11.5
Spain	2.2	4.3	0.8	1.8	1.8	3.5
Austria	2.5	4.2	0.7	1.3	6.5	10.5
Romania	2.0	4.0	2.9	7.1	9.7	17.8
Belgium	2.0	2.7	0.7	1.5	4.3	5.6
Portugal	1.0	2.0	3.8	5.1	4.9	9.3
Luxembourg	0	1.0	0	2.8	0	16.0
Latvia	0.5	1.0	9.8	9.6	17.2	32.6
Hungary	9.0	0.8	36.4	4.1	66.1	5.5
Czechia	2.0	0.4	3.5	0.6	9.5	1.7
Greece	0	0.4	0	3.9	0	2.0
Bulgaria	0	0	0	0	0	0
Cyprus	0	0	1.0	1.0	0	0
Estonia	0	0	0	0	0	0
Croatia	0	0	1.0	1.0	0	0
Ireland	3.2	0	3.3	0	9.9	0
Lithuania	1.0	0	17.2	0	22.0	0
Malta	0	0	1.0	1.0	0	0
Slovenia	1.0	0	5.5	0	21.8	0
Slovakia	0.5	0	2.1	0	5.6	0
EU27	**149.2**	**125.9**	**1.0**	**1.1**	**11.0**	**9.0**

Continues overleaf

Other Countries						
China	1 001.1	804.7	1.1	1.1	82.1	64.2
Korea	137.3	122.6	0.8	0.9	90.7	84.5
Japan	148.8	96.2	0.7	0.6	33.6	21.4
United States	85.4	72.7	0.7	0.8	56.4	3.9
Rest of the world*	111.9	93.7	1.7	1.7	1.9	1.5
out of which United Kingdom	*7.0*	*11.0*	*0.6*	*1.1*	*2.8*	*4.4*

** 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. Eurostat. WDI Database.***

Also in biofuels, China has filed by far the largest number of patents in 2018 and 2019. Behind China, the EU-27, Korea and Japan are next on the list. Within the EU-27 the most active countries in patent filing are France, Germany, the Netherlands and Finland.
In relation to their respective GDP, Korea, China, Finland and Denmark, stand out from the countries with significant number of patent families. In the rest of the world, Japan has the next significant GDP expenditure on patent filings in 2019.
With regard to the specialization among the more significant patent filing countries Latvia is most notable, followed by Romania, Finland and Hungary. Outside the EU-27, there are no significant or notable countries with a high specialization index. ■

WIND ENERGY

	Number of patent families		Patent specialization		Patents per € trillion GDP	
	2018	2019	2018	2019	2018	2019
EU-27						
Denmark	286.4	302.1	25.3	26.1	947.4	975.9
Germany	243.5	172.8	1.6	1.3	72.4	49.8
Spain	29.6	41.3	5.4	7.8	24.6	33.1
France	28.8	24.2	0.7	0.6	12.2	9.9
Netherlands	24.2	21.8	2.2	2.1	31.3	26.9
Austria	12.1	14.6	1.7	2.1	31.3	36.8
Poland	9.0	12.8	1.4	2.5	18.0	23.9
Italy	5.6	6.7	0.6	0.7	3.2	3.7
Sweden	6.9	6.3	0.7	0.7	14.6	13.2
Romania	3.3	5.0	2.5	4.1	16.2	22.3
Latvia	0	2.5	0	11.1	0	81.5
Finland	3.1	1.9	0.6	0.4	13.3	7.9
Belgium	16.3	1.1	3.1	0.3	35.3	2.3
Cyprus	0	1.0	0	6.6	0	43.1
Lithuania	0	0.8	0	4.1	0	17.0
Ireland	0	0.5	0	0.3	0	1.4
Malta	0	0.3	0	3.6	0	23.5
Portugal	0	0.3	0	0.4	0	1.6
Bulgaria	1.0	0	4.1	0	17.8	0
Czechia	0	0	0	0	0	0
Estonia	0	0	0	0	0	0
Greece	0.9	0	4.2	0	4.8	0
Croatia	0	0	1.0	1.0	0	0
Hungary	0.3	0	0.5	0	1.8	0
Luxembourg	3.0	0	4.5	0	49.9	0
Slovenia	0	0	0	0	0	0
Slovakia	0	0	0	0	0	0
EU27	**673.9**	**616.1**	**2.5**	**2.4**	**49.8**	**43.9**
Other Countries						
China	1 863.6	1 753.1	1.1	1.1	152.8	139.8
United States	191.3	135.7	0.8	0.7	126.3	7.2
Korea	127.7	127.1	0.4	0.4	84.3	87.6
Japan	139.4	114.2	0.3	0.3	31.5	25.4
Rest of the world*	116.2	115.4	0.9	0.9	2.0	1.8
out of which United Kingdom	*30.5*	*16.2*	*1.3*	*0.7*	*12.1*	*6.5*

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. Eurostat. WDI Database.***

In wind energy, it is also China that has the largest number of patent filings in our comparison. Behind China, the EU-27 follows and then the US, Korea and Japan (2019). Within the EU, Denmark and Germany are most active, followed by Spain, France and the Netherlands. A noteworthy fact is that the EU-27 shows a significant higher specialization in wind energy patent filings compared to China (and also compared to other RET's). Especially Denmark strikingly stands out in this regard.
In terms of patents per GDP in wind energy, Denmark is very clearly in the top position worldwide. With a large distance behind China, Korea and Germany follow. Of the countries with significant patent filings, Spain follows as the next highest expenditure of their GDP on patent filing, followed by the Netherlands.
The EU-27 clearly showed the highest indices on specialization compared to the rest of the world, with its main specialization coming from Denmark. Next, of the significant patent filing countries, Spain shows a relatively high specialization index (higher than Germany, the leader in patent filings for wind energy). ■


IPH

OCEAN ENERGY

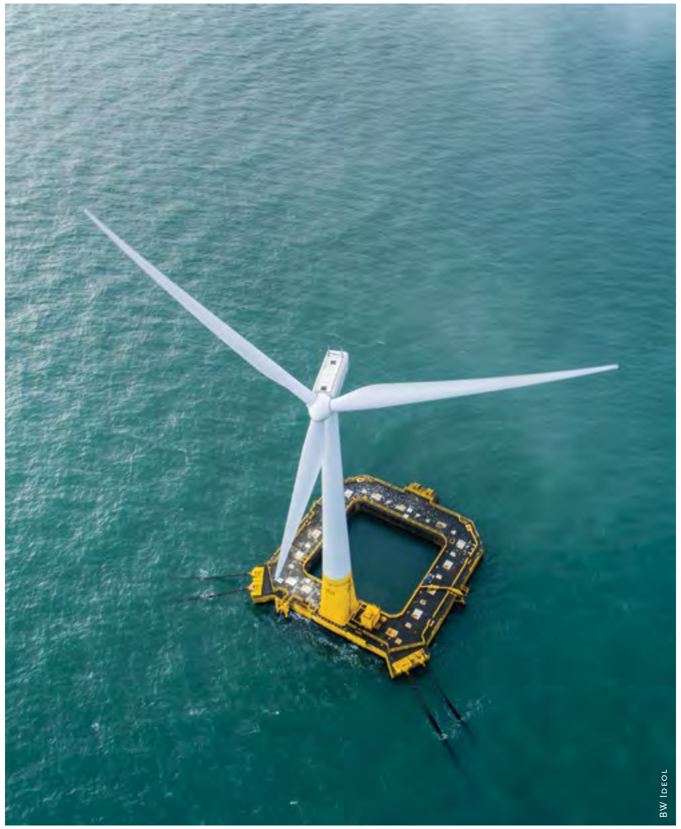
	Number of patent families		Patent specialization		Patents per € trillion GDP	
	2018	2019	2018	2019	2018	2019
EU-27						
France	9.3	7.0	1.6	1.2	3.9	2.9
Italy	1.0	3.5	0.8	2.7	0.6	1.9
Sweden	3.3	2.3	2.5	1.9	7.1	4.9
Spain	1.4	2.2	1.9	3.1	1.1	1.8
Portugal	1.5	2.0	22.5	17.4	7.3	9.3
Germany	3.7	1.3	0.2	0.1	1.1	0.4
Netherlands	1.5	1.0	1.0	0.7	1.9	1.2
Poland	0	1.0	0	1.5	0	1.9
Romania	0.5	1.0	2.8	6.0	2.4	4.5
Finland	1.0	0.5	1.4	0.7	4.3	2.1
Ireland	0	0.5	0	2.0	0	1.4
Slovenia	0	0.5	0	11.1	0	10.3
Austria	0	0	0	0	0	0
Belgium	0	0	0	0	0	0
Bulgaria	0	0	0	0	0	0
Cyprus	0	0	1.0	1.0	0	0
Czechia	0	0	1.0	1.0	0	0
Denmark	1.0	0	0.7	0	3.3	0
Estonia	0	0	1.0	1.0	0	0
Greece	0	0	1.0	1.0	0	0
Croatia	0	0	0	0	0	0
Hungary	0	0	1.0	1.0	0	0
Lithuania	0	0	1.0	1.0	0	0
Luxembourg	0	0	0	0	0	0
Latvia	0	0	1.0	1.0	0	0
Malta	0	0	0	0	0	0
Slovakia	0	0	0	0	0	0
EU27	**24.2**	**22.8**	**0.7**	**0.7**	**1.8**	**1.6**

Continues overleaf

Other Countries						
China	276.3	285.3	1.2	1.3	22.7	22.8
Korea	39.7	18.4	0.9	0.4	26.2	12.7
United States	31.2	17.1	1.0	0.6	20.6	0.9
Japan	16.2	11.0	0.3	0.2	3.7	2.4
Rest of the world*	26.1	32.2	1.5	1.9	0.4	0.5
out of which United Kingdom	*4.0*	*11.6*	*1.3*	*3.9*	*1.6*	*4.6*

** 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. Eurostat. WDI Database.***

Ocean energy is again a smaller field in terms of patent filings. The general observation that China is the frontrunner for RET's also applies here. After China, the EU-27, Korea and the US follow. Within the EU-27, in particular France is most active, followed by Italy, Sweden and Spain (2019). China and Korea are in the lead in terms of patent filings per GDP. In the EU-27, Slovenia and Portugal show the highest GDP expenditure on patent filings, followed by Sweden. Outside the EU-27, the UK showed the third largest number of patent filings per trillion GDP expenditure. Portugal also shows the highest specialization index within this field, followed by Slovenia and Romania. France, the country with the highest amount of patent filings, shows a relatively low specialization index within the EU-27. With a relatively low number of patents filed, the UK does show a significant specialization index, higher than France. ■



RENEWABLE ENERGY TECHNOLOGIES IN TOTAL

	Number of patent families		Patents per € trillion GDP	
	2018	2019	2018	2019
EU-27				
Germany	468.75	378.23	139	109
Denmark	306.89	317.55	1 015	1 026
France	191.01	170.38	81	70
Spain	68.42	82.78	57	66
Netherlands	74.89	74.63	97	92
Poland	65.90	56.42	132	106
Italy	50.83	46.54	29	26
Austria	29.94	34.75	78	87
Sweden	31.30	22.94	67	48
Finland	27.98	20.46	120	85
Romania	15.50	16.00	75	71
Portugal	4.00	12.83	19	60
Belgium	29.05	11.28	63	24
Latvia	1.50	3.50	51	114
Hungary	10.75	3.30	79	23
Cyprus	n.a.	3.00	n.a.	129
Czechia	5.70	2.38	27	11
Ireland	6.56	2.36	20	7
Slovakia	4.75	2.33	53	25
Greece	2.19	2.28	12	12
Lithuania	2.92	1.50	64	31
Luxembourg	4.50	1.50	75	24
Slovenia	2.60	1.27	57	26
Croatia	n.a.	0.50	n.a.	9
Malta	n.a.	0.33	n.a.	24
Bulgaria	1.50	n.a.	27	n.a.
Estonia	n.a.	n.a.	n.a.	n.a.
EU27	**1 407.45**	**1 269.05**	**104**	**91**
Other Countries				
China	10 329.83	8 813.40	847	703
Korea	1 867.14	1 767.96	n.a.	n.a.
Japan	1 119.71	917.02	253	204
United States	758.23	614.15	501	33
Rest of the world*	738.56	680.50	13	11
out of which United Kingdom	*85.56*	*67.77*	*34*	*27*

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. Eurostat. WDI Database.

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 2019, followed by Korea, the EU-27, Japan and the US. Within the EU-27, a strong position of Germany is noted followed by Denmark, France and Spain. When measured in terms of GDP shares, this ranking changes with Denmark being (far) ahead, followed by smaller countries such as Cyprus and Latvia. ■

CONCLUSIONS

Across nearly all fields in renewable energies technologies, the Asian countries, in particular China and Korea, 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 that files the largest number of patents. However, this is also due to its large size. Analysis in terms of patents per GDP shows Denmark in an uncontested first position in Europe.

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 Finland 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)*

Schoenenergie

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 has to 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 2019 and 2020. The export data were extracted from the UN Comtrade database. The fields were identified based on a selection of Harmonized System Codes (HS 2012).

1. *The HS 2012 codes used for the demarcation are: Photovoltaics (854140), 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). 2020 - all RES

	Imports (in € m)	Exports (in € m)	Net exports (in € m)	Share of global exports	Exports specialisation (RCA)
Denmark	423	1 891	1 469	2.8%	57
Germany	3 749	4 664	915	6.9%	-7
Hungary	273	434	162	0.6%	-4
Slovakia	48	76	29	0.1%	-58
France	1 243	1252	9	1.9%	-19
Bulgaria	73	76	3	0.1%	-22
Slovenia	114	114	0	0.2%	-12
Malta	5	0	-5	0.0%	-97
Luxembourg	50	43	-7	0.1%	-10
Latvia	27	5	-21	0.0%	-78
Cyprus	22	0	-21	0.0%	-94
Estonia	111	50	-61	0.1%	-13
Lithuania	110	45	-65	0.1%	-43
Ireland	85	18	-67	0.0%	-92
Austria	384	309	-75	0.5%	-31
Czechia	226	138	-88	0.2%	-63
Netherlands	3 538	3 437	-100	5.1%	19
Croatia	159	45	-113	0.1%	-17
Finland	128	10	-119	0.0%	-89
Portugal	386	229	-157	0.3%	-3
Italy	658	470	-188	0.7%	-55
Romania	250	7	-243	0.0%	-92
Spain	1 266	996	-270	1.5%	-10
Belgium	845	522	-324	0.8%	-34
Sweden	570	212	-357	0.3%	-43
Greece	491	36	-455	0.1%	-53
Poland	1 034	211	-823	0.3%	-59
Total EU-27	16 266	15 292	-973	23%	-13

Main EU partners' trade with the rest of the world (including EU-27). 2020 - all RES

	Imports (in € m)	Exports (in € m)	Net exports (in € m)	Share of global exports	Exports specialisation (RCA)
China	6 379	22 228	15 849	32.9%	32
Switzerland	360	194	-166	0.3%	-67
Brazil	1 435	1 257	-179	1.9%	18
Japan	3 364	3 111	-253	4.6%	9
Norway	334	4	-330	0.0%	-96
Russia	461	112	-349	0.2%	-79
Canada	1 098	365	-733	0.5%	-56
United Kingdom	1 147	285	-862	0.4%	-63
Turkey	1 125	164	-961	0.2%	-55
India	1 618	420	-1 198	0.6%	-39
USA	10 305	4 179	-6 125	6.2%	-13
Rest of the world	23 507	20 027	-3 481	29.6%	-1

Source: EurObserv'ER

In 2020, the largest importers of photovoltaics, wind energy equipment, biofuels and hydropower equipment in the EU27 were Germany (€3 749 million), the Netherlands (€3 538 million) and Spain (€1 266 million). Germany and the Netherlands were also the two main exporters of RET in 2020 with €4 664 and €3 437 million respectively. From the main trading partners, China is the largest by far with €6 379 million in imports and €22 228 in exports in 2020.

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, Germany, Hungary, Slovakia, France, Bulgaria and Slovenia. Since these countries exported more RET goods than they imported in 2020, 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, Turkey, the U.K., Poland and Canada. When taking a look at the export shares in all four selected renewable energy technology, it can be observed China has the largest values in 2020 with 33%. The EU-27 follows with an export share of 23% in 2020. Germany, the U.S., the Netherlands, Japan and Denmark display 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). Here, Denmark scores ahead of the remai-

EU-27 trade (incl. intra-EU trade). 2021 - all RES

	Imports (in € m)	Exports (in € m)	Net exports (in € m)	Share of global exports	Exports specialisation (RCA)
Denmark	465	1 688	1 223	2.2%	51
Germany	4 300	5 080	780	6.5%	-7
Hungary	322	520	198	0.7%	0
Belgium	561	593	32	0.8%	-36
Malta	4	0	-4	0.0%	-96
Slovakia	86	75	-11	0.1%	-61
Luxembourg	50	37	-13	0.0%	-20
Slovenia	93	73	-19	0.1%	-35
Latvia	27	8	-19	0.0%	-75
Cyprus	24	0	-24	0.0%	-98
Estonia	35	11	-24	0.0%	-70
Croatia	93	37	-56	0.0%	-32
Lithuania	160	90	-71	0.1%	-22
Ireland	89	18	-71	0.0%	-92
Bulgaria	157	65	-92	0.1%	-35
Czechia	350	200	-150	0.3%	-55
Finland	228	13	-214	0.0%	-87
Portugal	529	311	-218	0.4%	5
Austria	612	359	-253	0.5%	-30
France	1 560	1 305	-255	1.7%	-21
Romania	295	6	-289	0.0%	-94
Sweden	711	211	-500	0.3%	-48
Spain	1 682	922	-761	1.2%	-19
Italy	1 274	464	-810	0.6%	-59
Netherlands	4 659	3 645	-1 014	4.6%	16
Poland	1 420	229	-1 190	0.3%	-61
Greece	1 378	170	-1 208	0.2%	-30
Total EU-27	21 166	16 132	-5034	21%	-16

Main EU partners' trade with the rest of the world (including EU-27). 2021 - all RES

	Imports (in € m)	Exports (in € m)	Net exports (in € m)	Share of global exports	Exports specialisation (RCA)
China	8 265	29 744	21 479	37.9%	37
Japan	3 215	3 233	18	4.1%	7
Switzerland	429	185	-244	0.2%	-70
Norway	263	7	-256	0.0%	-96
Russia	397	113	-284	0.1%	-83
Turkey	958	132	-827	0.2%	-66
Canada	1 385	355	-1 030	0.5%	-61
Brazil	2 787	1 058	-1 729	1.3%	1
United Kingdom	2 644	360	-2 284	0.5%	-59
India	3 797	475	-3 322	0.6%	-45
USA	8 641	4 543	-4 098	5.8%	-15
Rest of the world	26 614	22 130	-4 484	28.2%	-1

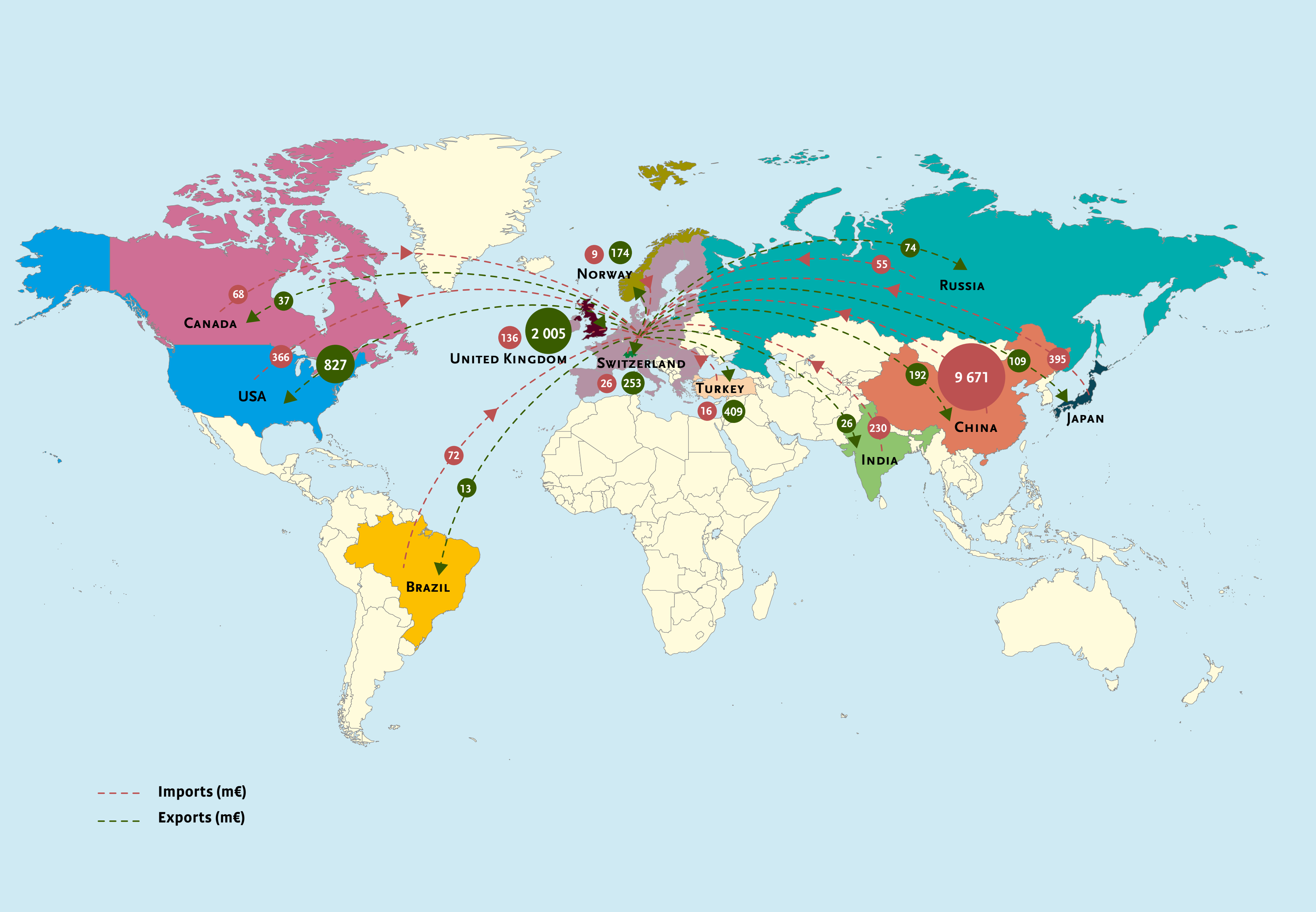
Source: EurObserv'ER

ning 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 Brazil, China, the Netherlands, and Japan 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 2020.

Both the total RET import and RET export values for the EU-27 increased in 2021 compared to 2020. The imports increased more than the exports, leading to a significantly larger negative trade balance in RET in 2021 for the EU-27. The most significant relative increases in imports can be observed for the Netherlands (€1 122 million), Greece (€887 million) and Italy (€616 million). The imports in Belgium decreased most of all the EU-27 (€285 million). A few countries also show a large relative increase in imports, most notably Germany, Spain, Poland and France. On the other hand, exports increased significantly in Germany (€416 million) and modestly in the Netherlands (€208 million), and Greece (€134 million). Large relative increases in exports can be seen in Hungary, Portugal, Belgium and Czechia, although the export volumes of these member states remain limited to up to €100 million. Net exports declined significantly in the Netherlands, due to a decrease in wind energy exports. Belgium went from a negative trade balance in 2020 to a positive one in 2021.

When looking at the main trading partners we see a large increase in imports in India (€2 180 million) and China (€1 886 million) in 2021 compared to 2020. Large decreases in imports can be seen for U.S. (€1 663 million), Turkey (€166 million), Japan (€148 million) and Norway (€71 million). For exports we see the largest shift in China (€7 517 million increase), followed by more modest shifts in the U.S. (€364 million increase) and Japan (€122 million decrease). The trade balances follow these trends, with India showing

EU-27 trade with its main trading partners. 2021 - all RES



Source: EurObserv'ER

the largest increase in the negative trade balance. Brazil also has a larger negative trade balance in 2021 compared to 2020. The U.S., Turkey, Norway and Russia still have a negative trade balance, but have improved their positions between 2020 and 2021.
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 2021 with 38%. For the EU-27, we see a decrease in export shares from 23% in 2020 to 21% in 2021.

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 increased by more than €3 billion in 2021 compared to 2020. The EU-27 also has a negative RET trade balance with Japan, India, Brazil and Canada in 2021. On the other hand the EU-27 has a significant positive RET trade balance with the U.S., the U.K., Turkey, Switzerland and Norway. The trade balance with Russia has significantly decreased by around €100 million from 2020 to 2021, although it remained positive. ■

WIND ENERGY

EU-27 trade (incl. intra-EU trade). 2020- wind energy

	Imports (in € m)	Exports (in € m)	Net exports (in € m)	Share of global exports	Exports specialisation (RCA)
Germany	77	2 116	2 039	30%	51
Denmark	170	1 851	1 681	26.3%	92
Netherlands	449	972	524	13.8%	56
Spain	113	582	469	8.3%	57
Estonia	0	13	13	0.2%	26
Portugal	6	12	6	0.2%	-31
Czechia	0	1	1	0.0%	-96
Latvia	0	0	0	0.0%	-92
Hungary	0	0	0	0.0%	-99
Slovakia	0	0	0	0.0%	-100
Austria	1	1	0	0.0%	-97
Malta	0	0	0	0.0%	-97
Slovenia	0	-	(0)	0.0%	0
Cyprus	0	-	(0)	0.0%	0
Luxembourg	0	-	(0)	0.0%	0
Romania	2	1	(0)	0.0%	-87
Bulgaria	1	0	(1)	0.0%	-100
Lithuania	6	5	(1)	0.1%	-39
Ireland	21	0	(20)	0.0%	-99
Italy	23	1	(22)	0.0%	-98
Finland	27	0	(27)	0.0%	-100
Croatia	107	0	(107)	0.0%	-99
France	124	2	(122)	0.0%	-97
Sweden	182	7	(175)	0.1%	-75
Greece	194	18	(176)	0.3%	10
Poland	195	7	(188)	0.1%	-83
Belgium	308	2	(306)	0.0%	-95
Total EU-27	2 004	5 591	3 587	80.0%	39

Main EU partners' trade with the rest of the world (including EU-27). 2020 - wind energy

	Imports (in € m)	Exports (in € m)	Net exports (in € m)	Share of global exports	Exports specialisation (RCA)
China	3	972	969	13.8%	-4
India	1	171	170	2.43%	17
Brazil	8	172	163	2.44%	29
Japan	92	91	-1	1.3%	-43
Switzerland	7	0	-7	0.0%	-100
Russia	146	0	-146	0.0%	-100
Canada	206	1	-204	0.0%	-97
Norway	246	0	-246	0.0%	-100
USA	418	20	-398	0.3%	-90
United Kingdom	445	1	-444	0.0%	-98
Turkey	606	4	-602	0.1%	-86
Rest of the world	2 685	5	-3 062	0.1%	-99

Source: EurObserv'ER

In wind power, Germany (30%) and Denmark (26%) are the major players in terms of export shares. They are followed by the Netherlands, which also shows large export shares in wind energy of nearly 14%. Spain is another large player with 8% of the global export share. Almost 80% of worldwide exports in wind technologies originate from these four countries. Chinese export shares have increased from 7.5% in 2017 to 13.8% in 2020, showing an increasingly large role for China in global wind energy exports. Brazil follows at quite some distance with 2.4% of the global wind energy export share.

Similar patterns can also be observed for the trade balance. Here, the largest values can be found for Germany, followed by Denmark, China, the Netherlands and Spain. In terms of export specialisation (RCA), Denmark is the most highly specialised in trade of wind technology related goods. Germany, Spain and the Netherlands are also highly specialised in wind technology exports. China's export specialisation in wind technology increased from -52 in 2017 to -4 in 2020, again showcasing the rapidly changing position of China in the global trade of wind technology goods.

EU-27 trade (incl. intra-EU trade). 2021 - wind energy

	Imports (in € m)	Exports (in € m)	Net exports (in € m)	Share of global exports	Exports specialisation (RCA)
Germany	86	2 080	1 994	34.3%	57
Denmark	165	1 644	1 479	27.1%	93
Spain	58	499	442	8.2%	57
Portugal	12	34	22	0.6%	21
Estonia	0	7	7	0.1%	7
Lithuania	25	28	3	0.5%	37
Latvia	0	1	1	0.0%	-53
Czechia	0	1	1	0.0%	-95
Slovakia	0	1	0	0.0%	-94
Cyprus	0	-	0	0.0%	0
Luxembourg	0	-	0	0.0%	0
Malta	0	-	0	0.0%	0
Slovenia	0	0	0	0.0%	-99
Hungary	0	0	0	0.0%	-100
Romania	0	0	0	0.0%	-99
Bulgaria	1	0	-1	0.0%	-98
Ireland	3	2	-1	0.0%	-91
Austria	13	0	-12	0.0%	-97
Belgium	24	1	-22	0.0%	-96
Netherlands	49	23	-26	0.4%	-73
Croatia	36	0	-36	0.0%	-98
Finland	108	4	-104	0.1%	-67
France	107	0	-107	0.0%	-99
Italy	129	1	-127	0.0%	-97
Poland	190	4	-186	0.1%	-88
Sweden	210	1	-208	0.0%	-93
Greece	273	54	-219	0.9%	30
Total EU-27	1 489	4 387	2 898	72%	37

Main EU partners' trade with the rest of the world (including EU-27). 2021 - wind energy

	Imports (in € m)	Exports (in € m)	Net exports (in € m)	Share of global exports	Exports specialisation (RCA)
China	4	1 215	1 212	20.0%	11
India	1	247	246	4.1%	33
Switzerland	0	0	0	0.0%	-100
Canada	62	1	-61	0.0%	-97
Japan	68	1	-67	0.0%	-99
Russia	87	0	-87	0.0%	-99
USA	160	13	-148	0.2%	-92
Brazil	275	98	-177	1.6%	9
Norway	180	0	-180	0.0%	-99
Turkey	416	1	-415	0.0%	-94
United Kingdom	1 662	99	-1 563	1.6%	-13
Rest of the world	4 379	5	-5 174	0.1%	-99

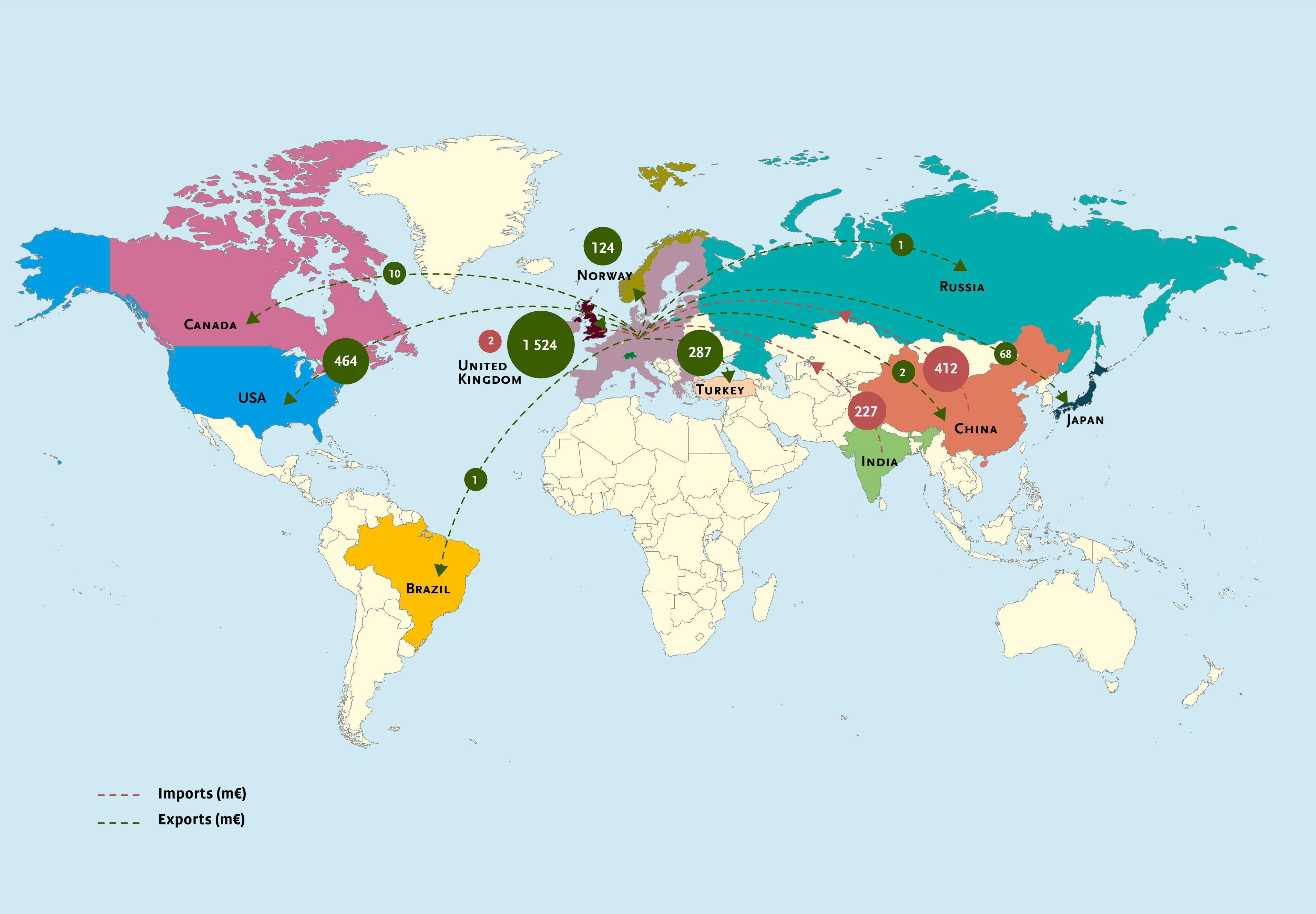
Source: EurObserv'ER

In 2021, Germany (34%) and Denmark (27%) remain major players in terms of export shares, despite the decrease in exports from Denmark compared to 2020. The Netherlands has significantly decreased its exports by almost €400 million, leading to an export share lower than 1%. Spain maintained an export share of 8%. In total, the net exports of the EU-27 decreased in 2021. Even with the decreased exports from Denmark and the Netherlands, more than 70% of worldwide exports in wind technologies originate from the EU-27. Chinese export shares have increased to 20% in 2021, continuing the growth of the role China has in global wind energy exports. Exports from Brazil and Japan decreased significantly in 2021, while exports from India and U.K. increased to modest shares of the global exports.

In 2021, neither Germany nor Denmark reached the €2 billion mark of positive trade balance. China followed at €1.2 billion in net exports. The Netherlands went from positive to negative net exports, while Spain kept its net exports above €400 million in 2021.

Denmark remains the most specialised wind energy exporter, followed by Germany and Spain. China's export specialisation in wind technology became positive (11) in 2021. In 2021 we also observe a positive RCA in wind energy for both Brazil and India.

EU-27 trade with its main trading partners. 2021 - 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 Russia and Brazil decreased significantly to around €1 million.
The EU was a net importer from China and India in 2021. Net imports from China and India increased by about €150 million and €200 million compared to 2020, respectively. ■

PHOTOVOLTAIC

EU-27 trade (incl. intra-EU trade). 2020 - photovoltaic

	Imports (in € m)	Exports (in € m)	Net exports (in € m)	Share of global exports	Exports specialisation (RCA)
Croatia	38	41	3	0.1%	-9
Luxembourg	46	42	-4	0.1%	2
Malta	4	0	-4	0.0%	-98
Latvia	5	1	-4	0.0%	-96
Ireland	26	17	-9	0.0%	-91
Slovenia	100	88	-11	0.2%	-10
Cyprus	18	0	-18	0.0%	-92
Slovakia	38	15	-22	0.0%	-84
Italy	412	371	-41	0.7%	-54
Lithuania	60	12	-48	0.0%	-73
Finland	56	7	-49	0.0%	-90
Bulgaria	55	6	-50	0.0%	-85
Czechia	148	72	-76	0.1%	-72
Estonia	79	3	-76	0.0%	-83
Denmark	110	29	-81	0.1%	-78
Sweden	133	36	-97	0.1%	-81
Romania	127	4	-123	0.0%	-94
Portugal	344	211	-133	0.4%	6
France	768	615	-153	1.2%	-36
Austria	296	104	-192	0.2%	-58
Greece	218	17	-201	0.0%	-66
Hungary	256	44	-211	0.1%	-72
Belgium	380	140	-240	0.3%	-67
Germany	2 733	2 124	-610	4.2%	-28
Poland	674	33	-640	0.1%	-88
Netherlands	2 069	1 304	-765	2.6%	-10
Spain	1 015	167	-848	0.3%	-63
Total EU-27	10 210	5 505	-4705	11%	-42

Main EU partners' trade with the rest of the world (including EU-27). 2020 - photovoltaic

	Imports (in € m)	Exports (in € m)	Net exports (in € m)	Share of global exports	Exports specialisation (RCA)
China	6 343	20 869	14526	40.9%	40
Japan	2 790	3 014	224	5.9%	19
Norway	27	2	-26	0.0%	-98
Switzerland	231	147	-84	0.3%	-67
Canada	358	201	-157	0.4%	-64
Turkey	315	146	-168	0.3%	-49
United Kingdom	315	142	-173	0.3%	-73
Russia	246	50	-196	0.1%	-86
Brazil	1 024	2	-1022	0.0%	-99
India	1 343	100	-1243	0.2%	-73
USA	9 165	2 004	-7161	3.9%	-32
Rest of the world	18 630	18 842	243	36.9%	9

Source: EurObserv'ER

In photovoltaics, China remains the largest player with almost 41% of global exports. It is followed at quite some distance by Japan (6%), Germany (4%) and the U.S. (4%). In total, the EU-27 reach a 11% share in 2020. The share of the «rest of the world» category is also very high (37% in 2020), showing that there are large exporters not included in the above list.

Regarding net exports in PV, only China has a significant positive balance. Croatia and Japan also have a positive trade balance in 2020. 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 the EU-27, India and Brazil, 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 Japan. In the EU only Luxembourg and Portugal have a positive RCA.

EU-27 trade (incl. intra-EU trade). 2021 - photovoltaic

	Imports (in € m)	Exports (in € m)	Net exports (in € m)	Share of global exports	Exports specialisation (RCA)
Malta	4	0	-4	0.0%	-99
Luxembourg	46	37	-8	0.1%	-10
Latvia	12	2	-10	0.0%	-91
Croatia	46	35	-11	0.1%	-25
Ireland	33	15	-19	0.0%	-92
Cyprus	23	0	-23	0.0%	-98
Estonia	31	3	-28	0.0%	-86
Slovenia	79	39	-40	0.1%	-50
Slovakia	72	15	-57	0.0%	-86
Finland	65	8	-57	0.0%	-90
Lithuania	80	17	-64	0.0%	-69
Denmark	149	39	-110	0.1%	-75
Sweden	173	42	-130	0.1%	-81
Bulgaria	147	7	-140	0.0%	-85
Czechia	249	104	-145	0.2%	-67
Romania	162	5	-157	0.0%	-94
Belgium	370	150	-220	0.2%	-70
Portugal	490	270	-220	0.4%	9
Hungary	308	55	-252	0.1%	-70
France	978	700	-278	1.1%	-37
Austria	514	140	-374	0.2%	-55
Italy	935	344	-591	0.5%	-62
Greece	878	115	-762	0.2%	-36
Germany	3 376	2 593	-783	4.1%	-26
Poland	1 125	62	-1063	0.1%	-83
Netherlands	3 375	2 250	-1125	3.6%	5
Spain	1 511	141	-1370	0.2%	-72
Total EU-27	**15 231**	**7 189**	**-8042**	**11%**	**-39**

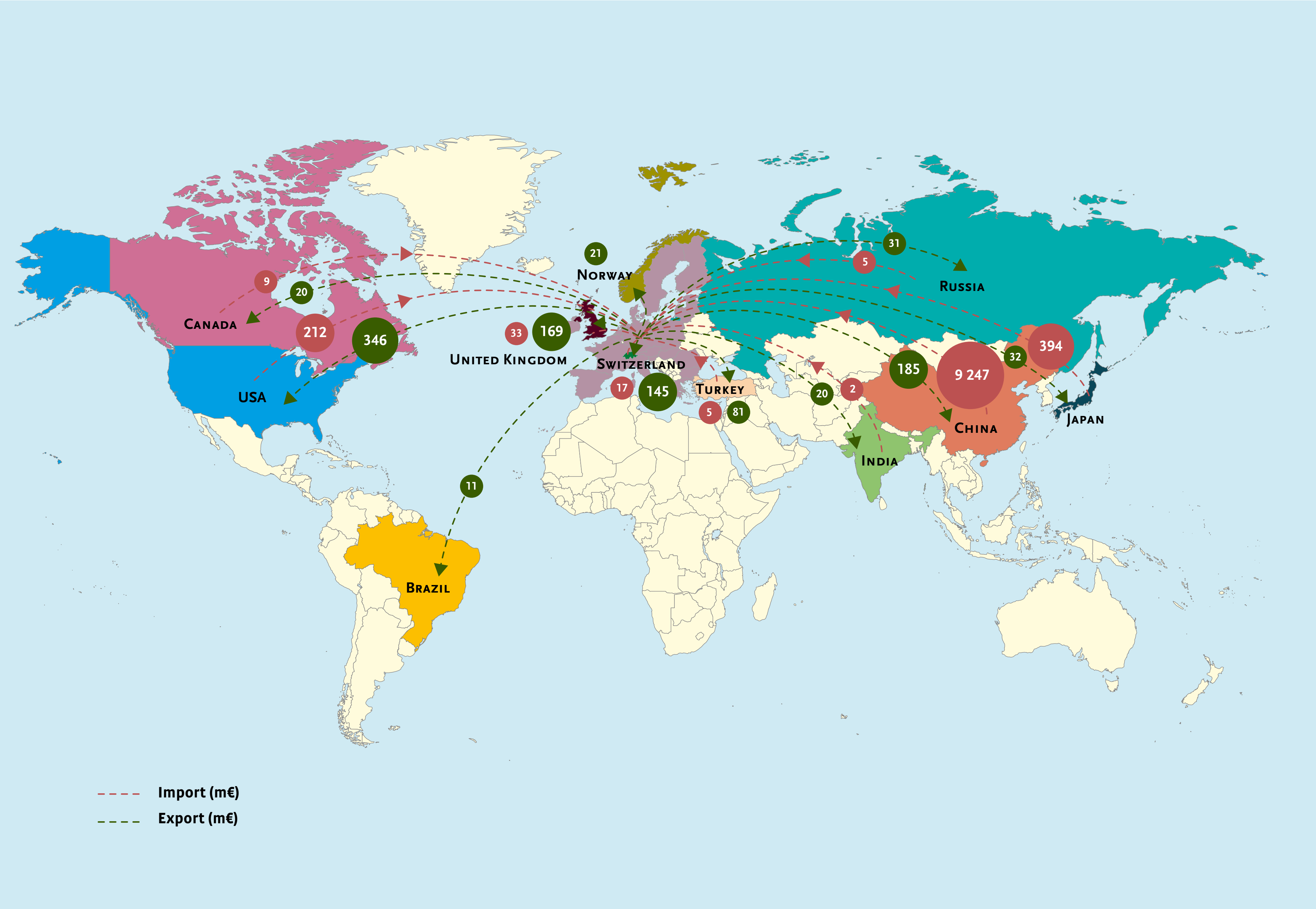
Main EU partners' trade with the rest of the world (including EU-27). 2021 - photovoltaic

	Imports (in € m)	Exports (in € m)	Net exports (in € m)	Share of global exports	Exports specialisation (RCA)
China	7 893	28 347	20454	45,3%	43
Japan	2 674	3 230	556	5,2%	16
Norway	41	2	-39	0,0%	-98
Switzerland	303	175	-129	0,3%	-66
Russia	237	43	-194	0,1%	-91
Canada	441	174	-266	0,3%	-73
Turkey	435	108	-328	0,2%	-66
United Kingdom	478	134	-344	0,2%	-77
Brazil	2 304	3	-2301	0,0%	-99
India	3 524	139	-3384	0,2%	-72
USA	8 080	2 076	-6005	3,3%	-37
Rest of the world	20 057	20 906	1004	33,4%	6

Source: EurObserv'ER

The top position of China can be confirmed again in 2021, with 45% of worldwide exports in PV originating from China. They are once more followed by Japan (5%), Germany (4%) and the Netherlands (4%). The EU-27 kept its share of exports at 11% in 2021. Regarding net exports in PV, China remains at a significant positive value. Japan is the only other country with a positive trade balance. In the EU all countries in this comparison have a negative trade balance. The U.S. decreased net imports by over €1 billion. Net imports increased significantly for the EU-27 and in many countries, such as Brazil and India. China remains the most highly specialised in goods related to PV, followed by Japan. Portugal retains its positive RCA, while the Netherlands increased its RCA to 5.

EU-27 trade with its main trading partners. 2021 - 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 increased by about €3 212 million compared to 2020. The EU also has a negative trade balance in PV with Japan. 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 the U.S., the U.K., Switzerland and Turkey. ■

EUROBSERV'ER – THE STATE OF RENEWABLE ENERGIES IN EUROPE – 2022 EDITION

BIOFUELS

EU-27 trade (incl. intra-EU trade). 2020 - biofuels

	Imports (in € m)	Exports (in € m)	Net exports (in € m)	Share of global exports	Exports specialisation (RCA)
Hungary	17	388	372	4.4%	66
France	332	605	274	6.9%	36
Belgium	157	379	223	4.3%	37
Netherlands	1 020	1 158	138	13.2%	54
Spain	134	231	97	2.6%	15
Slovakia	10	61	51	0.7%	13
Austria	51	99	48	1.1%	7
Bulgaria	15	61	45	0.7%	51
Estonia	32	34	2	0.4%	53
Malta	0	0	0	0.0%	-95
Luxembourg	3	0	-3	0.0%	-97
Poland	166	163	-3	1.9%	9
Cyprus	3	-	-3	0.0%	0
Slovenia	8	2	-6	0.0%	-80
Latvia	15	5	-11	0.1%	-22
Croatia	13	2	-11	0.0%	-55
Lithuania	43	27	-16	0.3%	20
Portugal	31	3	-27	0.0%	-75
Ireland	37	1	-37	0.0%	-97
Finland	43	-	-43	0.0%	0
Czechia	72	24	-48	0.3%	-55
Greece	77	1	-76	0.0%	-91
Sweden	248	166	-81	1.9%	31
Romania	117	1	-116	0.0%	-95
Denmark	143	11	-132	0.1%	-60
Italy	216	48	-168	0.5%	-62
Germany	927	363	-564	4.1%	-29
Total EU-27	3 929	3 833	-96	44%	15

Main EU partners' trade with the rest of the world (including EU-27). 2020 - biofuels

	Imports (in € m)	Exports (in € m)	Net exports (in € m)	Share of global exports	Exports specialisation (RCA)
USA	683	2 121	1438	24.1%	43
Brazil	401	1 043	642	11.8%	75
China	31	220	189	2.5%	-66
Russia	1	55	54	0.6%	-46
Norway	35	-	-35	0.0%	0
Switzerland	106	6	-100	0.1%	-89
India	269	95	-174	1.1%	-18
Turkey	182	5	-177	0.1%	-86
United Kingdom	376	134	-242	1.5%	-18
Canada	513	150	-364	1.7%	-13
Japan	468	1	-467	0.0%	-99
Rest of the world	1 787	1 143	-645	13.0%	-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. Around 80% of worldwide exports in biofuels originate from these three regions (2020 as well as 2021). 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. implies that the U.S. is exporting far more biofuels than they import. The next largest net export values can be observed for Brazil, Hungary, France and Belgium. The most negative trade balance becomes visible for Germany, Japan, Canada and the U.K., 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, Estonia, and Bulgaria.

EU-27 trade (incl. intra-EU trade). 2021 - biofuels

	Imports (in € m)	Exports (in € m)	Net exports (in € m)	Share of global exports	Exports specia-lisation (RCA)
Hungary	14	462	448	5.1%	71
Belgium	166	441	275	4.8%	41
Spain	107	256	149	2.8%	19
Netherlands	1 235	1 368	133	15.0%	58
France	460	578	118	6.3%	35
Austria	53	121	68	1.3%	15
Poland	103	160	56	1.8%	7
Slovakia	13	59	46	0.6%	12
Bulgaria	8	53	45	0.6%	45
Malta	0	0	0	0.0%	-81
Cyprus	1	0	-1	0.0%	-96
Luxembourg	3	0	-2	0.0%	-95
Estonia	4	0	-4	0.0%	-91
Slovenia	6	1	-6	0.0%	-92
Latvia	12	4	-8	0.0%	-27
Lithuania	54	45	-10	0.5%	39
Croatia	10	0	-10	0.0%	-91
Portugal	22	4	-18	0.0%	-70
Czechia	97	51	-46	0.6%	-27
Finland	50	-	-50	0.0%	0
Ireland	52	2	-51	0.0%	-94
Italy	195	68	-127	0.7%	-53
Romania	131	0	-131	0.0%	-99
Denmark	150	5	-146	0.0%	-79
Sweden	323	165	-158	1.8%	30
Greece	221	0	-221	0.0%	-98
Germany	826	347	-479	3.8%	-29
Total EU-27	**4 318**	**4 190**	**-128**	**46%**	**19**

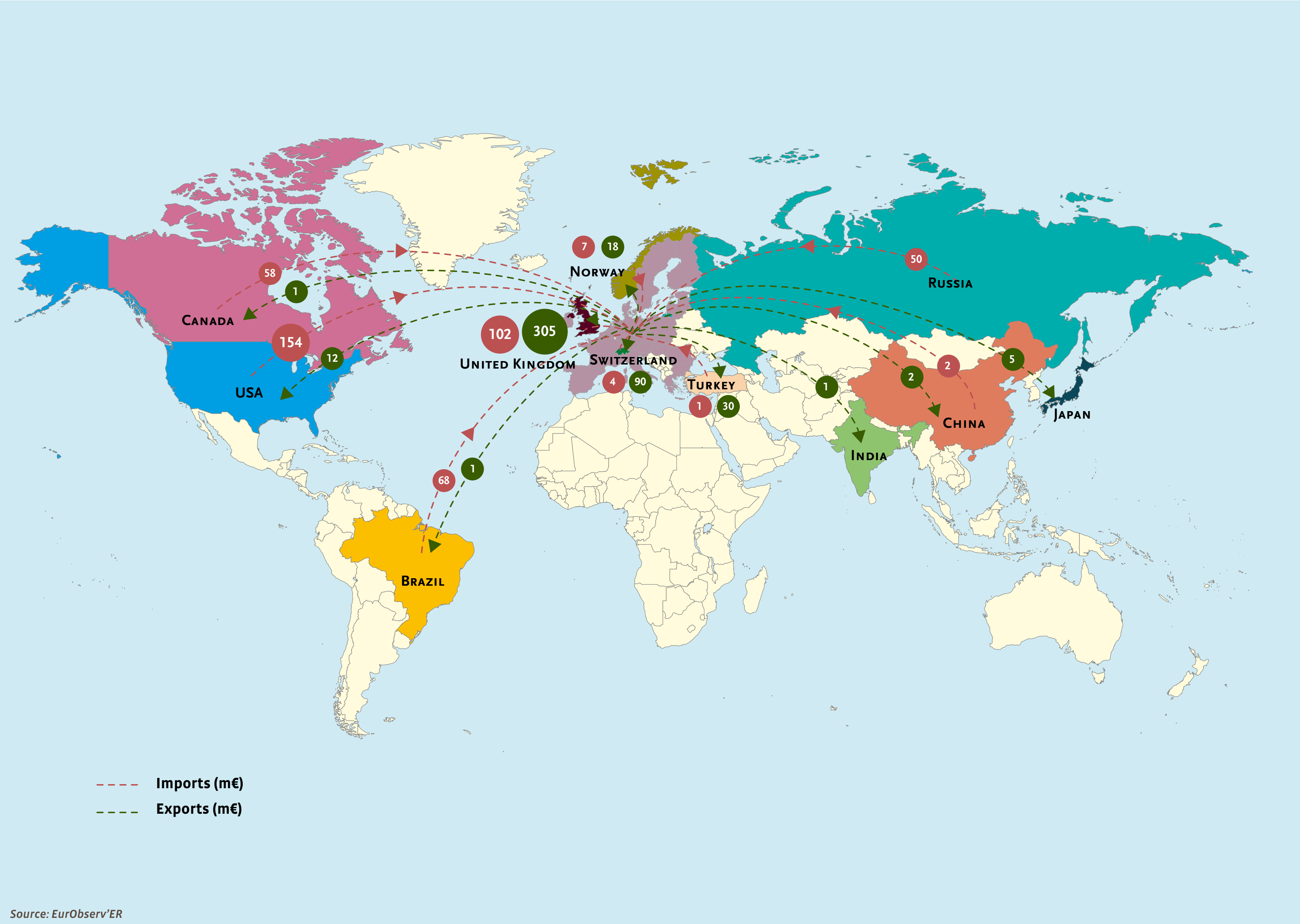
Main EU partners' trade with the rest of the world (including EU-27). 2021 - biofuels

	Imports (in € m)	Exports (in € m)	Net exports (in € m)	Share of global exports	Exports specia-lisation (RCA)
USA	378	2 421	2043	26.6%	47
Brazil	204	897	693	9.9%	71
Russia	0	48	48	0.5%	-56
Norway	27	0	-27	0.0%	-100
Turkey	100	10	-90	0.1%	-75
Switzerland	107	5	-101	0.1%	-90
India	267	56	-212	0.6%	-44
China	363	17	-346	0.2%	-96
United Kingdom	494	111	-384	1.2%	-25
Japan	460	1	-459	0.0%	-99
Canada	837	170	-666	1.9%	-10
Rest of the world	1 739	1 181	-558	13.0%	-34

Source: EurObserv'ER

In 2021, both imports and exports of biofuels increased in the EU, yet net imports increased to €128 million. The share of global exports increased from 44% in 2020 to 46% in 2021. The U.S., the Netherlands and Brazil remain the largest biofuel exporters. Brazil's net exports increased to €700 million, compared to around €650 million in 2020. Brazil remains the most specialised in biofuels trade.

EU-27 trade with its main trading partners. 2021 - biofuels



Source: EurObserv'ER

In 2021 the EU was a net importer of biofuels from the U.S., Brazil and Russia. Net imports increased from U.S. and Brazil when compared to 2020. Of the biofuels exported by the EU, the largest amounts go to the U.K., Switzerland, and Turkey. The EU also has a positive trade balance with the U.K., Switzerland and Turkey. ■

HYDROELECTRICITY

EU-27 trade (incl. intra-EU trade). 2020 - hydroelectricity

	Imports (in € m)	Exports (in € m)	Net exports (in € m)	Share of global exports	Exports specialisation (RCA)
Austria	36	106	70	11.9%	82
Germany	12	61	50	6.9%	-2
Italy	7	50	43	5.6%	33
Czechia	6	41	35	4.6%	58
Slovenia	6	24	18	2.7%	82
Spain	4	16	12	1.8%	6
France	19	30	11	3.3%	12
Bulgaria	2	10	8	1.1%	68
Poland	0	8	8	0.9%	-17
Netherlands	0	2	2	0.3%	-77
Croatia	0	2	2	0.2%	39
Hungary	0	2	1	0.2%	-50
Denmark	0	0	0	0.1%	-77
Belgium	0	0	0	0.1%	-89
Estonia	0	-	0	0.0%	0
Malta	0	0	0	0.0%	-100
Lithuania	1	1	0	0.1%	-43
Cyprus	0	-	0	0.0%	0
Slovakia	0	0	0	0.0%	-98
Finland	3	3	0	0.3%	-1
Ireland	0	0	0	0.0%	-100
Luxembourg	1	0	0	0.0%	-40
Portugal	5	2	-2	0.3%	-6
Greece	3	0	-3	0.0%	-90
Sweden	7	3	-3	0.4%	-31
Romania	5	1	-4	0.1%	-50
Latvia	6	0	-6	0.0%	-97
Total EU-27	124	364	241	41%	18

Main EU partners' trade with the rest of the world (including EU-27). 2020 - hydroelectricity

	Imports (in € m)	Exports (in € m)	Net exports (in € m)	Share of global exports	Exports specialisation (RCA)
China	2	166	164	18.6%	14
India	5	54	50	6.1%	56
Brazil	2	40	38	4.5%	55
Switzerland	16	41	25	4.6%	42
United Kingdom	11	7	-3	0.8%	-37
USA	39	34	-5	3.8%	-28
Canada	20	13	-8	1.4%	-15
Japan	13	4	-8	0.5%	-68
Turkey	23	9	-13	1.1%	8
Norway	25	2	-22	0.3%	-19
Russia	68	8	-61	0.8%	-30
Rest of the world	405	37	-368	4.2%	-66

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 (12%), Germany (7%), Italy (6%), Czechia (5%), France (3%) and Slovenia (3%). In sum, the EU-27 is responsible for more than 40% of the worldwide exports within hydropower. As a single country, China also shows a large value of 19%. China is followed by India and Switzerland, at 6.1% and 4.6% respectively. The largest positive net export values within the EU-27 are displayed for Austria, Germany, Italy, Czechia, Slovenia, Spain, and France. Yet, the largest value globally can be found for China. The U.S. display a negative trade balance. The specialisation values in hydroelectricity show a rather positive picture for Europe, with eight EU-27 members having a positive RCA value. Austria and Slovenia are most highly specialised in the export of hydropower goods. China also shows positive RCA values, but its specialisation in PV is still higher than it is in hydroelectricity.

EU-27 trade (incl. intra-EU trade). 2021 - hydroelectricity

	Imports (in € m)	Exports (in € m)	Net exports (in € m)	Share of global exports	Exports specialisation (RCA)
Austria	33	98	65	10.8%	81
Germany	12	60	49	6.6%	1
Czechia	4	44	39	4.8%	62
Italy	16	51	35	5.7%	35
Slovenia	8	34	27	3.8%	87
Spain	6	25	18	2.7%	24
France	15	27	12	3.0%	12
Bulgaria	2	5	4	0.6%	50
Netherlands	1	4	3	0.4%	-68
Hungary	0	3	3	0.4%	-19
Poland	1	3	3	0.4%	-47
Croatia	0	2	1	0.2%	37
Denmark	0	0	0	0.1%	-75
Lithuania	0	0	0	0.0%	-66
Estonia	0	-	0	0.0%	0
Malta	0	-	0	0.0%	0
Cyprus	0	-	0	0.0%	0
Romania	1	1	0	0.1%	-52
Belgium	1	0	0	0.0%	-95
Ireland	0	0	0	0.0%	-97
Slovakia	1	0	-1	0.0%	-95
Portugal	4	3	-2	0.3%	-1
Finland	4	2	-2	0.2%	-26
Luxembourg	2	0	-2	0.0%	-78
Latvia	3	-	-3	0.0%	0
Sweden	6	2	-4	0.2%	-49
Greece	7	0	-6	0.0%	-74
Total EU-27	127	366	239	40%	20

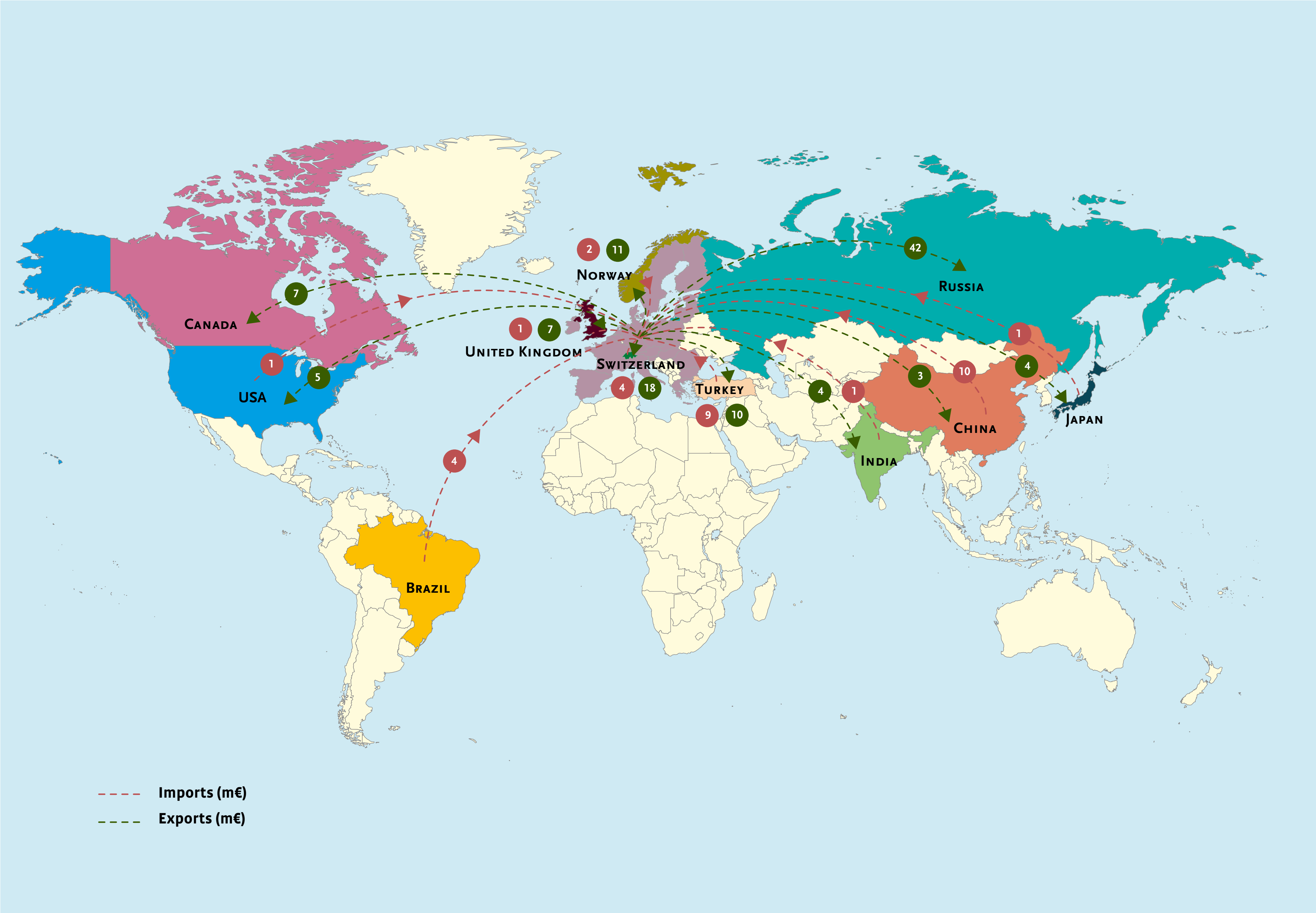
Main EU partners' trade with the rest of the world (including EU-27). 2021 - hydroelectricity

	Imports (in € m)	Exports (in € m)	Net exports (in € m)	Share of global exports	Exports specialisation (RCA)
China	5	165	160	18.2%	14
Brazil	4	60	56	6.6%	65
India	5	33	28	3.7%	36
USA	23	34	11	3.7%	-26
Turkey	6	13	7	1.4%	21
United Kingdom	10	16	6	1.8%	-1
Norway	15	5	-11	0.5%	-7
Japan	14	1	-13	0.1%	-90
Switzerland	19	5	-14	0.6%	-40
Canada	46	9	-37	1.0%	-29
Russia	71	22	-50	2.4%	9
Rest of the world	439	38	-401	4.2%	-64

Source: EurObserv'ER

In 2021, net exports of hydropower goods in the EU-27 slightly decreased compared to 2020. The export share of the EU decreased to 40% of global exports. The largest decrease in exports is observed for Austria. China's exports also decreased, as did its share of global exports. Brazil and Russia, on the other hand increased their export and export shares. Brazil especially shows a relatively large share of exports, surpassing even Switzerland. 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: Austria and Spain. Switzerland went from a positive RCA in 2020 to a negative one in 2021.

EU-27 trade with its main trading partners. 2021 - 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 Russia, Norway, Switzerland, and the U.K. Negative trade balances for hydropower are observed with China and Brazil. ■

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, wind energy 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 (11%) compared to China's share (45%).

In wind energy, especially Germany and Denmark, but also Spain can be seen as strong competitive countries, with large roles in the worldwide export markets. These three countries in sum generate a worldwide export share higher than 70%. The role of China in wind energy technology exports has been growing steadily in recent years, with a world export share that reached 20% in 2021, ranking third in net exports behind Germany and Denmark.

The EU is a large player in the biofuels market, with a 46% share in global exports. The U.S. and Brazil are responsible for another 36% of global exports, showing the large role of these countries and the EU. In the EU, the Netherlands and France are the largest exporters. They are followed by Hungary, Belgium and Germany. Germany, however, imports much more biofuels than they export and therefore has a negative trade balance. The other four EU countries have a positive trade balance.

In hydroelectricity, the picture is very balanced. Several European countries are active on worldwide export markets, while also China is responsible for comparably large shares. The EU's share in global exports is fairly constant in recent years at just over 40%.

Overall, the EU displays a strong competitiveness in all RET fields, and seems at least keeping its shares at a high level in 2021. The U.S. 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.S., the U.K., Turkey, Switzerland, Norway and Russia. ■

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- EBB – European Biodiesel Board *(www.ebb-eu.org)*
- EGEC – European Geothermal Energy Council *(www.egec.org)*
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BELGIUM

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BULGARIA

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CYPRUS

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- MCIT – Ministry of Commerce, Industry and Tourism *(meci.gov.cy/gr/)*
- CERA – Cyprus Energy Regulatory Authority *(www.cera.org.cy)*

CROATIA

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- HROTE – Croatian Energy Market Operator *(www.hrote.hr)*

CZECHIA

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DENMARK

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ESTONIA

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- STAT EE – Statistics Estonia *(www.stat.ee)*

FINLAND

- Statistics Finland *(www.stat.fi)*
- SULPU – Finnish Heat Pump Association *(www.sulpu.fi)*

FRANCE

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- AFPG – Geothermal French Association *(www.afpg.asso.fr)*
- DGEC – Energy and Climat Department *(https://www.ecologique-solidaire.gouv.fr)*
- Enerplan – Solar Energy organization *(www.enerplan.asso.fr)*
- FEE – French Wind Energy Association *(www.fee.asso.fr)*
- Observ'ER – French Renewable Energy Observatory *(www.energies-renouvelables.org)*
- OFATE – Office franco-allemand pour la transition énergétique *(enr-ee.com/fr/qui-sommes-nous.html)*
- SVDU – National Union of Treatment and Recovery of Urban and Assimilated Waste *(http://wwwfedene.fr/les-syndicats/svdu/)*
- SER – French Renewable Energy Organisation *(https:www.syndicat-energies-renouvelables.fr/en/home-page/)*
- SDES – Observation and Statistics Office – Ministry of Ecological Transition *(https://www.ecologie.goouv.fr/)*
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GERMANY

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- AGEE-Stat – Working Group on Renewable Energy Statistics *(www.erneuerbare-energien.de)*
- AGORA Energiewende – Energy Transition Think Tank *(www.agora-energiewende.de)*
- BAFA – Federal Office of Economics and Export Control *(www.bafa.de)*
- BDEW – Bundesverband der Energie und Wasserwirtschaft e.V *(www.bdew.de)*
- BMWi – Federal Ministry for Economics Affairs and Climate Action *(www.bmwi.de)*
- BWE – German Wind Energy Association - Bundesverband Windenergie *(www.wind-energie.de)*
- BSW-Solar – German Solar Industry Association - Bundesverband Solarwirtschaft *(www.solarwirtschaft.de)*
- BWP – German Heat Pump Association – Bundesverband Wärmepumpe *(www.waermepumpe.de)*
- Federal Network Agency – Bundesnetzagentur *(www.bundesnetzagentur.de)*
- Dena – German Energy Agency – Deutsche Energieagentur *(www.dena.de)*
- Biogas Association – Fachverband Biogas *(www.biogas.org)*
- Fraunhofer-ISE – Institut for Solar Energy System *(www.ise.fraunhofer.de/)*
- GtV – Geothermal Association - Bundesverband Geothermie *(www.geothermie.de)*
- UBA – Environment Agency – Umweltbundesamt *(www.umweltbundesamt.de)*

GREECE
- CRES – Center for Renewable Energy Sources and Saving *(www.cres.gr)*
- DEDDIE – Hellenic Electricity Distribution Network Operator S.A. *(www.deddie.gr)*
- EBHE – Greek Solar Industry Association *(www.ebhe.gr)*
- HELAPCO – Hellenic Association of Photovoltaic Companies *(www.helapco.gr)*
- HWEA – Hellenic Wind Energy Association *(www.eletaen.gr)*
- Ministry of Environment and Energy and Climate Change *(https://ypen.gov.gr/)*

IRELAND
- EIRGRID *(www.eirgridgroup.com/)*
- IWEA – Irish Wind Energy Association *(www.iwea.com)*
- REIO – Renewable Energy Information Office *(www.seai.ie/Renewables/REIO)*
- SEAI – Sustainable Energy Authority of Ireland *(www.seai.ie)*

ITALY
- Assotermica -Associazione produttori apparecchi e componenti per impianti termici *(https://www.anima.it/associazioni/elenco/assotermica/)*
- ENEA – Italian National Agency for New Technologies *(www.enea.it)*
- GSE – Gestore servizi energetici *(www.gse.it)*
- Terna – Electricity Transmission Grid Operator *(www.terna.it)*

LATVIA
- CSB – Central Statistical Bureau of Latvia *(www.csb.gov.lv)*

LITHUANIA
- LS – Statistics Lithuania *(www.stat.gov.lt)*

LUXEMBOURG
- NSI Luxembourg – Service central de la statistique et des études économiques
- STATEC – Institut national de la statistique et des études économiques *(www.statec.public.lu)*
- Le portail des statistiques (STATEC) *(https://statistiques.public.lu/fr/index.html)*

MALTA
- MRA – Malta Resources Authority *(www.mra.org.mt)*
- NSO – National Statistics Office *(www.nso.gov.mt)*

NETHERLANDS
- Netherlands Enterprise Agency *(RVO) (www.rvo.nl)*
- CBS – Statistics Netherlands *(www.cbs.nl)*
- ECN – Energy Research Centre of the Netherlands *(https://www.tno.nl/en/)*

POLAND
- URE / EROURE – Energy Regulatory Office of Poland *(htpp://www.ure.gov.pl)*
- GUS – Central Statistical Office *(www.stat.gov.pl)*
- Ministry of Energy, Renewable and Distributed Energy Department *(https://www.gov.pl/web/aktywa-panstwowe)*
- National Fund for Environmental Protection and Water Management *(https://www.gov.pl/web/nfosigw/)*
- SPIUG – Polish heating organisation *(www.spiug.pl/)*

PORTUGAL
- DGEG – Direcção geral de energia e geologia *(https://www.dgeg.gov.pt/)*

ROMANIA
- INS – National Institute of Statistics *(https://alba.insse.ro/)*
- Romanian Wind Energy Association *(www.rwea.ro)*

SPAIN
- AEE – Spanish Wind Energy Association *(www.aeeolica.org)*
- ASIT – Asociación solar de la industria térmica *(www.asit-solar.com)*
- MITECO - Ministry for the Ecological Transition and the Demographical Challenge *(www.miteco.gob.es/es)*

SLOVAKIA
- Ministry of Economy of the Slovak Republic *(www.economy.gov.sk)*

SLOVENIA
- SURS – Statistical Office of the Republic of Slovenia *(www.stat.si)*
- JSI/EEC – The Jozef Stefan Institute – Energy Efficiency Centre *(www.ijs.si/ijsw)*

SWEDEN
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