THE STATE OF RENEWABLE ENERGIES IN EUROPE

EDITION **2023**

22nd EurObserv'ER Report

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

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ENERGY UNION 2.0

Vincent Jacques le Seigneur, president of Observ'ER

As this new edition of the EurObserv'ER[1] barometer demonstrates, Energy Europe, that was so dear to Jacques Delors'[2] heart, is taking shape. Admittedly, the European Coal and Steel Community (ECSC) was the first building block of the Union, and it was followed by the Euratom Treaty that aimed to share the "benefits" of nuclear energy. However, nothing in the Treaty of Rome, that established the European Economic Community in 1957, made explicit reference to the area of energy which remained the preserve of the Member States. It was only fifty years later that the subject was tackled, and that energy became a full-blown policy of the Union in the Treaty of Lisbon.

As this report shows, at the end of 2022, nearly a quarter of final energy consumption was renewable[3], which is a testament to the success of this now resolutely European policy. While indicative national targets were set by the 2001/77 directive for 2010, it is actually the climate-energy package, adopted in 2008 under the French presidency, that set the binding targets in stone – the famous 20% – for energy efficiency, reduction of greenhouse gas emissions and renewable energies. This medium-term outlook encouraged policy makers and also investors, manufacturers and households to turn to these new energy sources. Since then, there has been no looking back.

With climate warnings ringing in our ears, international tensions flared up as Russia invaded Ukraine, triggering a spectacular hike in the price of energy indexed to the gas price. In so doing, it dealt Europe a new jolt and convinced it more than ever before that it should harness all the necessary resources to ensure not only energy transition but our emancipation. Hence, the REPowerEU plan was adopted to *"accelerate the transition to clean energy"*, the Renewable Energy Directive (RED III) was revised to do so and set the target to achieve by 2030 at 42.5% instead of the initial 30%, and the Net zero Industry Act was adopted in response to America's Inflation Reduction Act, so that 40% of the "critical" green technologies would be produced in Europe by 2030…

The roadmap is set, the Member States simply have to implement it. Brussels coordinates, finances but more to the point acts as its custodian. Accordingly, Kadri Simson, the European Commissioner for Energy, has just officially urged France, which last December submitted a National Energy Climate Plan (NECP) to the Commission without setting any quantified targets, to raise its renewable energy target to at least 44% of final consumption by 2030 or risk facing sanctions. The carrot and stick approach. A little of both is needed to move forwards as usual. Frankly, the energy and climate strategy for a carbon neutral Europe by 2050 is a tall order, but we have little choice in the matter and there is no sense in procrastinating. ■

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1. 22nd report on The State of renewable energies in Europe

2. See the recent report by the Jacques Delors Institute "Energy Union 2.0 to deliver the European Green Deal" https://institutdelors.eu

3. 23% of final energy consumption, 41.2% for electricity and 24.8% for heat and cooling

22ND EUROBSERV'ER REPORT MAIN HIGHLIGHTS

Energy indicators

- The renewable share of gross electricity consumption reached 41.2% in 2022. 1 155 TWh of renewable electricity were produced in 2022, with wind power being the most important source (438.8 TWh, i.e. 38.9% of all renewable electricity production). This is followed by hydro (345.3 TWh) and photovoltaics (210.3 TWh). Biomass came fourth with 166.4 TWh.
- 94% of all new electricity capacity connected in 2022 came from renewable sources (50.1 out of a total of 53.5 GW). The remaining 6% came from fossil gas.
- In 2022, the renewable share of heat and cooling consumption was 24.8%. 110.7 Mtoe were produced, of which 72.8% came from solid biofuels in a context of milder winter conditions than the previous year. Heat pumps came second with 6.5 Mtoe.
- Renewable energies covered 23.0% of gross final energy consumption in the EU27 in 2022. The pace must greatly accelerate to reach the new 42.5% target set by RED III by the end of 2030.

Socio-economic indicators

- The total direct and indirect employment from the renewable sectors is estimated at 1.69 million full-time equivalents by 2022. This figure is 15% higher than in 2021. The leading sector was heat pumps with 416 200 full-time equivalents.
- The economic activity around renewable energies in 2021 is estimated at €210 billion (+ 13% compared to 2021). As for jobs, heat pumps are the sector that has generated the highest turnover with €57.4 billion.

Investment indicators

- In 2022, EU MS invested $180 billion in renewable energy technologies, retaining second place behind China and followed by the US. The top EU investing countries were Germany, France, Spain, and Italy, with a notable shift towards electric vehicles, especially in Germany and France.
- In the wind energy sector, most countries invested less as compared to previous years. The offshore wind sector especially was influenced by major macroeconomic circumstances, with difficult economic and financing conditions increasing the risks for projects.
- Within the EU, the distribution of EU PV investments varies considerably. Germany maintained its position as the top investor in solar PV, investing €8.5 billion in 2021 and increasing to €9.4 billion in 2022. Spain, with a 2022 investment of €6.4 billion, ascended to second place, surpassing the Netherlands. Overall, investment costs of PV dropped slightly between 2021 and 2022.

Renewable energy costs and prices

After the uncertain macro-economic circumstances in the years 2021 and 2022 for which assessing costs was difficult we present for the year 2023 investment costs in line with the literature approach as used in previous years. Updated estimates for the weighted average cost of capital (WACC) were used to find levelized costs of energy (LCoE). Some highlights as reported for the year 2023:

- For electricity production, onshore wind has the lowest average LCoE in 2023 (55 €/MWh), ahead of hydropower (65 €/MWh) and offshore wind (68 €/MWh), followed by power from large commercial photovoltaic plants (72 €/MWh).
- For heat production, the lowest average LCoE observed is for heat from biomass (53 €/MWh).
- LCoE values differ across countries as a result of varying yield of renewable sources throughout the European Union and differences in financing parameters.
- Prices for natural gas and electricity for households and non-households show an increase from 2021 to 2022, which for both energy carriers is most pronounced for non-households. The effect of higher energy and supply prices on the average household price level was mitigated by tax alleviation and other support measures against high energy prices, as introduced by many European Union Member States.

Avoided Fossil fuel and resulting avoided costs

- In 2022, 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 €220 billion for the EU27.

Indicators on innovation and competitiveness

- €817 million of public investment in R&D was invested in 2021 in the EU27 for renewable technologies. €2 221 million were committed by private actors in 2020 (latest year available).
- The EU filed 1 325 patents in renewable energy in 2020 with Germany being the most active country (359 patents). China remains the world leader in number of patents filed in renewable energy with 10 004 patents.
- The trade balance (difference between imports and exports) of the renewable energy sectors in the EU27 as a whole shows a negative balance in 2022 of EUR €15 018 million. The main partner remains China, which exported €21 559 million of goods and services in renewable technologies to the EU27.

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 2023 for the wind power, photovoltaic, solar thermal, CSP, biogas, 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 2021 and 2022.

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, and renewable municipal waste. Thus, this document offers a comprehensive overview of the energy dimension of every industrially developed renewable sector in the European Union.

Methodological note

The tables set out the latest available figures for each sector. In view of the publication date of this edition, most of the indicators published in this opus were sourced from the 28 January 2024 revision of the Eurostat database (full energy balances), and the indicator specific figures of the Renewable Energy Directive (EU) 2018/2001 (RED II) provided by the Eurostat SHARES tool (Short Assessment of Renewable Energy Sources). The results presented in the section on the European RED II targets are quoted from the 6 February 2024 updated version of the Eurostat "Share of energy from renewable sources" database. (https://ec.europa.eu/eurostat/fr/data/database?node_code=nrg_ind_share).

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.

Eurostat is working on introducing new monitoring indicators for photovoltaic capacity. The first will represent the maximum net electrical capacity expressed in direct current and will cover the capacity of installed panels (peak capacity) that generate direct current electricity. The second will cover the maximum net electrical capacity expressed in alternating current and will represent electrical capacity as it leaves the inverter, namely, the maximum capacity that inverters can supply, which is a little less than the direct current capacity because of the slight loss incurred by the inverters. While Eurostat aims to produce these two different indicators for all European countries, starting with the 2022 figures, at the beginning of February 2024, most countries had only communicated one of the two figures (the vast majority provided the maximum net electrical capacity expressed in alternating current). Eurostat points out in its metadata that the lower of the two indicators must be taken into account (i.e., logically the alternating current capacity) to calculate the solar photovoltaic capacity that contributes to the country's total electrical capacity. If only one of the two indicators is available, that one is used to calculate the country's total electrical capacity.

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

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

WIND ENERGY

The European Union wind energy sector has not been knocked off course despite the fickle winds. Eurostat quantified net installed wind turbine in the European Union at the end of 2022, defined as the net maximum capacity that can be injected into the grid, at 203 554.6 MW (including 16 077.8 MW of offshore wind energy). This amounts to net additional capacity of 15 607.1 MW over the 2021 figure (including 938.5 MW of offshore wind energy). This infers that net additional wind energy capacity grew by 43.5% between 2021 and 2022 compared to the previous twelve months (10 875.7 MW), and that this figure includes the capacity of wind turbines that were dismantled during 2022, some of which were replaced by more powerful turbines (in repowering operations). Repowering enables the benefits of the latest technological innovations to be harnessed and replace old wind turbines with more recent, generally larger designs, that most importantly offer much higher yields. The main reasons for repowering operations are to increase a site's electricity output and reduce its operating costs. Newly installed turbine capacity is a more representative indicator of the wind energy market because the decommissioned capacities are taken out of the count. The WindEurope association, that acts as the voice of the wind energy industry in Europe, publishes its own indicators provided by its members whose data tends to precede that of the official statistical bodies. In March 2023, WindEurope in its annual Wind Energy in Europe report, quantified the European Union's new installation capacity in 2022 at 16 148 MW (including 1 221 MW of offshore capacity) – a year-on-year increase of 40%. WindEurope issued a warning that the European Union's current installation pace is too slow to meet the 2030climate and energy targets. It points out that in order to do so, achieve a 45% RES share of final energy consumption and the 440-GW capacity target, the European Union needs to install at least 31 GW of capacity every year between 2023 and 2030. WindEurope forecasts that average annual wind energy construction in the EU from 2023 to 2027 will probably approach 20 GW. Yet, it feels that an installation pace compatible with the EU's climate targets can still ne built up, provided that the European Union countries pursue the simplification of their authorisation rules and procedures, give investors clear signals and make substantial investments in the wind energy value chain (factories, grids, ports, vessels and qualified workers). The association considers that repowering also offers a major opportunity to revitalise wind energy facilities quickly in Europe. The fact is that the oldest wind farms are generally sited on the best locations for wind, the infrastructures are already in place (roads, sub-stations) and there tends to be less opposition from local communities, even if their involvement is essential, especially when new, taller and more powerful wind turbines are to be deployed.

ALMOST 1 GW OF OFFSHORE CAPACITY COMMISSIONED IN THE EU IN 2022

Eurostat quantified the EU's net maximum offshore wind energy capacity for 2022 at 16 077.8 MW, which is

Siemens AG

1

Wind power capacity installed in the European Union at the end of 2022 (MW)*

	2021	*of which Offshore*	2022	*of which Offshore*
Germany	63 711.0	*7 807.0*	66 163.0	*8 149.0*
Spain	27 907.7	*0.0*	30 113.8	*0.0*
France	18 551.1	*14.3*	20 810.6	*500.8*
Sweden	12 116.0	*193.0*	14 279.0	*193.0*
Italy	11 253.7	*0.0*	11 820.5	*0.0*
Netherlands	7 673.8	*2 459.5*	8 754.8	*2 569.5*
Poland	6 967.3	*0.0*	8 150.2	*0.0*
Denmark	7 003.9	*2 305.7*	7 083.8	*2 305.7*
Finland	3 257.0	*73.0*	5 677.0	*73.0*
Portugal	5 427.3	*25.0*	5 538.1	*25.0*
Belgium	4 948.4	*2 261.8*	5 303.4	*2 261.8*
Greece	4 649.1	*0.0*	4 702.3	*0.0*
Ireland	4 339.0	*0.0*	4 536.1	*0.0*
Austria	3 407.8	*0.0*	3 579.2	*0.0*
Romania	3 015.0	*0.0*	3 015.2	*0.0*
Croatia	986.9	*0.0*	986.9	*0.0*
Lithuania	671.0	*0.0*	946.0	*0.0*
Bulgaria	704.4	*0.0*	702.1	*0.0*
Czechia	339.4	*0.0*	339.1	*0.0*
Hungary	324.0	*0.0*	324.0	*0.0*
Estonia	315.0	*0.0*	316.0	*0.0*
Luxembourg	136.4	*0.0*	165.9	*0.0*
Cyprus	157.5	*0.0*	157.5	*0.0*
Latvia	77.1	*0.0*	82.4	*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	187 947.5	*15 139.3*	203 554.6	*16 077.8*

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

938.5 MW more than it found at the end of 2021. This performance exceeds Eurostat's additionnal net capacity figure for 2021 of 614.8 MW. The EurObserv'ER count for 2022 is slightly higher because it includes the connection of the Beleolico (30-MW) project in April 2022 off the port of Tarente… Italy's first offshore wind farm, which is also the first such facility to be installed in the Mediterranean. Eurostat ignores the wind farm because Italy's official data has not yet included it. Beleolico has the distinction of being the first European offshore wind farm to use Chinese wind turbines (ten Mingyang MySE 3.0-135 3-MW turbines). 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. The increase in the 2022 additional capacity figure can also be put down to the highly awaited commissioning of the 480-MW Saint-Nazaire wind farm. It is France's first commercial offshore wind farm, equipped with eighty General Electric GE Haliade 160-6 MW turbines, that has been fully functioning since 23 November 2022. Germany, which installed nothing in 2021, commissioned its sixth offshore wind farm, the Kaskasi (342-MW) Wind Farm, equipped with thirty-eight SG 8.0-167 DD Flex turbines, whose capacity has been upgraded to 9 MW. Kaskasi is the first offshore wind farm to be equipped with recyclable resin rotor blades. In 2022, the Netherlands connected the first wind turbines of its Hollandse Kust Zuid 1&2 Wind Farm, the world's first unsubsidised offshore wind farm. Statistics Netherlands (CBS) officially counted 111 MW of the project's 770 MW in 2022 on the basis that it only registers capacity that it can track from the functioning facility to the grid.

Offshore wind energy activity across the EU in 2023 surged as six large-scale wind farms were installed and completed. In the Netherlands, construction of the Hollandse Kust Zuid 1&2 and Hollandse Kust Zuid 3&4 Wind Farms continued (1.5 GW in all, namely one hundred and forty type SG 11.0-200 DD 11-MW turbines with 200-metre rotor diameter). The last wind turbine was installed in June 2023 enabling the wind farm to start up in September 2023. It should be fully operational in 2024, according to Vattenfall, the joint project owner with BASF, and will produce the equivalent of the annual power consumption of 2 million Dutch households. Construction of the Hollandse Kust Noord Wind Farm (759 MW, sixty-nine SG 11.0-200 DD turbines) that also started in October 2022 completed the installation of its last wind turbine in October 2023, leading to full capacity production at the end of 2023 (3.3 TWh of annual output normally expected). The project owner, CrossWind of the joint-venture between Shell and Eneco, will deploy several wind farm construction innovations, such as the offshore production of hydrogen and floating solar panels. Shell Nederland and Shell Overseas Investments, both Shell subsidiaries, have taken the final investment decision (FID) to construct Holland Hydrogen I, which will be Europe's largest renewable hydrogen plant when it comes on stream in 2025. Germany's Arcadis Ost 1 (257-MW) project generated its first kWh at the start of January 2023 and became fully operational in December 2023. This wind farm is the first commercial project to use a Vestas 9.5-MW turbine with a 174-metre rotor (V174-9.5 MW). Arcadis Ost 1 should supply enough power to cover the needs of up to 300 000 German households. France finalised the construction work on its Fécamp (497 MW, seventy-one SWT-7.0-154 turbines) and Saint-Brieuc wind farms (496 MW, sixty-two SG 8.0-167 DD turbines), that were partly connected in 2023 but will be fully operational in 2024. Output at the Fécamp Wind Farm will equate to 60% of the electricity consumption of the Seine Maritime department (380 000 households), while that of Saint-Brieuc will equate to 9% of Brittany's electricity consumption (also 380 000 households). Construction work on Denmark's Vesterhav Nord/Syd (344-MW) offshore wind farm foundations finally started in February 2023. The cables and forty-one turbines (SG 8.0-167 DD turbines, upgraded to 8.4 MW) were installed during the spring and summer, and the first MWh generated in November 2023. Wind farm commissioning operations will follow in Germany with Baltic Eagle (476.3 MW) and God Wind 3 (241.8 MW) in 2024, Borkum Riffgrund 3 (900 MW), EnBW He Dreiht (900 MW) and the N-3.7 (225 MW) in 2025, Nordsee Two (433 MW) and Windanker (300 MW) in 2026. Early in 2024 several French pilot floating offshore wind farms should be connected to the grid – Gulf of Lion (30 MW), Provence Grand large (25.2 MW), then Eolmed (30 MW) in the middle of the year. The Courseulles-sur-Mer

2

Electricity production from wind power in the European Union in 2021 et 2022 (TWh)

	2021	of which Offshore	2022	of which Offshore
Germany	114.169	24.374	124.816	25.124
Spain	62.061	0.000	62.784	0.000
France	37.119	0.031	38.004	0.649
Sweden	27.244	0.547	33.253	0.550
Netherlands	18.046	7.952	21.401	8.015
Italy	20.927	0.000	20.494	0.000
Poland	16.234	0.000	19.780	0.000
Denmark	16.054	7.593	19.028	8.743
Portugal	13.216	0.051	13.244	0.078
Belgium	11.998	6.926	12.353	6.652
Finland	8.507	0.267	12.022	0.272
Ireland	9.778	0.000	11.208	0.000
Greece	10.483	0.000	10.883	0.000
Austria	6.740	0.000	7.245	0.000
Romania	6.576	0.000	6.997	0.000
Croatia	2.062	0.000	2.138	0.000
Lithuania	1.362	0.000	1.512	0.000
Bulgaria	1.434	0.000	1.499	0.000
Estonia	0.733	0.000	0.668	0.000
Czechia	0.602	0.000	0.641	0.000
Hungary	0.664	0.000	0.610	0.000
Luxembourg	0.314	0.000	0.312	0.000
Cyprus	0.246	0.000	0.224	0.000
Latvia	0.141	0.000	0.190	0.000
Slovenia	0.006	0.000	0.006	0.000
Slovakia	0.005	0.000	0.004	0.000
Malta	0.000	0.000	0.000	0.000
Total EU-27	386.720	47.741	421.317	50.082

Source: Eurostat

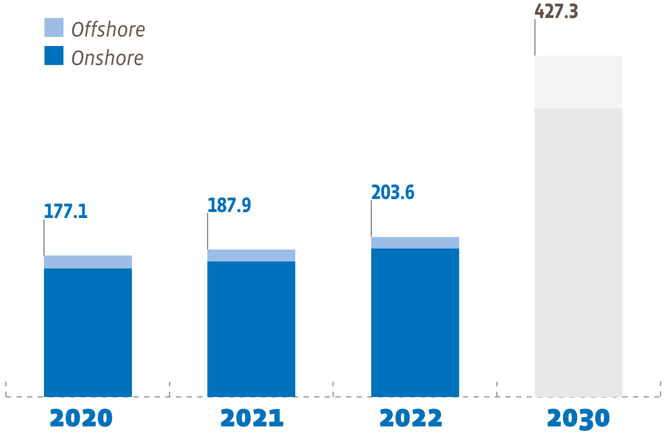
Wind Farm (448 MW) will be commissioned in 2025. The Netherlands will add its Hollandse Kust (West) VI (756 MW) and Hollandse Kust (West) VII (760 MW) wind farms in 2026. Denmark's Thor Wind Farm (1 000 MW) which should be fully operational at the latest at the end of 2027, will produce enough green electricity to supply the equivalent of over one million Danish households.

IMPROVING WINDS IN 2022

Many of Europe's major regions suffered from poor wind energy output in 2021. Across the European Union, weather condition driven output variations tend to be covered by increased production capacities, but 2021 was an exception to the rule. More severe wind drought events and lower than normal wind speeds resulted in an EU-wide wind energy output fall of about 2.8% in 2021 (from 398.0 TWh in 2020 to 386.7 TWh in 2021), despite the 10.9-GW net increase in usable installed capacity. In 2022, the winds, while being nothing to write home about, showed signs of reverting to normal. Combined onshore and offshore wind energy output of 421.3 TWh of across the European Union, resulting in an 8.9% YoY increase (34.6 TWh) can be attributed to better wind conditions in northern Europe, helped by the commissioning of new capacities. The increase in offshore wind energy output was slightly lower (4.9% between 2021 and 2022) but enough to cross the 50-TWh threshold (50.1 TWh at the end of 2022). However, the year's performance was uneven with lingering wind deficits in France, Germany and Belgium. The European Copernicus programme's ESOTC 2022 (European State of the Climate 2022) report claims that the average annual wind speed for all European land areas in 2022 was virtually equal to its 30-year average, yet masks regional variations across the continent. It was lower than average in most of the western, central and northeastern European countries, but higher than average in eastern and southeastern Europe. Nonetheless, the report considers that onshore wind energy's potential electricity output was lower than average in most of Europe, primarily in the central-southern regions. Wind energy had a much better year in 2023. Preliminary estimates go so far as to indicate that wind energy output overtook that of gas-fired power plants in Europe for the first time. ■

3

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



Source: EurObserv'ER

PHOTOVOLTAIC

Solar energy enjoyed a good year in 2022 in the European Union, as it may have been the first time that the European solar photovoltaic sector finally realized its potential. According to Eurostat, photovoltaic capacity clearly crossed the 200-GW threshold in 2022, by ramping up to 203.2 GW of maximum net electrical capacity output by the end of the year. European Union photovoltaic capacity leapt by 25.3% between 2021 and 2022, i.e., 41 GW, and smashed the installation record set in 2021 (26.3 GW of additional capacity).
The installed base increased by more than 30% in 18 of the EU countries and by much more still. Ireland's base more than doubled (by 103.2%), as did that of Lithuania (by 124.3%). The growth rate was in excess of 60% in Denmark (80.2%), Spain (70.0%), Poland (64.1%), Portugal (60.8%) and Croatia (60.5%).
Turning to the installation of new capacity during 2022, the increase exceeded one GW in 11 countries of the European Union. Eurostat reports that Spain's photovoltaic capacity increased the most over the year (by 9.6 GW), ahead of Germany (7.4 GW), the Netherlands (4.8 GW) and Poland (4.8 GW). The current EU photovoltaic market strength lies in the fact that almost all of the Member States are participating. Firstly, the high prices on the wholesale electricity markets greatly boosted the financial appeal of solar electricity, notwithstanding rising solar energy production costs. The surge in solar energy can also be attributed to geopolitical tensions with Russia, which led Europe to make solar energy a major component of the REPowerEU plan that aims to end EU dependency on Rus-

Methodological note

Eurostat is working on introducing new monitoring indicators for photovoltaic capacity. The first will represent the maximum net electrical capacity expressed in direct current and will cover the capacity of installed panels (peak capacity) that generate direct current electricity. The second will cover the maximum net electrical capacity expressed in alternating current and will represent electrical capacity as it leaves the inverter, namely, the maximum capacity that inverters can supply, which is a little less than the direct current capacity because of the slight loss incurred by the inverters. While Eurostat aims to produce these two different indicators for all European countries, starting with the 2022 figures, at the beginning of February 2024, most countries had only communicated one of the two figures (the vast majority provided the maximum net electrical capacity expressed in alternating current). Eurostat points out in its metadata that the lower of the two indicators must be taken into account (i.e., logically the alternating current capacity) to calculate the solar photovoltaic capacity that contributes to the country's total electrical capacity (table 1). If only one of the two indicators is available, that one is used to calculate the country's total electrical capacity.

1

Installed solar photovoltaic capacity in the European Union at the end of 2022 (MW)*

	2021	2022
Germany	60 036.0	67 477.0
Italy	22 594.3	24 555.2
Spain	13 715.2	23 311.3
Netherlands	14 822.9	19 599.8
France	14 603.2	17 341.3
Poland	7 415.5	12 170.4
Belgium	6 012.4	6 756.1
Greece	4 277.4	5 430.1
Hungary	2 968.0	4 235.0
Austria	2 782.6	3 791.7
Denmark	1 704.0	3 069.9
Portugal	1 646.0	2 646.3
Czechia	2 191.0	2 420.5
Sweden	1 606.0	2 388.0
Romania	1 393.9	1 808.9
Bulgaria	1 274.7	1 737.2
Finland	425.0	664.0
Slovenia	461.2	626.2
Lithuania	255.0	572.0
Slovakia	537.0	549.0
Estonia	394.8	520.0
Cyprus	314.5	424.1
Luxembourg	277.2	316.6
Malta	205.5	222.5
Croatia	138.3	222.0
Ireland	92.4	187.9
Latvia	7.2	113.0
Total EU-27	**162 151.0**	**203 155.9**

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

sian fossil fuels, with a headline target of 600 GW in 2030. Perception of solar photovoltaic energy has also changed. It is viewed as a sector with unbeatably fast rollout capacities to reduce dependence on Russian fossil fuels. Furthermore, and in contrast with 2021, demand was no longer constrained by Covid-19 pandemic-related supply chain bottlenecks.

RECORD SUNSHINE DURATION AND PV ELECTRICITY PRODUCTION IN THE EU

The European State of the Climate (ESOTC 2022) annual report compiled by the Copernicus Programme confirms that Europe experienced its highest recorded sunshine duration (over 40 years) with 130 more sunshine hours than average (compared to 31 more sunshine hours than average in 2021). This record indicates a marked trend towards longer sunshine duration. Over the past eight years, five have had 100 more sunshine hours than average and none have had fewer than average sunshine hours. We need to turn the clock back ten years (2013) to the last (slightly) lower than average sunshine duration. This record sunshine duration, coupled with the record amount of capacity installed in Europe, has led to solar electricity output records in the EU. According to Eurostat, solar photovoltaic electricity output increased by 29.3% between 2021 and 2022 to reach 205.7 TWh, which is 46.6 TWh more than in 2021. The vast majority of EU countries enjoyed double-digit production increases. Poland, which sharply increased its production capacities in 2021 and 2022, went so far

2

Gross electricity production from solar photovoltaic in the European Union in 2021 and 2022 (in GWh)

	2021	2022
Germany	50 472.0	60 304.0
Spain	21 922.0	31 187.0
Italy	25 039.0	28 121.5
France	15 371.3	19 642.2
Netherlands	11 303.9	17 078.8
Poland	3 934.4	8 309.7
Greece	5 251.0	7 139.7
Belgium	5 618.1	6 876.0
Hungary	3 796.0	4 732.0
Austria	2 782.6	3 791.7
Portugal	2 237.2	3 519.0
Czechia	2 249.9	2 626.3
Denmark	1 308.9	2 202.6
Bulgaria	1 466.6	2 093.8
Romania	1 703.4	1 988.4
Sweden	1 526.0	1 980.0
Slovakia	671.0	650.0
Slovenia	453.1	645.6
Cyprus	468.3	601.9
Estonia	353.7	596.0
Finland	297.5	392.3
Lithuania	190.8	342.0
Malta	255.8	289.5
Luxembourg	180.2	276.3
Croatia	148.9	151.9
Ireland	79.4	148.3
Latvia	6.8	41.3
Total EU-27	**159 087.7**	**205 727.7**

Source: Eurostat

as to double its output within the space of a year (by 111.2%). The solar PV share of total gross electricity output is gradually increasing in the EU. If we factor in the number of inhabitants in the Netherlands, which is the most solarized country of Europe, solar photovoltaic accounted for 14% of the country's electricity output in 2022 (9.3% in 2021) and according to Eurostat... a European record. The 2022 figures are also above 10% for Greece (13.6%), Hungary (13.2%), Malta (12.6%), Luxembourg (12.3%), Cyprus (11.4%) as well as Spain (10.7%) and Germany (10.4%).

GERMANY, SPAIN AND THE NETHERLANDS IN THE VANGUARD

Eurostat reports that at the end of 2022, Spain's maximum net electrical capacity stood at 23.3 GW, or 9.6 GW more than in 2021. This additional capacity is much more than originally estimated by the authorities and may be credited to an installation rush during the second half of the year, partly stemming from the geopolitical context and the need to reduce gas consumption. Most of the newly installed capacity was covered by power purchasing agreements (PPAs), which makes the Spanish market the largest solar market to operate without subsidies or state-guaranteed prices. The April 2019 adoption of a royal decree officially abolishing the solar tax while accompanying and encouraging collective and individual self-consumption, enabled the roof-mounted self-consumption segment to pick up. According to Solar Power Europe, the residential segment amounted to almost 3 GW at the height of

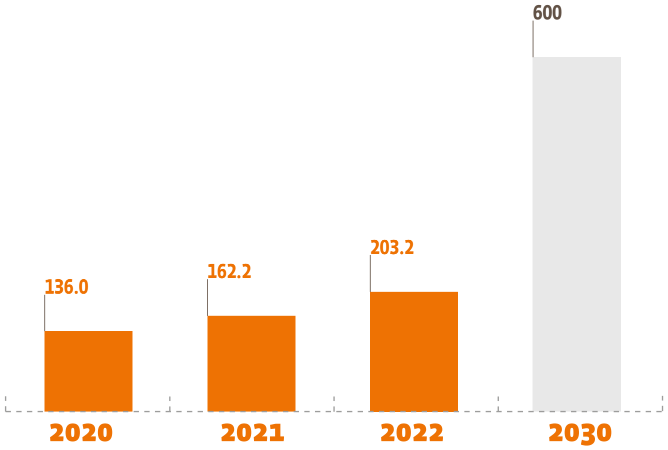
the energy crisis. Preliminary estimates suggest a slight falloff in the 2023 installation pace. The association claims that grid connection constraints, combined with current high interest rates and the fall in wholesale prices, have restrained PPA project connections in 2023.
Eurostat reports that Germany increased its solar photovoltaic capacity by 7.4 GW taking its base to 67.5 GW at the end of 2022. Germany's combined photovoltaic capacity to date amounts to a third of the photovoltaic capacity installed in the European Union. The 2023 installation pace has picked up considerable speed. The preliminary figures released by AGEE-Stat attest to just over 13 GW of capacity connected in 2023, which takes the total capacity to over 80.4 GW. On 6 April 2022, the government announced that it was raising its clean energy target to 80% of the electricity mix from 2030 onwards from the previous 65%. That implies that a minimum of 600 TWh per annum must be generated from renewable energies by that timeline. The publication of the new renewable energy law, which came into force on 1 July 2022, was brought forward because of Russia's invasion of Ukraine. Robert Habeck, Federal Minister for Economic Affairs and Climate Action said: "It is the largest energy policy revision for decades." The law contains a clause that identifies renewable energies as being in the interest of public security. Tenders, which were sometimes undersubscribed in previous years, will be significantly increased to meet the target.
The Netherlands should be viewed as a textbook case for gauging solar power's potential for development in a country's electricity mix. Although solar power accounted for less than 1% of the Dutch electricity mix in 2014 (a 0.61% share of total gross electricity output), its share was as high as 14% in 2022. Most of this rapid increase in production can be credited to the increase in installed capacity. The connected base has risen from 1 GW in 2014 to 19.6 GW at the end of 2022. Eurostat reports that maximum net electrical capacity increased from 4.8 GW year-on-year (3.7 GW between 2020 and 2021). Statistics Netherlands puts the number of solar systems installed in the country at 2.29 million in 2022 (1.73 million in 2021), a relatively high figure for a country with 17.6 million inhabitants. The two main solar photovoltaic drivers in the Netherlands are firstly, the net invoicing system for the residential and small business segments, and secondly, the SDE+ tendering system in the large power plant and major commercial systems segments, where solar photovoltaic competes with other renewable energy sources. SolarPower Europe feels that the Netherlands' market could be bigger, but at least 12 GW of projects are held back, facing challenges to secure connections and sites. The Dutch government, as authorized by European legislation, took another major step when it cut the value-added tax applied to photovoltaic systems used in residential applications from 21 to 0% starting on 1 January 2023. By the way, the Netherlands was a champion of the European Commission's decision to permit this kind of tax exemption. In contrast with most European Union countries, the Netherlands did not increase its photovoltaic ambitions in its latest NECP. Hence its new 2030 target of 25.7 GW, which seems very undervalued, could be achieved in less than two years.

NEW TARGETS AND AMBITIONS FOR 2030

The publication in the Official Journal of the European Union of the Renewable Energy Directive (RED III) No. 2023/2413 dated 18 October 2023 opened up new possibilities for the photovoltaic sector. It stipulates that «The Member States will collectively endeavour to ensure that the energy share produced from renewable sources in the Union's final gross energy consumption in 2030 is at least 42.5%» and that « The Member States will collectively endeavour to achieve a 45% share of the Union's final gross energy consumption in 2030 produced from renewable sources.» This new target with an extremely short deadline will force the Member States to radically reassess solar photovoltaic energy's contribution for the next seven year when they revise their integrated National Energy and Climate Plans (NECP). Regulation (EU) 2018/1999 on «Governance of the Energy Union and Climate Action» provides for the obligation to update the plans no later than 30 June 2023 for an updated project and finalisation by 30 June 2024. The NECP update process has significantly raised the solar photovoltaic ambitions of Member States that have submitted a new project to the European Commission. Spain's updated National Energy and Climate Plan (NECP), for example, raises the total installed photovoltaic capacity target for 2030 from 39 to 76 GW, which is almost double the previous NECP target. Germany's new 2023 National Energy and Climate Plan (NECP) plans to roll out an average of 22 GW per annum, amounting to cumulative capacity of 215 GW in 2030 and 400 GW in 2040. France has raised its photovoltaic targets to 54–60 GW in 2030 from 35.1–44 GW by 2028 in its previous NECP, and from 75–100 GW by 2035. Another major solar player, Italy, has raised its photovoltaic target of 51 to 79 GW for 2030, while Portugal's target photovoltaic contribution has risen from 9 to 20.4 GW.
At the start of February 2024, only Bulgaria and Poland had yet to submit their draft NECPs. EurObserv'ER, which has examined the new photovoltaic targets for 2030 detailed in the draft NEPCs submitted to the Commission in 2023, added to those of Poland and Bulgaria submitted in 2019, reckons that the overall EU-wide target has increased to 603.2 GW for 2030 (based on the high assumptions for France and Czechia), compared to a global target of 316 GW from the old NECPs submitted in 2019. The new European ambitions for solar amount to almost double the overall target. ■

3

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



Source: EurObserv'ER

EUROBSERV'ER – THE STATE OF RENEWABLE ENERGIES IN EUROPE – 2023 EDITION

SOLAR THERMAL

Solar thermal's competitiveness, in all its areas of application, is essentially driven by the price of energy. Furthermore, the situation has completely changed since 2021 with energy prices at record levels in 2022. The rises, stemming from the global hike in wholesale energy prices, started in 2021 as international demand recovered after the COVID-19 pandemic. The situation turned into a crisis aggravated by Russia's invasion of Ukraine as the price of gas spiralled upwards. It came as a blessing for solar thermal heat that had been waiting to make its comeback. Solar systems are not only viewed as making a major contribution to climate protection but also to protecting against energy price rises and as a way of reducing dependency on imports.

THINGS ARE LOOKING UP AGAIN FOR THE EUROPEAN SOLAR THERMAL MARKET

The solar thermal sector's bad old days appear to be behind it once and for all. The recovery initiated in 2021 continued throughout 2022 and even picked up speed. The 2022 solar thermal market data gathered by EurObserv'ER suggest a newly installed collector area of almost 2.4 million m^2 (2 374 034 m^2), which translates into 11.9% year-on-year growth. This newly installed collector area amounts to about 1 661.1 MWth of thermal capacity (compared to 1 483.8 MWth in 2021), the glazed surface of a 1-m^2 solar thermal collector has 0.7 kWth of thermal capacity. To put this into perspective, the surface area of the collectors installed over the twelve months equates to 300 times the grassed surface of a football pitch (8 000 m^2).

This market data covers systems that use flat-glazed and vacuum tube collectors, which are technologies geared to domestic hot water production or heating in the residential sector and heat and hot water production for 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.

NEWS FROM AROUND THE MAIN SOLAR THERMAL MARKETS

The four leading European Union member country markets (Germany, Greece, Italy, and Poland) all posted double-digit growth, with Italy leading the pack once again. According to Solar heat Europe, it increased by 43% between 2021 and 2022 to 321 750 m^2. The combination of the Conto Termico programme, which supports renewable heat installations, and the 110% Superbonus for energy efficiency in buildings is a real boon to solar thermal technology. In Greece, according to the EBHE (the Greek Solar Industry Association), 2022 was an excellent year for installations with at least 419 000 m^2 installed compared to 359 000 m^2 in 2021, … or 16.7% growth. This is a jump of 60 000 m^2 over 2021 and 114 500 m^2 over 2020. Costas Travasaros, who represents the EBHE and is also the President of Solar Heat Europe, believes that the installation market trend remains positive in Greece because of high energy prices and energy security concerns. The Polish solar thermal market posted 11.1% annual growth between 2021 and 2022 (i.e., 210 000 m^2 installed), which is somewhat poorer than the previous year's performance (17.3%). SPIUG (the Polish Association of producers and importers of heating devices) that released these figures, attributes this new large increase mainly to the municipal tenders financed by EU funds.

Germany's strong market upturn is also encouraging, as it is still the top European Union market for installed surface area. A joint press release published by BSW-Solar (the German solar association) and BDH (the Federation of German heating industry) asserts that the energy price hikes fuelled the demand for solar heating significantly last year. About 91 000 new solar heating systems were installed in 2022, marking a 12% increase on the previous year. The total gross solar collector area, mainly installed on buildings, was 709 000 m^2, which equates to about 100 football pitches. However, 2023 was not so active (376 000 m^2 installed, i.e., 55 000 new systems), attributable to the uncertainties caused by the introduction of a new law on heating and the promotion of renewable energy fuelled heating systems from 2024 onwards, which delayed investments. From now on, up to 60% of the modernisation of a solar thermal installation on an existing oil- or gas-fired heating system will be funded through the Federal Subsidy for Efficient Buildings (BEG). When a new hybrid heating system is installed combining either solar thermal energy with a heat pump or solar thermal energy with a pellet boiler, the basic funding rate rises to 30% and may rise to a maximum of 70% (through a 30% bonus pegged to income level and a 20% climate speed bonus for replacing a biomass- or gas-fired heating appliance that is over 20 years old or a gas-, oil- or coal-fired underfloor heating appliance).

MORE LINES ON THE EU'S SOLAR HEATING NETWORK MAP

Until recently, local authorities and energy service companies focused their attention on biomass and geothermal energy to make their heating networks greener. Heating networks

1

Annual installed surfaces in 2021 per type of collectors (in m²) and capacity equivalent (in MWth)

	Glazed collectors		Unglazed collectors	Total (m²)	Equivalent capacity (MWth)
	Flat plate collectors	Vacuum collectors			
Germany	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*	157 000			157 000	109.9
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	**1 980 726**	**136 128**	**2 930**	**2 119 784**	**1 483.8**

*+ 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). * Revised figures, including 90 000 m2 in the overseas departments.* ***Source: EurObserv'ER***

2

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

	Glazed collectors		Unglazed collectors	Total (m²)	Equivalent capacity (MWth)
	Flat plate collectors	Vacuum collectors			
Germany	524 000	185 000		709 000	496.3
Greece	419 000			419 000	293.3
Italy**	321 750			321 750	225.2
Poland	208 500	1 500		210 000	147.0
France***	163 300			163 300	114.3
Spain	126 500	7 000	2 000	135 500	94.9
Cyprus	73 924			73 924	51.7
Portugal	66 100			66 100	46.3
Austria	56 830	660	1 480	58 970	41.3
Netherlands	24 516	14 960	2 621	42 097	29.5
Czechia	23 167	2 336		25 503	17.9
Bulgaria+	45 863			45 863	32.1
Belgium	15 000	3 500		18 500	13.0
Slovakia+	16 000			16 000	11.2
Romania*	16 932			16 932	11.9
Hungary+	12 000			12 000	8.4
Croatia*	13 558			13 558	9.5
Finland+	8 000			8 000	5.6
Sweden*	2 014			2 014	1.4
Luxembourg	3 574			3 574	2.5
Denmark	2 664			2 664	1.9
Lithuania*	1 751			1 751	1.2
Latvia*	1 700			1 700	1.2
Estonia*	1 425			1 425	1.0
Slovenia*	1 479			1 479	1.0
Malta+	1 051	263		1 314	0.9
Ireland	1 116			1 116	0.8
Total EU	**2 151 714**	**215 219**	**6 101**	**2 373 034**	**1 661.1**

*+ EurObserv'ER estimation based on the market trend of recent years (these are not sufficiently accurate to be used for percentual change reference in these markets). * Estimation from Solar heat Europe «Decarbonising heat with solar thermal market,Market outlook 2022-2023). ** For Italy, breakdown not available between Flate plate and vacuum tube collectors. *** including 96 500 m² in the overseas departments.* ***Source: EurObserv'ER***

3

Cumulated capacity of thermal solar collectors installed in the European Union in 2021 and 2022*** *(in m² and in MWth)*

	2021		2022	
	m²	MWth	m²	MWth
Germany	22 057 000	15 439.9	22 415 000	15 690.5
Greece	5 175 000	3 622.5	5 442 000	3 809.4
Italy	4 657 622	3 260.3	4 953 763	3 467.6
Austria	4 774 554	3 342.2	4 616 474	3 231.5
Spain	4 359 743	3 051.8	4 449 343	3 114.5
France	3 957 437	2 770.2	4 072 360	2 850.7
Poland	3 195 690	2 237.0	3 405 690	2 384.0
Denmark	2 035 096	1 424.6	2 059 096	1 441.4
Portugal	1 478 955	1 035.3	1 545 055	1 081.5
Cyprus	1 121 667	785.2	1 139 643	797.8
Belgium	748 000	523.6	756 400	529.5
Netherlands	662 000	463.4	662 000	463.4
Czechia	586 000	410.2	611 000	427.7
Bulgaria	469 834	328.9	515 697	361.0
Sweden	445 000	311.5	435 000	304.5
Hungary	406 000	284.2	418 000	292.6
Ireland	344 829	241.4	345 907	242.1
Croatia	300 000	210.0	312 600	218.8
Slovakia	249 000	174.3	265 000	185.5
Romania	249 109	174.4	249 109	174.4
Slovenia	220 000	154.0	217 246	152.1
Luxembourg	77 376	54.2	90 950	63.7
Finland	88 000	61.6	88 000	61.6
Malta	52 136	36.5	46 485	32.5
Latvia	21 672	15.2	21 672	15.2
Total EU-27	**57 731 720**	**40 412.2**	**59 133 490**	**41 393.4**

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

are looking to new energy sources to decarbonise their networks and are working on innovative combinations that blend solar, biomass, heat pump and heat recovery, now that biomass is subject to tensions (procurement, competition for use and harder sustainability criteria in the new RES directive), and that Europe's forests are suffering from the consequences of climate change.

All the European Union countries are striving to eliminate natural gas as much and as fast as possible from their heating networks as a matter of urgency. The Steinbeis Solites Research Institute reports that 2022 was a record year for German solar district heating networks. The institute surveyed all the projects in service, under construction and on the drawing board for the Solnetplus project (a map of projects is available on the www.solare-waermenetze.de website). Solites identified 33 879 m² of new collector areas dedicated to solar district heating in 2022. This takes the total collector area used by Germany's solar district heating networks to 146 024 m² (30% more than in 2021) and brings the number of SDHs in service to 49. The corresponding thermal capacity has passed the 100 MWth mark (102 MWth at the end of 2022). The commissioning of the country's biggest solar thermal system, Greifswald MV (18 732 m²) and the third largest system, Lemgo (9 118 m²), are the main drivers behind the sharp rise in 2022. In the same year, Germany also connected the biggest roof-mounted urban heating solar thermal system at Dettenhausen (2 312 m²). Construction of the Groningen solar district heating network, in the Netherlands, started in November 2022, with 37 MWth of capacity. It will be the country's biggest network which should become fully operational in 2024. A 48 000-m² collector field will be connected to the city's heating network operated by the energy company Warmtestad. Solar energy will cover about 25% of the connected buildings' heating requirements.

Freepik

4

Heat consumption from solar thermal in the countries of the European Union in 2021 and 2022 (in ktoe)*

	2021			2022		
	Total	*of which final energy consumption*	*of which derived heat***	Total	*of which final energy consumption*	*of which derived heat***
Germany	735.3	*733.6*	*1.6*	837.2	*835.3*	*1.8*
Spain	337.2	*337.2*	*0.0*	344.1	*344.1*	*0.0*
Greece	303.9	*303.9*	*0.0*	319.6	*319.6*	*0.0*
Italy	246.8	*246.6*	*0.2*	263.2	*263.0*	*0.2*
France	224.8	*224.8*	*0.0*	234.1	*234.1*	*0.0*
Austria	176.2	*173.9*	*2.3*	177.0	*174.7*	*2.3*
Portugal	105.5	*105.5*	*0.0*	110.5	*110.5*	*0.0*
Poland	85.2	*85.2*	*0.0*	90.8	*90.8*	*0.0*
Denmark	69.0	*14.6*	*54.4*	79.5	*14.6*	*64.9*
Cyprus	75.7	*75.7*	*0.0*	76.9	*76.9*	*0.0*
Bulgaria	29.2	*29.2*	*0.0*	32.0	*32.0*	*0.0*
Netherlands	27.8	*27.8*	*0.0*	27.9	*27.9*	*0.0*
Belgium	26.0	*26.0*	*0.0*	27.9	*27.9*	*0.0*
Czechia	19.3	*19.3*	*0.0*	20.0	*20.0*	*0.0*
Croatia	17.1	*17.1*	*0.0*	16.1	*16.1*	*0.0*
Hungary	15.5	*15.5*	*0.0*	16.0	*16.0*	*0.0*
Ireland	14.0	*14.0*	*0.0*	14.1	*14.1*	*0.0*
Slovenia	10.2	*10.2*	*0.0*	10.0	*10.0*	*0.0*
Sweden	10.2	*10.2*	*0.0*	9.8	*9.8*	*0.0*
Slovakia	8.6	*8.6*	*0.0*	9.1	*9.1*	*0.0*
Malta	3.6	*3.6*	*0.0*	3.2	*3.2*	*0.0*
Luxembourg	2.7	*2.7*	*0.0*	2.8	*2.8*	*0.0*
Finland	2.6	*2.6*	*0.0*	2.6	*2.6*	*0.0*
Latvia	0.9	*0.0*	*0.9*	0.9	*0.0*	*0.9*
Romania	1.2	*1.2*	*0.0*	0.8	*0.8*	*0.0*
Estonia	0.0	*0.0*	*0.0*	0.0	*0.0*	*0.0*
Lithuania	0.0	*0.0*	*0.0*	0.0	*0.0*	*0.0*
Total EU-27	**2 548.2**	**2 488.8**	**59.5**	**2 726.1**	**2 655.9**	**70.2**

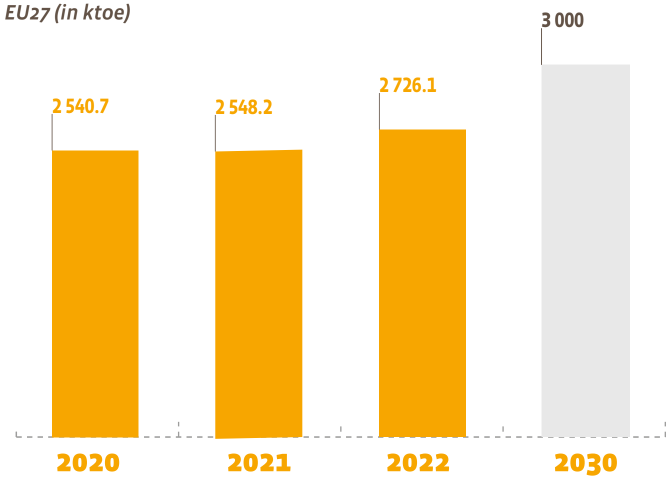
** Gross heat production in the transformation sector and Final energy consumption in «Industry» and «other sectors» excluding «transport». ** Derived heat is equivalent to Gross heat production in the transformation sector.* ***Source: Eurostat***

59.1 MILLION M² OF COLLECTORS IN SERVICE

Eurostat puts the total European Union collector area at the end of 2022 at 59.1 million m² (41.4 GWth), which equates to a 2.4% year-on-year increase. This combined area has increased by 1.4 million m². Eurostat's estimate covers the three main solar thermal technologies (flat glazed collectors, vacuum tube collectors and non glazed collectors) and factors in decommissioning allowance for the oldest installations included by each Member State. Incidentally, a few countries exclude non-glazed areas from their calculations because installations using this technology are not systematically monitored. However, Germany has reinstated an estimate of the non glazed collector area for two years – 437 190 m² for 2021 and 432 190 m² for 2022 – which has created the slight difference from the previous figure. Solar heat, both directly used by the end user and produced by heating networks, increased considerably across the EU (by 7.0% between 2021 and 2022) to reach 2 726.1 ktoe (including 70.2 ktoe of heat sold from heating networks). This growth can also be attributed to record sunshine levels.

5

EurObserv'ER projection of solar thermal heat consumption in the EU27 (in ktoe)*



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

THE STAKES ARE HIGH

«Solar thermal (panels) and solar power combined with heat pumps can replace natural gas boilers for heating residential or commercial spaces. Solar energy in the form of electricity, heat or hydrogen can replace natural gas consumption in industrial processes.» This European Commission assertion made in the RePowerEU plan clearly demonstrates the key role it intends to give solar heating for weaning Europe off Russian natural gas and for decarbonization... clearly no meagre goals. The Solar Heat Europe roadmap presented in June 2022 unveiled new ambitions for the sector together with an overview of the contributions that the sector can make towards decarbonizing energy. According to this roadmap, solar thermal has the potential to reach 140 GWth of installed capacity by 2030, or 73 GWth in 2030 in the building segment, 32 GWth in the district heating segment and 36 GWth for industrial heat if strong measures are applied. That is just over thrice the European Strategy goal for solar energy.

EurObserv'ER believes that the installation pace will clearly pick up speed from 2024-2025, but the Member States will have to be much more determined than they are currently if they are to reach these installation levels, especially as the decommissioning of installations over 20 years old will clearly accelerate as the end of the decade approaches. The effective rollout of the RePowerEU plan proposal making the installation of solar panels on new public and commercial buildings compulsory from 2026 onwards and on new residential buildings from 2029 onwards will also be instrumental in this drive. The ubiquity of solar roofs in new build should breathe new life into the renovation segment. ■

HYDROPOWER

The European Union suffered one of its worst ever hydroelectricity deficits in the middle of an energy crisis just as the market electricity price peaked. Eurostat put the EU27's gross hydroelectricity output from natural water flow, i.e., disregarding the electricity produced by pumping, at 276.3 TWh in 2022, which is a 20.7% fall on the previous year's output (348.3 TWh). It is a very far cry from its historic records of 2001 (373.4 TWh) and 2014 (370.0 TWh). Pumped storage power made up for a very small amount of this hydroelectricity deficit, which increased EU-wide by 26.5 to 31.3 TWh... is its highest output since 2006.

While hydropower is still the European Union's No. 2 renewable electricity production source behind wind power (421.3 TWh), it is steadily losing its lead over solar electricity production (with solar photovoltaic and CSP output standing at 205.7 TWh and 4.5 TWh respectively in 2022). In its ESOTEC 2022 (European State Of The Climate) report, the Copernicus Climate Change Service – one of the six themed services provided by the European

1

Hydraulic capacity of pure hydro plants, mixed plants and pure pumped plants in the European Union countries in 2021 and in 2022 (in MW)*

	2021				2022			
	Pure hydro power	Mixed hydro power	Pure pumped hydro power	Total	Pure hydro power	Mixed hydro power	Pure pumped hydro power	Total
France	18 890.2	5 372.9	1 727.7	**25 990.8**	18 863.7	5 372.3	1 727.7	**25 963.7**
Italy	15 528.7	3 280.6	3 940.4	**22 749.7**	15 598.7	3 334.1	3 928.0	**22 860.8**
Spain	13 719.3	3 081.6	3 331.4	**20 132.4**	13 724.1	3 081.6	3 331.4	**20 137.1**
Sweden	16 308.0	99.0	0.0	**16 407.0**	16 300.0	99.0	0.0	**16 399.0**
Austria	8 986.6	5 761.3	0.0	**14 747.9**	9 127.8	5 795.3	0.0	**14 923.1**
Germany	4 356.0	1 134.0	5354.0	**10 844.0**	4 487.0	1 134.0	5353.0	**10 974.0**
Portugal	4 490.5	2 764.4	0.0	**7 254.9**	4 541.4	3 647.2	0.0	**8 188.6**
Romania	6 291.4	279.3	91.5	**6 662.2**	6 293.2	277.9	91.5	**6 662.6**
Greece	2 722.0	699.0	0.0	**3 421.0**	2 722.0	699.0	0.0	**3 421.0**
Bulgaria	2 356.2	149.0	864.0	**3 369.2**	2 376.9	149.0	864.0	**3 389.9**
Finland	3 171.0	0.0	0.0	**3 171.0**	3 171.0	0.0	0.0	**3 171.0**
Slovakia	1 615.0	0.0	916.0	**2 531.0**	1 616.0	0.0	916.0	**2 532.0**
Poland	598.6	376.0	1 423.0	**2 397.5**	607.9	376.0	1 423.0	**2 406.8**
Czechia	1 113.4	0.0	1 171.5	**2 284.9**	1 113.6	0.0	1 171.5	**2 285.1**
Croatia	1 925.1	275.4	0.0	**2 200.5**	1 930.4	275.3	0.0	**2 205.7**
Latvia	1 587.2	0.0	0.0	**1 587.2**	1 587.7	0.0	0.0	**1 587.7**
Belgium	110.7	0.0	1 307.0	**1 417.7**	123.3	0.0	1 307.0	**1 430.3**
Slovenia	1 172.1	0.0	180.0	**1 352.1**	1 166.1	0.0	180.0	**1 346.1**
Luxembourg	34.5	0.0	1 296.0	**1 330.5**	34.0	0.0	1 296.0	**1 330.0**
Lithuania	117.0	0.0	760.0	**877.0**	117.0	0.0	760.0	**877.0**
Ireland	237.0	0.0	292.0	**529.0**	237.0	0.0	292.0	**529.0**
Hungary	60.0	0.0	0.0	**60.0**	60.0	0.0	0.0	**60.0**
Netherlands	37.7	0.0	0.0	**37.7**	37.7	0.0	0.0	**37.7**
Estonia	6.0	0.0	0.0	**6.0**	8.0	0.0	0.0	**8.0**
Denmark	7.1	0.0	0.0	**7.1**	6.6	0.0	0.0	**6.6**
Total EU-27	**105 441**	**23 272**	**22 654**	**151 368**	**105 851**	**24 241**	**22 641**	**152 733**

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

Union's Copernicus programme – attests to a particularly low precipitation year... the lowest observed since the 1960s. Drier than average conditions were declared in much of Europe in 2022, particularly in France, Italy, northern Germany, southern Sweden and northern Spain. The precipitation deficit detected in large swathes of Europe contrasts with the concomitant record sunshine levels across the continent. Nonetheless, the Copernicus Climate Change Service points out that the continent's annual long-term rainfall trends are positive, but will exhibit regional differences, with northern Europe becoming wetter and southern Europe becoming drier.

Hydropower output dropped significantly in almost all the EU countries in 2022. The largest drops in the main producer countries were felt in Spain (40.6%, 12 TWh), Portugal (45.1%, 5.4 TWh), Italy (37.4%, 17 TWh), France (23.6%, 14.1 TWh) and Romania (19.7%, 3.4 TWh).

For the purposes of calculating the Member States' renewable energy targets, 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 345.4 TWh as the normalized hydroelectricity output across the European Union in 2022, which is 0.4 % less than in 2021 (348.6 TWh that year). Thus, the normalized hydropower output figure for 2022 across the European Union, was very much higher (69.1 TWh higher) than the actual hydropower output, while only Sweden's and Lithuania's

2

Hydraulic gross electricity production (pumping excluded) in the European Union (in TWh) in 2021 and 2022

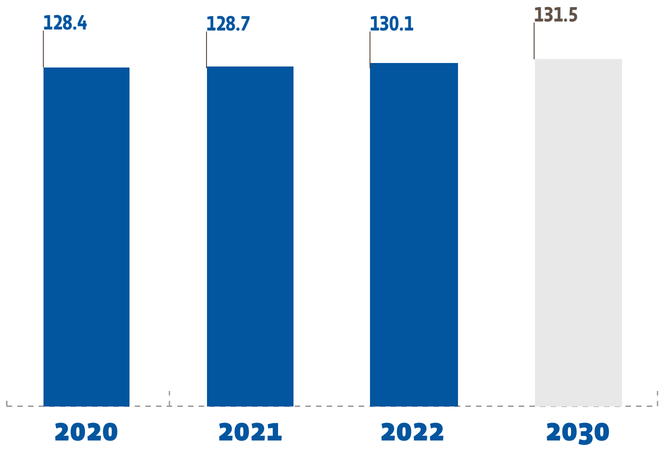
	2021	2022	Normalised production 2022*
Sweden	73.885	69.871	67.651
France	59.616	45.521	59.929
Austria	38.751	34.705	42.360
Italy	45.388	28.398	48.094
Germany	19.657	17.625	19.856
Spain	29.626	17.590	30.144
Romania	17.412	13.977	15.766
Finland	15.791	13.492	14.701
Portugal	11.908	6.536	12.606
Croatia	7.128	5.460	6.821
Greece	5.903	3.855	5.086
Bulgaria	4.819	3.803	4.112
Slovakia	4.258	3.678	4.259
Slovenia	4.713	3.149	4.559
Latvia	2.708	2.750	2.893
Czechia	2.409	2.093	2.202
Poland	2.339	1.968	2.315
Ireland	0.749	0.701	0.764
Lithuania	0.384	0.464	0.436
Belgium	0.418	0.271	0.349
Hungary	0.212	0.178	0.239
Luxembourg	0.107	0.064	0.099
Netherlands	0.088	0.050	0.087
Estonia	0.023	0.023	0.034
Denmark	0.016	0.015	0.015
Total EU-27	348.308	276.237	345.376

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

EUROBSERV'ER – THE STATE OF RENEWABLE ENERGIES IN EUROPE – 2023 EDITION

3

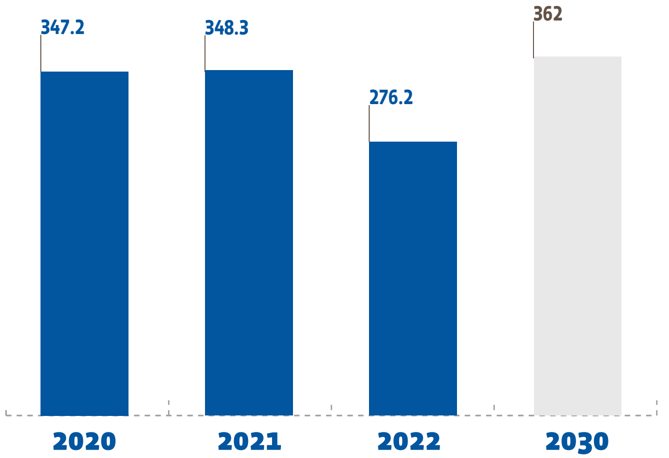
EurObserv'ER projection of the net hydraulic capacity (pure pumping excluded) in the EU-27 (in GW)



Source: EurObserv'ER

4

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



Source: EurObserv'ER

actual hydropower output exceeded the normalized output figure for the last 15 years.

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 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 EU27 pure hydro plants at 105 851 MW in 2022 (105 441 MW in 2021), compared to that of its mixed hydro plants at 24 241 MW (23 272 MW in 2021). The five best-equipped countries with pure hydro plants in 2022 were France (19 864 MW), Sweden (16 300 MW), Italy (15 599 MW), Spain (13 724 MW) and Austria (9 128 MW).

HYDROPOWER UP AGAINST CLIMATE CHALLENGE

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 cleaning (such as silt removal from dams), maintenance and modernization of plants (replacing turbines and generators) and extending existing hydroelectric complexes, rather than constructing new projects, even though major new projects still come out of the ground. Portugal is a case in point as it inaugurated the new Tâmega Hydropower complex in 2022. The complex, also known as the "Tâmega Gigabattery" because of its enormous storage capacity, is built on the River Tâmega, 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 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 project was given a grand opening in July 2022 by Portugal's Prime Minister António Costa, and Ignacio Galán, Iberdrola's CEO. Another major project was commissioned in November 2022 after 8 years of construction work, the Austro-Swiss cross-border project of the "Gemeinschaftskraftwerk Inn", the River Inn Joint Power Plant. This "run-of-the-river" 89-MW power plant is a diversion hydropower plant, as the water from the River Inn is collected and channelled through a 23.5 km-long pressurised tunnel to the Prutz/Ried power plant in Austria, and fed to two Francis turbines expected to produce 414 GWh of annual output. Other projects are still in negotiations such as the Bulgarian-Romanian Turnu Măgurele Nikopol hydroelectric plant on the River Danube (840 MW, with total output of 4.4 TWh). Once this project is completion after 8 years of construction work, the two countries will each have 420 MW of installed capacity.

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 projects equipped with PHES. They 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 them we would like to mention is the Silvermines (360-MW) pumped hydro power station in Ireland that will rehabilitate a historic disused metal mining site. It was awarded a 4.3 million euro European Union grant in June 2023, through the EU Connecting Europe Facility (CEF) mechanism, to fund the essential geological, environmental and technical studies. ■

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.

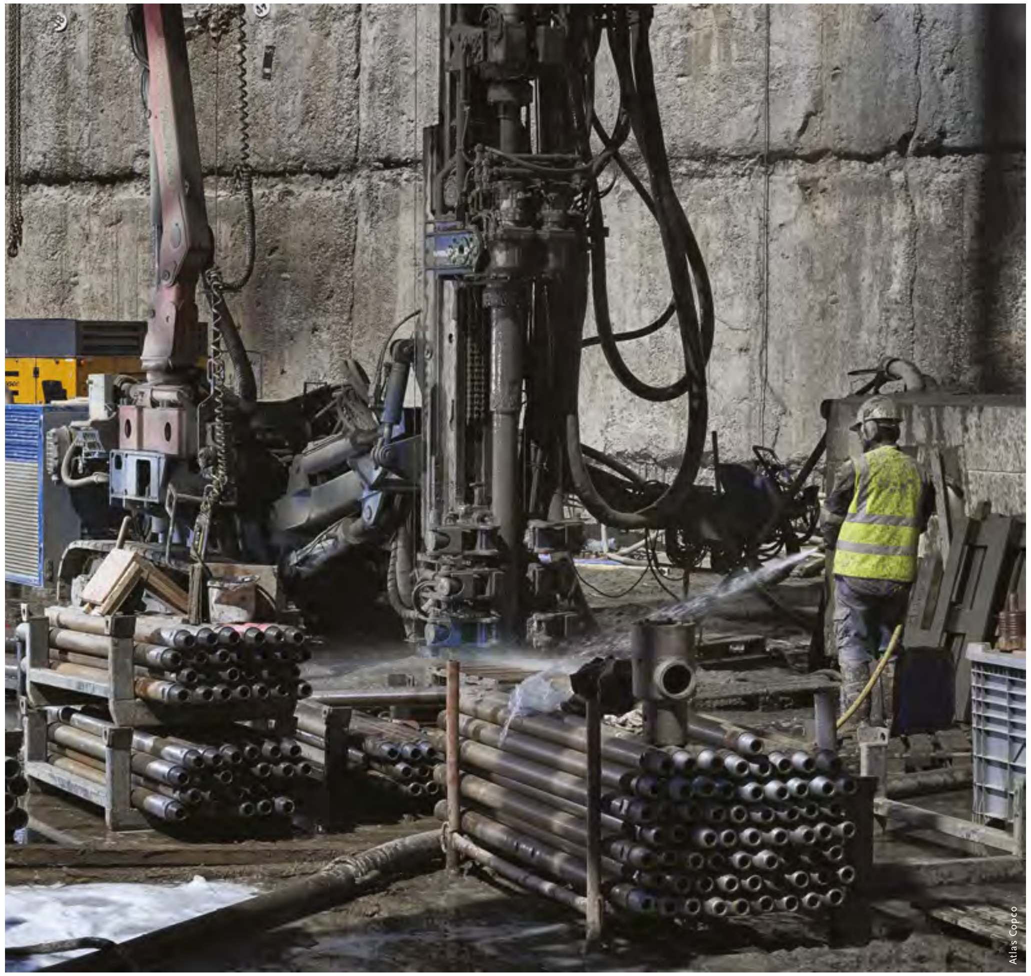
Electricity can also be produced using binary cycle technology when the aquifer temperature ranges from 90 to 150°C. In that case, the abstracted water, be it liquid or gaseous when it reaches the surface, transfers its heat to another working fluid that vaporizes at below 100°C. The steam obtained in 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 2021 and 2022 (in MWe)*

	2021		2022	
	Capacity installed	Net capacity	Capacity installed	Net capacity
Italy	915.5	771.8	915.5	771.8
Germany	54.0	46.0	59.0	50.0
Portugal	34.0	29.1	34.0	29.1
Croatia	16.5	10.0	16.5	10.0
France	17.2	16.2	17.2	16.2
Hungary	3.4	3.0	3.4	3.0
Austria	1.2	0.3	1.2	0.3
Romania	0.05	0.05	0.05	0.00
Total EU-27	**1 041.8**	**876.3**	**1 046.8**	**880.3**

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



2

Gross electricity generation from geothermal energy in the European Union countries in 2021 and 2022 (in GWh)

	2021	2022
Italy	5 913.8	5 836.9
Germany	244.0	206.0
Portugal	178.5	194.6
France	100.3	113.6
Croatia	89.7	72.7
Hungary	12.0	4.0
Austria	0.03	0.002
Romania	0.0	0.0
Total EU-27	6 538.4	6 427.8

Source: Eurostat

GEOTHERMAL HEAT PRODUCTION

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

The EGEC (European Geothermal Energy Council) monitors the capacity of Europe's and the European Union's geothermal heating networks. It reports that there were 280 heating networks with 2 254.2 MWth of combined capacity operating in the European Union in 2022. Eleven new urban geothermal heating and cooling systems were commissioned in the EU, which is the same number as in 2021. They added 90.7 MWth to the existing capacity (134.2 MWth in 2021). If we go into detail, France added 5 systems (48.7 MWth); Poland added 1 (18 MWth); Italy 1 (20 MWth); Spain 1 (1.5 MW); Finland 2 (1.3 MW) and Hungary 1 (1.2 MW). The purchasable EGEC "Geothermal Market Report 2022" published in August 2023 gives distribution details of geothermal heating network by individual country.

One of the major installations made in 2022, was the urban heating system of Toruǎ, in Poland, that was converted to geothermal energy in 2022. Preliminary geothermal studies started in 2008, so this was a long drawn-out conversion process. The 18-MWth project will generate an average of 234 000 GJ of energy per annum (equating to 5.6 ktoe). Toruǎ is one of Poland's oldest cities, dating back to the 8th century. It is a UNESCO World Heritage Site; hence, the construction must adhere to strict environmental and aesthetic standards for which geothermal energy, with its limited environmental footprint and infinite supply of renewable resources, was deemed ideal.

More recently, the geothermal plant that will supply heat and cooling to the Olympic Village and many other buildings in the Pleyel district of Saint Denis, France, started up on 22 December 2023. This project is part of the 10-kilometre extension of the Smirec (Syndicat MIxte des Réseaux d'Energie Calorifique) network that covers an area of eight communities in the Seine-Saint-Denis department. The project, that absorbed 29 million euros of investment, involved the drilling of two "geothermal doublet" boreholes in the Dogger aquifer comprising a production well and a geothermal water reinjection well. A heat pump system will be coupled to the heat exchangers to increase output temperatures. The forecast average thermal capacity of the new doublet is about 11.7 MW. The project will eventually cover requirements put at 52.7 GWh per annum.

The EGEC points out that 276 urban geothermal heating and cooling plants were being developed in the European Union in 2023. Germany (102), France (24), the Netherlands (22) and Italy (21) had the greatest numbers of projects in the pipeline. This potentially amounts to doubling the number of active projects compared to 2022. One of these projects is the construction of Europe's biggest geothermal plant with 110 MW of capacity by the Danish company Innargi to provide urban heating to Aarhus. Once completed, the plant will heat about 20% of the city with renewable heat.

Eurostat statistically monitors geothermal heat output data. In the EU27, heat output from the processing sector, which broadly matches heat sales distributed by heating networks, is put at 350.1 ktoe in 2022 (336.3 ktoe in 2021), to which should be added the heat directly used by end users put at 601.3 ktoe in 2022 (575.9 ktoe in 2021), bringing total geothermal heat used in the EU27 to 951.4 ktoe in 2022 (912.1 ktoe in 2021).

ELECTRICITY PRODUCTION

European Union geothermal power capacity increased only slightly between 2021 and 2022. Once again, Germany was the only country to move up a notch. According to AGEE-Stat, officially recorded capacity increased by 5 MW YoY, taking cumulative capacity to 59 MW at the end of 2022. According to EurObserv'ER, this additional capacity does not take in the operational commissioning of a thirteenth geothermal plant on German soil but coincides with the administrative authorisation to increase the injection capacity of the Kirchweidach geothermal plant in Bavaria, owned by the utility company E.ON. This plant, which is undergoing extension works, already has a 1-MWe ORC (Organic Rankine Cycle) electricity generating module that has been operating since the end of 2021. The works, carried out by Turboden, an Italian company that specialises in constructing turbogenerators based on ORC technology, will shortly raise the installation's capacity to 6 MWe.

Boring operations at another commercial project in Bavaria that uses the Eavor-Loop™ system developed by Canada's Eavor Technologies, started in July 2023 at Geretsried. Eavor-Loop™ is an innovative system that operates in a completely closed loop without fracking or GHG emissions, it does not produce any brine or contaminate the aquifers. The project calls for the boring of four loops (eight wells) to a depth of 4 500 metres and will benefit from high-collapse tubular solutions produced by the French company Vallourec. Partial commercial operation of the Geretsried facility is expected in October 2024 when the first loop is completed, but it will not be fully operational until the end of 2026. Over its initial 30-year lifecycle, it will produce 64 MW of thermal energy, 8.2 MW of electricity and deliver 44 000 tonnes of CO_2 emission savings per annum. This project has received a European Innovation Fund grant worth 91.6 million euros. The EGEC is highly optimistic about the future development of geothermal plants in the EU and claims that the geothermal power market has entered a new development phase. Many plants are due to start up in the next 5–7 years. It has identified 36 projects at development stage and 111 in the study phase.

Meanwhile, the EU's installed geothermal power capacity has risen to 1 046.8 MWe spread across 58 plants, according to EurObserv'ER. Eurostat puts net capacity, which is the maximum capacity presumed to be exploitable, at 880.3 MWe in 2022 (i.e., 4 MWe more than in 2021). Eurostat also reports that the European Union's gross geothermal power output slipped again over the 12-month period to 6.4 TWh (by 1.7%) with output drops measured in Italy, Germany, Hungary and Croatia and while rises were measured in France and Portugal. These annual variations may be put down to maintenance operations.

3

Heat consumption from geothermal energy in the countries of the European Union in 2021 and 2022 (in ktoe)***

	2021			2022		
	Total	*of which final energy consumption*	*of which derived heat***	**Total**	*of which final energy consumption*	*of which derived heat***
France	209.1	40.2	169.0	190.7	40.2	150.5
Germany	140.7	94.7	46.0	165.4	93.3	72.2
Netherlands	151.1	151.1	0.0	162.4	162.4	0.0
Hungary	139.0	68.8	70.2	154.7	79.8	74.8
Italy	140.6	115.0	25.6	135.3	109.6	25.7
Bulgaria	36.1	36.1	0.0	36.6	36.6	0.0
Poland	28.4	28.4	0.0	31.5	31.5	0.0
Austria	23.4	10.2	13.2	22.0	8.6	13.4
Romania	15.3	9.0	6.2	17.6	11.3	6.4
Slovenia	11.3	10.8	0.5	13.2	12.7	0.5
Greece	4.3	4.3	0.0	7.9	7.9	0.0
Slovakia	4.0	0.7	3.2	4.9	0.7	4.2
Croatia	5.0	5.0	0.0	4.7	4.7	0.0
Portugal	1.4	1.4	0.0	1.8	1.8	0.0
Belgium	1.6	0.0	1.6	1.6	0.0	1.6
Denmark	0.6	0.0	0.6	1.0	0.0	1.0
Spain	0.2	0.2	0.0	0.2	0.2	0.0
Total EU-27	**912.1**	**575.9**	**336.3**	**951.4**	**601.3**	**350.1**

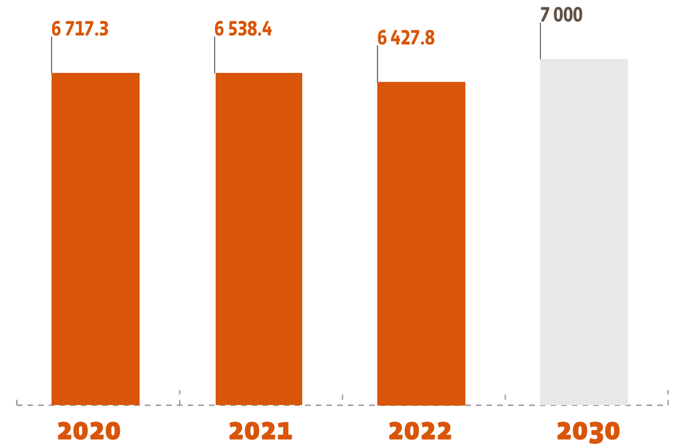
** Heat consumption is equivalent to Final energy consumption in «Industry» and «Others sectors» except transport and gross heat production in the transformation sector. ** Gross heat production in the transformation sector.* ***Source: Eurostat***

THE EUROPEAN GEOTHERMAL SECTOR MAKES ITS VOICE HEARD

"Geothermal Energy market developments in recent months in Europe have proven once again the essential role of geothermal in improving energy security with affordable heating, cooling, and electricity, in addition to its well-established effectiveness at reducing emissions. Last winter, Geothermal supplied clean heating to more than 10 million citizens in Europe", reported Philippe Dumas. (Secretary General of the EGEC) when the latest annual edition of the "Geothermal market report 2022" was published. The national and European decision makers are gradually getting the message. Proof of this is that geothermal energy is now one of the strategic clean technologies included in the "net zero" (NZIA act) regulation for an industry alongside HPs, which puts it on an equal footing with solar panels, wind turbines, sustainable biomethane biogas and storage technologies. This recognition was reiterated on 17 January 2024 when the European Parliament voted by an overwhelming majority to pass a resolution to support a European geothermal energy strategy. The resolution declares that complex national regulations, compounded by long authorisation processes have delayed the deployment of geothermal energy. To remedy the situation, the MEPs call for a European geothermal energy strategy, starting with the mapping of geothermal resources across the EU to ensure that all data on the subsoil is gathered in a single place and made accessible to the public. The strategy also aims to reduce administrative loads and support investments in the building, industry and agriculture sectors throughout the EU, create an industrial geothermal alliance to accelerate best practices and efficiently implement legislation, set up a harmonised insurance scheme to mitigate the financial risks. Lastly, the resolution aims to encourage Member States to devise national geothermal energy strategies following the examples of France, Germany, Poland and Austria and help the regions in transition and former coal regions to make the transition to geothermal energy. The resolution voted by the European Parliament is clearly about the importance to be given to geothermal energy, holding that "*Geothermal energy is vital not only for the energy transition, but for the just transition*". ■

4

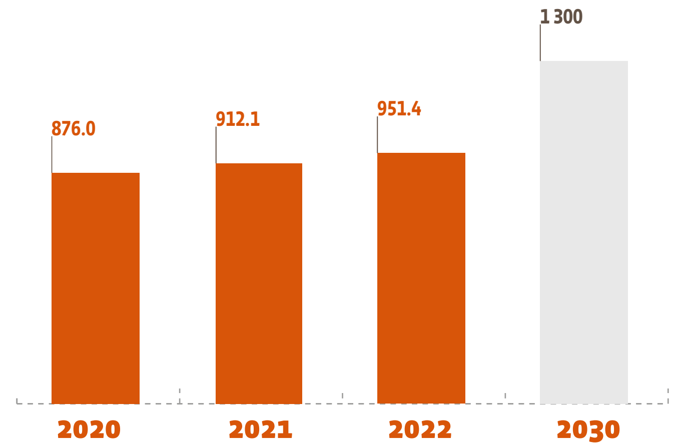
EurObserv'ER projection of geothermal electricity production in the EU-27 (in GWh)



Source: EurObserv'ER

5

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



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

HEAT PUMPS

The heat pump (HP) is one of the key technology options for achieving carbon neutrality, particularly as the electricity used to operate it tends to be decarbonized. HP technology can be used in all types (new, old, residential, tertiary, industrial or agricultural) and sizes of buildings (from single-family houses to large service sector tower blocks). Heat pumps cover heating, domestic hot water production and cooling needs. They can also be used in industrial processes that require heat, primarily in the agrifood sector, greenhouse heating and to raise the temperature of heating networks. The 2022 data for the European Union HP market displays historic growth in the heating market, following several years of strong growth. This momentum can be attributed to European and national policymakers' strong determination to promote the electrification of heating requirements at the expense of oil- and gas-fired heating to achieve European and national climate goals of slashing GHG emissions. Russia's February 2022 attack on Ukraine strengthened this resolve that was deepened by the urgent need to curb the EU's dependency on Russian fossil fuels.

A RANGE OF TECHNOLOGIES

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

ASHPS DOMINATE THE MARKET

EurObserv'ER puts the number of heat pumps sold in 2022 across the European Union at just over 6 million, taking all capacity

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1

Market of aerothermal heat pumps in 2021 and 2022 in the European Union (number of units sold)

	2021				2022			
	Aerothermal HP	of which air-air HP	of which air-water HP	of which exhaust air HP	Aerothermal HP	of which air-air HP	of which air-water HP	of which exhaust air HP
Italy	2 006 404	1 909 431	96 973	0	2 200 957	1 911 912	289 045	0
France	1 104 850	837 629	267 221	0	1 118 637	772 324	346 313	0
Spain	438 000	385 290	52 710	0	497 541	423 463	74 078	0
Netherlands	346 350	296 584	49 766	0	398 011	304 031	93 980	0
Portugal	286 500	286 126	374	0	332 300	331 982	318	0
Germany	150 665	0	127 665	23 000	242 059	0	205 702	36 357
Finland	119 859	103 136	12 416	4 307	184 587	161 920	19 035	3 632
Sweden	152 003	114 000	17 865	20 138	187 213	150 000	19 162	18 051
Belgium	99 915	86 915	13 000	0	111 040	87 286	23 754	0
Poland	90 383	11 018	79 350	15	208 574	20 374	188 160	40
Denmark	70 236	50 030	19 971	235	83 720	48 472	34 975	273
Malta	60 796	60 796	0	0	60 796	60 796	0	0
Slovakia	43 778	38 961	4 626	191	50 774	39 219	11 555	0
Greece	48 942	48 942	0	0	30 519	30 519	0	0
Czechia	28 542	0	28 380	162	57 644	0	57 524	120
Slovenia	28 400	18 900	9 500	0	28 750	18 650	10 100	0
Austria	25 914	173	25 741	0	44 645	1 201	43 444	0
Ireland	25 288	6 397	17 554	1 337	25 288	6 397	17 554	1 337
Lithuania	24 420	15 180	9 240	0	14 866	8 907	5 959	0
Estonia	18 448	13 902	4 509	37	19 575	13 902	5 636	37
Hungary	6 504	0	6 504	0	99 127	87 659	11 468	0
Luxembourg	281	0	281	0	303	0	303	0
Total UE-27	5 176 478	4 283 410	843 646	49 422	5 996 926	4 479 014	1 458 065	59 847

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

2

Market of geothermal (ground source) heat pumps in 2021 and 2022 in the European Union (number of units sold)*

	2021	2022
Sweden	25 499	28 160
Germany	24 542	25 320
Netherlands	21 792	22 693
Finland	9 516	11 772
Poland	5 650	7 521
Austria	5 270	5 748
Denmark	4 033	5 113
Belgium	3 605	5 922
France	3 220	3 260
Estonia	2 191	2 191
Czechia	1 637	2 419
Slovenia	1 163	1 318
Italy	953	625
Lithuania	710	2 428
Hungary	416	911
Spain	326	246
Slovakia	274	319
Ireland	190	190
Luxembourg	184	199
Greece	178	356
Portugal	57	82
Total UE-27	111 406	126 793

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

EUROBSERV'ER – THE STATE OF RENEWABLE ENERGIES IN EUROPE – 2023 EDITION

ranges and technologies together, and amounting to a 15.9% increase on 2021 (when 5.3 million units were sold). This should be taken as a broad assessment as it includes all the thermodynamic technologies designed to produce heat for space heating, including reversible heat pumps (that produce heat or cooling to order), whose main use is for cooling. This caveat is important, as the market for HPs whose main function is heating, is smaller. The EHPA (European Heat Pump Association) puts 2022 sales of HPs mainly dedicated to heating at 3 million units, amounting to 39% growth (see below).

The inclusion of reversible HPs primarily used for cooling purposes is justified by the contribution that these appliances make towards EU's renewable energy production targets both for heating and cooling, provided that their performance criteria make them eligible. Since the Commission defined a specific calculation method (delegated regulation 3022/759 of 14 December 2021), modifying

Annex VII of the Renewable Energy Directive (2018/2001) (RED II), the accounting of renewable energy production used for cooling and cooling networks has greatly improved. Annex VII initially only provided a calculation method for renewable energy from heat pumps used exclusively in heating mode.

These figures are particularly representative of the residential and tertiary markets (with power ranges starting at a few kW to several tens of kW), as the medium- and high-capacity HP market is much smaller. It should be remembered that the various types of HPs produce different amounts of renewable energy. Their outputs depend on the thermal energy source tapped (ground, water, air), the application (heating or cooling), the usage period and installation climate zone. The unit power ratings of air-to-air HPs are generally much lower than those of water-borne HPs. A low power reversible air-to-air HP installed in a hot climate zone primarily used for cooling will produce much less renewable heat than a ground-source or air-to-water HP installed in Finland or Sweden.

Reversible air-to-air ASHPs still dominate HP sales in the European HP market, which EurObserv'ER puts at over 4.5 million units for 2022 – a 4.6% year-on-year rise. A significant part of this growth can be ascribed to Italy's exceptionally high replacement rate, in particular of small mono-split heat pumps (featuring an external unit coupled to an internal unit) that are for the most part used for cooling purposes. The EHPA (European Heat Pump Association), in the 2023 edition of its annual publication European Heat Pump Market and Statistics report, claims that at about 1.9 million reversible air-to-air HP units were sold in Italy in 2021 and 2022. Yet, the industry association counts only 178 775 new air-to-air HPs mainly used for heating in 2022, to which 30 070 direct expansion type VRF (variable refrigerant flow) HPs should be added.

The water-borne ASHP market specifically caters for heating needs. Sales in this market segment were very high. EurObserv'ER reports that about 1.5 million water-borne units were sold across the European Union, recording a 72.8% increase on the 2021 performance. Two-or three-digit growth rates were observed in most of the major European Union markets – such as 198.1% in Italy, 137.1% in Poland, 88.8% in the Netherlands, 82.7% in Belgium, and 61.1% in Germany.

The geothermal (and hydrothermal) HP segment also caters specifically for heating needs but is less popular. Segment growth was also positive across the European Union. Between 2021 and 2022, the number of geothermal HP units sold increased by about 13.8% to reach almost 127 000 in 2022. Sweden, Germany, the Netherlands and Finland are the European Union's biggest markets for these HPs.

Taken together, the sales volume of water-borne HPs (air-to-water ASHPs, geothermal and hydrothermal) rose year-on-year by 65.9% to about 1.6 million units (1 584 858 systems).

THE EUROPEAN HP BASE STANDS AT OVER 50 MILLION UNITS

Estimating the number of HPs in service is a tricky task as the exercise must make allowance for the decommissioning assumptions factored in by each country and the availability of statistics supplied by the Member States or HP industry associations. EurObserv'ER puts the combined total of installed HPs in the European Union at roughly 50.9 million units (48.8 million ASHPs and 1.9 million GSHPs). This figure reflects not only the heating uses, but the cooling and heating uses, provided that the system performance coefficients meet the Renewable Energy Directive criteria.

The EHPA's approach to the heat pump function is more restrictive and historical, as it contends that for inclusion in the statistics, the heat pumps' main function must be heating, thus excluding HPs systems whose main application is cooling. In its 2023 *European Heat Pump Market and Statistics* report, the EHPA estimated that the total base of HPs in service in Europe (including Norway and Switzerland) mainly used for heating (space heating and domestic hot water production) was about 19.79 million in 2022. It concludes that the 2022 market grew by 39% – i.e., only about 3 million units (just under 2.7 million for heating and 320 000 exclusively producing domestic hot water). The HP equipment rate of Europe's building stock is over 16% on the basis of 115–120 million buildings.

ROYAL ROAD FOR THE HP MARKET

HPs are not only identified as a promising key technology for decarbonising the building sector but are also accepted as harnessing one of the technologies that already makes the greatest contribution to the increase in renewable energy produc-

3

*Total number of heat pumps in operation in 2021 and 2022 in the European Union **

	2021			2022		
	Aerothermal HP	Geothermal HP	Total	Aerothermal HP	Geothermal HP	Total
Italy	20 706 000	17 098	20 723 098	20 831 000	17 723	20 848 723
France	8 600 000	172 000	8 772 000	9 500 000	170 000	9 670 000
Spain	4 996 334	3 816	5 000 150	5 493 875	4 062	5 497 937
Sweden	1 598 485	560 333	2 158 818	1 767 110	560 997	2 328 107
Portugal	2 133 800	1 105	2 134 905	2 326 400	1 187	2 327 587
Netherlands	1 364 349	106 264	1 470 613	1 760 665	125 374	1 886 039
Germany	989 241	427 391	1 416 632	1 216 249	449 742	1 665 991
Finland	1 050 128	146 124	1 196 252	1 234 715	157 896	1 392 611
Denmark	511 528	77 798	589 326	585 783	82 316	668 099
Belgium	519 995	22 602	542 597	631 035	28 524	659 559
Greece	576 497	3 878	580 375	607 017	4 234	611 251
Poland	257 458	71 468	328 926	466 032	78 989	545 021
Malta	534 578	0	534 578	535 000	0	535 000
Bulgarie	349 667	4 695	354 362	349 667	4 695	354 362
Austria	172 058	114 919	286 977	215 997	118 013	334 010
Slovenia	266 100	14 817	280 917	284 120	16 135	300 255
Czechia	209 164	29 393	238 557	266 808	31 812	298 620
Estonia	195 175	21 566	216 741	214 750	23 757	238 507
Slovakia	180 638	4 454	185 092	231 412	4 773	236 185
Hungary	25 124	3 508	28 632	124 251	4 419	128 670
Ireland	76 121	5 228	81 349	101 409	5 418	106 827
Lithuania	30 734	22 372	53 106	45 600	24 800	70 400
Luxembourg	2 792	1 514	4 306	3 095	1 596	4 691
Total UE-27	45 345 966	1 832 343	47 178 309	48 791 990	1 916 462	50 798 452

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

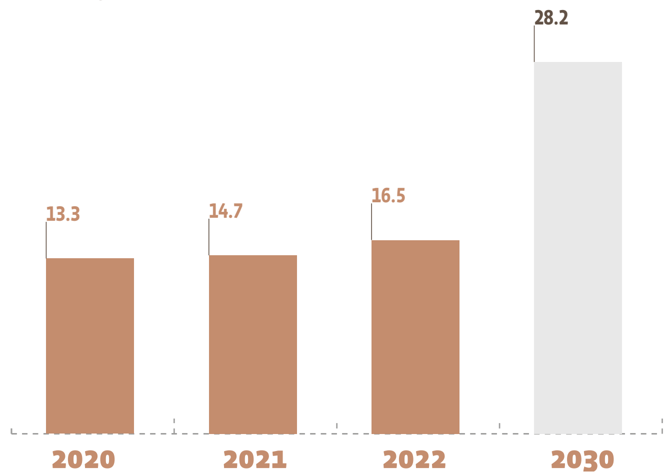
tion. The Eurostat SHARES tool puts the total renewable heating contribution of HPs in the EU27 at 16 479 ktoe in 2022… a YoY rise of 1 787.9 ktoe. In 2022, air source HPs and hydrothermal HPs produced 13 782.3 ktoe of renewable energy compared to 2 696.8 ktoe by geothermal HPs. For the first time, the renewable energy output of HPs provided 14.9% of the renewable heat and cooling total in 2022 (13.2% in 2021), overtaking that of district heating networks (derived heat). SHARES puts the renewable energy output of HPs for refrigeration and cooling at 855.5 ktoe in 2022 (cf. 690.7 ktoe in 2021).

The sharp market upturn of 2022 was boosted by Europe's response to Russia's February invasion of Ukraine. This led to one of the REPowerEU plan's targets to install an additional 60 million residential heat pumps by 2030 (to slash reliance on Russian fossil fuels as fast as possible). The target, supported by the EHPA, is clearly geared to fast-tracking HP installations, primarily by stimulating the industry and its installation segments. The European Union at last has a tool for accelerating the industrial deployment of decarbonised technologies. On 6 February 2024, the European Parliament, Council and Commission reached an agreement to adopt the "Net-Zero Industry Act", Europe's answer to the USA's Inflation Reduction Act launched in the summer of 2022 to fund its energy transition. The EU aims to produce at least 40% of the decarbonised technologies on its own soil by 2030, such as wind energy, solar energy, batteries, biomethane, specific nuclear components and also HPs. The EHPA points out that 60% of the heat pumps sold in Europe are manufactured in Europe and that given the sector's record sales, it believes that with the right combination of support mechanisms, this level can be sustained or even expanded. In particular, this new act should enable the Member States to shorten factory creation authorisation times and support the rollout of the most robust and sustainable "Made in Europe" technologies on European soil (as opposed to price considerations dominating their decisions).

For the current decade, everything is lined up to accelerate heat pumps' contribution to the climate targets, supported by a much more proactive policy for energy renovation in buildings. The energy policy through to 2030 is now plotted by the new Renewable Energy Directive (RED III) No. 2023/2413 dated 18 October 2023, which creates an indicative 49% renewable energy target in buildings across the European Union. *"In order to promote the production and use of renewable energy in the building sector, Member States shall determine an indicative national share of renewable energy produced on-site or nearby as well as renewable energy taken from the grid in final energy consumption in their building sector in 2030 that is consistent with an indicative target of at least a 49% share of energy from renewable sources in the building sector in the Union's final energy consumption in buildings in 2030."* The Directive also sets the Member States a minimal annual average binding increase of 0.8 of a percentage point from the 2020 reference level in the use of renewable energy for heating and cooling between 2021 and 2025 and one of at least 1.1 percentage points between 2026 and 2030. ■

4

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



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

BIOGAS

Methanation is a natural biological process in which many microorganisms break down organic matter in an oxygen-free environment. Biogas produced by anaerobic fermentation breaks down into three sub-sectors that are segmented by the origin and treatment of the waste. They include biogas from non-hazardous waste storage facilities (landfill biogas), anaerobic digestion of urban or process waste water treatment plant sludge (sludge digestion gas) and the anaerobic digestion of non-hazardous waste or raw plant matter ("other biogas" category). This "other biogas" category is very broad and covers various installation types. It includes small farming anaerobic digesters that basically ferment agricultural materials from farms, and larger territorial or industrial methanation plants. These co-digestion plants can treat a mixture of different feedstocks (agricultural waste, food processing industry waste, green waste and so on). It also includes household waste and biowaste anaerobic digestion units that treat selectively collected biowaste or the organic fraction of plant-sorted household waste. Landfill biogas is naturally produced in non-hazardous waste storage facilities by decomposition. The organic fraction of this waste is recovered by capture networks. So, this is not considered as methanation biogas, because it is not produced with the aid of a digester. A fourth biogas sector is also monitored in international nomenclature and results from heat treatment ("thermal process biogas") by thermal gasification of solid biomass (wood, forest residue, solid and fermentescible household waste) or by hydrothermal gasification of liquid biomass. These processes result in the production of a methane-rich syngas that is purified to biomethane. Biogas can be used unaltered in production plants that operate using low-methane gas (50–75%, depending on the production sources) or if previously "washed" to be converted into biomethane, a gas with >97% of methane content, similar to natural fossil gas. This biogas (or biomethane) can in turn be used directly locally as electricity (in cogeneration),

1

Primary energy production from biogas in the European Union in 2021 and 2022 (in ktoe)

	2021					2022				
	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	112.8	478.6	7 610.0	0.0	**8 201.4**	111.6	472.2	7 540.9	0.0	**8 124.7**
Italy	267.0	49.8	1 754.0	7.3	**2 078.1**	242.8	42.1	1 610.1	4.2	**1 899.3**
France	336.1	42.2	998.6	0.0	**1 376.9**	370.5	49.0	1 222.2	0.0	**1 641.7**
Denmark	3.3	30.2	591.4	0.0	**625.0**	3.1	28.3	657.6	0.0	**689.0**
Czechia	19.6	41.5	529.8	0.0	**590.8**	19.0	43.7	535.7	0.0	**598.4**
Netherlands	9.4	67.9	356.7	0.0	**434.0**	11.0	63.1	359.1	0.0	**433.2**
Poland	47.6	119.2	152.6	0.0	**319.4**	52.1	129.4	171.2	0.0	**352.7**
Spain	147.3	98.5	77.3	2.8	**325.9**	154.5	98.9	78.8	1.1	**333.3**
Belgium	16.2	28.3	200.0	1.4	**245.8**	15.4	28.0	213.4	1.4	**258.1**
Sweden	6.6	76.3	111.8	0.0	**194.8**	5.6	79.6	110.7	0.0	**195.9**
Austria	1.7	35.2	124.1	0.0	**161.1**	2.2	41.2	140.8	0.0	**184.2**
Finland	12.5	17.7	39.8	124.5	**194.4**	10.9	16.9	43.4	105.3	**176.4**
Greece	47.0	20.4	59.8	0.0	**127.2**	45.2	18.3	81.8	0.0	**145.3**
Slovakia	6.9	6.9	116.9	0.0	**130.7**	6.0	6.8	90.1	0.0	**102.8**
Hungary	7.7	30.8	46.1	0.0	**84.7**	6.9	32.8	57.1	0.0	**96.8**
Croatia	7.1	3.5	88.6	0.0	**99.2**	7.0	3.8	80.0	0.0	**90.7**
Portugal	69.0	7.4	10.8	0.0	**87.2**	63.2	8.2	15.2	0.0	**86.6**
Latvia	7.9	1.9	56.2	0.0	**66.0**	6.9	1.5	47.1	0.0	**55.5**
Ireland	29.4	7.7	15.0	0.0	**52.0**	25.8	9.5	17.7	0.0	**53.0**
Bulgaria	0.0	5.9	53.8	0.0	**59.7**	0.0	5.4	44.7	0.0	**50.1**
Lithuania	5.5	8.1	26.5	0.0	**40.2**	5.5	8.2	28.1	0.0	**41.8**
Romania	0.0	0.0	23.2	0.0	**23.2**	0.0	0.0	26.3	0.0	**26.3**
Slovenia	1.3	1.2	22.4	0.0	**24.9**	1.3	1.2	21.9	0.0	**24.5**
Luxembourg	0.0	1.0	16.6	0.0	**17.6**	0.0	1.8	17.3	0.0	**19.1**
Estonia	1.0	6.6	10.6	0.0	**18.2**	1.0	5.0	12.1	0.0	**18.2**
Cyprus	0.1	0.8	12.4	0.0	**13.4**	0.3	0.9	11.2	0.0	**12.4**
Malta	0.0	0.0	1.9	0.0	**1.9**	0.0	0.0	2.0	0.0	**2.0**
Total EU-27	1 163.0	1 187.6	13 106.9	136.0	15 593.5	1 167.7	1 195.9	13 236.5	111.9	15 712.0

Source: Eurostat

heat, or vehicle fuel. Alternatively, when accessibility to the natural gas grid is economically viable, biomethane can be injected into the grid once it has been odorised with THT (tetrahydrothiophene). As a result, its use can be postponed and occur away from its production site. This solution offers better energy yield with 80% of the primary energy recovered compared to 40–55% for cogeneration). The biomethane will be used in the same way as grid gas, as electricity in gas-fired or CHP plants, as heat from the processing sector (e.g.: heat grid) or used directly by the final user in industry (process heat, cooling), households (heating, domestic hot water, cooking, etc.) and even as fuel for natural gas vehicles.

BIOGAS PRODUCTION IN THE EUROPEAN UNION APPROACHES 16 MTOE

The Russian-Ukrainian conflict has intensified the urgency of accelerating the European Union's transition to energy self-sufficiency and given the European biogas sector a vital strategic role. Europe's biogas producers are making headway but explain that it will take time to increase their output significantly, obtain administrative authorisations and build production plants. The growth in European biogas output observed between 2021 and 2022 primarily reflects the investment decisions made after the rollout of the REPowerEU plan. The plan was launched in May 2022 and aims to protect EU citizens and businesses from energy shortages, accelerate the transition to clean energy and retrench European purchases of Russian

2

Gross electricity production from pure biogas and from biogas blended in the grid in the European Union in 2021 and 2022 (in GWh)

	2021				2022			
	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	8 381.2	23 975.0	32 356.2	3 167.0	8 279.0	23 943.0	32 222.0	2 993.0
Italy	2 508.6	5 615.6	8 124.2	0.0	2 403.1	5 441.0	7 844.1	0.0
France	348.4	2 670.3	3 018.6	301.3	304.2	2 680.5	2 984.7	727.7
Czechia	37.2	2 555.6	2 592.8	0.9	37.2	2 579.3	2 616.5	0.7
Poland	0.0	1 307.3	1 307.3	0.0	0.0	1 394.2	1 394.2	0.0
Belgium	59.2	917.1	976.3	9.9	56.7	956.3	1 013.0	20.8
Spain	727.0	252.0	979.0	18.9	718.0	272.0	990.0	34.8
Netherlands	13.1	854.7	867.8	245.4	15.7	826.1	841.8	267.2
Austria	557.2	44.4	601.6	14.4	542.1	51.5	593.5	16.7
Denmark	1.5	613.1	614.6	277.0	1.6	572.7	574.3	268.2
Greece	80.4	376.5	456.8	0.0	68.6	449.2	517.8	0.0
Croatia	39.0	401.2	440.2	0.0	37.0	372.2	409.2	0.0
Slovakia	85.0	402.0	487.0	0.0	74.0	317.0	391.0	0.0
Hungary	52.0	243.0	295.0	4.6	37.0	278.0	315.0	4.9
Finland	4.1	324.9	329.0	20.9	2.2	262.5	264.7	10.5
Portugal	248.6	19.0	267.6	0.0	238.4	21.3	259.8	0.0
Latvia	0.0	291.9	291.9	0.0	0.0	249.6	249.6	0.0
Bulgaria	52.0	164.2	216.2	0.0	45.9	144.9	190.9	0.0
Ireland	118.8	54.0	172.8	1.3	100.5	58.3	158.8	7.7
Lithuania	0.0	156.7	156.7	0.0	0.0	158.7	158.7	0.0
Slovenia	1.5	101.1	102.6	0.0	1.1	99.1	100.2	0.0
Romania	20.6	52.3	72.9	0.0	24.1	66.1	90.2	0.0
Cyprus	0.0	59.9	59.9	0.0	0.0	57.8	57.8	0.0
Luxembourg	0.0	60.9	60.9	1.1	0.0	48.8	48.8	0.7
Sweden	0.0	12.0	12.0	8.7	0.0	12.0	12.0	5.9
Malta	0.0	7.2	7.2	0.0	0.0	7.4	7.4	0.0
Estonia	0.0	16.4	16.4	0.0	0.0	5.6	5.6	0.0
Total EU-27	**13 335.4**	**41 548.4**	**54 883.9**	**4 071.4**	**12 986.4**	**41 325.2**	**54 311.7**	**4 358.7**

Note: The ranking in this table is based on the cumulative biogas electricity production from biogas used pure or mixed with the natural gas network. ***Source: Eurostat***

hydrocarbons. Eurostat reports that primary energy output from biogas across the European Union made an annual increase of 0.8 % to 15.7 Mtoe (15.6 Mtoe in 2021). Eurostat found that France and Denmark contributed the most to the 2022 increase in EU biogas output. French production rose by 264.9 ktoe to 1 641.7 ktoe and Danish production rose by 64 ktoe to 689 ktoe. German biogas output, which was subject to a statistical upward revision in 2021 (see further on) slipped very slightly between 2021 and 2022 (by 0.9% or 76.6 ktoe) along with Italian biogas output which fell by much more – 8.6% or 178.9 ktoe. Nonetheless, Germany is still far and away the leading EU biogas producer country and accounted for 51.7% of the EU total in 2022, ahead of Italy with 12.1% and France with 10.4%. If we consider per capita biogas output, then Denmark leads the field with 117.3 toe/1 000 inhabitants, ahead of Germany (97.6 toe/1 000 inh.) and Czechia (56.9 toe/1 000 inh.).

DIFFERENT STATISTICAL PATHWAYS FOR MONITORING FINAL BIOGAS ENERGY

More widespread biomethane injection into the natural gas grid has complicated the task of accurately monitoring the biogas sector's final energy recovery. For while primary biogas energy production includes all the output, the quantity of renewable biomethane injected into the grid (and thus blended with fossil gas) is absorbed in the statistical indicators for gas (factored into the Eurostat "Natural Gas" questionnaire). Hence,

3

Gross heat production in the transformation sector from pure biogas and from biogas blended in the grid in the European Union in 2021 and in 2022 (in ktoe)

	2021				2022			
	Heat only plants	CHP plants	Total pure biogas	Heat from biogas blended in the grid	Heat only plants	CHP plants	Total pure biogas	Heat from biogas blended in the grid
Germany	10.7	252.4	263.2	198.1	10.8	280.3	291.1	187.8
France	3.1	85.2	88.3	15.2	1.4	83.2	84.6	24.2
Denmark	2.0	47.4	49.4	61.2	2.0	42.3	44.3	56.3
Italy*	0.1	290.8	290.9	0.0	0.2	27.6	27.7	0.0
Poland	0.9	22.0	22.9	0.0	1.6	20.3	22.0	0.0
Finland	7.3	14.0	21.3	2.8	6.1	12.4	18.5	1.9
Belgium	0.0	21.4	21.4	0.2	0.0	19.9	19.9	0.3
Czechia	0.0	17.6	17.6	0.1	0.1	18.7	18.7	0.1
Latvia	0.2	19.3	19.5	0.0	0.3	15.1	15.4	0.0
Croatia	0.0	16.9	16.9	0.0	0.0	14.5	14.5	0.0
Netherlands	0.0	7.7	7.7	5.6	0.0	7.4	7.4	6.5
Slovakia	0.1	17.6	17.7	0.0	0.2	11.2	11.4	0.0
Sweden	1.5	3.8	5.3	2.8	2.0	3.8	5.8	1.9
Austria	1.2	3.6	4.8	1.1	1.0	3.3	4.3	1.0
Romania	1.8	2.9	4.6	0.0	1.3	3.4	4.6	0.0
Bulgaria	0.0	3.8	3.8	0.0	0.0	4.0	4.0	0.0
Slovenia	0.0	3.7	3.7	0.0	0.0	3.6	3.6	0.0
Hungary	0.0	2.7	2.7	0.4	0.0	2.7	2.7	0.4
Luxembourg	0.0	2.8	2.8	0.2	0.0	2.5	2.5	0.2
Lithuania	0.0	2.4	2.4	0.0	0.0	2.6	2.6	0.0
Cyprus	0.0	0.9	0.9	0.0	0.0	1.0	1.0	0.0
Estonia	0.3	1.3	1.6	0.0	0.2	0.2	0.4	0.0
Total EU-27	**29.1**	**840.3**	**869.4**	**287.6**	**27.1**	**579.9**	**607.0**	**280.6**

Note: The ranking in this table is based on the cumulative gross heat production from biogas used pure or mixed with the natural gas network.
** Italy changed methodology on reporting derived heat. On 28th January 2024 changes have been applied only for year 2022, an update will be carried out later to make the 2021 figures coherent with 2022.* ***Source: Eurostat***

fossil and renewable gas are no longer distinguished once the biomethane is used in the processing sector (power, cogeneration or heat plants) or in the total final energy consumption of transport, industry and other sectors. The traditional monitoring indicators for final biogas energy published by Eurostat refer exclusively to the use of "pure" biogas, which is not blended with fossil gas unless otherwise indicated by the national statistical authorities.
Eurostat, through its SHARES tool, lets Member States allocate the biomethane that is mixed into the grid across the various final energy recovery modes to a dedicated spreadsheet. Hence, tracking of this final "renewable" grid-injected biomethane energy is not lost, and can be included in the renewable energies target accounting of the Member States and European Union. Empirical and verifiable data, such as mass balance certificates must be used by the Member States when tracking. This distribution allows them to estimate the corresponding electricity, heat (or cooling) yields from the processing sector (heat sold) and heat (or cooling) directly used by end-users, as well as the biomethane fuel used in transport. Member States are also obliged to distinguish the fraction of these outputs deemed to comply with the Renewable Energy Directive specifications, which further obfuscates statistical monitoring.

OPPOSING TRENDS FOR ELECTRICITY AND HEAT

Renewed interest in biomethane injection into the grid and the conversion of several existing biomethane produc-

4

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 2021 and in 2022 (in ktoe)

	2021		2022	
	Pure biogas	Biogas blended in the grid	Pure biogas	Biogas blended in the grid
Germany	1 251.8	185.2	1 258.9	195.2
France	263.4	258.8	283.4	387.7
Denmark	20.8	304.5	24.9	354.3
Netherlands	135.9	73.8	123.0	77.1
Czechia	152.6	0.6	152.7	0.7
Spain	102.9	3.9	103.9	4.9
Poland	87.7	0.0	105.7	0.0
Belgium	96.8	4.4	97.6	7.8
Finland	97.9	4.1	89.2	6.5
Sweden	38.9	13.8	51.3	17.9
Italy	35.5	0.0	56.2	0.0
Austria	25.4	6.5	30.8	6.4
Greece	34.5	0.0	35.1	0.0
Hungary	14.4	2.9	22.7	2.9
Slovakia	25.0	0.0	19.6	0.0
Ireland	12.4	0.2	13.4	0.8
Portugal	7.2	0.0	12.4	0.0
Lithuania	10.2	0.0	10.9	0.0
Bulgaria	10.3	0.0	9.9	0.0
Latvia	6.9	0.0	7.3	0.0
Luxembourg	0.9	3.7	3.2	3.3
Cyprus	5.4	0.0	4.8	0.0
Slovenia	2.7	0.0	3.2	0.0
Romania	2.6	0.0	2.5	0.0
Estonia	2.7	0.0	2.0	0.0
Malta	0.6	0.0	1.0	0.0
Croatia	0.5	0.0	0.6	0.0
Total EU-27	**2 446.0**	**862.4**	**2 526.3**	**1 065.6**

Note: The rank of this table is based on the cumulative final energy consumption from biogas used pure or mixed with the natural gas network. ***Source: Eurostat***

5

Gross electricity production from biogas (pure and blended in the grid) in the European Union in 2022 compliant with the Directive (EU) 2018/2001 (in GWh)*

	2022		
	Biogas (pure and blended in the grid)	of which compliant	% compliant
Germany	35 215.0	35 215.0	100.0%
Italy	7 844.1	7 844.1	100.0%
France	3 712.4	3 712.4	100.0%
Czechia	2 617.2	2 617.2	100.0%
Poland	1 394.2	1 394.2	100.0%
Belgium	1 033.8	1 032.4	99.9%
Spain	1 024.8	1 024.8	100.0%
Netherlands	1 108.9	396.6	35.8%
Austria	610.2	130.0	21.3%
Denmark	842.6	842.6	100.0%
Greece	517.8	517.8	100.0%
Croatia	409.2	409.2	100.0%
Slovakia	391.0	391.0	100.0%
Hungary	319.9	133.9	41.9%
Finland	275.2	272.3	98.9%
Portugal	259.8	259.8	100.0%
Latvia	249.6	249.6	100.0%
Bulgaria	190.9	126.2	66.1%
Ireland	166.5	21.4	12.9%
Lithuania	158.7	158.7	100.0%
Slovenia	100.2	100.2	100.0%
Romania	90.2	25.9	28.7%
Cyprus	57.8	57.8	100.0%
Luxembourg	49.5	49.5	100.0%
Sweden	17.9	17.7	99.1%
Malta	7.4	7.4	100.0%
Estonia	5.6	5.6	99.2%
Total EU-27	**58 670.4**	**57 013.2**	**97.2%**

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

tion units are partly responsible for the relative stability or slight drop in electricity and heat output from local dedicated biogas (or biomethane) recovery plants across the European Union. Eurostat puts the electricity output from plants in 2022 that use pure biogas (not blended in the grid), produced and used locally at 54.3 TWh, which amounts to a 1.0% dip. This contrasts with the 7.1% increase in electricity output from biogas mixed into the grid to just under 4.4 TWh. If we add the two together, pure biogas and biogas mixed into the grid, output slipped by 0.5% from its 2021 figure (59 TWh) to 58.7 TWh in 2022.

Data on biogas heat output from the processing sector is skewed. Italy, which until now had been the number two country for this indicator revised its reporting method for derived heat and only applied the change to 2022, while an update is shortly awaited that should come into force at the start of 2024. Thus, the new indicator which slashes Italy's derived biogas heat figure and that of the European Union total is insignificant. If Italy is removed from the calculations, derived pure biogas heat and biogas mixed into the grid remained almost stable across the EU (slipping 0.7% between 2021 and 2022) to 859.9 ktoe.

There are no indicator issues with the direct use of biogas energy for heat (and cooling) output. In the case of "pure" biogas, it increased by 3.3% to 2.5 Mtoe in 2022 and the indicator for biogas mixed into the grid rose sharply by 23.6% to 1.1 Mtoe.

The data available through the Eurostat SHARES tool shows that almost all of the output

6

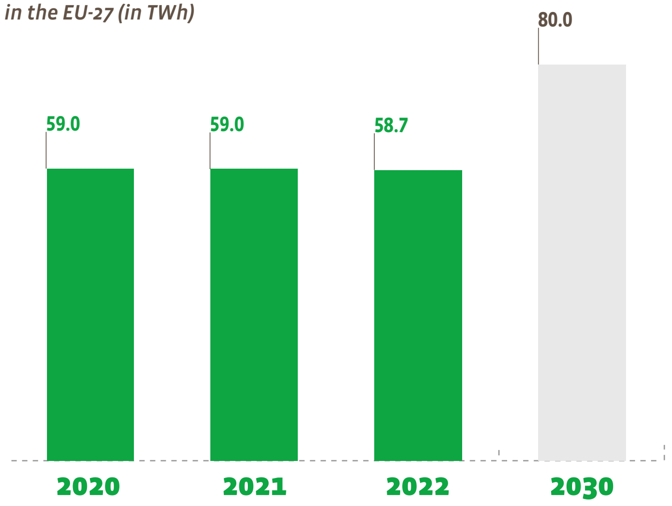
Heat consumption biogas (pure and blended in the grid) of which compliant with the Directive (EU) 2018/2001** in the European Union in 2022 (in ktoe)*

	Gross heat in the transformation sector			Final energy consumption in industry and other sectors (except Transport)			Total Heat		
	Biogas (pure and blended in the grid)	of which compliant	% compliant	Biogas (pure and blended in the grid)	of which compliant	% compliant	Biogas (pure and blended in the grid)	of which compliant	% compliant
Germany	478.9	478.9	100.0%	1 454.1	1454.1	100.0%	1 932.9	1932.9	100.0%
France	108.7	108.7	100.0%	671.0	671.0	100.0%	779.8	779.8	100.0%
Denmark	100.6	100.6	100.0%	379.2	379.2	100.0%	479.8	479.8	100.0%
Netherlands	14.0	6.3	45.4%	200.1	103.4	51.7%	214.1	109.7	51.3%
Czechia	18.9	18.9	100.0%	153.5	153.5	100.0%	172.4	172.4	100.0%
Poland	22.0	22.0	100.0%	105.7	105.7	100.0%	127.7	127.7	100.0%
Belgium	20.2	20.2	99.9%	105.4	104.9	99.5%	125.6	125.1	99.6%
Finland	20.4	20.2	99.0%	95.7	94.7	99.0%	116.0	114.9	99.0%
Spain	0.0	0.0	-	108.8	108.8	100.0%	108.8	108.8	100.0%
Italy	27.7	27.7	100.0%	56.2	56.2	100.0%	83.9	83.9	100.0%
Sweden	7.7	7.6	99.1%	69.2	69.1	99.8%	76.9	76.7	99.8%
Austria	5.3	0.9	17.8%	37.3	30.8	82.7%	42.5	31.8	74.7%
Greece	0.0	0.0	-	35.1	35.1	100.0%	35.1	35.1	100.0%
Slovakia	11.4	11.4	99.6%	19.6	19.6	100.0%	31.0	31.0	99.8%
Hungary	3.2	2.0	63.3%	25.6	11.9	46.5%	28.7	13.9	48.4%
Latvia	15.4	15.4	100.0%	7.3	7.3	100.0%	22.6	22.6	100.0%
Croatia	14.5	14.5	100.0%	0.6	0.0	0.0%	15.1	14.5	96.1%
Ireland	0.0	0.0	-	14.3	10.1	70.6%	14.3	10.1	70.6%
Bulgaria	4.0	2.0	50.8%	9.9	7.5	75.5%	13.9	9.5	68.5%
Lithuania	2.6	2.6	100.0%	10.9	10.9	100.0%	13.5	13.5	100.0%
Portugal	0.0	0.0	-	12.4	12.4	100.0%	12.4	12.4	100.0%
Luxembourg	2.8	2.8	100.0%	6.5	6.5	100.0%	9.3	9.3	100.0%
Romania	4.6	4.6	99.4%	2.5	2.5	98.2%	7.2	7.1	98.9%
Slovenia	3.6	3.6	100.0%	3.2	3.2	100.0%	6.8	6.8	100.0%
Cyprus	1.0	1.0	100.0%	4.8	4.8	100.0%	5.8	5.8	100.0%
Estonia	0.4	0.4	100.0%	2.0	2.0	100.0%	2.3	2.3	100.0%
Malta	0.0	0.0	-	1.0	1.0	100.0%	1.0	1.0	100.0%
Total EU-27	887.6	872.1	98.3%	3 591.9	3 466.3	96.5%	4 479.5	4 338.4	96.9%

** 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

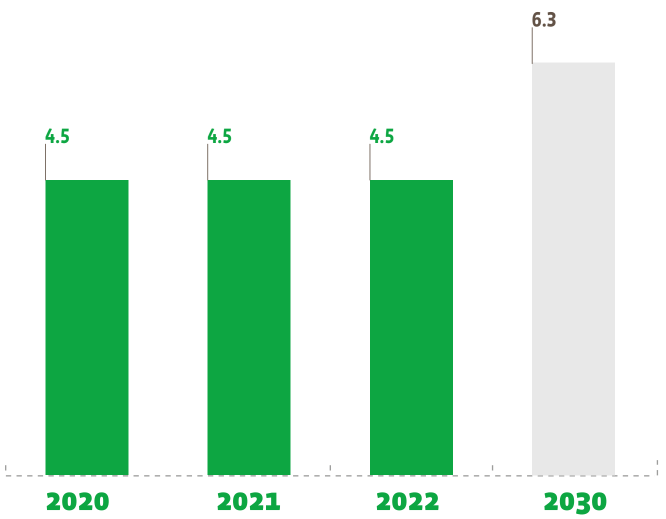
EurObserv'ER projection of electricity production from biogas in the EU-27 (in TWh)



Source: EurObserv'ER

8

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



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

of electricity, derived heat and final energy consumption is deemed to comply with the requirements of RED II and thus is included in the renewable energy target calculations of the Member States. When the pure biogas and biogas mixed into the grid are added together, the compliance percentage was 97.2% for electricity, 98.3% for derived heat and 96.5% for final energy consumption (excluding transport).

METHANATION'S ROLE DIFFERS FROM COUNTRY TO COUNTRY

FRANCE SEEKS TO SPEARHEAD EUROPEAN BIOMETHANE PRODUCTION

France is currently investing more than any other EU country in its biogas sector and in particular, in its biomethane sector. According to Eurostat, France increased its primary biogas energy output by 19.2% between 2021 and 2022 to 1 641.7 ktoe… an increase of 264.9 ktoe in the space of twelve months. The ADEME expert file on methanation counted over 1 450 anaerobic digesters in service in January 2023, of which 108 were in industry and 95 at wastewater sewage plants. There were 1 238 farm-based digesters and centralized installations in service, with strong growth momentum driven by the farming sector, sometimes in co-digestion with biowaste. Most of the projects (roughly 9 out of 10) commissioned in 2022 recover biogas injecting biomethane into the grid. As of 31 December 2022, according to the Statistical Studies and Data Service (SDES), 514 installations had injected biomethane, following biogas production and purification into the natural gas grid, i.e., 149 more than in 2022 (152 in 2021). Their capacity had risen to 9.0 TWh p.a. by the end of 2022, which is a 38% YoY rise. Over the course of the year 2022, 2 506 GWh p.a. of additional capacity was installed, which is higher than the previous year's newly installed capacity (2 359 GWh p.a.). Total injected biomethane output stood at 7.0 TWh in 2022, which is a 61% rise over 2021.

BIOGAS, AN ELEMENT OF FLEXIBILITY IN GERMANY

Yet again in 2022, over half of the European Union's biogas output was produced in German digesters, i.e., 8.1 Mtoe of the 15.7 Mtoe for the whole of the EU. It should be borne in mind that Germany has almost 10 000 biogas plants, 9 876 at the end of 2022 according to Fachverband Biogas (the German biogas association), 242 of which inject biomethane into the gas grid. Now, the new installation pace is much slower than that of the end of the 2000s and the beginning of the 2010s when over a thousand biogas units were started up every year (1 314 new plants in 2009, 1 107 in 2010 and 1 526 in 2011). Since 2017, Germany's market has revolved around a hundred or so new digesters every year, a large number of which are small slurry digesters (122 in 2017, 113 in 2018, 91 in 2019, 97 in 2020, 167 in 2021 and 77 in 2022).

Since the 2014 and 2017 German renewable energies law (EEG) reforms, the government has changed tack and no longer seeks the proliferation of digesters, but instead to make the biogas electricity production of its existing units more flexible. It has changed its priority to expanding the sites in service, gaining flexibility by boosting their installed capacity so that their output coincides with peak demand periods. As a result of this policy, the electrical capacity of Germany's biogas facilities has surged since 2016, and according to the German biogas association, capacity has risen from 4 018 MW in 2015 to 5 895 MW in 2022 although the installed capacity used has only risen from 3 723 MW in 2015 to 3 833 MW in 2022. Ofate (the Franco-German Office for Energy Transition) explains that the German government introduced a flexibility premium in 2012 for the purpose of increasing usable electrical capacity during peaks in demand, thus distinguishing between "total capacity" and "used capacity". In order to take advantage of this additional peak capacity, facility operators must reduce the amount of biogas that they inject the remainder of the time and must maintain the same average injected capacity level over the year as they applied before the upgrade works. This distinguishes "total peak capacity" from "usable installed capacity".

BIOMETHANE OUTPUT TO BE DOUBLED BY 2030

The investments already made in European biogas production, motivated both by environmental considerations and the determination to reduce Member States' energy dependency on gas, have been given real meaning since Russia invaded Ukraine. The European Union's over-reliance on Russian gas has had dramatic consequences leading to increased energy bills for households, institutions and businesses. The European Union responded as fast as possible when it rolled out its REPowerEU plan as early as May 2022. One of the flagship measures introduced by the Commission was to introduce an action plan for biomethane that defines tools such as a new industrial partnership for biomethane and financial incentives that aim to raise output to 35 billion m³ by 2030, falling within the auspices of the Common Agricultural Policy. A few months later, on Wednesday 29 September 2022, the European Commission and the biomethane sector leaders launched the Biomethane Industrial Partnership (BIP) that aims to turn the REPowerEU plan's aims into reality at reasonable cost. At the same time, it will make a substantial contribution to a net zero emission integrated energy system, diversify farmers' incomes and contribute to a circular approach. The financial undertakings to meet this immense challenge are becoming clearer. In June 2023, the EBA presented its first edition of the Biomethane Investment Outlook, based on a partial response by association investors and project developers. It shows that investments are on track with 18 billion euros already set aside for investment in biomethane production. Between 2023 and 2025, 4.1 billion euros should be invested, while an additional 12.4 billion euros will be released between 2026 and 2030, and a further one billion euros coming at an as yet unspecified date. ■

RENEWABLE MUNICIPAL WASTE

According to Eurostat, 9 Mtoe of primary energy (9 031.8 ktoe to be precise) was generated from renewable municipal waste treated in waste-to-energy (WtE) plants in the EU27 in 2022, amounting to a 246.6-ktoe (2.7%) drop in output. The figure does not include all the energy recovered in WtE plants but is restricted to the energy recovered from biodegradable waste feedstock (cartons, paper, kitchen waste, etc.). The non-biodegradable fraction of urban waste (miscellaneous plastic packaging, mineral water bottles, etc.) produced an equivalent amount of energy (8 854.3 ktoe in 2022, a drop of 2.5 % from the 2021 figure). Convention has it that the waste accounted for as renewably sourced is put at 50% of all incinerated urban waste, as it is hard to distinguish biodegradable waste from other waste, unless a Member State conducts specific studies.

Incidentally, non-renewable industrial waste is separately quantified and generated an estimated 4 864.5 ktoe of primary energy in 2022 (a 0.2% year-on-year decline). The renewable (biodegradable) fraction of industrial waste is conventionally assimilated with solid biofuels, which is covered in its own fact file in this opus. For information, it generated 1 535.6 ktoe of primary energy in 2022 (8% less than in 2021).

FIRST DECLINE FOLLOWING THREE YEARS' GROWTH

Unlike in 2021, the vast majority of European Union countries generated less primary energy from renewable waste. Output plummeted in Germany (by 126.8 ktoe), the Netherlands (by 82.1 ktoe), Belgium (by 32.9 ktoe), Poland (by 26.1 ktoe) and Finland (by 19.1 ktoe). France was one of the few countries to buck the trend, increasing its renewable waste-sourced primary energy output (by 61.8 ktoe), as did Ireland (by 7.9 ktoe) and Sweden (by 6.6 ktoe). EurObserv'ER reckons that this EU-wide contraction after three consecutive years of increase (8.9 Mtoe in 2018 to 9.0 Mtoe in 2019, 9.2 Mtoe in 2020 and 9.3 Mtoe in 2021), is a downturn symptomatic of the economic crisis and lower consumption (resulting in lower tonnage of waste requiring treatment) and also a structural consequence for countries that vigorously pursue waste recycling and collection (of biowaste, cartons, etc.), as their efforts are rewarded by a fall in the amount of waste that requires incineration.

This renewables sector has an asset in that WtE incineration plants are usually sited close to major urban centres which provide the waste feedstock and consume a lot of energy. This proximity fosters optimum, local use of the energy as heat, electricity, or more commonly both, through cogeneration. Thus, heat can be easily exported to supply an urban heating network or as process heat to industrial sites.

If only the renewable fraction of household waste is considered eligible for quantification, then WtE plants generated 19.3 TWh of renewable electricity in 2022 – a slip of 1.2%. Cogeneration is the main energy recovery method used by these plants and electricity accounted for 63.5% of their output in 2022. Belgium and Denmark enjoyed the

1

Primary energy production of renewable municipal waste in the European Union in 2021 and 2022 (in ktoe)*

	2021	2022
Germany	3 150.4	3 023.6
France	1 242.6	1 304.3
Italy	829.8	818.1
Netherlands	863.0	780.9
Sweden	737.3	743.9
Denmark	460.9	450.3
Belgium	397.8	364.9
Finland	366.2	347.1
Spain	283.2	284.2
Austria	204.9	200.2
Ireland	143.8	151.7
Portugal	118.6	121.4
Poland	140.1	114.0
Czechia	95.9	95.2
Hungary	62.5	57.0
Lithuania	54.2	52.9
Bulgaria	42.5	42.4
Slovakia	38.5	34.0
Estonia	21.2	22.0
Luxembourg	12.8	12.5
Latvia	6.5	5.6
Cyprus	3.8	4.0
Romania	2.1	1.6
Total EU-27	9 278.4	9 031.8

Source: Eurostat

2

Gross electricity production from renewable municipal waste in the European Union in 2021 and 2022 (in GWh)

	2021			2022		
	Electricity only plants	CHP plants	Total	Electricity only plants	CHP plants	Total
Germany	3 590.0	2 202.0	5 792.0	3 299.0	2 263.0	5 562.0
Italy	1 094.4	1 213.9	2 308.3	1 004.6	1 321.1	2 325.7
Netherlands	0.0	2 208.1	2 208.1	0.0	2 223.7	2 223.7
France	896.2	1 228.4	2 124.6	863.3	1 250.5	2 113.7
Sweden	0.0	1 813.0	1 813.0	0.0	1 761.0	1 761.0
Denmark	0.0	971.1	971.1	0.0	1 020.3	1 020.3
Belgium	367.0	569.6	936.6	230.3	778.7	1 009.0
Spain	750.0	104.5	854.6	765.5	98.0	863.5
Finland	0.0	581.9	581.9	0.0	587.9	587.9
Austria	219.3	135.2	354.5	205.7	148.3	354.0
Ireland	351.4	0.0	351.4	346.8	0.0	346.8
Portugal	343.4	0.0	343.4	309.2	0.0	309.2
Poland	0.0	353.8	353.8	0.0	301.6	301.6
Lithuania	0.0	142.1	142.1	0.0	155.7	155.7
Hungary	13.0	148.0	161.0	9.0	121.0	130.0
Czechia	0.0	127.3	127.3	0.0	129.7	129.7
Slovakia	0.0	32.0	32.0	0.0	50.0	50.0
Luxembourg	0.0	42.6	42.6	0.0	41.6	41.6
Estonia	25.8	32.6	58.4	20.5	20.0	40.5
Total EU-27	7 650.5	11 905.9	19 556.4	7 053.8	12 272.0	19 325.8

Source: Eurostat

3

Gross heat production in the transformation sector from renewable municipal waste in the European Union in 2021 and in 2022 (in ktoe)

	2021			2022		
	Heat only plants	CHP plants	Total	Heat only plants	CHP plants	Total
Germany	262.9	643.4	906.4	249.3	616.7	866.0
Sweden	82.2	565.7	647.9	79.2	542.0	621.2
France	108.8	289.1	397.8	110.8	299.6	410.4
Denmark	31.8	345.1	376.9	26.6	332.8	359.4
Netherlands	0.0	209.6	209.6	0.0	203.7	203.7
Finland	54.2	135.6	189.8	60.1	123.5	183.7
Italy	0.0	123.1	123.1	0.0	102.5	102.5
Austria	13.9	73.6	87.5	12.7	69.9	82.6
Poland	0.7	37.5	38.2	0.6	37.0	37.6
Czechia	0.0	40.2	40.2	0.0	36.0	36.0
Lithuania	0.0	34.7	34.7	0.0	34.4	34.4
Belgium	0.4	40.8	41.2	0.0	33.8	33.8
Hungary	0.0	18.8	18.8	0.0	20.2	20.2
Estonia	0.0	14.1	14.1	0.0	13.9	13.9
Slovakia	0.0	2.0	2.0	0.0	2.4	2.4
Luxembourg	0.0	1.0	1.0	0.0	0.9	0.9
Total EU-27	554.8	2 574.3	3 129.1	539.4	2 469.2	3 008.6

Source: Eurostat

highest increases in renewable electricity output from urban waste in value terms (by 72.4 GWh and 49.2 GWh respectively). The sharpest drops in output were felt in Germany (230 GWh), Poland (52.2 GWh) and Sweden (52 GWh). Eurostat reports that by the end of 2021, the net maximum electrical capacity of plants treating municipal waste in the EU27 had fallen to 7 798 MW (from 8 149.3 MW), mainly because Sweden has reduced its use of WtE plants.

Heat sales from the processing sector constitute the other major outlet for these incineration plants. Between 2021 and 2022, sales of renewable heat sourced from urban waste declined, partly because milder climate conditions weakened the demand for heating. The plants, 82.1% of which operated as CHP plants, generated 3 008.6 ktoe in 2022 (3 129.1 ktoe in 2021). The most significant drops in value terms occurred in Germany (40.4 ktoe), Sweden (26.7 ktoe) and Italy (20.6 ktoe).

GREATER GROWTH POTENTIAL IN EASTERN AND SOUTHERN EUROPE

In those countries that still dispose of a large fraction of their household waste in landfills, the energy potential of energy recovery through waste incineration remains high. All Member States are obliged to comply with the targets set in the recast directive (EU) 2018/850 (modifying directive 1999/31/EC) for waste disposal in landfills. The (EU) 2018/850 directive introduces restrictions from 2030 onwards, on the disposal of waste in landfills whose materials or energy lend themselves to recycling or recovery, to support the EU's transition to a circular economy but most importantly, it limits the fraction of municipal waste landfilled to 10% by 2035. In 2021 (the latest year for available data), nine Member States had already met the target (Finland, Belgium, Sweden, Denmark, the Netherlands, Germany, Austria, Luxembourg and Slove-

4

Final energy consumption of renewable municipal waste in the European Union in 2021 and 2022 (in ktoe)

	2021	2022
Germany	537.9	516.5
France	90.2	131.8
Ireland	46.7	53.9
Latvia	39.3	43.6
Bulgaria	42.5	42.4
Denmark	45.0	41.8
Netherlands	41.6	39.4
Finland	40.2	36.6
Cyprus	35.4	26.8
Czechia	21.3	21.4
Hungary	14.2	18.3
Poland	34.8	14.2
Slovakia	21.4	10.3
Spain	6.9	8.7
Italy	0.0	6.5
Sweden	0.0	6.2
Romania	2.1	1.6
Total EU-27	**1 019.4**	**1 019.8**

Source: Eurostat

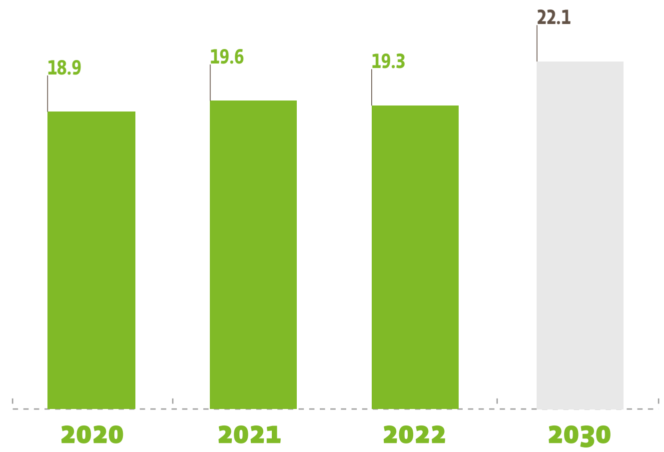
nia), although several of them still incinerated a considerable amount of municipal waste. European countries' landfill disposal rates for municipal waste are subject to strong variations, even if significant progress has been made in the last decade (primarily in Italy, Lithuania, Slovenia, Estonia, Bulgaria and Finland). Nonetheless, some countries such as Malta, Greece and Romania, have lagged behind and still had landfill disposal rates in excess of 70% in 2021. Cyprus, Croatia, Portugal, Latvia, Spain and Hungary have made more progress, but their landfill disposal rates are still in excess of 50%.

The new energy-to-waste infrastructure requirements to achieve the 2035 target of less than 10% landfill disposal are formidable, especially in Europe's central and southern countries, which frequently announce new construction projects.

The city of Rome, for instance, recently published (in November 2023) a tender for a WtE plant to treat 600 000 tonnes of waste per annum. It will reduce the city's emissions of CO2e by 120 000 tonnes, generate energy for 200 000 families and create 150 new jobs. The plant will be sited on the Santa Palomba industrial estate (to the south of Rome) where it will treat 600 000 tonnes of unsorted waste. The plant will cost about one billion euros in investment and be equipped with two 300 000-tonne furnaces. The construction of a technical landfill centre has not been envisaged in order to comply with the "zero landfill" target. Construction work should start in the summer of 2024 and be completed in 2026. Malta should also have a WtE plant shortly (Ecohive project), designed to treat 40% of the non-recyclable waste originated in the country, after diverting it from its landfills. It will generate 126 GWh of electricity per annum to be injected into the grid and also heat. The 185 million euro investment should produce a plant processing 192 000 tonnes of waste per annum and the plant is scheduled to come on stream in December 2026. Poland is now one of the most active countries investing in new WtE plants, backed by European Union funding. Four WtE plants with annual treatment capacity of over 600 000 tonnes are under construction. One of them at Olsztyn, in northwestern Poland will have 110 000 tonnes of treatment capacity. The investment at Olsztyn amounts to 183.3 million euros, 39.6 million of which comes from the European Union Cohesion Fund. The plant is designed with 48 MWth of thermal capacity, and 22 MWe of capacity to supply electricity to the grid. Another plant will be built in Warsaw,

5

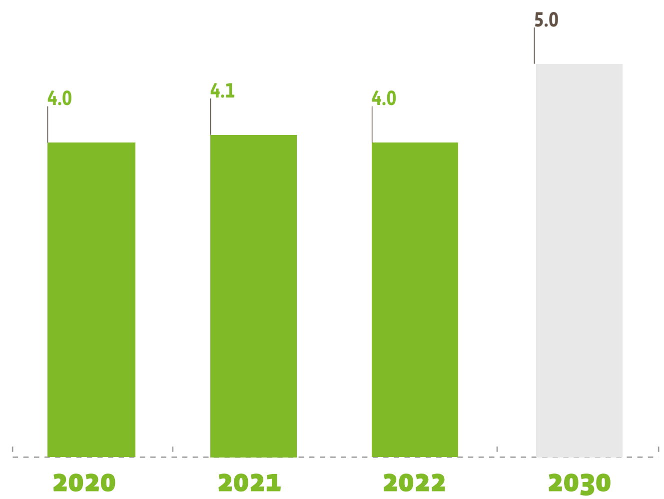
EurObserv'ER projection of electricity production from renewable municipal waste in the EU-27 (in TWh)



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

with 265 200 tonnes of treatment capacity and is scheduled to go on stream in 2024. This new plant whose construction was ordered by the waste treatment company MPO, will supply 20 MW of power and heat by treating the daily load of 730 tonnes of waste thrown out by Warsaw's 850 000 citizens.

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

SOLID BIOFUELS

Eurostat measured solid biofuel energy consumption, in the European Union of 27 in all its forms (from roundwood to wood pellets, wood waste and by-products, residue, plant and other renewable industrial waste) at 100.2 Mtoe, after consumption peaked in 2021. This is the second highest annual consumption level ever recorded in the EU.

The slide from the 2021 peak can be attributed first and foremost to the year's milder average temperatures, which reduced heating needs across the European Union The solid biofuel energy consumption trend played out in a different context from that of 2021, leaving aside climate variations. The main event was the geopolitical crisis unleashed by Russia's invasion of Ukraine at the end of February 2022, which led to the most serious energy crisis since the oil price shock of the early 70s. Record energy prices ensued, triggered by Russia's natural gas exports extortion strategy. The crisis had specific implications for solid biofuel trading. As early as April 2022, the European authorities pronounced an embargo on forest product imports (including wood pellets) to the European Union from Russia and Belarus. It immediately revoked the FSC (Forest Stewardship Council) and SBP (Sustainable Biomass Program) sustainability and traceability certificates for these countries, while a total ban on wood pellet imports came into effect on 10 July 2022. These sanctions disrupted the traditional flow of Russian and Belarusian wood pellets to Europe's markets (amounting to about 2 million tonnes from Russia alone). The upshot took the form of supply shortages in the main wood pellet importing countries, namely Denmark, the Netherlands, Belgium and Italy. The latter were forced to diversify their wood pellet supply sources and draw up emergency plans to mitigate the impact of the crisis. Another limitation that major heat and/or power plant operators (with ≥20 MWth boilers) had to deal with was the implementation of certificates demonstrating that their biofuel feedstocks meet the Renewable Energy Directive 2018/2001 sustainability criteria (and more particularly the sustainability and GHG emission reduction criteria or low risk of indirect change of land use criteria), which are essential for eligibility for the production incentives and for inclusion in the Member States's national target calculations.

The Member States' statements avow that final solid biofuel energy consumption, be it as electricity or heat, generally complies with the Renewable Energy Directive's criteria, the exceptions being the countries that have yet to implement certification mechanisms (namely, Austria, Ireland and Bulgaria).

On further reflection, the use of solid biofuels to meet energy requirements has clearly increased over the last two decades. Their consumption in the EU27 has practically doubled since 2000 (53.6 Mtoe in 2000, 89.3 Mtoe in 2010 and 100.2 Mtoe in 2022), even if we can point out that better statistical monitoring by Member States of solid biomass consumption flows helped to achieve this result. The trade associations remind us that this rise coincided with the increase in the potential supply of solid biofuel energy. Europe's forests have developed over the last

1

Primary energy production and gross inland consumption of solid biofuels in the European Union in 2021 and 2022 (in Mtoe)*

	2021		2022	
	Production	Consumption	Production	Consumption
Germany	13.893	13.973	14.383	14.551
France	10.788	10.931	10.120	10.271
Sweden	10.264	10.199	10.082	10.052
Poland	8.859	9.081	8.675	8.745
Finland	9.037	9.538	8.462	8.704
Italy	7.834	9.118	7.117	8.254
Spain	5.278	5.278	5.297	5.297
Austria	5.294	5.210	4.944	4.833
Czechia	3.913	3.689	3.727	3.512
Romania	3.625	3.639	3.471	3.419
Denmark	1.526	3.644	1.554	3.128
Portugal	2.922	2.700	2.971	2.800
Netherlands	1.752	2.760	1.742	2.481
Hungary	2.187	2.187	2.091	2.116
Belgium	1.320	1.895	1.302	1.881
Bulgaria	1.821	1.792	1.589	1.605
Latvia	2.314	1.505	2.514	1.535
Croatia	1.669	1.437	1.593	1.377
Slovakia	1.496	1.484	1.383	1.362
Lithuania	1.396	1.419	1.297	1.292
Estonia	1.810	1.138	1.766	1.143
Greece	0.787	0.816	0.797	0.824
Slovenia	0.604	0.604	0.528	0.528
Ireland	0.232	0.267	0.251	0.273
Luxembourg	0.183	0.180	0.187	0.178
Cyprus	0.024	0.028	0.031	0.035
Malta	0.000	0.002	0.000	0.001
Total EU-27	**100.830**	**104.514**	**97.874**	**100.198**

Excluding charcoal.* ***Source: Eurostat*

three decades not only in forested areas but also that the forest carbon stock has increased through better management. In 1990, the average forest stock was 133 m3/ha while in 2020, this figure had increased by more than 30% to 173 m3/ha.

IMPORTS FROM OUTSIDE THE EU PLUMMET

Eurostat reckons that solid biofuel output in 2022, namely the inputs taken from European soil, stood at about 97.9 Mtoe, which is a 2.9% YoY decline on 2021 (EU output fell by 3 Mtoe). The difference between the national output data and gross domestic consumption equates to the import-export balance, as well as stock variations. Net solid biofuel imports across the European Union, were fairly low and below the 2021 level (3.7 Mtoe in 2021 and 2.3 Mtoe in 2022). Most can be ascribed to biomass fuel imports (wood and wood pellets) from non-EU countries and North America. As explained earlier, the Russian and Belarusian wood pellet embargo is partly responsible for the 2022 slump in imports and European legislation on solid biofuel sustainability, that is being phased in, is most probably hitting certain supply flows outside the European Union, and North America in particular.

FALLING SOLID BIOFUEL POWER AND HEAT OUTPUT

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 distinguishes two types of use of solid biofuel-sourced final energy, namely electricity (table 2) and heat (or cooling). Solid biofuel heat is differentiated according to whether it comes from the processing sector transformation, i.e., is distributed via heating networks (table 3) or used directly by the end users (in the residential, industrial and agricultural sectors), excluding the transport sector (table 4). In the European Union of 27, solid biofuel electricity output was measured at 88 TWh in 2022, 76.1% of which was produced by CHP plants. This output is below the 2021 record production level of 92.7 TWh (meaning that output fell by 5% between 2021 and 2022), yet it is higher than its 2020 level (83 TWh). The Member States measured output of compliant solid biofuel electricity at 80.0 TWh, leaving 8 TWh specified as non-compliant and thus this amount does not contribute to the renewable targets of the countries in question.

The top three (compliant and non-compliant) European Union solid biofuel electricity producer countries remain unchanged. The two major forestry countries, Finland and Sweden, monopolise the top rankings with solid biofuel electricity outputs of 11.9 TWh (6% less than in 2021) and 11.3 TWh (0.7% more than in 2021) respectively. All of this output was generated in cogeneration plants. Germany lies in third place with 10.3 TWh and 4.5% less output. The sharpest drops in solid biofuel power output were felt in the two highest wood pellet importing countries, namely Denmark whose output fell by 20.4% to 5.7 TWh (a YoY drop of 1.5 TWh) and the Netherlands whose output fell by 14.3% to 6.7 TWh (a YoY drop of 1.1 TWh). Their reduced wood pellet consumption is directly responsible for the drops in output, be it in the Dutch power plants or Danish CHP plants. Turning to the main producer countries, Poland's solid biofuel electricity output also logged a fall (of 7.3%, i.e., an annual contraction of 0.5 TWh). Solid biofuel electricity output rose in France (by 5.7% to 4.7 TWh), Austria (by 6.2% to 3.7 TWh) and Portugal (by 4.5% to 3.5 TWh), as if to confound the main European producers.

The heat production sector across the EU27 contracted in 2022 after rising sharply in 2021, mainly because of lower heating needs. Nonetheless they were above their 2020 level. According to Eurostat, solid biofuel heat used directly by end users fell by 3.4% between 2021 and 2022 to 69.1 Mtoe, which is 2.4 Mtoe less than in 2021. Germany, one of the European countries most exposed to dependency on Russian gas, is the only country to have recorded a clear increase in its solid biofuel final energy consumption – from 0.8 Mtoe to 11.5 Mtoe – as consumers have sought to substitute as much gas as possible. Final energy consumption also grew slightly in Spain (by 0.1 Mtoe to 3.8 Mtoe in 2022) and was stable in Sweden (57 ktoe added to reach 5.5 Mtoe). Steady final biomass energy consumption in Sweden can be put down to the growing need for solid biofuel process heat (2.3% more to 4.6 Mtoe).

Gross solid biofuel heat output sold to heating networks (and so produced by the processing sector) fell by 0.9 Mtoe between 2021 and 2022 to 12.3 Mtoe (a drop of 6.7%). This can mainly be

2

Gross electricity production from solid biofuels in the European Union in 2021 and 2022 (in TWh)*

	2021			2022				
	Electricity only plants	CHP plants	Total	Electricity only plants	CHP plants	Total	Compliant**	Compliant (%)
Finland	0.000	12.668	12.668	0.000	11.908	11.908	11.726	98.5%
Sweden	0.000	11.174	11.174	0.000	11.257	11.257	11.239	99.8%
Germany	4.974	5.764	10.738	4.806	5.448	10.254	10.254	100.0%
Netherlands	2.385	5.457	7.842	1.882	4.838	6.720	5.739	85.4%
Poland	1.713	4.686	6.398	1.222	4.712	5.934	5.934	100.0%
Denmark	0.000	7.133	7.133	0.000	5.679	5.679	5.622	99.0%
Spain	4.116	0.979	5.095	4.125	0.807	4.932	4.611	93.5%
France	0.691	3.732	4.423	0.889	3.785	4.674	4.674	100.0%
Italy	2.385	2.144	4.529	2.266	2.092	4.358	4.358	100.0%
Austria	0.709	2.815	3.523	0.764	2.979	3.743	0.820	21.9%
Portugal	1.346	2.046	3.392	1.473	2.071	3.544	3.544	100.0%
Belgium	1.458	1.306	2.763	1.464	1.379	2.843	2.489	87.6%
Czechia	0.001	2.663	2.665	0.001	2.658	2.659	2.659	100.0%
Bulgaria	0.372	2.001	2.373	0.409	1.644	2.053	0.001	0.1%
Hungary	0.610	1.165	1.775	0.620	1.073	1.693	1.463	86.4%
Estonia	0.609	1.085	1.694	0.553	0.970	1.523	1.503	98.7%
Slovakia	0.000	1.325	1.325	0.006	1.043	1.049	1.049	100.0%
Croatia	0.000	0.660	0.660	0.000	0.720	0.720	0.720	100.0%
Romania	0.032	0.548	0.580	0.062	0.494	0.557	0.149	26.7%
Latvia	0.000	0.570	0.570	0.000	0.552	0.552	0.552	100.0%
Ireland	0.447	0.024	0.471	0.482	0.026	0.508	0.022	4.2%
Lithuania	0.000	0.387	0.387	0.000	0.394	0.394	0.394	100.0%
Luxembourg	0.000	0.285	0.285	0.000	0.268	0.268	0.268	100.0%
Slovenia	0.000	0.169	0.169	0.000	0.162	0.162	0.162	100.0%
Greece	0.016	0.026	0.042	0.009	0.043	0.052	0.052	100.0%
Total EU-27	21.863	70.810	92.673	21.033	67.001	88.035	80.004	90.9%

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

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3

Gross heat production in the transformation sector from solid biofuels in the European Union in 2021 and in 2022 (in Mtoe)*

	2021			2022				
	Heat only plants	CHP plants	Total	Heat only plants	CHP plants	Total	Compliant**	Compliant %
Sweden	0.761	1.982	2.743	0.709	1.902	2.611	2.587	99.1%
Finland	1.024	1.056	2.080	0.961	1.013	1.975	1.944	98.5%
Denmark	0.538	1.178	1.716	0.507	1.032	1.540	1.525	99.0%
France	0.682	0.615	1.297	0.659	0.622	1.281	1.281	100.0%
Austria	0.661	0.368	1.029	0.601	0.355	0.956	0.209	21.9%
Germany	0.192	0.467	0.659	0.148	0.474	0.622	0.622	100.0%
Lithuania	0.413	0.149	0.562	0.393	0.149	0.543	0.543	100.0%
Poland	0.148	0.352	0.500	0.145	0.353	0.498	0.498	100.0%
Latvia	0.230	0.172	0.402	0.244	0.165	0.408	0.408	100.0%
Estonia	0.099	0.237	0.335	0.140	0.224	0.364	0.364	100.0%
Netherlands	0.120	0.280	0.400	0.113	0.222	0.335	0.201	59.9%
Czechia	0.051	0.200	0.251	0.044	0.178	0.222	0.222	100.0%
Italy	0.089	0.295	0.385	0.087	0.121	0.208	0.208	100.0%
Bulgaria	0.013	0.185	0.198	0.015	0.133	0.147	0.014	9.4%
Slovakia	0.053	0.099	0.152	0.052	0.087	0.139	0.139	100.0%
Luxembourg	0.005	0.099	0.103	0.005	0.094	0.099	0.099	100.0%
Hungary	0.036	0.059	0.094	0.033	0.060	0.093	0.076	81.6%
Croatia	0.000	0.095	0.096	0.000	0.091	0.091	0.091	100.0%
Romania	0.018	0.067	0.085	0.011	0.060	0.071	0.071	99.9%
Slovenia	0.013	0.030	0.044	0.015	0.031	0.046	0.046	100.0%
Belgium	0.000	0.021	0.021	0.000	0.024	0.024	0.024	100.0%
Total EU-27	**5.146**	**8.006**	**13.152**	**4.884**	**7.390**	**12.274**	**11.173**	**91.0%**

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

4

Final energy consumption from solid biofuels** in the European Union in 2021 and in 2022 (in Mtoe)*

	2021	2022	Compliant*** 2022	Compliant 2022 %
Germany	10.656	11.459	11.459	100.0%
France	8.458	7.673	7.673	100.0%
Poland	7.286	7.083	7.083	100.0%
Italy	7.324	6.708	6.701	99.9%
Sweden	5.476	5.533	5.514	99.6%
Finland	5.491	4.910	4.858	98.9%
Spain	3.709	3.816	3.768	98.7%
Romania	3.551	3.367	3.367	100.0%
Austria	3.522	3.176	3.095	97.4%
Czechia	2.830	2.663	2.663	100.0%
Portugal	1.766	1.821	1.821	100.0%
Hungary	1.623	1.570	1.563	99.6%
Belgium	1.320	1.267	1.263	99.7%
Croatia	1.146	1.040	1.040	100.0%
Bulgaria	1.059	1.007	0.970	96.4%
Latvia	0.922	0.953	0.953	100.0%
Slovakia	1.024	0.940	0.940	100.0%
Denmark	1.011	0.843	0.843	100.0%
Greece	0.789	0.804	0.804	100.0%
Netherlands	0.710	0.686	0.634	92.4%
Lithuania	0.637	0.610	0.610	100.0%
Slovenia	0.533	0.454	0.454	100.0%
Estonia	0.422	0.445	0.445	100.0%
Ireland	0.170	0.175	0.100	56.9%
Luxembourg	0.029	0.034	0.034	100.0%
Cyprus	0.026	0.031	0.031	100.0%
Malta	0.002	0.001	0.001	100.0%
Total EU-27	**71.489**	**69.070**	**68.687**	**99.4%**

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

5

Heat consumption from solid biofuels** in the countries of the European Union in 2021 and 2022 (in Mtoe)*

	2021	2022	Compliant*** 2022	Compliant 2022 %
Germany	11.315	12.081	12.081	100.0%
France	9.755	8.954	8.954	100.0%
Sweden	8.218	8.144	8.101	99.5%
Poland	7.787	7.581	7.581	100.0%
Italy	7.708	6.917	6.909	99.9%
Finland	7.571	6.884	6.802	98.8%
Austria	4.551	4.133	3.304	80.0%
Spain	3.709	3.816	3.768	98.7%
Romania	3.636	3.438	3.438	100.0%
Czechia	3.080	2.885	2.885	100.0%
Denmark	2.727	2.383	2.368	99.4%
Portugal	1.766	1.821	1.821	100.0%
Hungary	1.717	1.663	1.639	98.6%
Latvia	1.324	1.361	1.361	100.0%
Belgium	1.341	1.290	1.287	99.7%
Bulgaria	1.257	1.154	0.984	85.3%
Lithuania	1.199	1.153	1.153	100.0%
Croatia	1.242	1.131	1.131	100.0%
Slovakia	1.176	1.080	1.080	100.0%
Netherlands	1.110	1.022	0.835	81.7%
Estonia	0.757	0.809	0.809	100.0%
Greece	0.789	0.804	0.804	100.0%
Slovenia	0.577	0.500	0.500	100.0%
Ireland	0.170	0.175	0.100	56.9%
Luxembourg	0.132	0.133	0.133	100.0%
Cyprus	0.026	0.031	0.031	100.0%
Malta	0.002	0.001	0.001	100.0%
Total EU-27	**84.641**	**81.344**	**79.861**	**98.2%**

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

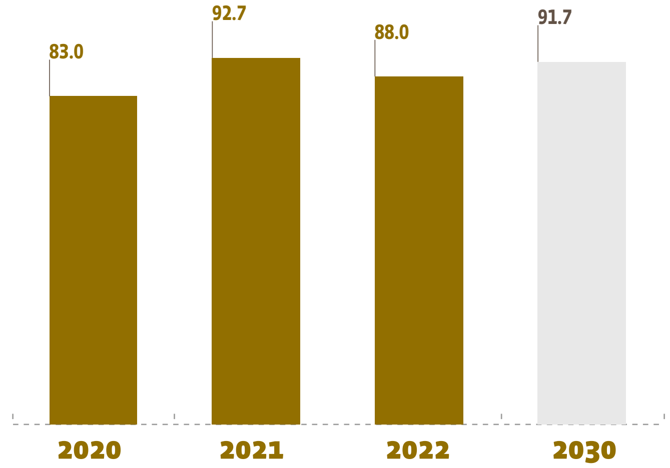
ascribed to CHP plants, which garnered a 60.2% share in 2022 (60.9% in 2021). It should be borne in mind that this drop followed the unusually long heating season in 2021. The three countries with the densest solid biofuel heating networks, (Sweden, Finland, and Denmark), all saw their output contract. The sharpest fall was recorded in Denmark (10.3%, for a total of 1.5 Mtoe in 2022). We estimate total solid biofuel heat consumption by adding the processing sector's heat output to the output directly used by end-users (final process and "other sectors" energy consumption excluding transport). Across the European Union it should stand at about 81.3 Mtoe in 2022 compared to 84.6 Mtoe in 2021, denoting a 3.9% fall. According to Member States' data detailed in the Eurostat SHARES statistical tool for 2022, most of this heat consumption was specified as compliant with the RED II requirements (only 1.5 Mtoe was specified as being non-compliant). Thus, in 2022, 98.2% of heat consumption (gross heat output in the processing sector and final energy consumption in industry and other sectors excluding transport) contributed to the renewable energy targets.

RED III GIVES SUSTAINABILITY CRITERIA A BROADER SCOPE

For the European Commission, greater use of solid biofuels in the EU may contribute to diversifying Europe's energy supply both in the heat production and electricity production segments, creating growth and jobs and reducing GHG emissions. However, if energy recovery from solid biofuels is to be efficient in reducing GHG emissions and if it is to continue maintaining ecosystem services (such as oxygen and air production) and preserving biodiversity, the biomass must be sustainably produced and used. Solid biofuel production involves a chain of activities, ranging from growing the raw materials to final energy conversion. Each stage of the process may pose various sustainability challenges that must be managed. To this end, the European Union has laid down tougher sustainability criteria firstly within the framework of the Renewable Energy Directive 2018/2001 (known as RED II), and subsequently "broadened" them within the framework of the recast Renewable Energy Directive 2023/2413 (known as RED III) on 18 October 2023. RED III aims to extend the scope of the sustainability criteria further so that they apply to an even higher number of installations. It also aims to discourage the use of sawlogs, industrial quality timber for energy purposes, and similarly the use of biofuels exclusively for producing electricity. It also ensures that the Member States respect the cascading principle of using waste according to its hierarchy, the solid biofuels energy must be produced so as to minimise the distortive effects on the raw materials market. The text of RED III came into force on 20 November 2023 giving the Member States 18 months (until 21/05/25) to transpose a specified number of the text's provisions into their national legislation, including those that amend articles 3, 29 and 30 that cover bioenergies and strengthening the sustainability criteria. Article 3 introduces restrictions on public aid for the exclusive production of electricity from forestry biomass. It stipulates that the Member States shall grant no new support or renew support to promote electricity production from forestry biomass in exclusively electrical facilities, with the exception of electricity produced in an outermost region (NB: an outermost region is a European Union territory situated outside the European continent) or if is produced by CO2 capture and storage. The Member States must not award direct financial support for the use of sawlogs or veneer, industrial quality roundwood, stumps or roots for energy production. The same applies to the production of renewable energy through waste incineration, unless the separate collection obligations laid down in Directive 2008/98/EC have been met. As for Article 29 paragraph 1, the directive lowers the minimum application threshold of the sustainability criteria applicable to biomass-sourced fuels in installations that produce heat, electricity and cooling from the current 20 MW to 7.5 MW. It aims to guarantee greater environmental efficiency of the sustainability and GHG emission reduction criteria. Article 29-3 adds "subnatural forests" (namely, semi-natural ancient forests) and moors in areas where felling is forbidden to safeguard biodiversity. Lastly, Article 30, paragraphs 1 and 6, stipulate the obligations for conducting audits and setting up simplified national systems for electricity, heating and cooling producing installations whose total rated thermal input is between 7.5 and 20 MWth. ■

6

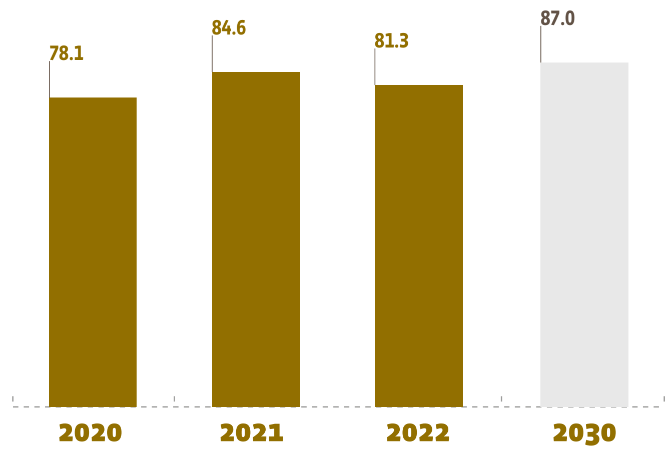
EurObserv'ER projection of electricity production from solid biofuels in the EU-27 (in TWh)



Source: EurObserv'ER

7

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



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

EUROBSERV'ER – THE STATE OF RENEWABLE ENERGIES IN EUROPE – 2023 EDITION

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.


DLR

2 333.1 MW OF INSTALLED CSP CAPACITY IN THE EU AT THE END OF 2022

According to the csp-guru database compiled by Richard Thonig and Alina Gilmanova in conjunction with the SolarPACES secretariat (an international network of CSP researchers) that presented an update on the concentrated solar thermal power market as of 1 January 2023, 115 CSP plants were officially running in the world with 6 318.2 MW of combined capacity to date. Only one project was commissioned in 2022, making it a slack year. The plant in question was the Italian SOLINPAR CSP at Partanna (Sicily) owned by the Italian SOL.IN.PAR srl company. This Fresnel-type CSP plant with 4.26 MW of electrical capacity, was constructed by FATA spa of the Danieli group. The total solar field area is 83 000 m² (roughly 10 football pitches), where 126 linear Fresnel-type solar collectors have been installed arranged in 9 loops. The plant has a 180-MWh thermal molten salts storage system designed to operate for about 15 hours at full load even in the absence of sun rays. The plant can produce electricity for more than 1 400 households (about 30% of the municipal area's population). It is planned to couple the plant with a 5.6-MW photovoltaic collector field and so provide 9.86 MW of combined electrical capacity. The SOLINPAR CSP project takes Italy's 2022 CSP capacity to 12.4 MW and that of the European Union to 2 333.1 MW.

EurObserv'ER identifies five European Union countries with CSP capacity, whereas Eurostat only identifies the capacity installed in Spain (2 304 MW) and Germany (2 MW). It only has electricity production data available for Spain, whose gross CSP output was measured at 4 536 GWh in 2022 (5 176 GWh in 2021), which made 2022 a mediocre year. The preliminary results for 2023 point to much better performance that should be at about the same level as 2021.

EUROPE'S FUTURE WILL ENTAIL HYBRIDIZATION AND PAYMENT FOR STORAGE

CSP's future in Europe will go down the hybridization route. That is the gist of the message sent to the European Union's authorities by the industry organisations that promote concentrated solar energy, such as Spain's Protermosolar. The latter entreated the European Commission to make a closer evaluation of the possibility of hybridizing the two solar technologies, photovoltaic and solar thermal as a competitive solution to provide electricity systems with flexibility, when it was drawing up the European Strategy for solar energy. One great advantage of CSP is that it can be the perfect complement to photovoltaic. Some plants, primarily in China, are betting on hybrid designs that only generate power by photovoltaic technology in the daytime and with energy stored by CSP during nighttime. Spain's new regulations have introduced the hybridization concept of the connection point to maximize the existing grid's actual capacity. This regulation enables an existing plant to be hybridised with another plant provided that the connection capacity is adhered to. One of the most advanced of Spain's hybrid CSP/PV projects, that of Solgest 1 has entered a new stage. The central government has effectively approved the environmental impact declaration of the Solgest-1 CSP project, which paves the way for a construction announced for the end of 2023. However, at the beginning of February 2024 no kick-off date had been mooted. It is a hybrid project involving a 110-MW parabolic trough plant coupled with a 40-MW photovoltaic power plant. The

1

Concentrated solar power plants in operation in the European Union at the end of 2022*

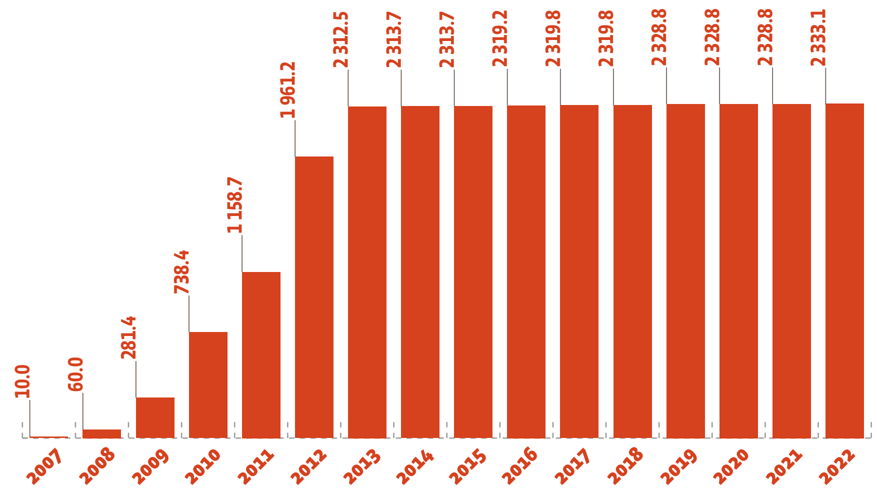
Project	Technology	Capacity (MWe)	Commisionning date
Spain			
Planta Solar 10	Central receiver	10	2007
Andasol-1	Parabolic trough	50	2008
Planta Solar 20	Central receiver	20	2009
Ibersol Ciudad Real (Puertollano)	Parabolic trough	50	2009
Puerto Errado 1 (prototype)	Linear Fresnel	1.4	2009
Alvarado I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

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

Continues overleaf

2

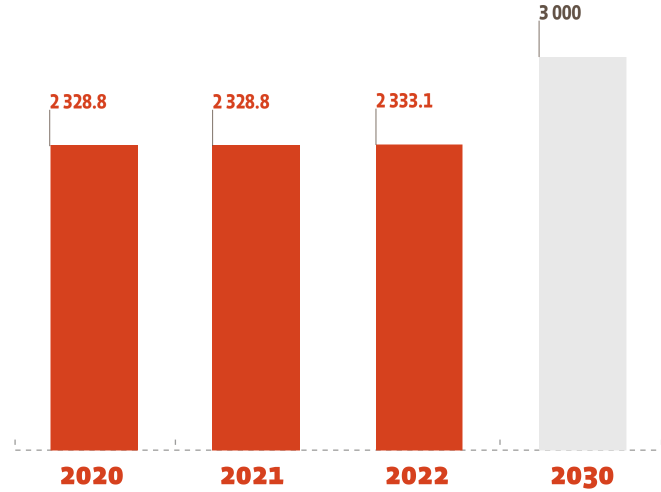
European Union concentrated solar power capacity trend (MW)



Source: EurObserv'ER

3

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



Source: EurObserv'ER

CSP plant will have a thermal molten salts storage system with two tanks making for 1 900 MWh of storage capacity. According to the developer, this hybrid plant will be able to produce electricity 24 hours round the clock, by injecting it into the grid, via a high voltage (220-kV) evacuation line to the Carmona substation, in Seville. The site will be located at the Fuentes de Andalucía facility, where the Gemasolar tower plant constructed by Sener, has been running since 2011.

An opportunity has already been missed to revive Spain's CSP sector. One year late, the government launched its first tenders with capacity quotas for technologies in October 2022, setting aside 200 MW for solar thermal. Unfortunately, the solar thermal section of the tender was rejected as the bid prices were higher than the reserve price. New tenders for a volume of 200 MW were expected for 2023 but did not materialise. David Trebolle, Protermosolar's Secretary-General, stresses that the main challenge of future tenders will be "to work on a new design that will enable the reserve prices to be adapted to the real costs of the technology, and consideration of backup technologies with renewable, synchronous nighttime scope. The market, on its own, does not offer incentives for investment nor revenue stability to cover the costs of renewable technologies with storage capable of providing the back-up that the electricity system needs, especially at night." The sector also decried the lack of incentive to encourage research into complementary renewable technologies, and the renovation of existing solar thermal plants by adding the storage systems they do not have. According to Protermosolar, storage capacity could be doubled in Spain as only 19 of the 49 CSP plants constructed, have provision for storage. The Spanish government has made storage a strategic priority and announced at the very end of 2023 that it had awarded 150 million euros of State aid from NextGenEU funds to support 34 energy storage projects sharing sites with renewable energy installations all over Spain. These funds, awarded through tenders, will subsidise the installation of a total of 904 MW of energy storage systems, mainly in solar photovoltaic and wind farms. The government's NEPC aim is to achieve 22 GW of storage capacity (all technologies, STEP, batteries, chemical and mechanical storage) by the 2030 timeline, compared to 10.8 GW at the end of 2022… enough to equip all of Spain's CSP plants. ■

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.

THE EU HAD 247.6 MW OF CAPACITY IN 2022

Eurostat carries out the official statistical monitoring of net capacity of projects that use tide, wave and ocean energy, as defined by the international energy products classification. As it stands, only two EU27 countries – France and Spain – monitor net marine energy capacity. The SDES (Monitoring and Statistics Directorate) of the French ministries of the environment, energy, construction, housing and transport releases data on the capacity and electricity output of the La Rance tidal range power plant and of the Sabella tidal turbines off the coast of Ushant Island, Brittany. The La Rance tidal range power plant produced 490.5 GWh of output in 2022 (483.8 GWh in 2021), with net maximum capacity at 212.1 MW.

Spain's Ministry for Ecological Transition similarly quantified the capacity and electricity output of the previously described Enagas ocean thermal plant and the 296-kW capacity of the Mitriku wave energy plant, giving total capacity of 4.8 MW at the end of 2022 and output of 23 GWh (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 monitoring, because of the low output levels and statistical confidentiality rules.

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

Minesto

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1

List of projects using ocean energy having been active during the year 2022 in the European Union*

Summary	Device Developper	Device Name	Technology	Location	Date	Total capacity (MW)
France						
Rance tidal power plant (EDF)	Alstom	Bulb Turbine (La Rance)	Tidal range	Brittany - La Rance	1966	240.00
DIKWE Project	Groupe Legendre & GEPS techno	DIKWE	Wave Energy	Brest	2022	0.01
Ushant Island	Sabella	D10	Tidal current		2021	1.00
Bordeaux	Hydrokinetic	Evo25	Tidal current	Bordeaux	2022	0.025
Brest	EEL Energy	EEL	Tidal current	Brest	2022	0.03
Total France						241.07
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
Total Spain						4.80
Netherlands	Tocardo	T2	Tidal_Stream	Oosterscheldedam	2015	1.25
Oosterscheldedam	Tocardo	T2	Tidal current	Oosterscheldedam	2015	1.25
100 kW VAWT for Vlissingen	Water2Energy	VAWT	Tidal current	Vlissingen	2021	0.1
Total Netherlands						1.35
Denmark						
Pilot plant at the Afsluitdijk	Redstack	TRL7	Salinity Gradient	Breezanddijk on the Afsluitdijk	2014	0.05
First commercial project SEV	Minesto	DG100	Tidal current	Vestmannasund (Faroe Islands)	2020	0.1
Second commercial project SEV	Minesto	DG100	Tidal current	Vestmannasund (Faroe Islands)	2021	0.1
Total Denmark						0.25
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
Total Italy						0.07
Slovenia						
Adriatic	Sigma Energy	Sigma WEC	Wave energy	Adriatic Sea	2022	0.03
Total Slovenia						0.03
Total UE 27						247.6

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

2

Capacity and electricity production from ocean energy in European Union in 2021 et 2022 (GWh)*

	2021		2022	
	MW	GWh	MW	GWh
France**	211.2	483.8	212.1	490.5
Espagne	4.8	19.0	4.8	23.0
Total EU-27	**216.0**	**502.8**	**216.9**	**513.5**

Net maximum electrical capacity. ** Electricity production excluding pumped storage. For information, production from pumping of the Rance tidal power plant was 65 GWh in 2022, 66 GWh in 2021. Note: Most countries with marine energy demonstrators or prototypes do not officially include them in the capacity and production data communicated to Eurostat. **Source: Eurostat.*

accounting. Nonetheless, the European association, Ocean Energy Europe, has a monitoring service that publishes its statistics on the installed machine and fleet capacity in service in European waters during 2022. Table 1 displays another indicator monitoring installed marine energy capacity, that includes the capacity of prototypes, pre-commercial and commercial demonstrators that were operating (immersed) in European Union and UK waters. Any prototypes and demonstrators decommissioned or moved to sites outside the European Union and Europe have been removed from this list. As a result, the EU27 ocean energy capacity increased to 247.6 MW in 2022, including the 240 MW of capacity at the La Rance tidal power plant and the 4.5 MW of Spain's Enagas LNG terminal's ocean thermal plant. A further 2.7 MW of tidal stream energy capacity and 0.4 MW of wave energy converter capacity (rounded figures) off the Faroe Islands have been added. The UK, whose test centres accommodate many projects funded by European programmes, contribute ten additional megawatts, including 9.9 MW of tidal stream projects.

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, crossflow turbines and oscillating profiles such as underwater wings. Marine turbines are much smaller than wind turbines at equivalent capacity, because the density of water is 833 times higher than that of air. Another advantage is the low visual impact of completely submerged or low height models, while turbines placed or anchored on the seabed that are not exposed above the surface level present fewer navigational constraints.

According to Ocean Energy Europe, in its "Ocean Energy, Key trends and statistics 2022" publication that came out in March 2023, Europe has amassed 30.2 MW of marine turbine capacity since 2010 using tidal streams, 13 MW of which were still immersed in European waters (European Union, UK and Norway) in 2022. Very few new tidal stream machines were commissioned, and they were small units designed to be installed in rivers, tributaries and estuaries. There are two in France and one in Northern Ireland. The first one in France was developed by the Canadian company HPG (Hydrokinetic Power Generation) and was installed on the Garonne river in the city of Bordeaux. The 25-kW capacity vertical-axis water turbine, called Evo25, is not actually immersed (only the turbine blades are in the water). It is designed to be deployed in rivers, tributaries, canals and shallow water tidal sites. The second, developed by EEL Energy, was installed in the port of Brest and is also a non-submerged river water turbine with 30 kW of capacity operating at current speeds of 1.2 to 3 metres per second. The third was installed at Strangford Lough in Northern Ireland and is a 12-kW vertical axis water turbine developed by Gkinetic.

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 2022 attests to 12.7 MW of wave energy projects installed in Europe (the EU, UK and Norway) since 2010, of which 400 kW of capacity is currently immersed and 12.3 MW has been decommissioned since the test and demonstration programmes were completed. Once again, very few (3) prototypes were installed in Europe over the year. The Slovenian company Sigma Energija deployed the most powerful (30-kW) WEC prototype in the Adriatic Sea off the Montenegro coast in the middle of July 2022 after 2½ years of development. It is a point type absorber WEC. The deployment is the result of Sigma Energy's successful bid for the "Dopolnjevanje SME Instrumenta – Faza 2" (Supplement to the SME instrument – Phase 2) public tender for co-funding the full-scale Sigma WEC development project. The investment is co-funded by the Republic of Slovenia and the European Union through the European Regional Development Fund.

Another WEC project, developed by AWS, was installed at the EMEC (European Marine Energy Centre) test site off Orkney, Scotland. The device, called Archimedes Waveswing. Is a totally submerged point type absorber WEC with 16 kW of capacity. The last, smaller device was installed on the Blue Accelerator test platform just by the Port of Ostend, Belgium. It is a 3.5-kW WEC10 developed by Exowave, the Danish startup, based on the oscillating wave surge converter that extracts kinetic energy from ocean waves through bottom-hinged flaps.

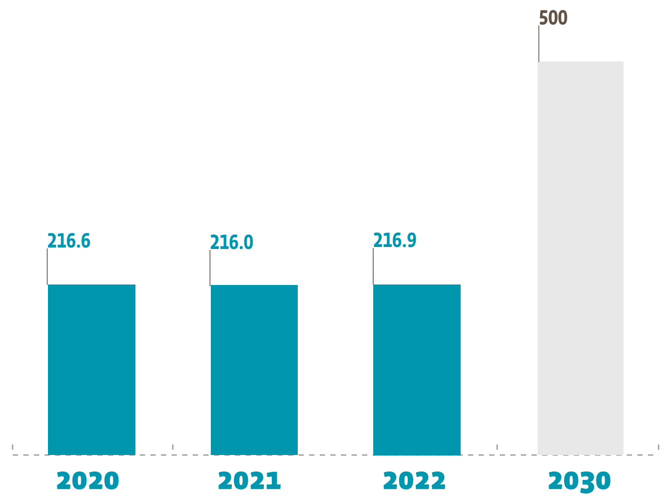
Ocean current deployments in Europe should continue through 2023 and 2024 when commercial size devices will be commissioned. However, the sector is expected to take off during the second half of the decade. The most recent and eagerly awaited launches include that of Nova Innovation, which extended its tidal wave fleet in the Shetlands to total six turbines in service by adding two 100-kW units at the start of 2023. The Swedish developer Minesto plans to deploy a full-scale unit of its Dragon class D12 tidal stream kite array in the Faroes. The device was produced and towed to the site at the end of 2023 and successfully anchored to the seabed at the start of 2024.

Full-scale WEC projects should be commissioned in 2023 and 2024. In October 2023, CorPower Ocean completed the first commissioning stages of its commercial scale CorPower C4 wave energy converter programme, which will enable the machine to start exporting energy to Portugal's grid. The CorPower C4 WEC, with its 300 kW of capacity was developed as part of the HiWave-5 project. The machine will be disconnected after an initial operating cycle and towed to the neighbouring port of Viana do Castelo for onshore inspection and maintenance before being reconnected to the site.

At the end of 2023, the Wavepiston modular device was still being installed off Spain's Canary Islands and should be fully

3

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



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

Orbital Marine Power

operational in 2024. The company's WEC system comprises an energy collector line submerged in the ocean. Its buoys produce pressurised seawater. The Wavepiston comprises a series of energy collectors assembled in a chain on a pipe about 200 metres long, fixed at each end by buoys anchored to the seabed. The collectors harnessing the patented theory of force cancellation and the repetitive circular movement of the sea's waves, generate pressurised water, which is conveyed to the shore where the electricity production units and reverse osmosis desalination units are sited. The French start-up Seaturns has launched its oscillating column demonstrator (¼-scale) prototype, on its test site at Sainte-Anne du Portzic, near Brest. The project was funded by the French government as part of the France 2030 plan and by the European Union as part of the Next Generation EU programme.

THE COMMERCIAL PHASE IS COMING INTO FOCUS

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. By 2027, the capacity of the Meygen project alone should rise from 6 to 34 MW. France, on the other side of the Channel, also plans to develop its marine turbine sector. On 28 November 2023, during the Assises de l'économie de la mer (Maritime Economy Congress), the French President announced that commercial tenders would be included in the forthcoming Multiannual Energy Programme (PPE). President Macron also mentioned the rapid launch, at the La Hague cape, in the Channel, of a "pilot project to try to restart the tidal turbine battle", "with the unprecedented State support of 65 million euros". He was talking about the FloWatt project developed by Hydroquest and Qair that plans to operate seven HQ2.5 tidal turbines each with 2.5 MW of capacity (for a total of 17.5 MW) in the Alderney Race straits, starting in 2025. Another project could follow in quick succession, the NH1 project scheduled for the last quarter of 2026, developed by Normandie Hydroliennes is due to install four 3-MW 4 AR3000 marine turbines, currently the world's most powerful marine turbine, also in the Alderney Race.
The French Renewable Energy Trade Association [Syndicat des énergies renouvelables (SER)] welcomes these announcements and hopes that 750 MW of capacity will soon be allocated in the forthcoming PPE (2023-2028) in the Alderney Race and the Fromveur Passage, and an additional 1 750 MW (totalling 2.5 GW of capacity) by the end of the next PPE in 2033.
Despite these encouraging declarations, it has to be admitted that the current trajectory is way off course from the European Union's strategy roadmap for renewable marine energies that was published on 19 November 2020. The strategy's medium and long-term aims are to achieve total marine energy capacity of 100 MW in the EU by 2025 (not including the La Rance tidal range power plant), then about 1 GW by 2030, rising to 40 GW in 2050. The new Renewable Energy Directive (RED III) also sets a development framework for these technologies as it provides for 5% of the capacities installed by 2030 to be innovative technologies that include renewable marine energies. ■

RENEWABLE ENERGY IN TRANSPORT

A 9.6 % RES SHARE OF EU TRANSPORT IN 2022

Eurostat, using the SHARES tool, quantified the renewable energy share used in European Union transport for 2022 at 9.6% as defined by the RED II calculation rules, amounting to a year-on-year increase of 0.5 of a percentage point (9.1% share in 2021). We should bear in mind that the European Union-wide renewable energy share in transport, calculated using the calculation rules defined by the previous renewable energy directive (2009/28/CE) (known as RED I), was put at 10.3% in 2020. This drop between 2020 and 2021 can be broadly explained by the changes to the accounting rules arising from RED II. The renewable energy shares in transport calculated for 2021 and 2022 are comparable because the same rules were applied.

The 2022 renewable energy shares in EU Member States' transport ranged from 29.2% in Sweden and 18.8% in Finland to less than 5% in Croatia (2.4%), Latvia (3.1%) and Greece (4.1%). Only six other countries besides Sweden and Finland had RES shares of over 10%, namely Austria (10.1%), Italy (10.1%), Denmark (10.2%), Belgium (10.4%), Malta (10.5%) and the Netherlands (10.8%). Germany was close behind with a 9.9% share ahead of Spain (9.7%) and France (9%).

While across the European Union, the renewable energy share in transport increased by a half of a percentage point, the RES shares of about ten countries actually decreased between 2021 and 2022. The sharpest drops were felt in Croatia (4.6 pp), Latvia (3.3 pp), Slovenia (2.8 pp), Estonia (2.6 pp) and Finland (1.9 pp) and can all be explained by lower biofuel consumption.

The healthiest growth was registered in Germany (1.9 pp), the Netherlands (1.8 pp) and Hungary (1.6 pp). The rise in Germany is due to the launching of more virtuous biofuels that are eligible for double accounting in the transport target calculations (see below), rather than through increased biofuel consumption (which actually slipped). Germany also registered a significant increase in renewable electricity in transport, which can be attributed to both its electric mobility-friendly policy (EVs and charging infrastructures) and to the increase in the renewable energy share of its gross electricity output. The impact was even greater as under the RED II framework electric mobility benefits from multipliers in the transport target calculations (see below). In the Netherlands, the increase in the renewable energy share of transport between 2021 and 2022 can be explained exclusively by the rise in renewable electricity consumption in road and rail transport. Exclusively, because biofuel consumption in the Netherlands slipped between 2021 and 2022. In Hungary, in contrast with Germany and the Netherlands, the increase in the renewable energy share can be essentially explained by a rise in biofuel consumption.

INCREASINGLY VIRTUOUS EUROPEAN CONSUMPTION OF BIOFUEL

Across the European Union, the increase in the renewable energy share consumed in transport has less to do with the slight (1.2%) rise in directive-com-

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1

Biofuels consumption for transport in the European Union in 2021 (in ktoe)

	Biodiesel*	Biogasoline	Biogas**	Total	Compliant biofuels***	Compliant biofuels %
Germany	2 166.6	734.7	82.8	2 984.0	2 961.4	99.2%
France	2 206.6	716.4	1.6	2 924.6	2 924.6	100.0%
Italy	1 388.4	27.1	136.5	1 552.0	1 551.9	100.0%
Spain	1 410.1	140.6	0.0	1 550.6	1 549.9	100.0%
Sweden	1 221.8	117.3	112.6	1 451.8	1 451.8	100.0%
Poland	911.7	208.0	0.0	1 119.7	1 119.7	100.0%
Belgium	606.8	118.7	0.0	725.5	725.5	100.0%
Finland	557.2	113.5	12.1	682.8	663.9	97.2%
Netherlands	360.8	233.2	40.8	634.8	634.8	100.0%
Romania	374.8	120.9	0.0	495.8	495.8	100.0%
Austria	370.4	52.1	0.4	422.9	422.9	100.0%
Czechia	287.2	55.5	18.9	361.6	361.6	100.0%
Portugal	323.1	17.1	0.0	340.2	340.2	100.0%
Hungary	196.7	87.0	0.0	283.7	283.7	100.0%
Denmark	179.0	81.8	8.8	269.7	269.7	100.0%
Greece	148.7	67.9	0.0	216.5	160.8	74.2%
Ireland	161.5	20.3	0.4	182.2	182.2	100.0%
Bulgaria	148.8	20.8	0.0	169.6	166.8	98.4%
Slovakia	134.4	26.1	0.0	160.5	160.5	100.0%
Luxembourg	118.6	17.9	0.0	136.5	136.5	100.0%
Lithuania	110.4	16.5	0.0	126.9	126.9	100.0%
Slovenia	94.0	8.6	0.0	102.6	102.5	99.9%
Croatia	90.4	0.8	0.0	91.2	91.2	100.0%
Estonia	41.4	4.2	11.8	57.5	57.5	100.0%
Latvia	34.0	11.7	0.0	45.8	45.8	100.0%
Cyprus	26.2	0.0	0.0	26.2	26.2	100.0%
Malta	10.6	0.0	0.0	10.6	10.6	99.4%
Total EU-27	**13 680.3**	**3 018.8**	**426.8**	**17 125.9**	**17 024.7**	**99.4%**

** 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 (articles 29 and 30 of Directive 2018/2001 EU). Note: Breakdown between types of biofuel has been estimated by EurObserv'ER.*
Source: SHARES Eurostat (Total and compliant biofuels).

2

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

	Biodiesel	Biogasoline	Biogas*	Other liquid biofuels	Total	Compliant biofuels**	Compliant biofuels %
France	2 213.7	849.6	3.6	33.3	3 100.2	3 100.2	100.0%
Germany	2 194.9	761.0	91.3	1.8	3 048.9	2 919.1	95.7%
Sweden	1 404.8	150.8	120.3	0.0	1 675.9	1 675.9	100.0%
Italy	1 354.1	35.0	184.9	0.0	1 573.9	1 573.0	99.9%
Spain	1 327.6	118.6	0.0	0.0	1 446.2	1 445.5	100.0%
Poland	971.5	231.9	0.0	0.0	1 203.4	1 203.4	100.0%
Belgium	629.2	133.8	0.0	0.0	763.0	763.0	100.0%
Netherlands	301.2	251.1	40.7	21.0	613.9	613.9	100.0%
Finland	426.3	118.6	26.5	0.0	571.5	545.8	95.5%
Romania	414.8	143.9	0.0	0.0	558.7	558.7	100.0%
Austria	351.2	51.6	0.4	0.0	403.2	403.2	100.0%
Czechia	259.8	63.2	39.1	0.0	362.1	362.1	100.0%
Portugal	315.4	25.7	0.0	0.0	341.1	341.1	100.0%
Hungary	212.7	90.2	0.0	0.0	302.9	302.9	100.0%
Denmark	164.9	79.9	8.8	0.0	253.6	242.7	95.7%
Ireland	206.3	23.3	0.9	0.0	230.6	230.6	100.0%
Greece	149.5	67.9	0.0	0.0	217.3	160.8	74.0%
Bulgaria	165.2	20.9	0.0	0.0	186.1	183.1	98.4%
Slovakia	140.6	28.1	0.0	0.0	168.7	168.7	100.0%
Luxembourg	107.8	19.9	0.0	0.0	127.7	127.7	100.0%
Lithuania	99.9	19.7	0.0	0.0	119.6	119.6	100.0%
Slovenia	73.3	6.5	0.0	0.0	79.7	78.6	98.6%
Estonia	26.0	2.0	12.9	0.0	40.9	40.9	100.0%
Cyprus	24.9	0.0	0.0	0.0	24.9	24.9	100.0%
Croatia	20.8	0.2	0.0	0.0	21.0	21.0	100.0%
Latvia	5.6	10.1	0.0	0.0	15.8	15.8	100.0%
Malta	12.6	0.0	0.0	0.0	12.6	12.6	100.0%
Total EU-27	**13 574.5**	**3 303.3**	**529.4**	**56.1**	**17 463.3**	**17 234.3**	**98.7%**

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

3

Consumption of biofuels produced from raw materials that are considered to be equivalent to twice their energy content in in 2021 and 2022 (in ktoe)

	2021			2022		
	Advanced biofuel[1]	Used cooking oil and animal fats[2]	Total	Advanced biofuel[1]	Used cooking oil and animal fats[2]	Total
Italy	538.3	800.1	1 338.4	612.9	857.6	1 470.5
Spain	471.3	396.0	867.3	767.7	401.3	1 168.9
Germany	183.7	507.9	691.7	464.1	640.3	1 104.4
Sweden+	332.2	300.6	632.7	231.5	565.5	797.0
Netherlands	145.7	361.6	507.2	168.5	299.4	467.9
France	71.6	112.8	184.4	139.1	200.0	339.1
Portugal	83.8	172.4	256.2	96.3	172.0	268.3
Hungary	0.2	163.8	164.0	36.8	127.3	164.1
Ireland	0.4	159.8	160.2	18.9	187.6	206.5
Czechia	19.2	67.8	87.1	48.5	47.0	95.4
Finland	92.4	6.1	98.5	77.9	5.7	83.6
Slovenia	30.9	56.3	87.2	27.0	41.8	68.8
Belgium	27.6	39.8	67.4	28.4	55.3	83.7
Bulgaria	9.1	62.3	71.3	9.6	57.3	66.9
Luxembourg	0.0	55.3	55.3	3.3	49.8	53.0
Slovakia	8.0	37.7	45.7	8.6	41.2	49.8
Estonia	34.1	4.2	38.3	30.1	0.9	31.0
Croatia	0.0	35.5	35.5	0.0	9.4	9.4
Greece	0.0	34.9	34.9	0.0	34.9	34.9
Denmark	17.4	38.0	55.5	12.7	18.2	30.8
Cyprus	2.1	20.1	22.2	3.6	19.6	23.1
Poland	6.6	16.8	23.4	2.5	27.4	30.0
Latvia	12.3	0.0	12.3	4.7	0.0	4.7
Malta	1.8	8.8	10.5	0.8	11.8	12.6
Austria	0.0	0.5	0.5	0.0	18.0	18.0
Lithuania	0.0	0.0	0.0	5.6	2.9	8.5
Romania	18.3	0.0	18.3	0.0	0.0	0.0
Total EU-27	2 107.2	3 458.8	5 565.9	2 798.9	3 892.2	6 691.1

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

pliant biofuel consumption from 17 Mtoe in 2021 to 17.2 Mtoe in 2022, than it has with the sharp rise in biofuel consumption, the most sustainable not sourced from food crops, whose contribution can be viewed as equivalent to double their energy content in the targets, which rose from 5.6 Mtoe in 2021 to 6.7 Mtoe in 2022 (by 20.2%). This double accounting applies to "advanced" biofuels produced from the raw materials listed in annex IX, part A of RED II) and the biofuels produced from used cooking oils or certain animal fats (raw materials listed in annex IX, part B). Incidentally, RED II sets a 1.7% cap on the contribution of biofuels produced from used cooking oils or certain animal fats to the European Union targets of the energy content of fuels intended for the transport sector except in Cyprus and Malta. The import and use of these fuels are not limited by this ceiling which only affects their contribution to the European Union targets. The co-legislators of RED II primarily took this decision to encourage the use of advanced and innovative renewable fuels. Now, according to the detailed data of the Eurostat SHARES tool of each Member State, advanced biofuel consumption in the European Union increased from 2.1 Mtoe in 2021 to 2.8 Mtoe in 2022 (by 32.8%) and the consumption of biofuels produced from used cooking oils and animal fats increased from 3.5 to 3.9 Mtoe (by 12.5%).

RENEWABLE ELECTRICITY CONSUMPTION IN TRANSPORT RISING ALL THE TIME

Another reason for the increase in the renewable share in transport is the rise in renewable electricity consumption in transport, which stems from both an increase in road and rail traffic, the registration of about 2 million additional EVs in 2022 (out of a total EU fleet of 6 million) and above all, the rising renewable energy share of the EU's gross electricity output. Since 2021, the Renewable Energy Directive 2018/2001 rules have applied to the calculation of the EU's renewable electricity consumption in transport.

4

Renewable electricity used in transport (road, rail, other transport modes) in 2021 and 2022 (in ktoe)

	2021				2022			
	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	48.9	404.9	0.0	453.7	94.0	445.2	0.0	539.2
Italy	13.2	155.9	158.3	327.4	19.6	182.6	92.8	295.0
Sweden	42.9	156.7	0.0	199.6	72.4	170.3	20.0	262.7
France	15.3	150.6	17.1	182.9	30.1	175.8	25.0	230.9
Austria	17.6	120.9	74.1	212.5	18.2	125.1	83.2	226.5
Spain	11.3	99.4	7.2	117.9	19.7	120.8	8.5	149.0
Netherlands	16.9	25.7	0.0	42.7	38.0	39.2	0.0	77.2
Romania	6.9	42.6	1.8	51.3	8.3	37.6	0.9	46.8
Denmark	12.9	25.7	0.0	38.6	22.0	28.0	0.0	50.0
Poland	0.8	39.8	1.3	41.9	2.3	46.4	0.2	48.9
Belgium	4.6	27.6	0.7	32.9	10.5	32.7	3.8	47.0
Finland	7.7	22.6	0.0	30.3	13.6	23.4	0.0	37.0
Portugal	0.8	20.8	0.2	21.8	2.0	22.6	0.3	24.9
Czechia	0.9	18.9	0.9	20.8	0.9	20.6	1.0	22.5
Hungary	0.7	9.9	0.1	10.7	1.2	12.0	0.1	13.4
Croatia	0.3	10.2	1.6	12.2	0.6	11.2	1.6	13.4
Slovakia	0.5	8.9	1.8	11.1	0.5	9.9	2.8	13.2
Bulgaria	0.8	8.3	0.2	9.3	0.9	8.2	0.3	9.4
Slovenia	0.1	6.3	0.2	6.6	0.8	7.3	0.2	8.3
Latvia	1.3	3.0	0.1	4.5	1.6	3.0	0.1	4.6
Greece	0.5	4.5	0.0	5.0	0.6	5.7	0.0	6.3
Ireland	3.1	1.5	0.0	4.7	5.3	1.6	0.0	7.0
Luxembourg	0.2	1.4	0.0	1.6	0.6	1.7	0.0	2.2
Lithuania	0.8	0.2	0.3	1.3	1.0	0.2	0.4	1.6
Estonia	0.3	0.2	0.0	0.6	0.5	0.3	0.0	0.8
Malta	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.1
Cyprus	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total EU-27	209.4	1366.3	266.1	1841.8	365.4	1531.5	241.0	2137.9

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

RES in transport at the heart of the EU's ecological transition

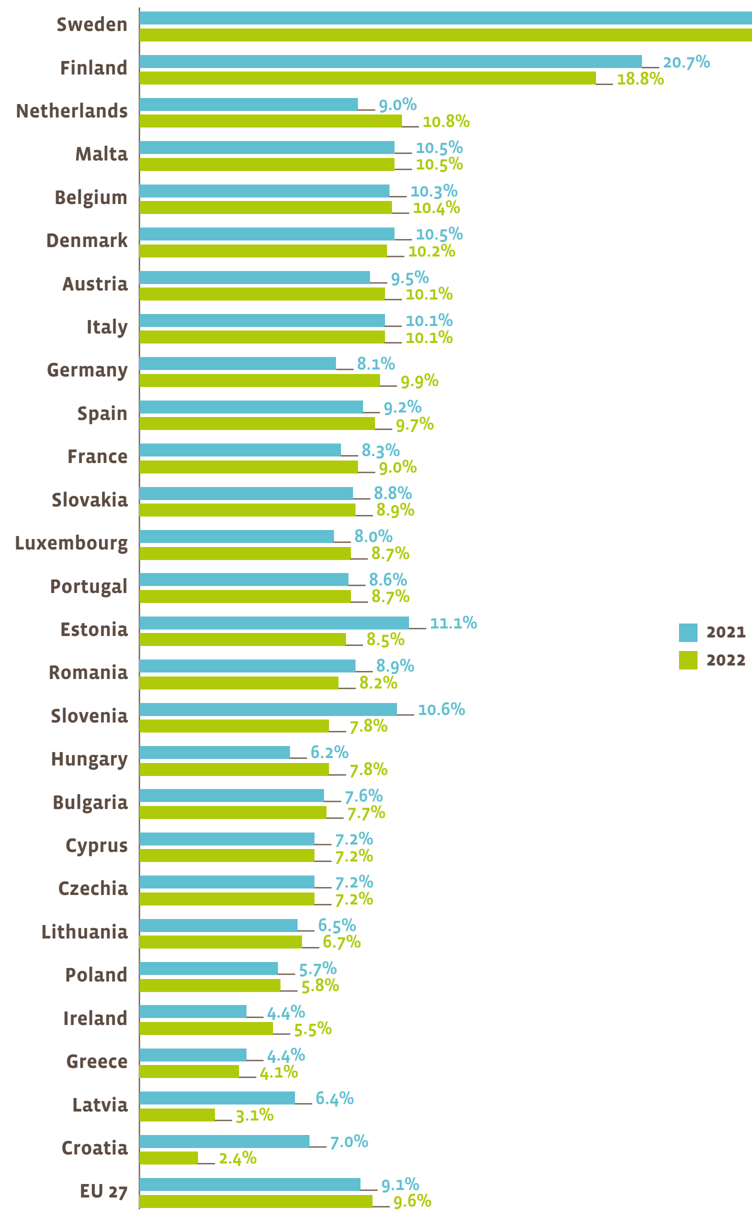
The European Union shifted its renewable energy policy for transport by requiring biofuels used in the EU to comply with sustainable development criteria, when the first renewable energy directive 2009/28/EC (known as RED I) was rolled out. It subjected them to quantitative criteria relating to GHG emissions and qualitative criteria relating to land use, to prevent their production on biodiversity-rich and high carbon store lands or peat bogs. The sustainability criteria for using biomass and biofuels have since been considerably toughened. The first time was in 2015, when the 2015/1513 "ILUC" (Indirect Land Use Change) Directive was enacted. It embodied the lawmakers' wish to take into account the effects of land use change by setting limits to the use of food crop biofuels. Since then, adoption of the Renewable Energy Directive 2018/2001 (known as RED II) has reinforced the biomass sustainability criteria even further by identifying the raw materials most at risk from the ILUC effect (such as palm oil), with measures to cap their incorporation and phase them out altogether by 2030. The European transport decarbonisation policy now favours consumption of "advanced" biofuels and biogas, renewable fuels of non-biological origin (RFONBOs) produced from hydrogen and recycled carbon fuels (RCFs), "green" hydrogen fuel. It also aims to electrify road transport which in tow with the European policy for decarbonising the electricity mix through renewable energies. More recently, new steps have been taken to accelerate energy transition. The European Green Deal presented by the European Commission in December 2019, is the European Union strategy implemented to achieve the goal of climate neutrality by the 2050 timeline. The Green Deal aims to reduce transport related GHG emissions by 90% by that date to achieve a more sustainable mobility system. The European Green Deal was launched in July 2021 when the Commission presented detailed measures geared to reducing net GHG emissions by at least 55% from 1990 levels by 2030. These climate measures are covered by the «Fit for 55» package. Following a lengthy legislation process involving the European Parliament and the European Council, many pieces of legislation governing transport (regulations and directives) were adopted during 2023, including the long-awaited recast Renewable Energy Directive, directive 2023/2413 (known as RED III) that was formally adopted on 18 October 2023 and published in the Official Journal of the European Union (OJEU) on 31 October 2023. The renewable energy consumption target for transport, which RED II originally set at 14% for each Member State was amended by RED III to offer the states more flexibility by allowing them to choose between two goals. They can choose between a binding goal of reducing GHG intensity in transport by 14.5% resulting from the use of renewable energies by 2030, and a binding renewable energy share of at least 29% in the transport sector's final renewable energy consumption by 2030.

From that date, when the possibility of calculating it from the European Union's production mix was abolished, the consumption of renewable electricity used in transport has had to be calculated from the national electricity production mix. Thus, individual Member States must refer to the previous two-year period prior to the current year when the electricity was supplied on their territory (normalized electricity output for wind power and hydropower), which also applied in the previous directive.

The Eurostat SHARES tool database shows that renewable electricity consumption in transport (road, rail and other transport modes) increased across the European Union from 1.8 Mtoe in 2021 to 2.1 Mtoe in 2022 (by 16.1%). Renewable electricity consumption in road transport rose from 209.4 ktoe in 2021 to 365.4 ktoe in 2022 (by 74.5%), rail transport from 1 366.3 to 1 531.5 ktoe (by 12.1%) while consumption in the other transport modes slipped from 266.1 to 241 ktoe (by 9.4%). Some countries (such as Italy), do not clearly monitor a signifi-

5

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



Source: Eurostat

cant share of the renewable electricity consumption in transport, but allocate it by default to "other transport modes", a category to which multipliers do not apply. Better monitoring of electricity consumption in transport by the administrations provides the explanation for the reduction in the value of this indicator. As part of RED II, multipliers were also introduced to promote electricity consumption in transport. Thus, when calculating the transport target numerator, the renewable electricity share is considered equivalent to four times its energy content when earmarked for road transport and can be considered equivalent to 1.5 times its energy content when earmarked for rail transport.

To conclude, according to the Eurostat SHARES tool, calculation of the renewable energy target numerator in transport taking into account all the multipliers points to 24 Mtoe of renewable energy consumption in transport in 2021 and of 26.1 Mtoe in 2022 (8.7% growth). If these multipliers are omitted, renewable energy consumption in transport drops to 18.9 Mtoe in 2021 and to 19.4 Mtoe in 2022 (2.7% growth). Thus, the subsidy system introduced by the legislators plays a full incentive role by increasing consumption of the most virtuous biofuels (and biogas fuel) and by accelerating renewable electricity consumption in transport.

98.7% OF BIOFUELS (AND BIOGAS FUEL) INTENDED FOR TRANSPORT IS CERTIFIED COMPLIANT

Almost all biofuels (and biogas fuel) available in the European Union market comply with the sustainability requirements of the RED II directive (98.7% certified compliant in 2022). According to the Eurostat SHARES tool, only 228.9 ktoe of biofuel across the European Union in 2022, was not certified compliant (101.2 ktoe in 2021). Total biofuel consumption used in European Union transport, both compliant and non-compliant with the RED requirements, was quantified at just below 17.5 Mtoe in 2022 (17.1 Mtoe in 2021). The distribution of the major biofuel types is still dominated by the biodiesel sectors, FAME (Fatty Acid Methyl Esters) or HVO (Hydrotreated Vegetable Oil) (13.6 Mtoe in 2022, i.e., a 77.7% share), ahead of bio-based petrol (3.3 Mtoe in 2022, i.e., an 18.9% share), biogas fuel (529.4 ktoe, i.e., a 3.0% share) and the other types of liquid biofuels (such as biokerosene) (56.1 ktoe in 2022, i.e., a 0.3% share). Biogas fuel includes the biomethane injected into the natural gas grid and allocated to the transport sector with appropriate traceability requirements.

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FIT FOR 55 – THE TRANSPORT CHAPTER COMES INTO EFFECT

Following long legislative work initiated by the " Fit for 55" package, the first texts agreed to set up instruments to reduce GHG emissions in transport were published in the OJEU during 2023, while others are about to be published. These pieces of legislation relate to the implementation of a separate emissions trading scheme (ETS) for road transport, buildings and other sectors (not covered by the existing ETS), infrastructure targets for EVs and substitution fuel, emissions reduction targets for light-duty vehicles in road transport, emissions reduction for heavy-duty vehicles, targets for the use of renewable and low carbon fuels in maritime (FuelEU maritime) and air (ReFuelEU aviation) transport. The high point is the eagerly awaited recast Renewable Energy Directive, directive 2023/2413 (known as RED III), which was finally adopted and published in the OJEU on 31 October 2023. RED III clearly raised the European Union's renewable energy targets to bring them in line with the European Union Green Deal that set 2050 as the EU's climate-neutral target date. It sets an interim target of reducing net GHG emissions of at least 55% from 1990 levels by 2030, and also aligns the targets with the RePowerEU Plan outlined in the Commission's communication of 18 May 2022 that aims to end the EU's dependence on Russian fossil fuels long before 2030. Broadly speaking, the new directive raises its renewable energy share targets of the EU's gross final electricity consumption in 2030 from at least 32 to 42.5% and encourages the Member States to aim for 45%.

As for the transport chapter, it offers the Member States more flexibility by allowing them to choose between two goals – either a binding goal of reducing GHG intensity in transport by 14.5% resulting from the use of renewable energies by 2030, or a binding renewable energy share of at least 29% in the transport sector's final renewable energy consumption by 2030. Thus, based on the reference value EF(t) for fuel or fossil fuel set at 94 gCO_2eq/MJ, in compliance with an indicative trajectory set out by the Member State; or a binding renewable energy share of at least 29% in the transport sector's final renewable energy consumption by 2030. This second target is much more ambitious than its predecessor, RED II, that aimed at a binding renewable energy share of at least 14% in the transport sector's final renewable energy consumption in 2030. The binding target for reducing GHG intensity resulting from renewable energies appears to be much more accessible and should logically be given preference in many Member States. Sweden and Finland, which have the highest RES shares in their transport, believe that they should have no difficulty achieving their renewable energy share targets.

The new RED III rules furthermore establish a combined binding sub-target of 5.5% in 2030 (and an interim target of 1% in 2025) for advanced biofuels and biogas (produced from the non-food raw materials listed in Annex IX, part A) and renewable fuels of non-biological origin (mainly renewable hydrogen and hydrogen-based synthetic fuels) in the share of renewable energies supplied to the transport sector. This target has a minimum requirement of 1% of RFNBOs in the share of renewable energies supplied to the transport sector in 2030.

The recast directive also retains the limit on the use of fuels produced from human and animal food crops. Their use must not exceed more than one percentage point of the share of these fuels in a Member States' transport sector's final energy consumption in 2020, with a maximum 7% share of final energy consumption in that Member State's transport sector. It also retains the provision limiting the share of biofuels and biogas produced from the raw materials listed in Annex IX, part B (namely used cooking oils and animal fats) to 1.7% in the energy content of fuels and electricity supplied to the transport sector, with the exception of Cyprus and Malta. Nonetheless, the Member States may increase this limit, when justified by the availability of the raw materials in question, providing they submit any increase for approval by the European Commission. A minor accounting nuance has been added to deter countries from agrofuel consumption. This is because when the share of biofuels produced from human and animal food crops in a Member State, is capped at less than 7% or a Member State decides to limit this share even further, it can consequently reduce the minimum share of renewable energy as a or the GHG intensity reduction target, on the basis of the contribution that these fuels would have had on the minimum share of renewable energy or GHG emissions reductions.

The main calculation rules have not been changed to calculate the target's numerator. Recycled carbon-based fuels can be included as well as a certain number of incentives. The share of biofuel and biogas produced from the raw materials listed in Annex IX and the share of renewable fuels of non-biological origin are considered to equate to twice their energy content; the renewable electricity share is considered to equate to four times its energy content when intended for road transport and can be considered to equate to 1.5 times its energy content when intended for rail transport. The share of advanced biofuel and biogas produced from the raw materials listed in Annex IX, part A, supplied in air and maritime transport modes is considered to equate to 1.2 times their energy content, and the share of renewable fuels of non-biological origin is considered to equate to 1.5 times their energy content supplied in air and maritime transport modes. ■

EUROBSERV'ER – THE STATE OF RENEWABLE ENERGIES IN EUROPE – 2023 EDITION

READY TO DO BATTLE

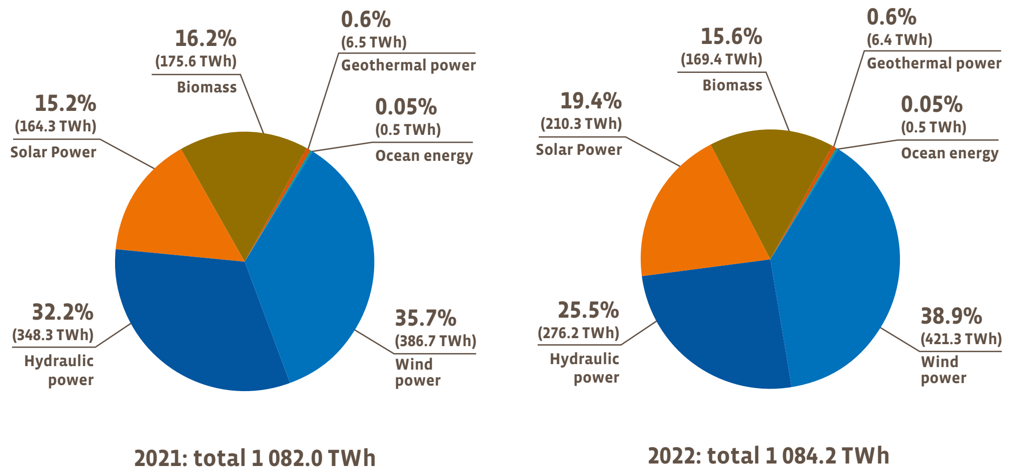
The Green Deal presented in December 2019 has been the European Commission's environmental roadmap throughout the current European mandate (2019-2024) that ends this year. It was driven by the ambition not only to transform many sectors of society but also to make a societal sea change while achieving climate neutrality in 2050 comes into its sights. The Green Deal commits the Member States to reducing net greenhouse gas emissions by setting them the task of cutting them by at least 55% by 2030 compared to 1990 levels. This target was finally adopted in June 2021 when the European Climate Act was passed. Climate action and the societal transformations that it calls for are not discretionary because climate change is an existential threat, wreaking disaster on human society's well-being and the very integrity of ecosystems and biodiversity. These outcomes have been scientifically documented in the IPCC (Intergovernmental Panel on Climate Change) reports. The gamble as viewed by the political decision-makers, consists of ensuring that this Green Deal also doubles as the compass of the European Union's new growth strategy to reduce greenhouse gas emissions while creating jobs and improving our quality of life. Thus, the European Union must keep and enjoy "net zero" technologies and industries on its own territory, capable of ensuring its long-term growth and well-being, without becoming technologically dependent on other countries.

Limiting climate warming to 1.5°C by the end of this century is a huge challenge. We must create a new civilisation based entirely on decarbonised, mainly renewable energies, that are the most economic and easily deployable energies rather than merely optimise the current system.
The urgency of rapid implementation of energy transition increased to red level in 2022 and 2023, firstly, because of Russia's military aggression against Ukraine, in February 2022. The Kremlin's gas cut extortion strategy plunged the European Union into an acute energy crisis. The Commission rapidly stepped in by publishing its REPowerEU plan to end European dependence on Russian fossil energies which resulted in new momentum for the renewable energy sectors, and also an increase in LNG (liquefied natural gas) imports from North-American schist gas.
Secondly, the energy transition technology war waged by China and the United States, as well as Japan and South Korea, was in the same vein. American legislation on inflation reduction (the Inflation Reduction Act) enacted in the summer of 2022 that provides for support worth 369 billion dollars for the United-States green industry over a decade, was the decision-making catalyst and accelerator for the European authorities. The Union's response was the February 2023 publication of a long-term strategy, a "Green Deal Industrial Plan" to boost the competitivity of Europe's net zero emissions industry. The European Parliament and Council reached political agreement on 6 February 2024 on a common text for the "Net Zero Industry Act" (NZIA) following drawn-out exchanges. The law targets some ten net-zero strategic technologies, in which renewable energies play a major role, namely, onshore and offshore wind technologies, solar photovoltaic and solar thermal, heat pump and geothermal energy, sustainable biogas and biomethane, storage and battery technologies, electrolysers and fuel cells, carbon storage technologies and grid infrastructure, as well as nuclear technologies and sustainable substitution fuels. Broadly speaking, the listed industrial sectors should benefit as a result of this act from the streamlining of regulatory procedures, faster access to funding, training programmes and trade agreements. However, nothing is settled. It will be up to the Member States to take up the newly established facilities and tools, to be prepared to do battle so that the EU remains in control of its energy transition without creating new dependencies. The next European mandate must strengthen the policy rolled out under the Green Deal framework. A report[1] on the European climate investment deficit published on 21 February 2024 by the Institute for Climate Economics (I4CE) identifies an additional annual requirement of 406 billion euros on top of the 407 billion already invested.
Many legal texts have been produced during this mandate with the European Commission making proposals on energy and climate issues, and often protracted negotiations between the European Parliament and Council. They include the new Renewable Energy Directive (known as "RED III") that was finally published in the Official Journal of the European Union on 31 October 2023, leaving the Member States to transpose it into their own national law within 18 months. The broad outlines show that it raises the 2030 European renewable energy targets to meet the European Climate Act's greenhouse gas reduction targets. By that deadline, the European Union should benefit from a 42.5% share of renewably sourced energy in its gross final consumption of energy, and as much as 45% if possible. This act is as crucial as it is ambitious because it plans to at least double the renewable energy share between 2021 and 2030, ensuring that this growth is sustainable, particularly with regard to biomass use, environmental protection and preserving biodiversity. Thus, even if bioenergies continue to underpin energy transition, there is no question of making them bear the brunt of the efforts made to achieve the European Union's hardened target.
Before conducting a deeper inventory of the first RED II monitoring indicators, this conclusion sets out to make an initial assessment of the state of actual renewable electricity production in 2022. It covers non-normalized output for hydroelectricity, , including all the electricity produced from biomass (solid, liquid and gaseous biofuels), irrespective of whether or not they were RED II-compliant. The same applies to how the share of the various renewable energies used for heating and cooling in the EU-27 countries is presented. It includes all biomass energy output, irrespective of whether or not it was RED II compliant. These "conventional" indicators were obtained from the Eurostat database by reference to

1. *https://www.i4ce.org/en/publication/european-climate-investment-deficit-report-investment-pathway-europe-future/.*

1

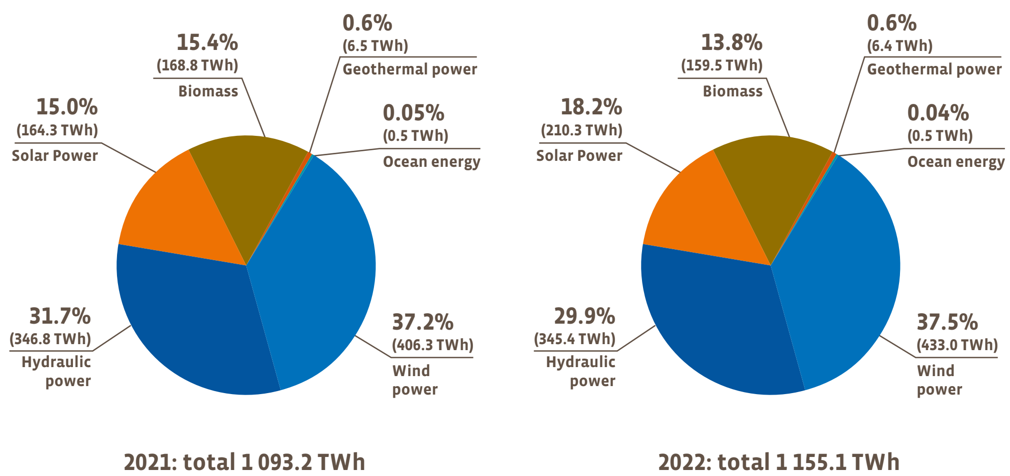
Share of each energy source in renewable electricity generation in the EU27 (in %)



Notes for calculation: Hydro is actual (not normalised) and excluding pumping. Wind is actual (not normalised). All electricity production, compliant or not with renewable Directives, from solid biofuels, biogas (pure and blended in the gas natural grid) and bioliquids is included.
Source: EurObserv'ER from Eurostat database (updated 28 january 2024)

2

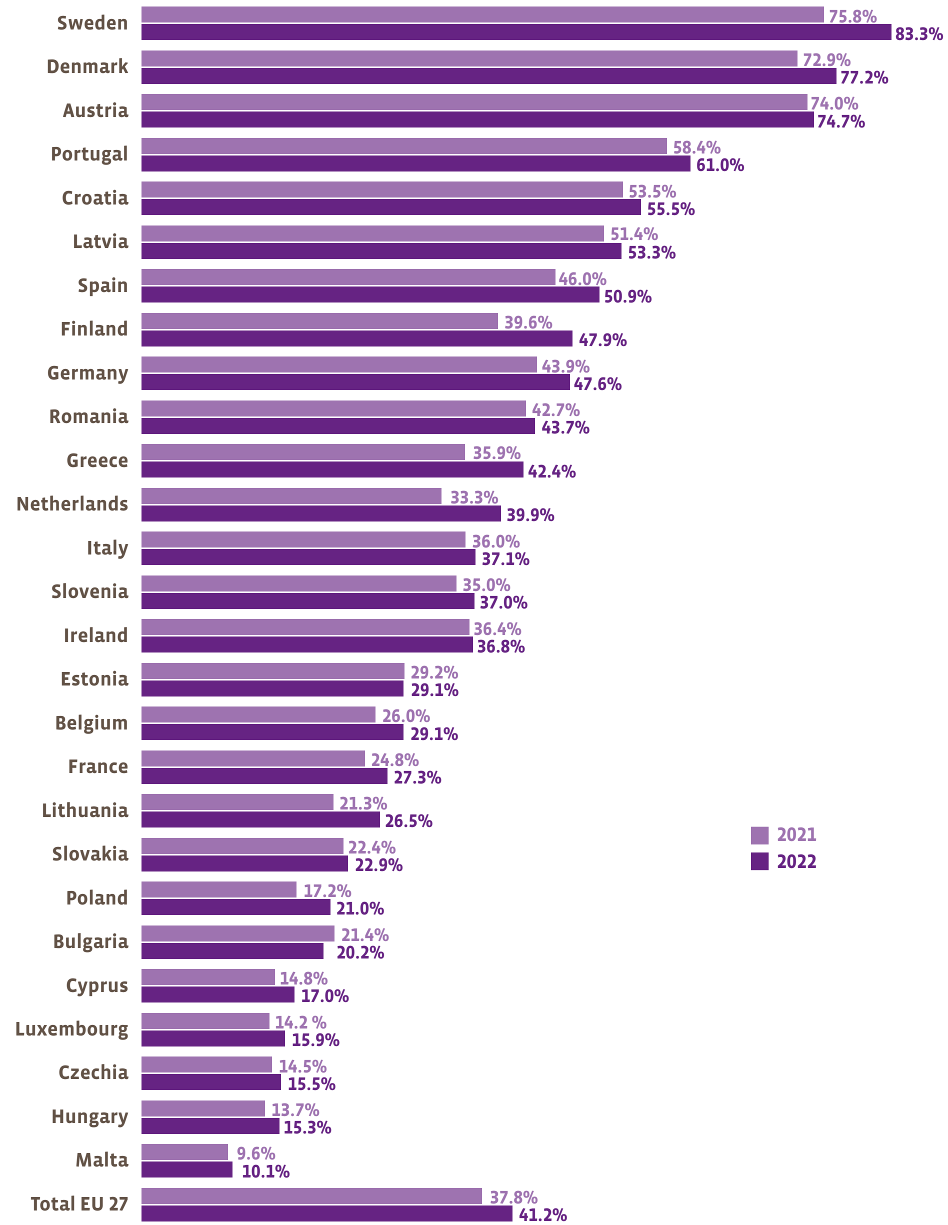
Share of each energy source in renewable electricity generation in 2021 and in 2022 in the EU-27 (in %) according the Directive (EU) 2018/2001 specifications.



Notes for calculation: Hydro is normalised and excluding pumping. Wind is normalised. Solar includes solar photovoltaics and concentrated solar power generation. Biomass includes electricity generation from solid biofuels, liquid biofuels and biogas (pure and blended in the natural gas grid) calculated according to their compliance with the criteria of Directive (EU) 2018/2001 and also renewable municipal waste.
Source: EurObserv'ER from Eurostat database (updated 28 january 2024) and SHARES

3

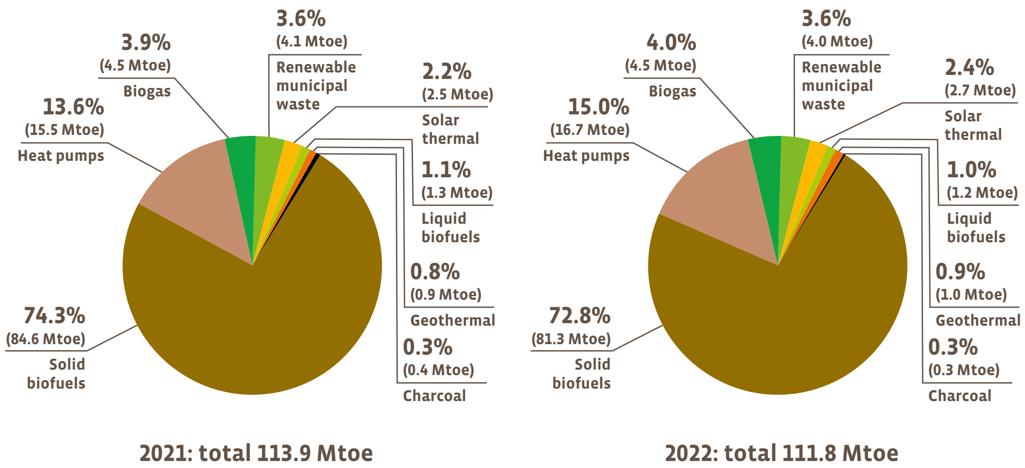
Share of energy from renewable sources in gross electricity consumption (%) - According the Directive (EU) 2018/2001



Notes for calculation: Hydro is normalised and excluding pumping. Wind is normalised. Solar includes solar photovoltaics and concentrated solar power generation. Biomass includes electricity generation from solid biofuels, liquid biofuels and biogas (pure and blended in the natural gas grid) calculated according to their compliance with the criteria of Directive (EU) 2018/2001 and also renewable municipal waste.
Source: Eurostat (updated 6th February 2024)

4

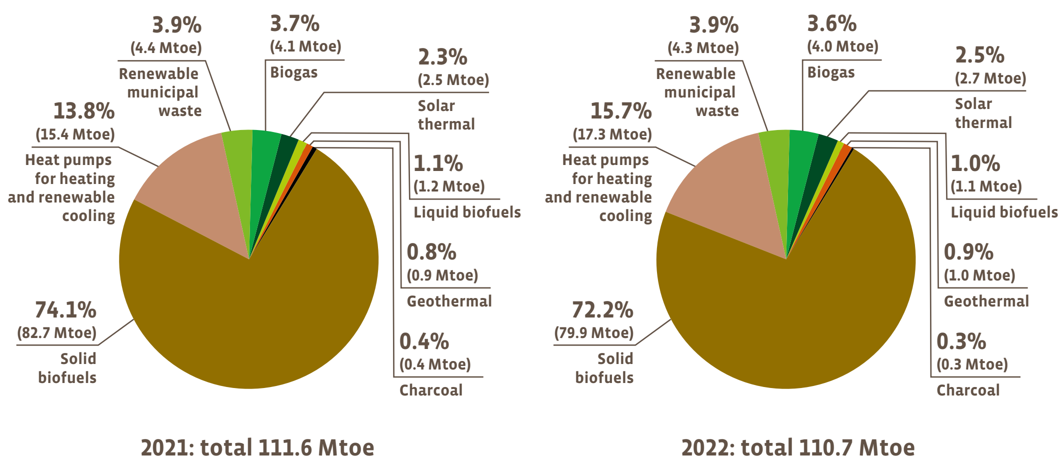
Share of each energy source in renewable heat and cooling consumption in the EU-27 (in %).



Note for calculation: Renewable sources for heating and cooling correspond to the sum of final energy consumption of renewables fuels in Industry and other sectors (excepted transports), of production of derived heat from renewable fuels and heat pumps (final energy consumption and derived heat). Final energy consumpion and derived heat from biogas blended in the grid is included. All final energy consumption and derived heat from solid biofuels, liquid biofuels and biogas (pure and blended in the grid) is including, complying or not with the requirements of renewable Directives. ***Source: EurObserv'ER from Eurostat database (updated 28 january 2024)***

5

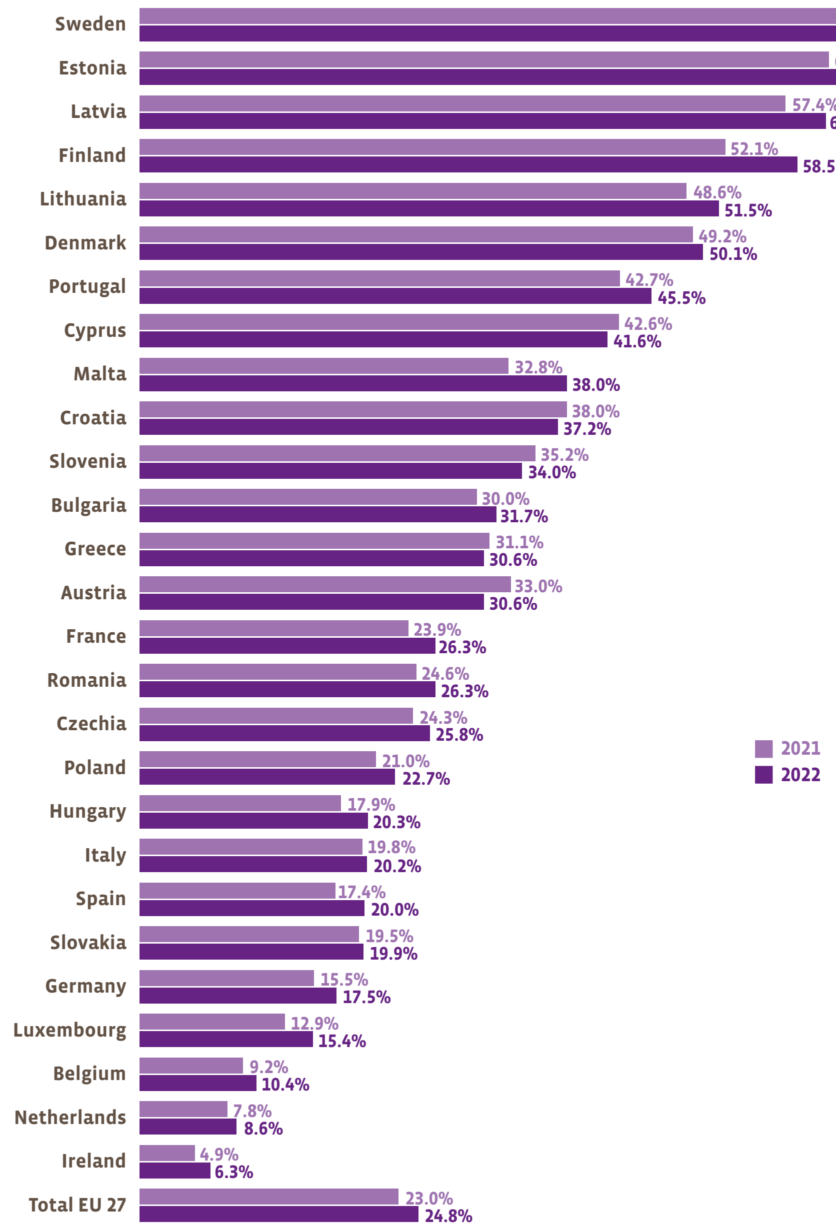
Share of each energy source in renewable heat and cooling consumption in the EU-27 (in %) according to the Directive (EU) 2018/2001 specifications.



Note for calculation: Renewable sources for heating and cooling correspond to the sum of final energy consumption of renewables fuels in Industry and other sectors (excepted Transport), of production of derived heat from renewable fuels, heat pumps for heating and renewable cooling. For final energy consumption and derived heat from solid biofuels, liquid biofuels and biogas (pure and blended in the grid), only the part complying with the requirements Directive (EU) 2018/2001 is included. ***Source: EurObserv'ER from Eurostat database (updated 28 january 2024) and SHARES***

6

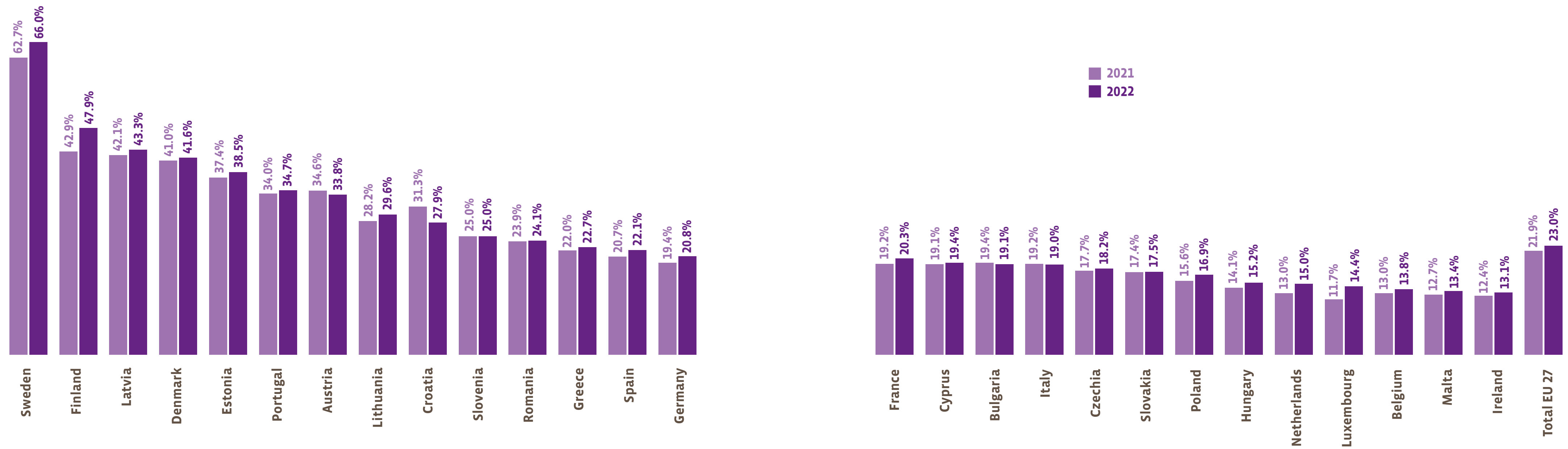
Share of energy from renewable sources for heating and cooling (%) - According the Directive (EU) 2018/2001



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

7

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



Source: Eurostat (updated 6th February 2024)

the member countries' full energy balance, updated on 28 January 2024. They are valuable in that they highlight the differences from the "eligible" energy indicators that meet the legal specifications of RED II.

SOLAR AND WIND ENERGY BAIL OUT HYDROPOWER

If we stick to actual renewable electricity output, i.e., non-normalized for wind and hydro power, and excluded pumped-storage hydroelectricity, overall renewable electricity output across the European Union remained stable between 2021 and 2022 (rising by 0.2%, i.e., growth of 2.2 TWh) to reach 1 084.2 TWh. Renewable electricity production in the European Union can be said to have been treading water, while it concealed an exceptional climate event that affected much of the European continent. The lack of rainfall created a record hydraulic deficit in many countries (France, Italy, Germany, Spain, Portugal, and others). Across the European Union, actual hydropower output excluding pumped storage actually fell by 20.7% to 276.2 TWh. One has to go back to the 1960s to find a precipitation deficit of such magnitude. Fortunately, the dearth of rainfall measured in 2022 coincided with record sunshine levels across the continent. Combined with a record level of photovoltaic grid connections, it enabled solar power output (97.8% of photovoltaic origin and 2.2% from Spanish thermodynamic power plants) to increase by 28% across the EU between 2021 and 2022 (46 TWh) to 210.3 TWh. In 2022, renewable electricity output was also boosted by wind power rebounding following on from the previous year's wind drought in many regions. While the wind conditions were not exceptional, an 8.9% increase in output was made between 2021 and 2022 (i.e., 34.6 TWh) to 421.3 TWh in the European Union, despite lower-than-average winds measured in several countries such as Germany. Biomass electricity, across all its component parts (solid biomass, biogas, renewable municipal waste, liquid biomass), slipped (by 3.6%, a drop of 6.2 TWh), part of which can be attributed to lower wood pellet consumption for generating electricity in the Netherlands and Denmark. This drop resulted from the sharp rise in the price of wood pellets and the introduction of an EU embargo on imports of Russian and Belarusian pellets. If we look at the breakdown of the European Union's biomass electricity output in 2022, 52.0% of it came from solid biomass, 34.6% from biogas (including biomethane mixed into the natural gas grid), 11.4% from renewable municipal waste recovered in incineration plants and 2.0% from liquid biomass. The European Union's geothermal electricity production (essentially Italian) and marine energies sectors (essentially French) were fairly static between 2021 and 2022 with respective 2022 output levels of 6.4 TWh (a 0.1 TWh decline) and 0.5 TWh (a 0.0 TWh rise). Thus in 2022, renewable energies accounted for 38.4% of total gross electricity output in the EU-27 (that Eurostat measured at 2 824.3 TWh). This is better than the previous year's performance, when this indicator stood at 37.1% (for total electricity output of 2 915.7 TWh).

RENEWABLE HEAT ENJOYS ITS SECOND BEST YEAR

The Eurostat data from the member countries' full energy balance updated on 28 January 2024 shows that the renewable energy used for heating and cooling contracted a little between 2021 and 2022, from 113.9 to 111.8 Mtoe (or 1.8%). A shorter heating season in 2022 was mainly to blame for the lower solid biomass consumption figure (see below).

Final consumption of energy from renewable sources is defined for the purpose of calculating the renewable energy share of heating and cooling, as the final consumption of renewable energy in industry, households, services, agriculture, forestry and fishing for heating and cooling, plus urban heating produced from renewable energies. Total final consumption for heating and cooling is the final consumption of all energy products, excluding electricity, for purposes other than transport, supplemented by heat consumption for own use in electricity and heat plants and heat losses in heating

8

Statistical transfers reported by countries for reference year 2022 (ktoe)

		Amount added to the share of renewables			
		Belgium	Slovenia	Germany	Luxembourg
Amount deduced from the share of renewables	Denmark	57.8	0	4.6	**103.2**
	Croatia	0	102.6	0	**0**

Source: Eurostat

networks. EurObserv'ER has opted to add an estimate of the final energy consumption (of "industry" and "other sectors", for other non-transport purposes) and the derived heat of biomethane injected and mixed into the natural gas grid. In several countries (Denmark, Germany and France), this consumption which can be substantial is excluded from the biogas indicators of the full energy balance that correspond to the use of "pure" biogas energy. The Eurostat SHARES tool country fact files provide an estimate of the final energy and derived heat consumption from biomethane injected into the natural gas grid, that distinguishes the RED II-compliant fraction.
Note, data based on the Member States' energy balance cannot be used for RED II target calculations as is, because RED II has its own calculation specifications and modes including, for example, specific biomass indicators that factor in conformity criteria, and specific indicators that measure renewable energy production by HPs designed solely for renewable heating and cooling.
According to EurObserv'ER, about 1.7 Mtoe of renewable biomass heat (all its component parts) was not considered compliant in 2022 and thus was excluded from the RED II target calculations. This is comparatively little compared to the total consumption of biomass heat. Most of the European Union's solid biomass feedstock was sourced from European Union soil in forestry and energy recovery operating conditions that comply with RED II criteria.
No underlying renewable energy consumption trend can be quantified for heat and cooling production on the basis of the last two years' annual climate variations and alternating harsh and mild winters. As it happens, the first provides an explanation for the slight dip in the European Union's renewable energy consumption for heating and cooling compared to the previous winter.
In the long term, there is no doubt that renewable energy consumption for heating and cooling requirements will grow. It passed the 90 Mtoe mark at the beginning of the 2010s, 100 Mtoe in 2018 and 110 Mtoe in 2021. Eurostat points out that statistical data revisions by the declaring countries have also played a part in how data has changed over the long term. Countries now monitor the renewable energy raw materials flows in their economies more thoroughly as stipulated by the Renewable Energy Directive and the demands of the energy statistics regulation to communicate detailed data on households' energy consumption. Biomass consumption is subject to particular scrutiny as countries launch new, more detailed surveys that reveal higher quantities of biomass and therefore an increase in its final energy consumption. The renewably sourced energy fraction, following data revisions by several countries, has grown substantially and made it easier to attain their 2020 targets. Some countries' bottom lines have moved through more accurate accounting of the renewable energy produced by heat pumps for heating and more recently for cooling.
The growth of renewable heat over the past years owes a lot to heat pumps. The sector's momentum is so strong that even when heating requirements shrink, the renewable energy contribution remains positive from year to year. A case in point is 2022, when despite the shorter heating season, the contribution was 16.7 Mtoe… signalling 1.3 Mtoe (8.1%) of year-on-year growth. The solid biomass contribution declined by 3.3 Mtoe (3.9%). A positive contribution was made by solar thermal heat, which rose by 178 ktoe (7.0%) to 2.7 Mtoe. It is essentially used for domestic hot water production, but also as a top-up in hybrid solar heating installations and solar heating networks. Record sunshine levels in 2022 across Europe are partly responsible for this result, as well as a good year for new installations across the European Union, primarily in Germany and Greece. Astute use of rounding (951 ktoe in 2022) on the 39 ktoe increase brought geothermal's contribution to heat and cooling consumption closer to the one Mtoe threshold. This positive thrust was driven particularly by German investments in binary cycle plants that produce both electricity and heat for networks simultaneously.
If we focus on the respective share of the various renewable sectors, the trend observed in recent years prevails. The solid biomass share in renewable heating and cooling was disproportionate at 72.8% in 2022 (1.6 pp less than in 2021), but the heat pump sector that has grown a little every year reached a 15% share in 2022 (1.4 pp more than in 2021). The other contributors to heat consumption in order of importance, are biogas (4% in 2022) including biomethane mixed into the grid, followed by renewable municipal waste (3.6%), solar thermal (2.4%), liquid biomass (1%), geothermal energy (0.9%) and charcoal (0.3%).

THE SPECIFIC RED II DIRECTIVE TARGETS

A 41.2% RENEWABLE SHARE OF GROSS ELECTRICITY CONSUMPTION

The renewable electricity output monitoring indicator used for calculating the Renewable Energy Directive (EU) 2018/2001 target is specific, because it includes normalized hydropower and wind energy output (separating figures for onshore from offshore wind power) to smooth out the effects of climate vagaries and more accurately reflects the efforts made by each Member State. Furthermore, it only includes the electricity output produced from RED II-compliant liquid, solid and gaseous biomass. The directive has also modified specific accounting rules for the renewable energy contributions made by heat pumps to renewable heat and renewable cooling.
Thus, the normalized hydropower output figure for 2022 adopted for the EU-27 was 345.4 TWh (346.8 TWh in 2021), and that of normalized wind power, 433.0 TWh 406.3 TWh in 2021). Incidentally, in 2022, a year plagued by wild climate fluctuations, the use of normalized output had a very positive impact on the target calculations for both hydroelectricity (excluding pumped storage) and for wind power output that were actually quantified at 276.2 TWh and 421.3 TWh, respectively. The legislators felt it was unnecessary to normalize solar electricity output, which thus took full advantage of the year's record sunshine levels with output quantified at 210.3 TWh. The electricity output figure for RED II-compliant solid, liquid biomass and biogas (pure and mixed into the natural gas grid) can be found in the Eurostat SHARES tool country fact files. EurObserv'ER, which has compiled all the sub-indicators, reckons that compliant biomass electricity output came to 159.5 TWh, which signifies that 9.9 TWh of biomass electricity was disregarded. The breakdown shows that wind energy still leads the renewables sectors for generating electricity with a 37.5% share (a 0.3 pp rise), in front of hydropower with 29.9% (a 1.8 pp fall). Solar power, essentially photovoltaic, comes third with 18.2% (a 3.2 pp rise), but is the fastest growing segment having increased output by 46 TWh (28% year-on-year). Compliant biomass electricity output comes fourth with a 13.8% share (1.6 pp fall), its contribution having dropped year-on-year by 9.3 TWh. The contributions of geothermal and marine energies remain negligible with respective shares of 0.6% and 0.04%.
Total renewable electricity output in 2022, i.e., the numerator used for calculating the renewable energy share of gross electricity consumption, is put at 1 155.1 TWh. The total electricity output figure adopted (the denominator) is 2 805.4 TWh. So, the renewable share of gross electricity consumption for 2022 is put at 41.2% compared to 37.8% in 2021 (a 3.4 pp rise), applying the RED II (EU) 2018/2001) calculation specifications and methods.
Graph 3 shows that the Member States' renewable electricity shares vary wildly depending on a country's renewable energies potential, particularly for hydropower and wind energy, and the support policies rolled out. In 2022, Sweden had the highest share (83.3%) followed by Denmark (77.2%) and Austria (74.7%). The renewable electricity shares of Portugal (61.0%), Croatia (55.5%), Latvia (53.3%) and Spain (50.9%)

were also over 50%. Only five countries had renewable electricity shares of less than 20% – Cyprus (17.0%), Luxembourg (15.9%), Czechia (15.5%), Hungary (15.3%) and Malta (10.1%).

A QUARTER OF THE ENERGY USED FOR HEATING AND COOLING IS RENEWABLY SOURCED

In 2022, renewable sources fuelled 24.8% of total final energy consumption for heating and cooling in the European Union, i.e., 1.8 percentage points more than in 2021. The Eurostat SHARES tool appraised total renewable energy for renewable heating and cooling at 110.7 Mtoe in 2022 compared to 111.6 Mtoe in 2021 (a 0.9% year-on-year fall). Now, since the Commission defined a specific calculation method (delegated regulation 3022/759 dated 14 December 2021), modifying Annex VII of the Renewable Energy Directive (2018/2001) (RED II), calculation of the renewable energy output used for cooling and cooling networks has considerably improved. Initially, Annex VII stipulated a renewable energy calculation method for heating-only heat pumps. The inclusion of a specific calculation for renewable cooling since 2021 enables the renewable energy output of heat pumps used for heating to be separated from systems that produce cooling, such as reversible HPs in cooling mode and cooling networks. The latter can tap renewable energy sources through heat pumps and also when refrigeration units are cooled by seawater or freshwater, or by direct use of a naturally cold source of water, such as pumped deep seawater or river water in winter to cool the network. This new indicator is gradually being introduced and explains the upwards consolidation for 2021. Thus, the renewable energies employed for cooling were quantified at 690.7 ktoe in 2021 and at 855.6 ktoe in 2022. The renewable energy contribution from heat pumps used solely for heating purposes was quantified at 14.7 Mtoe in 2021 and at 16.5 Mtoe in 2022. Heat pump technology has contributed more than any other to the increase in the renewable energy share to meet heating and cooling needs. If we add the figures for heat pumps for heating and cooling together, their share of the renewable total rose from 13.8% in 2021 to 15.7% in 2022… a 1.9 pp gain. Directive-compliant solid biomass contributed 72.2% in 2022 (74.1% in 2021), i.e., it fell 1.9 pp year-on-year. Biomass across all its component parts is far and away the renewable energy most used for heating, if we add together compliant biogas (3.9% in 2022) solid biomass, including the fraction mixed into the natural gas grid, renewable municipal waste (3.6%), compliant liquid biomass (1.0%) and charcoal (0.3%), the total share comes to 81% in 2022 (83.1% in 2021). Solar thermal and geothermal energy bring up the rear with respective shares of 2.5% and 0.9% (2.3% and 0.8% in 2021).

The denominator, namely all fuels used for heating and cooling, as well as the renewable energy from heat pumps (using ambient heat) used for heating along with the renewable energy used for cold production was quantified at 446.0 Mtoe in 2022, a drop of 8.1%. This is the sharpest ever fall in the denominator, which confirms that the renewable share is rising. This finding is highly encouraging because it clearly shows that renewable energies are substituting fossil energy. It stands to reason that the renewable energy share used for heating and cooling by Member States is higher in forested countries where biomass is the main, uncontested renewable heat source. Yet again, Sweden tops the rankings with a 69.4% share in 2022 (a 0.6 pp rise on 2021). Not only does it fully harness its forestry potential (industries and heating networks), but it has made the use of heat pumps in the habitat ubiquitous. The share is also over 50% in Estonia (65.4%, a 4.1 pp rise), Latvia (61.0%, a 3.6 pp rise), Finland (58.5%, a 6.5 pp rise), Lithuania (51.5%, a 2.9 pp rise) and Denmark (50.1%, a 0.9 pp rise). This contrasts with the very low shares in Luxembourg (15.4%, a 2.5 pp rise), Belgium (10.4%, a 1.2 pp rise), the Netherlands (8.6%, a 0.8 pp rise) and Ireland (6.3%, a 1.4 pp rise).

THE RENEWABLE ENERGY SHARE UP TO 23% IN 2022

Eurostat concludes that the renewably sourced share of final gross energy consumption in the EU rose to 23.0% in 2022, which is about 1.1 percentage points higher than in 2021. With the European Directive 2023/2413 the renewable energy target for 2030 was revised upwards from 32 to 42.5% (with the ambition of raising it to 45%). The EU countries must redouble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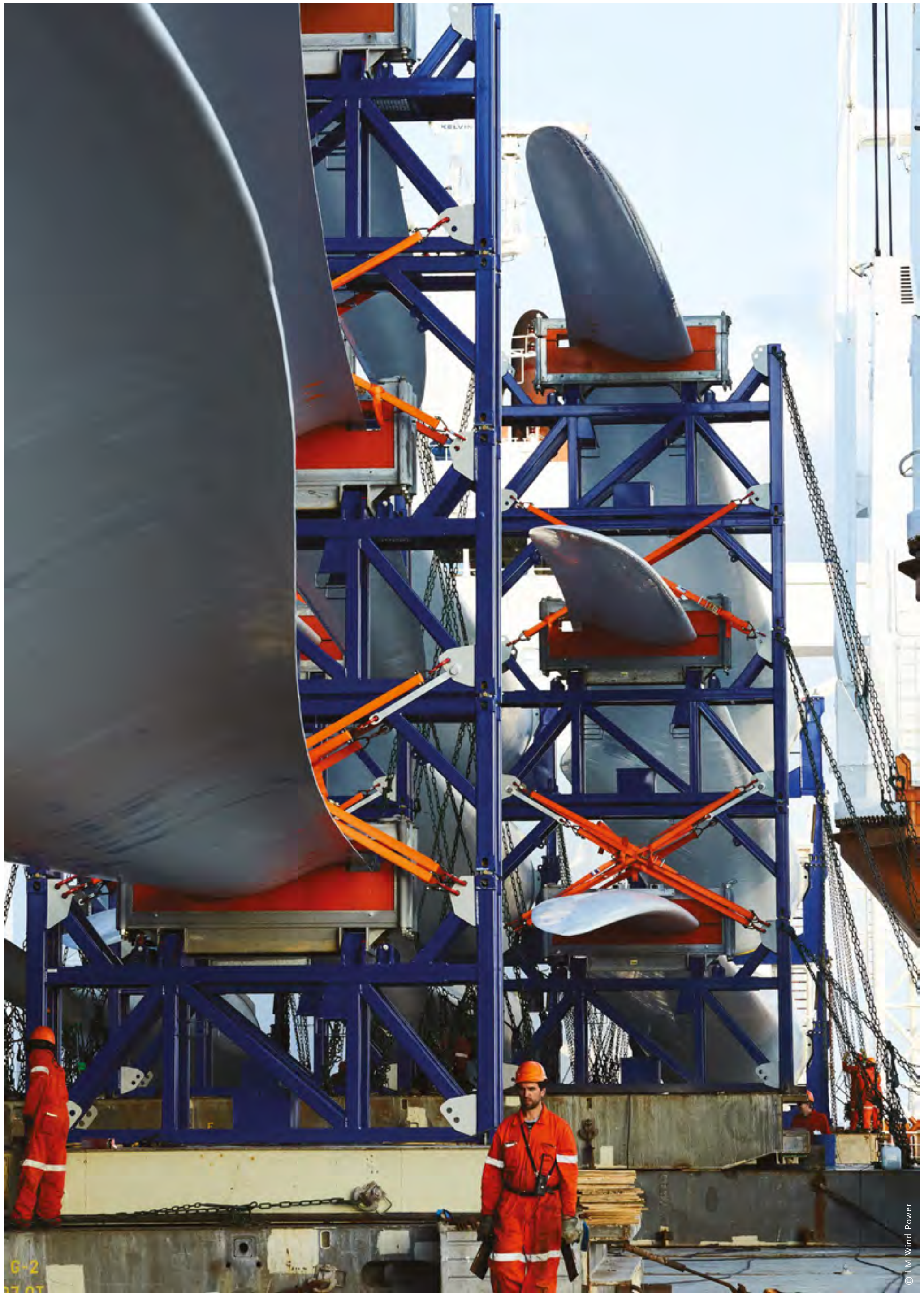
their efforts to collectively meet the new EU target for 2030. Hence, the share of renewable energy sources in the Union's gross final consumption of energy must rise by almost 20 percentage points. The efforts demanded are commensurate with the issues at stake. It has taken the EU-27 18 years to increase its renewable energy share from 9.6% (2004) to 23.0% (2022), i.e., a 13.4 pp rise. It has only eight years left to reach between 42.5 and 45.0%, namely a minimum increase of 19.5 pp.

Several countries have already exceeded this level in 2022, such as Sweden (66% share), Finland (47.9%) and Latvia (43.3%). These countries, and we could add Estonia (38.5%), are fortunate enough to be able to rely on sizeable forestry assets that they have successfully harnessed and are also endowed with major hydropower resources. Furthermore, they have embraced heating by heat pumps wholescale, invested in mainly renewable heating networks, a growing wind energy sector, and more recently in solar photovoltaic.

Denmark, whose forestry and hydraulic resources are less generous, has successfully made its energy mix greener, for both electricity and heating by developing top-rate wind energy industry and manufacturing sectors (onshore and offshore), pioneering co-digestion biogas, heat pumps, and also by heavily integrating renewable energies in its heating networks, with solid biomass, solar thermal, geothermal energy and more recently high-capacity HPs. Denmark is in the throes of constructing Europe's largest geothermal urban heating plant at Aarhus, with 110 megawatts of capacity. Once completed, the plant will supply about 20% of the city with renewable heat. What is interesting about citing Denmark as an example is that of all the European Union countries it is one whose renewable energy share increased most between 2004 and 2022, starting from a relatively low base of 14.8% and reaching a 41.6% share in 2022 (a 26.8 pp rise). This could have been a 42.7% share (a 27.9 pp rise) had Denmark not helped out Belgium and Luxembourg that were struggling to meet their renewable energy commitments in 2020, by transferring part of its output to them (via the statistical transfer mechanisms). Only its European Union neighbour, Sweden, has outclassed it. Its renewable energy share has risen from 38.4% in 2004 to 66.0% in 2022 (a 27.6 pp rise). Denmark's energy transition has been swift and sets an example to countries whose renewable energy shares are still very low such as Ireland (13.1%), Malta (13.4%), Belgium (13.8%) and Luxembourg (14.4%). The latter's renewable energy shares were negligible in 2004, so they have not been idle.

While all the renewable energy sectors and technologies will contribute at their own levels to the new RED III targets, it is clear that in the coming years renewable electricity production, with wind and solar power in the lead, will play an increasingly important role in the European Union's energy transition. Both the electrification of heating and cooling needs (via the proliferation of heat pumps) and the electrification of transport needs combined with the development of storage technologies and the deployment of new interconnections between European countries, will play a growing role, bolstered by the development of storage technologies and the deployment of new interconnections between European countries. Here too, there is huge potential for improvement. The European Union has agreed to set a common target of 29% for the renewable energy share used in transport by 2030, compared to the 2022 share of 9.6%, or a greenhouse gas intensity reduction of at least 14,5 % by 2030 compared to the baseline set out in Article 27(1), point (b). This issue is covered specifically in the chapter on renewable energies in transport. While RED III (Directive 2023/2413), that amended RED II has been adopted, the transposition period will end in 2025. Then the calculations will be adjusted and result in implications for the use of biomass energy by applying tougher sustainability criteria to consider its eligibility for inclusion in the targets. ■



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

The share of RES in the building stock has grown strongly in Europe in recent years. In general, RES are particularly successful in the area of electricity generation. However, RES consumption is still lagging somewhat behind in the heating and cooling sector. In 2021, RES reached around 38% of electricity generation but only around 23% of total EU heating and cooling energy use (Eurostat). At the same time, energy for heating and cooling is the largest energy demand in buildings. In residential buildings, space heating and cooling account for up to 70%, while electricity consumption for lighting and appliances amounts only to about 14% (EU building factsheets). In the following, the first chapter focuses on the integration of RES heating and cooling in the building stock and urban infrastructure. The second chapter looks into the integration of RES electricity, with a focus on self-consumption of electricity from photovoltaics.

INTEGRATION OF RES HEATING AND COOLING

Heating and cooling demand is met by a variety of decentralised technologies integrated into the building or by centralised heating infrastructures. Decentralised renewable heating technologies in buildings include heat pumps, electric boilers, biomass boilers and solar thermal collectors. Centralised heating infrastructures are collective heating systems based on underground pipes that transport heat to multiple consumers. A distinction can be made between gas and district heating networks. District heating is based on large-scale plants such as biomass CHP, deep geothermal, solar thermal fields and large 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 heterogeneous 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, and 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 sales data were unavailable for several 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 decentralized technologies in buildings. For this purpose, the total market stock share of decentral heat pumps and direct electric boilers in buildings is depicted.

CONSUMPTION SHARES OF RES IN HEATING AND COOLING

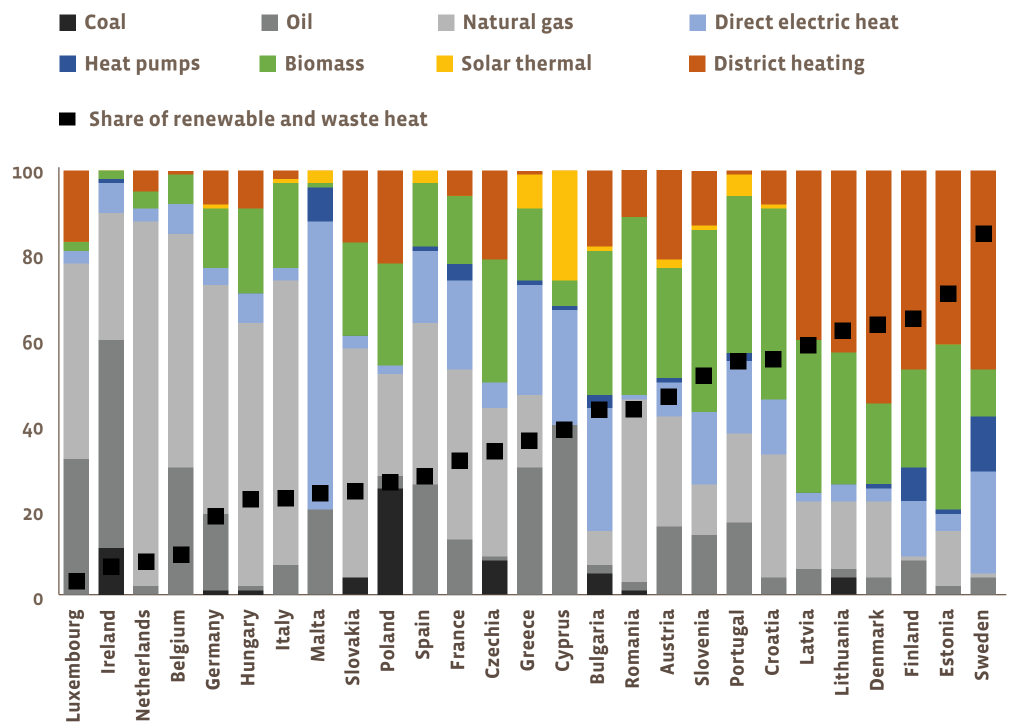
Figure 1 presents the consumption shares of RES heating and cooling in 2021 for residential buildings and services. This share is a combined indicator for the integration of RES in buildings and urban infrastructure. It depicts the share of RES in the total final energy demand for heating and cooling. 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.

Fraîcheur de Paris

RESULTS ON THE INTEGRATION OF RES HEATING AND COOLING

1

Consumption shares in heating in 2021



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

Gas remains a crucial source of heating for most countries. Especially in the Netherlands, Italy, Hungary, Belgium, Germany and Slovakia, gas is dominating the heating market. Although oil boilers are in steady decline in the heating market, they are still an important source of heating in Ireland, Cyprus, Luxembourg, Greece and Belgium. In Poland, a large share of heating relies on coal, while direct electric heating plays a dominant role in Malta. Bulgaria, Cyprus, Greece and Sweden also exhibit shares above one quarter for direct electric heating. District heating prevails particularly in the Scandinavian and Baltic countries, with leading shares. Eastern European countries, with established networks and a long history of district heating, also rely prominently on this system.

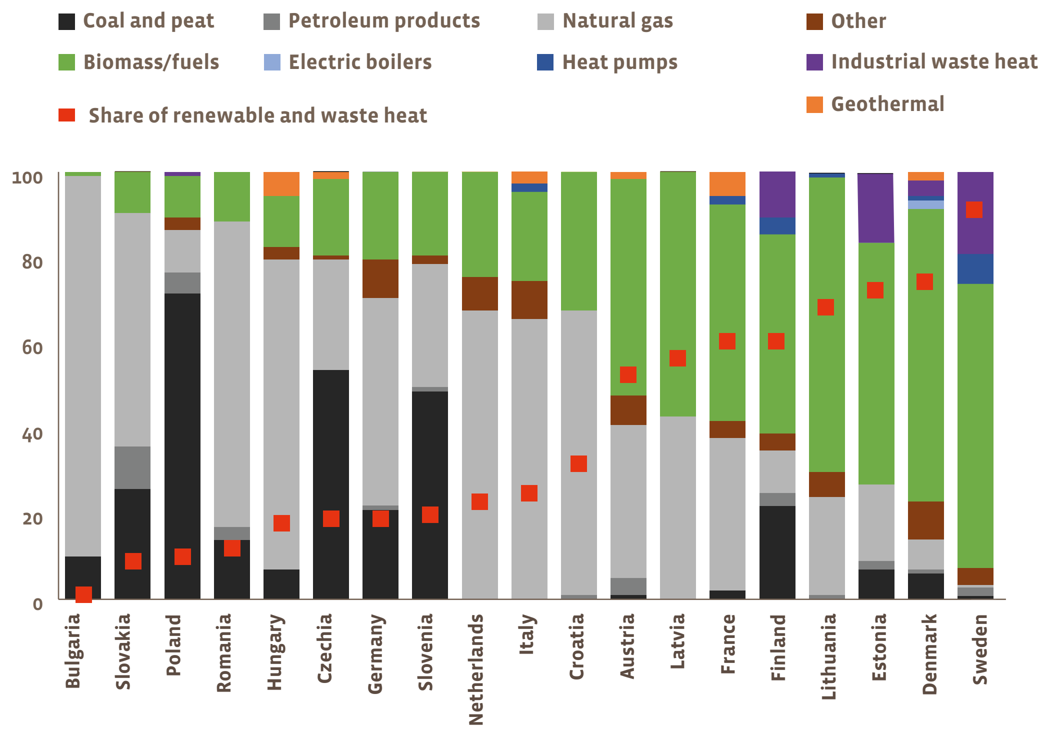
The share of renewable and industrial waste heat in Figure 1 depicts the total of RES shares in decentral heating and central district heating, including RES shares in electricity used to generate heat. RES and waste heat dominate in Sweden (85%), Estonia (71%), Finland (65%), Denmark (64%),

Lithuania (63%) and Latvia (59%). In addition, these countries have the highest shares of district heating in Europe, highlighting the advantage of district heating to integrate large shares of RES and waste heat that cannot be used in individual heating systems.

In contrast, Croatia (45%), Slovenia (43%) and Romania (42%) reach high RES 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 Estonia (39%), Portugal (37%), Latvia (36%), and Bulgaria (34%). Decentral heat pumps are growing in importance every year. However, higher shares are reached in Scandinavian countries such as Sweden (13%) and Finland (8%), but also Malta (8%). Solar thermal displays the smallest shares in most countries. It is mainly used in southern Europe countries with high solar radiation potential, such as Cyprus (26%) or Greece (8%).

2

District heating supply mix in 2021



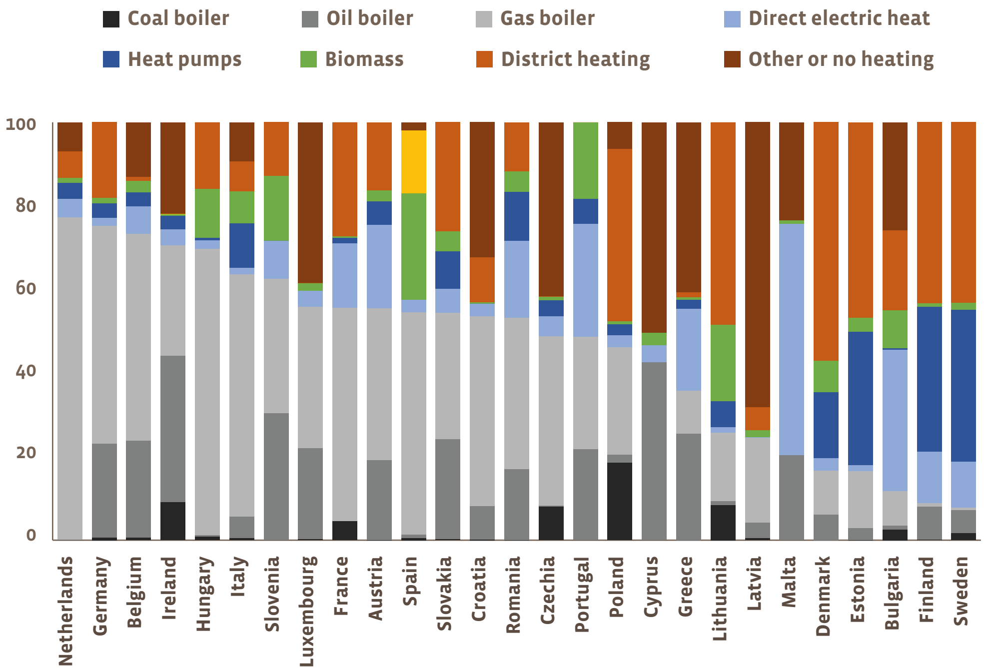
Source: Own assessment based on diverse sources: Eurostat, Euroheat & Power DHC Market Outlook Insights & Trends 2023 and data from national statistic institutes of the MS. *Notes: Based on 2021 data for: BG, DE, AT, FI, SE, HR, RO, PO, CZ, SI, HU, IT, EE, FR, DK, LT; 2018 data for: NL, SK. Other includes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

SHARE OF RES IN DISTRICT HEATING

Figure 2 shows the district heating supply mix in the countries where district heating covers at least 2% or more of the heating and hot water demand in 2020. In most countries, the existing district heating networks still rely on fossil fuels, with natural gas and coal as the dominant sources. Coal and peat are mostly used in Poland (72%), Czechia (54%) and Slovenia (49%). Oil as a source for DH consumption still plays a relevant role in the supply mix of Slovakia (10%). In contrast, Sweden (92%), Denmark (75%), and Estonia (73%) have very high shares of RES and industrial waste heat in district heating.
The most dominant RES in district heating are biofuels such as biomass, biogas and renewable waste. Especially in Denmark (69%), Lithuania (68%), Sweden (67%), Austria (51%), France (51%), Latvia (57%), Estonia (57%), and Finland (47%) biofuels are the most important source in district heating. Large-scale heat pumps are mostly used in Sweden (7%), Finland (4%) and Denmark (1%). Waste heat from industrial processes reached high shares in Sweden(18%) and Estonia (16%). Geothermal energy reaches only low shares in a few countries, such as Hungary (6%) and France (6%). 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 2021



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

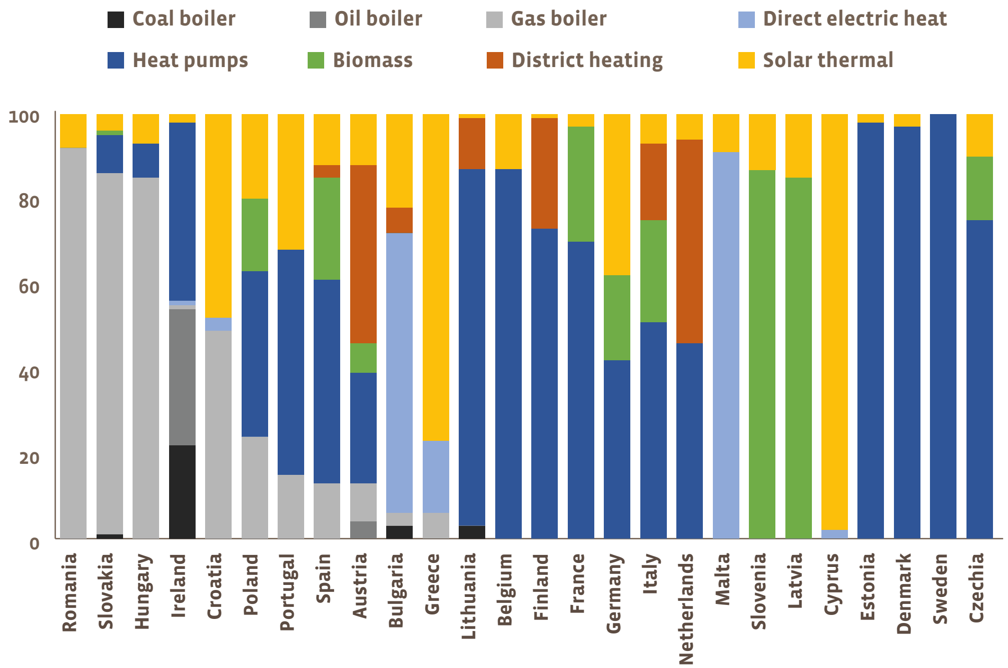
MARKET STOCK AND MARKET SALES SHARES OF RES IN HEATING

Figure 3 depicts the technology shares in the building stock. In contrast to Figure 1 above, it shows the share of 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 high for Latvia, Cyprus, Estonia, Czechia, Greece and Croatia. 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, this share is decreasing in most countries compared to the previous year, indicating that data availability is increasing.

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

4

Market sales shares of RES in heating in 2021



Source: Own assessment based on diverse sources: Eurostat, EHPA Market and Statistic Report, Bioenergy Europe Statistical Report and Solar Heat Europe Market Statistics. *Notes: Fossil fuel boilers, electric boilers and district heating are calculated based on the change in market stock share. One unit of solar thermal contains 4 m2 per household. Luxembourg is excluded due to a lack of data. According to a German association (BDH), there were also sales of oil and gas boilers in Germany in 2021, but no net sales were observed (due to the methodology used, i.e. change in market stock).*

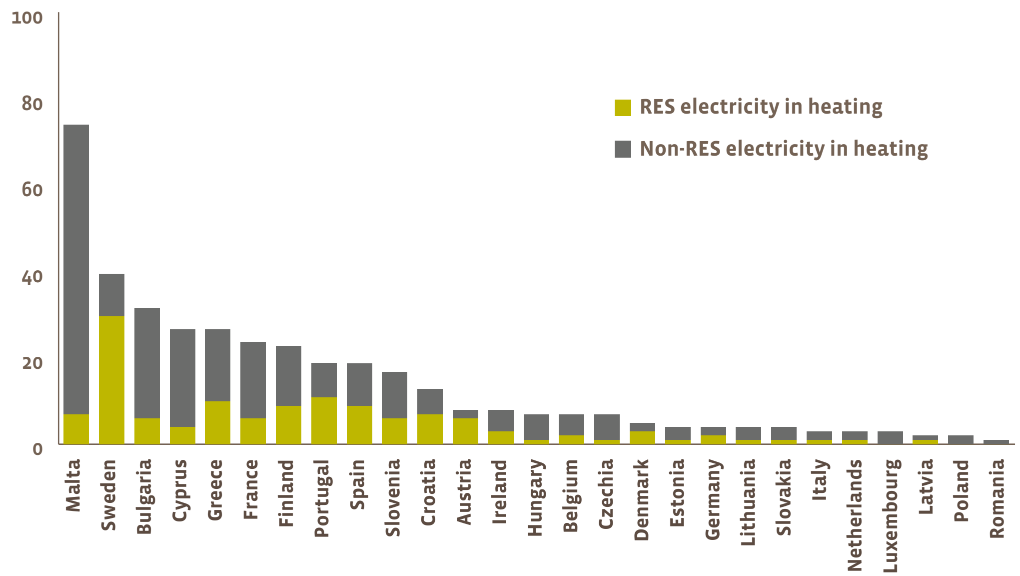
Heat pumps show very high dynamics in most countries, especially in Sweden, Czechia, Denmark and Estonia. Direct electric heating technologies are pushed out by heat pumps and only have a high share of sales in a few countries. Solar thermal energy shows very high sales rates in countries where it has already a high share, such as Cyprus and Greece. Biomass boilers display a high dynamic in Slovenia and Latvia. Sales of fossil fuel-based heating systems are still at a high level in countries like Romania, Slovakia, Hungary, Ireland, and Croatia. 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.

SHARES OF RES ELECTRICITY FOR HEATING

As the share of RES in the electricity sector increases, electric heating becomes more important. Figure 5 shows the share of RES electricity used for heating of buildings, including the share of electricity in district heating. This indicator thus shows the share of RES electricity used in small and large direct electric heaters and in small and large heat pumps.
Figure 5 shows that even though electricity as a source of heating is gaining importance, the EU average of RES electricity for heating purposes is still below 5%. Malta and Sweden are leading countries using high shares of RES electricity in their heating mix. Bulgaria, Cyprus, Greece, France and Finland also have a higher share of electricity in their heating mix (above 20%). In Malta, Bulgaria and Cyprus, electricity is still largely generated from fossil fuels. The heat demand in Malta and Cyprus is rather low, so the high fossil share in electricity is not significant in absolute terms, while the opposite is true for Bulgaria.

5

Share of RES and fossil-based electricity used in heating in 2021



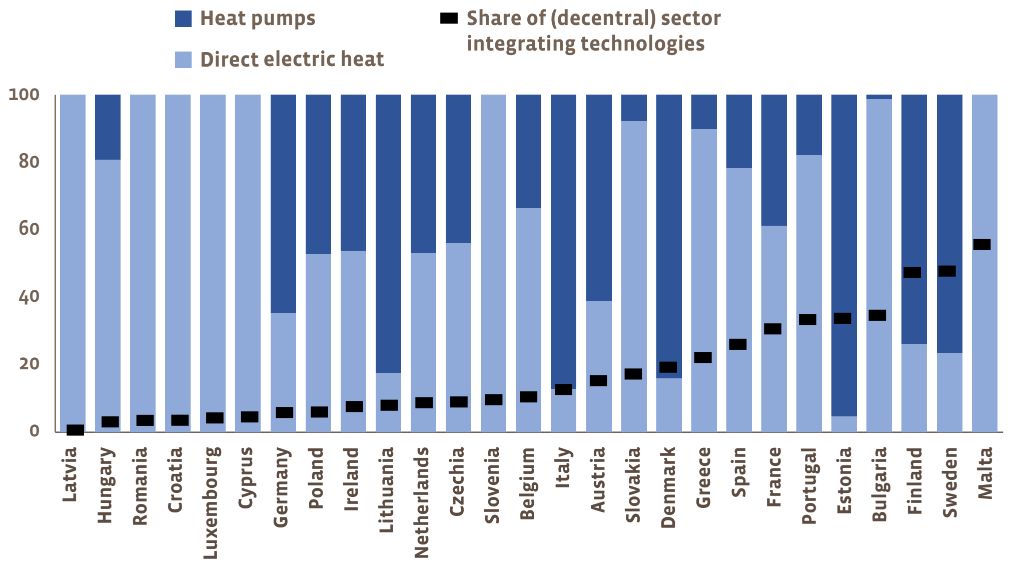
Source: Own assessment based on other indicators and Eurostat.

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, Sweden, and Finland, market stock shares are above 40% and in Bulgaria, Estonia, and Portugal, market stock shares of more than 30% can be observed. However, in half of the countries, decentral direct electric heaters and heat pumps still play a minor role, with less than 10% shares.

6

Market stock share of (decentral) sector-integrating technologies in 2021



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 heat pumps + direct electric heating of total number of heating systems.*

CONCLUSION RES HEATING AND COOLING INTEGRATION IN BUILDINGS

In conclusion, natural gas boilers are still the most commonly used heating technology, followed by district heating. The consumption and market share of coal and oil boilers are slowly declining. However, due to their long life cycle and ongoing sales, these boilers are expected to continue playing a role in the next years. Gas boilers, in particular, still receive financial support in several countries because of the potential to use synthetic fuels or green hydrogen.

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

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

INTEGRATION OF RES ELECTRICITY (SELF-CONSUMPTION)

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

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

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

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

METHODOLOGICAL APPROACH TO ASSESS RES ELECTRICITY SELF-CONSUMPTION

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

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

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

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

Input of the calculation are hourly amounts of consumed electricity of a household in kWh («load») and the hourly amounts of produced electricity by the PV system in kWh. The «load» means the hourly load, equal to the terms demand and consumption, of a household in the respective country. It is calculated as the product of the average yearly electricity consumption of a household in the respective country and the hourly load, derived from standard load profiles. For the calculation, climate-corrected unit consumption data of electricity per dwelling (Odyssee indicators database) were used to adjust the average load to the year of consideration. Production is defined as the hourly produced electricity and calculated as the product of the specific hourly production in kWh per kWp and the capacity of a residential PV system. The values of the hourly production are also used as the denominator to calculate the self-consumption shares per hour. The specific hourly production is based on data provided by the ENTSO-E transparency platform and Eurostat for the production of installed PV systems in a country.

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

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

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

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

1

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

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

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

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

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

RESULTS OF PV BASED SELF-CONSUMPTION OF ELECTRICITY IN BUILDINGS

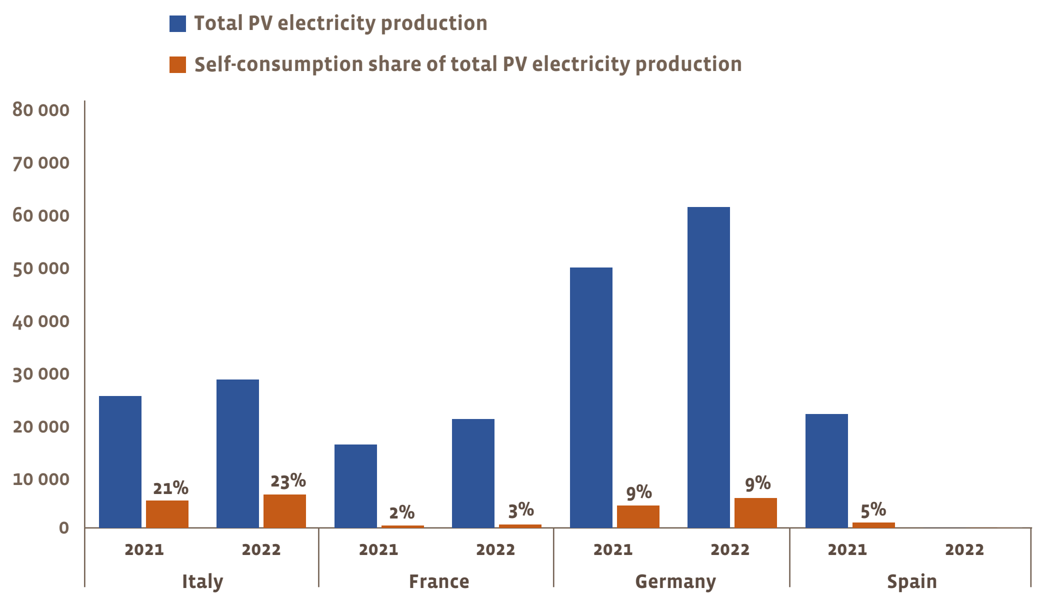
RESULTS OF THE EMPIRICAL APPROACH

In a first step, the deployment of PV on buildings as well as the share of self-consumed PV is assessed empirically, using a compilation of survey data sources.
For presentation reasons, PV based electricity production and self-consumption is illustrated in two figures, Figure 1 and Figure 2. They depict the development of total electricity production from PV per country and year as well as the share of self-consumed PV electricity in total PV electricity production in selected MS. The first figure depicts the situation in bigger and more populous MS with total electricity production from PV above 10,000 GWh annually (Italy, France, Germany, Spain), while the second figure compares countries where total electricity production from PV is below 4,000 GWh per year (Austria, Portugal, Czechia, Sweden, Lithuania, Malta, Luxembourg).

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

7

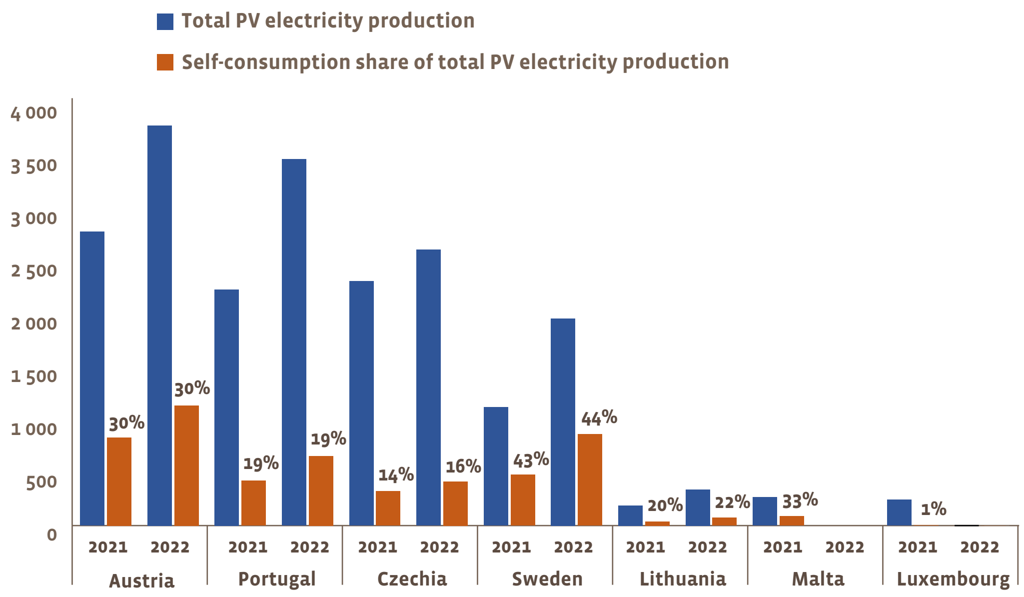
Electricity production from photovoltaics in 2021 and 2022 in larger EU MS



Sources: Ministry of Ecological Transition - Directorate General for Infrastructure and Security (Italy); Ministry of Ecological Transition and Territorial Cohesion, General Commission for Sustainable Development, Service for statistical data and studies (France); Working Group on Renewable Energy Statistics (AGEE-Stat) (Germany); Ministry for the Ecological Transition and the Demographic Challenge and Institute for Diversification and Saving of Energy (IDAE) (Spain), own calculations

8

Electricity production from photovoltaics in 2021 and 2022 in smaller EU MS

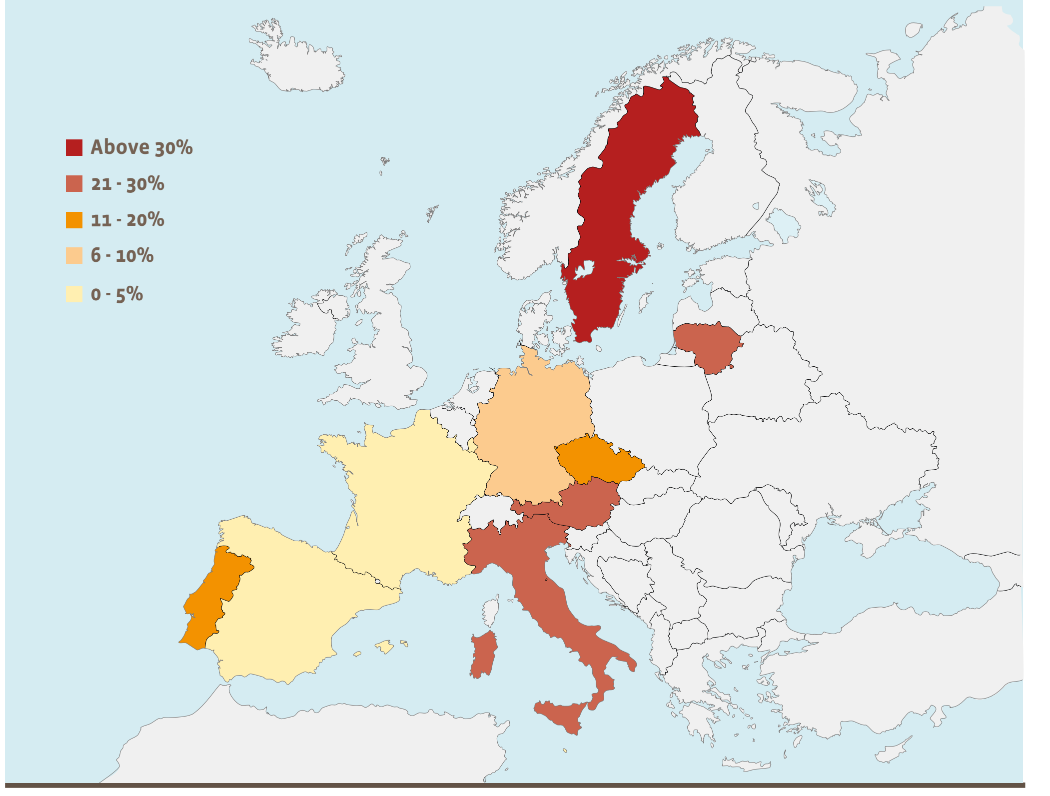


Sources: Ministry of Ecological Transition - Directorate General for Infrastructure and Security (Italy); Ministry of Ecological Transition and Territorial Cohesion, General Commission for Sustainable Development, Service for statistical data and studies (France); Working Group on Renewable Energy Statistics (AGEE-Stat) (Germany); Ministry for the Ecological Transition and the Demographic Challenge and Institute for Diversification and Saving of Energy (IDAE) (Spain)

or remained at least constant between 2021 and 2022. In the sub-set of countries analysed, self-consumption shares are highest in Sweden, increasing slightly between 2021 and 2022. High self-consumption shares can also be observed in Malta and Austria. As for Malta, the 2021 self-consumption share reported was 33%, but no data was provided for 2022. In Austria, the self-consumption share remained constant at 30%, despite a noticeable increase in overall PV electricity production from 2021 to 2022. A similar development happened in Portugal, but at a lower level. In Portugal, the share of self-consumption remained constant at around 19%, while overall electricity production from solar PV rose. SHARES around 20% can also be observed in Italy and Lithuania. In both countries, the self-consumption share increased between 2021 and 2022. Germany exhibits a self-consumption share slightly below 10%. Lower self-consumption shares below or close to 5% can be seen in France and Spain. The lowest self-consumption share, however, in the sub-set of analysed countries is observed in Luxembourg, where only roughly 1% of the total PV electricity production is self-consumed at the moment. However, no data were provided for 2022.
It has to be noted that some respondents indicated that the provided numbers include estimates. The low number of survey respondents might also be explained by the fact that not all MS have a consistent approach to collect and track self-consumption indicators. While the depicted shares do give an indication on the situation in different countries, the lack of uniform definition and standards on how to meter and calculate self-consumption, makes it difficult to do cross-country com-

9

Self-consumption shares in 2022



Sources: Own assessment and calculation based on survey data

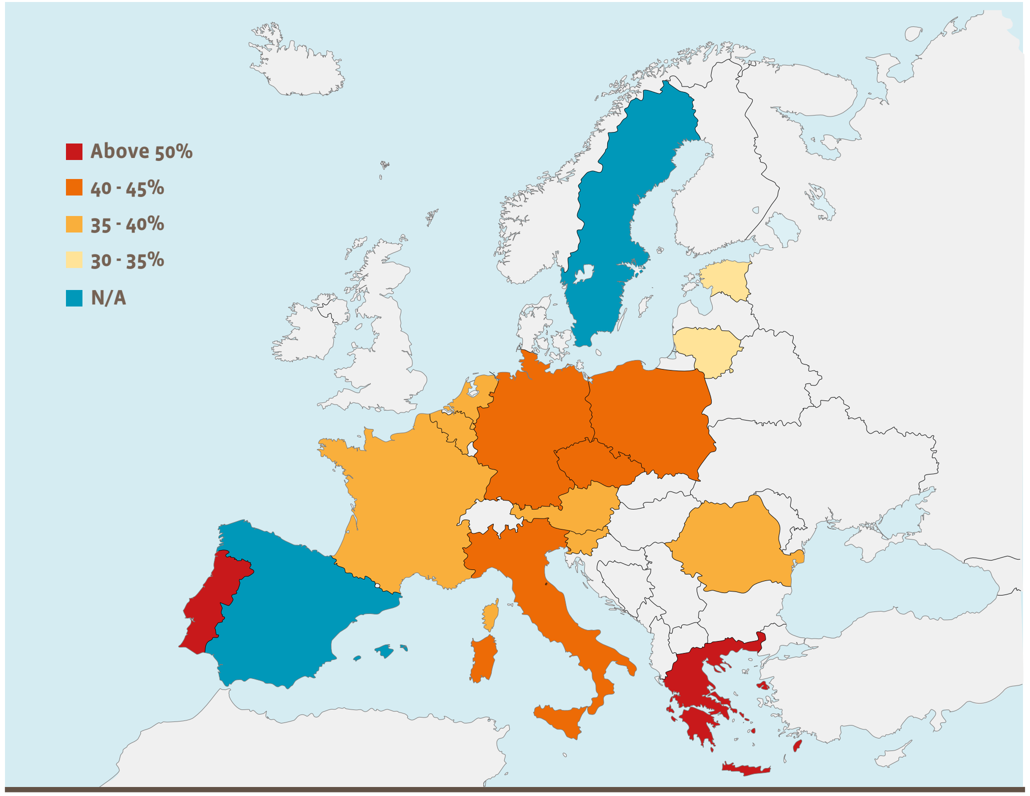
parisons. Over the coming years improvements of data availability, accessibility and quality of data on self-consumption are to be expected.

RESULTS OF THE TECHNICAL APPROACH

The technical assessment takes into account technical aspects via the generation and load profiles of households. It assesses the theoretical self-consumption share of PV based electricity, without taking into account any other factors. It is defined as the overlap of the generation profile (PV energy production) and load profile (home energy use) of a hypothetical household, using synthetic load profiles. Thus, it represents a theoretical, maximum self-consumption potential. In times when the production exceeds the load, i.e. the required electricity, self-consumption is equal to the load because the total electricity demand can be covered by the PV production. In that case, the excess electricity can be fed into the grid. If production is zero, self-consumption is zero as well and all the electricity has to be taken from the grid. When the PV system produces less electricity than needed, for example in periods with very little sunshine, all of the produced electricity is self-consumed and the remaining demand is withdrawn from the grid.
Figure 4 represents the results for these technical maximum shares per country for 2021. This year 17 EU MS were looked at, representing a balanced sample all across different parts of Europe. In the next report, all EU MS will be covered.

10

Technical maximum self-consumption shares



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

The highest technical self-consumption shares are possible in Portugal and Greece. Most countries are within the middle of the distribution and have technical self-consumption shares between 35 and 45%. The lowest technical self-consumption shares are observed in Estonia and Lithuania. The calculated optimal shares are broadly in line with the literature which suggests technically optimal self-consumption shares around 30 to 40%. The EU average is at about 42%. It is, however, possible that the technical self-consumption shares are over- or underestimated for certain countries due to the use of generic synthetic load profiles that might not adequately represent energy use patterns across Europe. The results might be improved by assuming country-specific load profiles, taking into account the different climatic conditions and electricity-consumption patterns. So far, only two synthetic load-profiles are used for all countries, one for Southern European countries and one for the rest. Also, due to lack of data the approach does not consider the option of shifting consumption via storage or demand side management. It can be assumed that the presence of battery systems can considerably boost demand coverage.

As the technical self-consumption share is based on different assumptions and approaches, the calculations deviate from the empirically grounded self-consumption shares described above. Overall, the considerable gap between empirical self-consumption and technical

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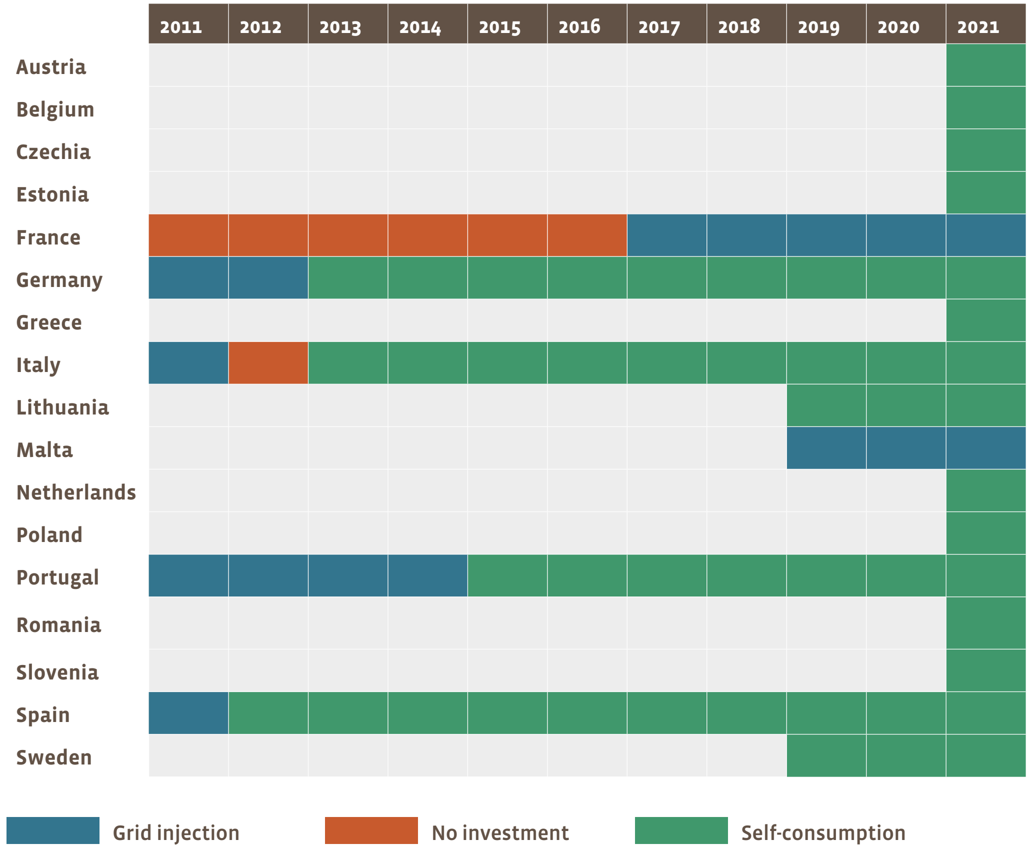
Economically optimal decision on self-consumption option per country per year



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

maximum shares suggests that self-consumption is not yet fully exploited from a technical perspective which means that there is potential for growth and optimisation.

RESULTS OF THE ECONOMIC APPROACH

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

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

The economic evaluation showcases for each country which is the most lucrative «self-consumption scenario», thus revealing the most probable choice for investment decisions.

Table 2 depicts the results for the seventeen selected countries. 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 exactly what can be seen in the results. Overall, self-consumption seems to become the more and more dominant scenario and also was the most profitable decision in fifteen out of the seventeen analysed countries in 2021. This suggests that in many countries effective incentives are put in place to stimulate self-consumption and that investing in solar PV systems is generally profitable. 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 grid injection more attractive.
What the scenario analysis cannot adequately depict, is that the decision to self-consume or not will vary from consumer to consumer and that also «mixed strategies» are possible. This means that under temporal differing price structures «hybrid» consumption models, i.e. self-consuming and feeding the electricity into the grid present another financially profitable solution. Hence, the results should be understood in light of the particular conditions and circumstances existing in each individual case.
The results are, of course, also influenced by non-economic factors such as individual preferences, e.g. a preference for sufficiency, the specific reference electricity price, or the presence of additional support mechanisms. Nevertheless, the findings presented above can give some indication as to which decisions households are likely to make in a particular country during a specific time period and to assess whether self-consumption is advantageous or not from a general perspective.

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CONCLUSION RES ELECTRICITY INTEGRATION IN BUILDINGS

In conclusion, the analysis of RES electricity integration in buildings presented in this chapter sheds light on both economic and technical aspects of self-consumption, comparing it against actual self-consumption shares which we can observe empirically. The economic approach underscores the viability of self-consumption in a large set of analysed countries. To complete this picture, the technical approach provides a theoretical framework for self-consumption, depicting what would be the optimal level from a purely technical point of view, albeit without factoring in storage options. Comparing the technically-optimal self-consumption shares with the empirical results we collected, we show that there still is a large potential for more self-consumption in the European Union at that no single country seems to have exploited its potential for self-consumption. The findings thus affirm a substantial technical potential for self-consumption of electricity, indicating a significant opportunity for harnessing renewable energy sources within buildings. This potential aligns with economic feasibility, particularly in countries where self-consumption emerges as the predominant scenario. However, the empirical analysis exposes notable gaps between the actual level of self-consumption and the technical optimum, particularly evident in France and Spain.

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The economic analysis suggests that self-consumption stands as an attractive option across most countries. It also implies that the barriers to widespread adoption may not be primarily rooted in direct support policies for remuneration but are likely influenced by other factors. These barriers could encompass challenges related to grid access, additional fees or taxes, and administrative processes. Particularly, if the procedures and regulatory framework for installing, connecting, or managing PV systems are perceived as cumbersome or unclear, households may be deterred from making investments in self-consumption. It might also be the case that the level of awareness regarding self-consumption profitability is general low and that more information and support needs to be provided to different stakeholder groups.
In moving forward, addressing these non-financial barriers becomes crucial for unlocking the full potential of self-consumption. Policy efforts should therefore be closely looked at but also extend beyond economic incentives. Streamlining administrative processes, reducing additional fees, and ensuring clarity in regulations can all be important additional steps. By doing so, countries can pave the way for a more efficient and widespread integration of renewable energy sources in buildings and onsite self-consumption.

FOCUS: RENEWABLE ENERGY COMMUNITIES

The COVID crisis in 2020 and the war in Ukraine in 2022 raised the issues of energy sovereignty and the need to move away from dependence on fossil fuels, for both geopolitical and climatic reasons. These are major challenges and meeting them 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.

HANDS-ON POWER

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

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

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

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

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

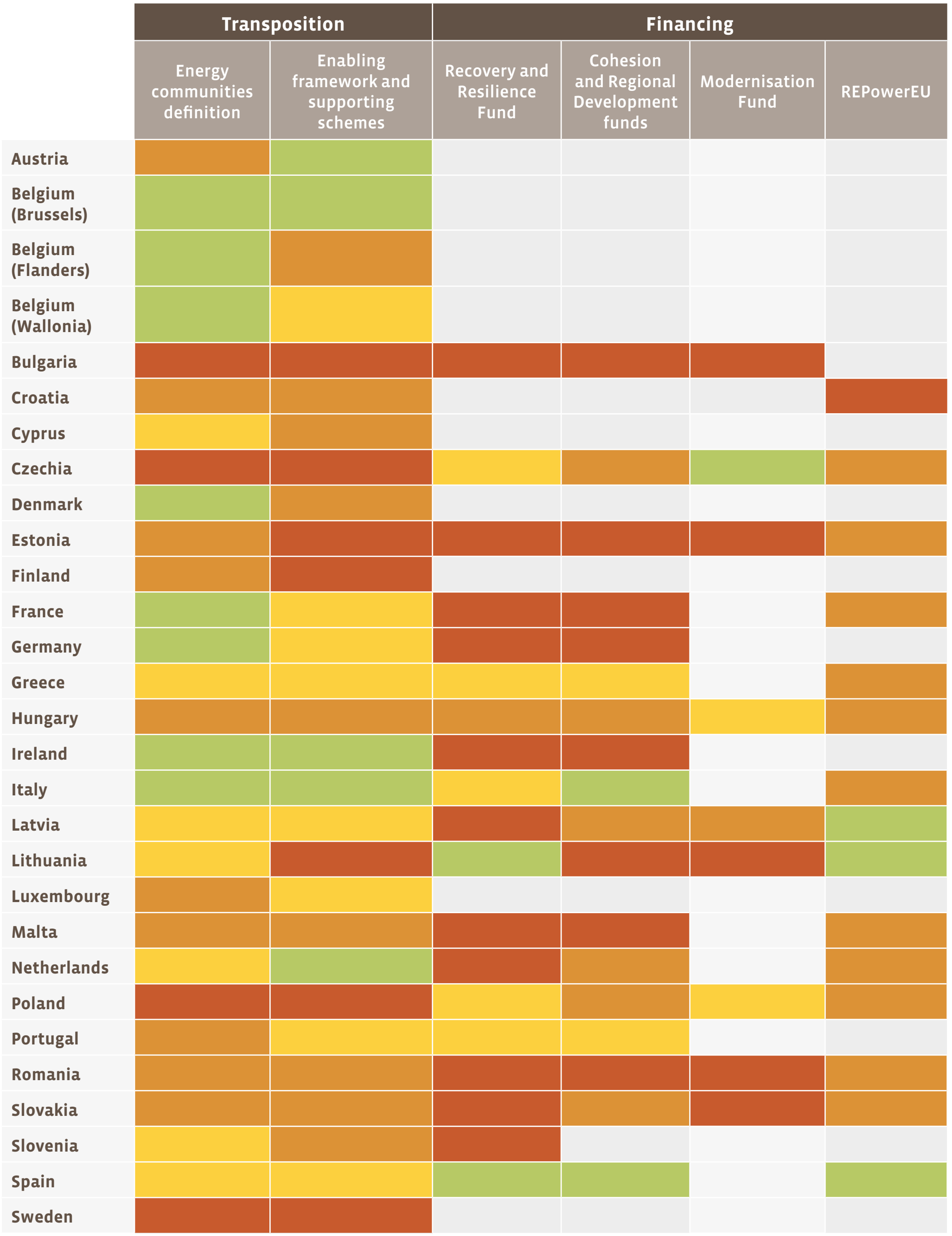
RESCOOP.EU – AN INFORMED OBSERVER

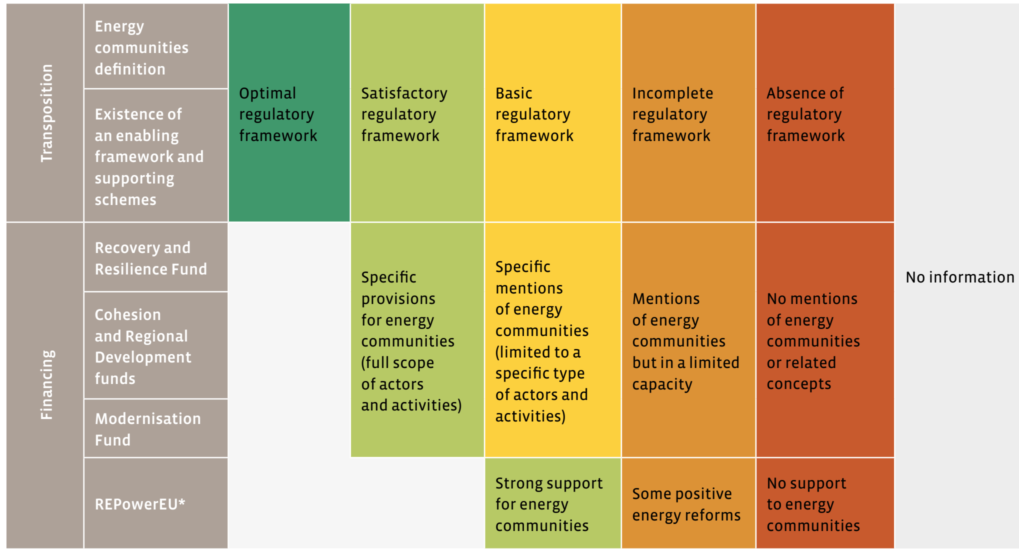
The REScoop.eu federation is a network of European actors that actively promotes citizen energy. REScoop.eu has developed a tool for the purposes of its activities, to track and assess the process of transposing the EU directive texts relating to citizen energy projects in the Member States. It is used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

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

1

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





Note: RESCoop's REPowerEU assessment applies three criteria (transparency and inclusivity during the drafting process of the REPowerEU chapter by the governments, potential support for fossil fuels and conducive reforms and investments towards collective self-consumption and energy communities). **Source: RESCoop, 2023*

The European Union has recently tried to foster the development of renewable energy communities. In its *EU Solar Strategy* roadmap presentation of May 2022, the European Commission declared that it would like every community of over 10 000 inhabitants to have at least one renewable energy based energy community by 2025. The European Commission launched two initiatives to achieve this – the *Energy Communities Repository* and the *Rural Energy Communities Advisory Hub*. These platforms offer technical assistance to Europe's urban and rural energy communities, primarily by sharing best practices for setting up renewable energy communities. In 2024, they should be succeeded by the *Energy Communities Facility* programme, tasked with supporting them especially during the pre-development phase. Incidentally, the European RED III Directive, adopted in October 2023, includes provisions for simplifying authorisation procedures for certain operations. Its texts set a maximum authorisation waiting period of one month for < 100 kW solar equipment, even if the installation is to be operated by a renewable energy community.

FRANCE ESTABLISHES A LEGAL FRAMEWORK

High capital requirements have traditionally led to major players such as private or state enterprises developing renewable energy projects. Yet, this has not prevented citizens from actively producing the energy they use, both by taking stakes in renewable energy generating projects and becoming involved in their governance. In 2010, citizen energy passed a milestone, driven by federations such as Centrales Villageoises, when the Énergie partagée association was created, whose charter first coined the "citizen project" definition. Most of these projects are small photovoltaic installations, but over the past few years, increasingly ambitious citizen energy projects have emerged, such as the citizens' Bégawatt Wind Farm at Béganne (Morbihan), which was commissioned in 2014 with 8 MW of installed capacity. This trend is still being pursued to this day (cf. table). Most of the energy generated by citizens' projects is electrical, overwhelmingly dominated by photovoltaic. Nonetheless, citizens also invest in renewable heat and gas production, albeit to a lesser extent. The emergence of renewable energy commu-

2

The state of citizens' projects in France

Renewable electricity production technologies	Number of projects	Capacity (MW)	Annual output (GWh)
Photovoltaic	638	118.7	144.8
Wind	15	120.6	256.8
Hydroelectricity	5	1.5	6.0
Total	658	240.8	407.6
Renewable heat production	**Number of projects**	**Capacity (MWth)**	**Annual output (GWh)**
Solid biomass	160	17.5	32.2
Renewable gas production	**Number of projects**	**Capacity (MWth)**	**Annual biogas output (GWh)**
Biogas	30	3.5	31.3

Source: EurObserv'ER on the basis of Énergie Partagée and Centrales Villageoises figures

nities in France results from over three decades of citizen energy movement structuring. The process of transposing the RED II directive began in 2021, when the French government introduced the notions of renewable energy community and citizen energy community by way of orders. An implementation decree, drawn up after consultation with the stakeholders, was scheduled for publication in the spring of 2022, but did not go before the State Council for consideration, resulting in a piecemeal legal framework governing renewable energy communities. Legislation on energy communities moved on after about a year's wait, namely in March 2023, with the Renewable Energy Acceleration Bill, which specified the communities' legal forms, along with certain governance rules. Thus, the spectrum of renewable energy community participants was extended, in particular to local semi-public companies. Clarifications on the notions of effective control and autonomy – the essential attributes of a renewable energy community – were introduced. An implementation decree supplementing the March 2023 bill was enacted in December 2023. The Enercoop cooperative commissioned a solar plant at Pousse-Pisse, in the Tarn department in March 2022. This 250-kW capacity project is one of the largest citizen-led facilities that creates a local energy loop, whose beneficiaries based close to the plant consume almost all of its 330 MWh of annual output.

SPAIN SEEKS TO STIMULATE RENEWABLE COMMUNITY PROJECTS

Co-management of renewables projects is not new to Spain. Individuals wishing to engage in this activity may do so through collective self-consumption operations, under a helpful legal framework that waives network costs and taxes. Renewable energy communities strictly speaking made their way into Spanish law in June 2020, albeit somewhat unsatisfactorily, as the European directive has been transposed word for word, resulting in a bare bones version of the directive's definition of communities. Subsequently, in practice, renewable energy communities rely more heavily on the legal framework for collective self-consumption. In June 2023, Spain's renewable energy communities legislation was amended to recognise the right of RECs to produce, share, use, store and sell renewable energy, and they can also access energy markets. The public authorities must treat them even-handedly and ensure that unjustified regulatory and bureaucratic obstacles are removed. Spain appears to want to offer financial support to its renewable energy communities through these new provisions. It has earmarked 100 million euros for direct support to them in its national recovery and resilience plan. These funds are due to be allocated applying a coherent strategy that aims to fund the various lifecycle stages of the energy communities (linking potential members, the processes of creating and subsidising certain projects). There is a plan to set up reference offices across the country to inform and raise general awareness of the concept. They will also be expected to give guidance to energy communities as they roll out. Furthermore, several regional programmes deployed under the framework of the European Regional Development Fund specifically target RECs, through the financial resources allocated to them. Lastly, Spain intends to earmark investments for renewable energy communities in its REPowerEU plan. The Som Energia cooperative is an example of citizen participation in energy production through its ownership of solar and biogas projects and involving its members in decision-making. The cooperative is a Som Comunitats alliance member whose brief is to promote energy communities and back them by offering them several practical guides.

AN UPTURN IN SIGHT FOR ITALY

At the beginning of the 2020s, the Italian legal landscape had a foretaste of energy communities in the form of an experiment. But it was in November 2021 that the provisions for renewable energy communities were formally transposed into national law. The legislator took pains to rewrite the key constituent criteria of these communities (open and voluntary participation, control by their members, autonomy), while offering a clear framework detailing some practical operating details (for example, the maximum capacity of installations operated by renewable energy communities was increased to 1 MW) and by extending the geographical perimeter for renewable energy communities. However, the legislation is flawed, hence, the renewable energy communities are slow in taking off, the main obstacles being bureaucratic, long licence waiting times and high grid connection costs.

Recent changes to Italian legislation made in November 2023 could enable the country's renewable energy communities to step up a gear. An implementation decree introducing incentive measures for RECs was approved after a two-year wait. A 5.7 billion euro state aid programme, partly financed by reforms to the energy chapter of Italy's national recovery and resilience plan is being rolled out with two funding streams. The first takes the form of a preferential tariff, spread over a 20-year period, that will cover a portion of electricity used by self-consumption and by renewable energy communities. The second paves the way for investment grants (up to 40% of eligible costs) to be awarded for projects based in towns with fewer than 5 000 inhabitants. At the same time, the regional authorities have embarked on proactive policies towards renewable energy communities. Typically, the regions offer guidance on developing such projects within their catchment area, providing partial funding for feasibility and techno-economic studies. Examples of this are the Ministry of Environment, Lombardy Region allocation of 22 million euros through to 2024 to support energy communities. In April 2023, Sardinia approved funds (€ 2m for 2023 and € 2m for 2024) for feasibility and techno-economic studies for energy communities, giving priority to communities off the methane grid. Two success stories at Villanovaforru and Ussaramanna highlight community energy as an added value for Sardinia. These small towns have overcome the problems of depopulation by financing solar panel installations with public funds, thereby making community energy attractive to their members. In the latest edition of its Electricity Market Report, Milan Polytechnic University identified some 84 "collective self-consumption configurations" in service in Italy (including 24 energy communities), and an additional hundred or so development phase projects. The report observes that while the numbers of initiatives are rising, their growth is trammelled by slowness to adopt the energy community regulations. Thus, the success and development pace of Italy's renewable energy communities are contingent on the dismantling of bureaucratic barriers, the coherent rolling out of support measures and clarification of the regulatory frameworks.

GERMANY… EUROPE'S TESTING GROUND

Renewable energy communities and citizen's communities stretch back several decades without there being any official regulatory framework in place. A legal definition for citizen energy communities (Bürgerenergiegesellschaften, BEG) was first formulated in the 2017 Renewable Energies Act (EEG 2017). The legal definition of BEGs was updated to comply with European legislation through amendments adopted by the German parliament in July 2022. Thus, these citizens' ventures are exempt from having to submit bids for tenders for PV projects below 6 MW and for wind energy projects below 18 MW. In addition, a BEG must comprise at least 50 individuals as voting members or shareholders, while at least 75 percent of the voting rights must be held by private individuals who reside in a postcode area that is entirely or partly within a 50-kilometre radius of the project. The remaining 25% of voting rights may be held by SMEs with fewer than 250 employees with turnover of less than 50 million euros or by local authorities. Despite the progress made, there are unsettled issues to be resolved before Germany's renewable energy community legislation is fully harmonised with RED II and a complete regulatory framework is established. Regulatory oversight, provided by the National Energy Regulator, oversees the concept's implementation, guaranteeing competition and facilitating community energy projects. Germany has a raft of programmes that support community energy initiatives financially, primarily the Renewable Energies Act (EEG), the KfW funding agency's "Renewable Energies - Premium" programme, the National Climate Initiative (NKI), the Market Incentive Programme (MAP) and the Energy Duty Act (EnergieStG), that offer incentives, allowances, loans, subsidies and aid. Although the cooperative model enjoys a longstanding tradition and is socially accepted, differences remain between the urban and rural forms adopted as legal entities. Cooperatives are the majority form in rural contexts, while private ventures tend to be the norm in towns, reflecting the scale of the projects. Recent legal adjustments have resulted in positive progress being made to harmonise with the EU directives. Yet, outstanding issues must be resolved to formulate a complete and facilitating framework and for RECs, especially with regard to facilitating energy sharing. The country's most well-known energy community is ElektrizitätsWerke Schönau (EWS), which was set up as a cooperative in 1994 at Schönau, Southwest Germany. Through the community's involvement and referendums, EWS has taken control of the local grid and now supplies clean energy to over 185 000 users all over the country. The EWS projects include solar and wind farms, gas and electricity grids and initiatives that support green energy as shown in the following table. Schönau has the highest concentration of solar energy in Germany. Since 2015, EWS owns almost all the biogas share and uses part of the gas price as a «solar cent» to promote clean energy production. Promoting individual involvement in energy distribution and production is one of the main EWS goals. The cooperative helps new members to join and strengthens its operational capacities. The cooperative's members can take part in decision-making processes, attend general meetings and influence the cooperative's management. Apart from governance, the cooperative's members contribute financially by purchasing its shares, thereby supporting the initiatives and projects undertaken by Elektrizitätswerke Schönau. The Druiberg wind farm at Dardesheim is another first-rate model of a community energy project. Share ownership of the wind farm is exclusively reserved for local residents, and some 90% of Dardesheim's inhabitants have been shareholders since 2014. The profits generated have been reinvested, as initially planned, to ensure that renewable energies continue to grow in the region, to develop local infrastructures and support various regional projects. The 82-MW capacity wind farm produces 40 times more electricity than is needed by the town's 800 residents and businesses. In addition to the wind turbines, Dardesheim's inhabitants can also count on integrated photovoltaic roofs, that add a further 1.15 MW of capacity. Thus, the energy requirements of all the town's households have now been outstripped. The wind farm, which came on stream in 2008, includes the first electric vehicle charging station in Saxe-Anhalt. The wind farm has converted 12 AUDI A2 cars into electric vehicles since 2010. These initiatives are grouped together under the «Energiepark Druiberg» moniker.

3

Energy overview of the energy community EWS - 2022

Installed electrical capacity (wind, photovoltaic, co-generation, fuel cells)	**22.1 MW**
Installed thermal capacity (co-generation, fuel cells, wood-fired boilers, solar thermal)	**6.5 MW**
Electricity output from co-generation/fuel cells	**1 711.1 MWh**
Photovoltaic electricity output	**8 085.9 MWh**
Wind power output	**37 565.2 MWh**
Heat output from biomass, solar thermal and co-generation	**16 724.4 MWh**

Source: Elektrizitätswerke Schönau, 2023

WHAT PROSPECTS LIE AHEAD FOR RENEWABLE ENERGY COMMUNITIES?

While a growing number of European Union Member States have started to transpose the European provisions on renewable energy communities, establishing a national legal framework conducive to their development is an iterative process. Several months and even years may elapse between different legislative texts, hindering the deployment of these projects that generate energy at local level and benefit local communities.

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

EUROBSERV'ER – THE STATE OF RENEWABLE ENERGIES IN EUROPE – 2023 EDITION

FOCUS: MARKET SHARES OF THE POWER GENERATING CAPACITIES INSTALLED IN 2022 BY TECHNOLOGY

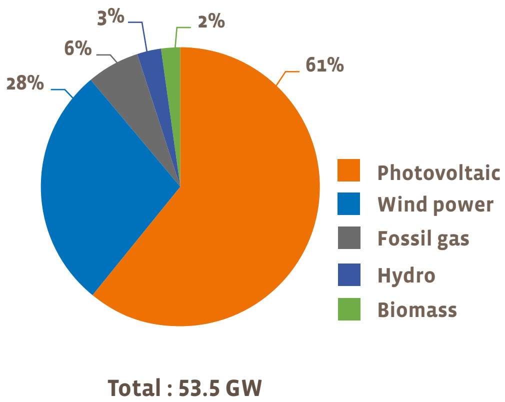
In 2022, 94% of newly connected electricity capacity within the European Union was related to renewable technologies. Photovoltaics remains by far the leading technology ahead of wind power.

Graph 1 shows that in 2022, 94% of newly connected electricity capacity in European Union countries came from renewable technologies (compared to 96% in 2021), i.e. 50125 MW out of a total of 53 475 MW. Photovoltaic is still the most representative sector with 32 819 MW installed, accounting for 61% of the additional electrical capacity in 2022 slightly below its performance in 2021 (67%). Wind power remains around 30% (28% in 2022 against 29% in 2021). As for fossil fuels, gas represented 6%. No new nuclear and coal capacities 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 2022. This year, seven countries commissioned fossil power plants, mostly for gas. The largest additional gas plant, totaling 1520 MW, is in Germany, accounting for 13% of the total additional electrical capacity connected in the country. This proportion is quite similar to that of Greece (14%), which installed 830 MW of gas capacity. Italy and France both commissioned 450 MW of gas, representing 9% of their new electrical capacities in 2022. Hungary and Poland also expanded their electrical production facilities with new capacities operating from fossil gas (respectively 50 and 20 MW). Lastly, Estonia put into service 30 MW of other fossil fuels. ■

1

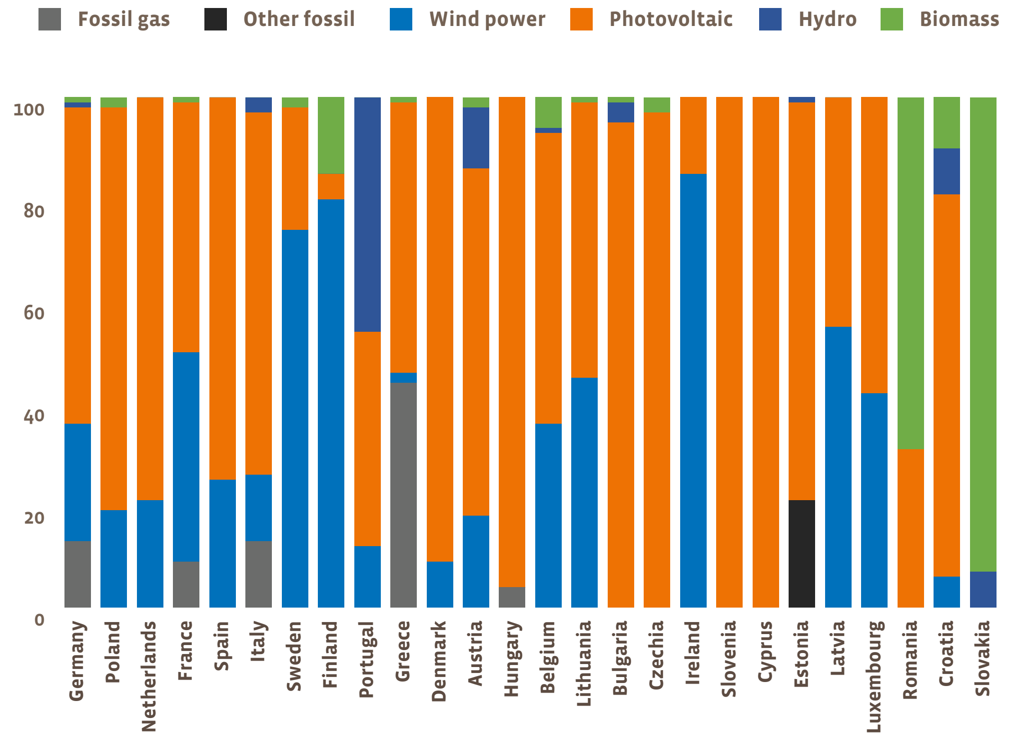
Distribution of additional electrical capacities connected to EU27 grids in 2022 by technology



Source: EurObserv'ER - Ember

2

Distribution of additional electrical capacities connected to EU27 grids in 2022 by technology



Source: EurObserv'ER - Ember

FOCUS: ELECTRICITY STORAGE CAPACITIES

WHY ENERGY STORAGE IS SO IMPORTANT

In terms of electricity production and consumption, the European Union's energy landscape has been undergoing profound change for several years. Under the urgency of global warming, but also of events such as the conflict in Ukraine or the COVID-19 crisis, European countries have reoriented their priorities in terms of energy dependence and sovereignty. Overall, efforts to combat climate change are leading to a decline in the use of fossil fuels, driven by more sober consumption patterns combined with an increase in the use of renewable technologies. The environmental transition that has begun is also illustrated by a move to convert a growing proportion of the various needs (mobility, heating) from fossil fuels to electricity. The result is a major planned increase in the production and consumption of electricity from renewable sources in the energy balances of European countries. Wind power and photovoltaics are the sectors that best illustrate this trend, with respectively 15 and 33 GW of additional capacity connected in 2022 alone for all EU27 countries. This development is set to accelerate significantly, as the RePowerEU programme aims to connect an additional 320 GW of photovoltaic solar power over the period 2020-2025. However, these latest technologies are characterized by variability in their energy production, heavily linked to weather conditions.

APPLICATIONS OF ENERGY STORAGE

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

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

Storage facilities maintain grid frequency

To ensure the required grid frequency of 50 or 60 Hz (depending on the country) the Transmission System Operators (TSO) of each country need instruments to maintain these reference values. These instruments are the balancing services: reactive short-term means to level out frequency deviations in the power grid. When frequency deviations occur, e.g. in consequence of a power plant outage, the Frequency Containment Reserve (FCR) intervenes automatically within seconds in the entire synchronous area to restore the balance between supply and demand. The FCR, also known as primary control reserve, is the first response to frequency disturbances. If the deviation persists, the Automatic Frequency Restoration Reserves (aFRR) subsequently replaces the primary control reserve. Large-scale battery storage systems have been playing an increasingly important role in the various energy markets for several years. In Germany, 480 MW of large-scale battery storage have been prequalified for the frequency containment reserve (FCR) since 2022.
Automatic Frequency Containment Reserve (aFCR): aFCR is an automated reserve that responds within short time to grid frequency deviations, injecting or withdrawing power to maintain grid stability, and it is crucial for ensuring the grid operates within acceptable frequency limits.
Automatic Frequency Restoration Reserve (aFRR): aFRR is a mechanism that provides rapid automated response as fast as possible to large frequency deviations in the power grid, helping restore grid frequency to its nominal value following significant disturbances or events.
Manual Frequency Containment Reserve (mFCR): mFCR requires manual intervention and control by grid operators to address frequency deviations, providing an additional layer of response when needed to ensure grid stability and reliability.
The specific response time requirements for each balancing power product may vary based on regional grid regulations and specific grid operator guidelines. It's essential for energy storage systems providing balancing services to meet the response time requirements outlined by the relevant grid operator or regulatory authority to ensure effective grid frequency management and compliance with grid stability standards. Response time can be in the range of seconds to several minutes.

A WIDE RANGE OF AVAILABLE TECHNOLOGIES

There are many different technologies and types of electricity storage facility. These range from pumped-storage hydroelectric plants to individual batteries installed in private homes to complement photovoltaic roofs. This chapter covers only part of the existing storage infrastructure, focusing on large-capacity electricity storage facilities located close to production sites. These facilities are referred to as «front-of-meter» facilities, as opposed to facilities located at the point of consumption (typically an individual battery at a private home), which are referred to as «behind-the-meter» facilities. The available storage equipment technologies are listed on Table 1, grouped by family.

Currently, the most commonly used electricity storage solution in Europe in terms of capacity is mechanical, specifically in the form of Pumped Hydro Storage (PHS). During low-electricity price periods, the plant pumps water from the lower to the upper reservoir to ensure that when the plant is faced with peak electricity demand and high prices, the water can be released through the turbines to the lower reservoir. Pumped hydro storage offers flexibility in conjunction with other hydroelectric infrastructures. The limiting factor for PHS is that not all countries have the natural geographical reliefs needed to develop this type of hydropower facility. The next most common form of electricity storage solution is electrochemical in the form of batteries. The most common technology uses a lithium-ion solution and usually cobalt (positive terminal) and graphite (negative terminal) electrodes. Thermal electricity storage technologies exist as well. These technologies use stored heat, which raise the temperature of a fluid or solid, change the physical state of a material, or produce endothermic (heat-absorbing) chemical reactions, exploiting the thermal capacities of the different materials. Steam turbines use this restored heat by reversing the state change to generate electricity. The main thermal development in Europe has been in molten salts sub-technology, but in the fairly restricted context of electricity storage on concentrated solar power sites.

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

THE EUROPEAN COMMISSION IS INVOLVED

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

1

Electricity storage technologies and sub technologies

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

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

2

Electricity storage capacities installed in the EU27 at the end of 2023 (in MW)

	Mechanical		Thermal		Electro-Chemical		P2G	
	Pumped Hydro	Other technologies	Molten Salt	Other technologies	Li-ion	Other technologies	P2G	Total
Germany	6 703.2	321.0	0.0	1.5	1 406.9	85.8	15.0	8 533.3
Italy	7 464.1	0.0	4.7	0.4	17.9	36.3	0.0	7 523.4
Spain	4 700.6	0.5	1 069.3	62.4	15.6	6.1	0.0	5 854.5
Austria	5 701.3	0.0	0.0	0.0	20.8	0.0	0.0	5 722.1
France	5 137.3	0.0	9.0	12.0	115.6	350.8	5.0	5 594.7
Portugal	2 949.8	0.0	0.0	0.0	7.5	0.0	0.0	2 957.3
Poland	1 733.0	0.0	0.0	0.0	2.3	5.0	0.0	1 740.3
Belgium	1 304.0	0.0	0.0	0.0	116.6	1.9	0.0	1 422.5
Bulgaria	1 399.0	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	1 294.0
Czechia	1 149.8	0.0	0.0	0.0	12.0	0.0	0.0	1 161.8
Lithuania	900.0	0.0	0.0	0.0	200.0	0.0	0.0	1 100.0
Slovakia	882.3	0.0	0.0	0.0	6.9	0.0	0.0	889.2
Ireland	292.0	0.0	0.0	4.6	121.8	314.6	0.0	733.0
Greece	705.9	0.0	0.0	0.0	0.0	0.0	0.0	705.9
Slovenia	605.0	0.0	0.0	0.0	41.6	1.0	0.0	647.6
Croatia	621.2	0.0	0.0	0.0	0.0	0.0	0.0	621.2
Sweden	425.0	0.0	0.0	10.0	14.0	0.0	0.0	449.0
Netherlands	0.0	2.8	0.0	0.0	165.7	3.0	0.0	171.5
Romania	154.5	0.0	0.0	0.0	1.0	0.0	0.0	155.5
Finland	0.0	0.0	0.0	0.0	37.9	2.0	0.0	39.9
Hungary	0.0	0.0	0.0	0.0	7.2	0.0	0.0	7.2
Denmark	0.0	0.0	0.0	0.0	2.3	0.0	1.2	3.5
Latvia	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
Cyprus	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Estonia	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total EU-27	44 121.8	324.3	1 083.0	90.9	2 278.5	806.5	21.2	48 726.1

Source: EurObserv'ER data based on continued verification and active surveillance of the Database of European energy storage

3

Planned capacities by country at the end of 2023 (in MW)

	Mechanical		Thermal		Electro-Chemical		P2G	
	Pumped Hydro	Other technologies	Molten Salt	Other technologies	Li-ion	Other technologies	P2G	Total
Spain	6 846.5	0.0	0.0	0.0	1 081.5	0.3	0.0	7 928.3
Germany	3 998.0	960.0	0.0	0.0	1 270.1	1.2	200.0	6 429.4
Ireland	1 260.0	27.5	0.0	0.0	464.5	1 674.9	0.0	3 426.9
Greece	2 715.1	0.0	52.0	0.0	411.8	73.0	0.0	3 251.9
Austria	1 539.5	0.0	0.0	0.0	0.0	100.0	0.0	1 639.5
Romania	1 448.8	0.0	0.0	0.0	6.0	0.0	0.0	1 454.8
Belgium	550.0	0.0	0.0	0.0	480.0	0.0	0.0	1 030.0
Croatia	889.7	0.0	0.0	0.0	53.0	0.0	0.0	942.7
Bulgaria	864.0	0.0	0.0	0.0	0.0	0.0	0.0	864.0
Estonia	600.0	0.0	0.0	0.0	225.0	0.0	0.0	825.0
Portugal	668.0	0.0	0.0	0.0	0.0	0.0	1.0	669.0
Italy	572.0	0.0	0.0	32.0	40.0	4.0	0.0	648.0
Netherlands	0.0	640.0	0.0	3.0	1.0	0.0	1.0	645.0
Slovakia	0.0	0.0	0.0	0.0	454.6	0.0	0.0	454.6
Denmark	0.0	320.0	1.0	0.0	1.0	0.0	0.0	322.0
Poland	0.0	0.0	0.0	0.0	260.0	0.0	0.0	260.0
Lithuania	225.0	0.0	0.0	0.0	0.0	0.0	0.0	225.0
Sweden	0.0	0.0	0.0	0.0	185.4	20.0	0.0	205.4
Finland	0.0	0.0	0.0	0.0	138.6	0.0	0.0	138.6
Latvia	0.0	0.0	0.0	0.0	80.0	0.0	0.0	80.0
France	12.0	0.0	0.0	0.0	13.0	35.0	0.0	60.0
Slovenia	0.0	0.0	0.0	0.0	0.0	60.0	0.0	60.0
Cyprus	0.0	0.0	0.0	0.0	46.0	0.0	0.0	46.0
Czechia	0.0	0.0	0.0	0.0	30.0	0.0	0.0	30.0
Hungary	0.0	0.0	0.0	0.0	3.8	0.0	0.0	3.8
Malta	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	22 188.6	1 947.5	53.0	35.0	5 245.5	1 968.3	202.0	31 639.9

Source: EurObserv'ER data based on continued verification and active surveillance of the Database of European energy storage

MORE THAN 48 GW IMPLEMENTED IN THE EU27

Operational storage increased from around 44.4 GW to 48.7 GW from 2022 to 2023. The majority of storage in Europe is from Pumped Hydro Storage (44 GW), with the majority of facilities in Germany, Italy, France, Spain, Austria and Portugal, their aggregate being 32 GW. Worth noting, the growing capacity of electrochemical projects is significant, as it more than doubled, from around 1 GW to 3 GW over the past year. Table 3 gives details of the planned projects in the European Union (licensed, under construction, in the pipeline, etc.). The total capacity identified amounts to 31,6 GW. While mechanical storage dominates this capacity (22.2 GW), an additional 7.2 GW is expected from electrochemical storage in the next few years. EurObserv'ER collected energy storage project data from 2022 and 2023 and updated the European Commission's 2020 Database of the European Energy Storage Technologies. Verification of projects was completed by extensive research using publicly available grid data, press releases, news coverage, energy storage association data and interviews.

SPOTLIGHT ON THE MAJOR COUNTRY PLAYERS AND NOTEWORTHY EFFORTS

The large-scale storage (LSS) market is experiencing rapid expansion in ***Germany***. Several large-scale applications are gaining momentum in the German energy storage landscape, including services such as frequency containment reserve (FCR - see highlight), renewable energy integration, industrial energy supply, multi-use operation, which includes arbitrage trading, and grid booster projects. Of particular interest is the automatic frequency restoration reserve market, which is approximately three to four times larger in size compared to the FCR market, making it an attractive option. Grid booster projects are instrumental in enhancing the network's carrying capacity and addressing the need for costly grid infrastructure investments by TSOs. An enhanced network's carrying capacity can contribute to less curtailment of variable renewable energy generation.
Several example projects showcase the dynamic landscape of energy storage in Germany. Energy firm *EnBW* has received approval to embark on a pumped hydro energy storage (PHES) project in Germany. This ambitious project involves upgrading the *Rudolf Fettweis* hydropower plant in *Forbach* into a modern PHES facility. The project includes the installation of a new 54 MW discharge power turbine for the *Schwarzenbach* power plant, Francis turbines and a new cavern water reservoir in the adjacent hillside. Completion is expected by the end of 2027. In another project, system integrator Fluence is spearheading the deployment of a 250 MW 'Grid Booster' battery energy storage system for transmission system operator *TransnetBW*. This project, scheduled for completion in 2025, will function as a one-hour, 250 MWh system. Its implementation aims to optimize the existing transmission infrastructure, reducing the need for preventive redispatch measures and conventional network reinforcements, ultimately lowering operating costs.

The German Federal Network Agency, the *Bundesnetzagentur*, conducted their second Innovation Tender in Germany resulting in 32 solar-plus-storage projects with a total capacity of 408 MW. The auction received significant interest, with a total of 53 bids and 779 MW of capacity proposed, nearly double the 400 MW limit set for the auction. *Encavis*, a wind and solar park operator, acquired a solar-plus-storage project featuring a 12 MW/24 MWh battery storage unit. Set to be operational in the first half of 2024, this battery energy storage system (BESS) will enable renewable load shifting and price arbitrage in the day-ahead and intra-day electricity markets. Additionally, it will optimize the output of all Encavis' solar and wind parks across Germany. Deutsche Telekom unveiled plans for a battery energy storage system installation as part of a 300 MWh rollout in Germany with Norwegian technology firm *Pixii*. The initial system, a 1 MW/6 MWh unit, will function to address peak shaving, arbitrage, maximizing renewable energy utilization, and participating in the German electricity market to enhance grid stability. Renewable energy company *ABO Wind* and project system integrator *Tricera* have joined forces to construct three battery energy storage systems (BESS) with a combined capacity of 25 MWh. These projects, slated for commissioning in 2023, will be co-located with solar PV installations in Bavaria, North Rhine-Westphalia, and Hesse. All three projects have secured contracts under Germany's innovation tenders, which offer incentives for hybridization with renewables. Additionally, the German stationary home storage system (HSS) market has witnessed remarkable growth in recent years and stands as the largest in the country. As of the end of 2022, it is estimated that there was approximately 650,000 HSS installations, boasting an impressive combined installed capacity of around 3.1 GW. Notably, nearly all of these installed HSS units, amounting to 98%, are equipped with lithium-ion batteries, continuing the prevailing trend from previous years.

Ahead of much of the EU, ***Ireland*** is demonstrating impressive viability for short-term battery energy storage. For the relatively small county (population 5 million), Ireland currently operates around 670 MW of primarily lithium-ion short-term duration batteries and the Irish Energy Association is estimating another 4.3 GW of storage projects are in the pipeline. Their operational storage evolved quickly, given the first project (Kilathmoy, 11 MW) was connected to the grid in 2020. The framework behind Ireland's success as an Energy Storage leader is worth noting. The DS3 (Delivering a Secure, Sustainable Electricity System) program, designed by TSOs to secure the Irish power system while also meeting the EU Irish targets for increased renewable energy consumption, has allowed Ireland to not only reach renewable energy objectives but incentivized a prosperous revenue-driven

short term battery storage market. DS3 was devised to address frequency responses and the power response services and functions by releasing dispatch instructions to certified providers for contractual payment. The program facilitates the ability of TSOs on the island to increase instantaneous levels of injected power in millisecond time frame. DS3 revenues are based on quick response (half hour to an hour), with currently no incentive for long-term batteries. The DS3 program has been extended to 2031. The roughly 16 operational short-duration battery sites in Ireland and Northern Ireland are generally between 2 and 100 MW power, but some larger power projects are in the pipeline. Ireland's national planning group recently approved the largest short duration battery project. The proposed battery storage facility will provide 200 MW near Dunnstown, County Kildare, making it the single largest grid-scale battery in Ireland. The project will be realised by Strategic Power Projects and investment firm Gresham House.
Modelling of the Ireland's future market requirements demonstrates that longer duration batteries and other storage technologies will be necessary in order to avoid renewable curtailment and also provide additional benefits, such as energy arbitrage, peak shaving, capacity adequacy, absorbing surplus renewable energy and congestion management. Attention is therefore shifting to varying levels of longer-duration batteries. Newcomer to the European storage market, Mitsubishi Power along with ION Renewables has announced an 185.5 MW/371 MWh BESS project to be commissioned in 2024 at the existing Brownfield Industrial site that will offer two-hour duration. The first four-hour battery project is also under construction in Cushaling, Co Offaly. Co-located with the 55.8 MW Cushaling Wind Farm, the 20 MW BESS by Statkraft will store wind-generated energy during low demand periods, reducing curtailment and dispatch down, while dispatching during peak demand periods. The system is designed to provide 20 MW for up to four hours, which will help ensure stability to EirGrid. The project will be connected in 2024 and is a collaboration of Fluence Energy Ireland and Statkraft.

In a decisive move to meet its ambitious CO2 reduction targets and lessen its dependence on imported fossil fuels, the ***Netherlands*** is significantly focusing on the development of battery electricity storage systems. This strategic pivot is essential for addressing grid capacity shortages and aligns with global sustainability goals. In a major policy development on June 9, 2023, Climate and Energy Minister presented the Energy Storage Roadmap to the Dutch House of Representatives. This roadmap outlines the expected developments in energy storage in the Netherlands up to 2035 and beyond, indicating a long-term vision for the country's energy strategy. The roadmap encompasses various forms of energy storage, including electricity, molecule, and heat storage. These diverse forms are considered essential for ensuring sufficient flexibility in the Dutch energy system, which is increasingly relying on variable energy sources like solar and wind. The roadmap's main elements include an analysis of the current state of energy storage in the Netherlands, an inventory of actions for the successful rollout of energy storage technologies until 2035, and an in-depth analysis for policy choices for the National Energy System Plan (NPE). The Dutch government has committed a substantial sum of €416.6 million for the construction of utility-scale batteries. Dutch TSO TenneT has highlighted the need for 9 GW of large-scale BESS capacity by 2030. This need arises from several challenges on the electricity network, where BESS projects ranging from 70 MW to 500 MW in size could offer solutions like FRR and FCR (see highlight). Additionally, these systems can assist in power transport across the grid and provide flexibility through various contracts and market-based congestion management. In conjunction with this, TenneT has introduced a novel contract providing reduced grid transmission fees to battery operators, with discounts of up to 65%, to encourage them to assist in limiting grid congestion. By modelling the quantity of diverse BESS applications, TenneT forecasts that by 2030, 2.2 GW of EV batteries, 4.2 GW of 'household batteries' and 3.7 GW of 'solar PV batteries' will be installed to help with grid flexibility, alongside the 9 GW of grid-scale systems. SemperPower is making significant strides with its third large-scale energy storage project, Project Pollux, to be commissioned in 2023. Project Pollux along with project Castor, also under construction, boast capacities of 30 MW each. These projects are among the largest in North-West Europe and are directly connected to the Stedin network. They are pivotal for the long-term stability and faster integration of sustainable energy in the Dutch electricity market.
RWE, a German renewable energy company, has greenlit a substantial 35 MW storage project in Eemshaven, with an investment of approximately 24 million euros. The project, involving the installation of 110 lithium-ion battery racks, is expected to start construction in late 2023 and begin supplying control energy from 2025. This battery storage facility, which can operate at its installed capacity for over an hour, is a key component of RWE's strategy to integrate the fluctuating power generation profile of the "OranjeWind" offshore wind farm into the Dutch energy system. Dutch projects use not only battery technology, but also compressed air technology, demonstrated by the 320 MW Compressed Air Energy Storage (CAES) project in Groningen. A joint venture between Eneco and Corre Energy, CAES Groningen marks a significant advancement in long-duration energy storage. After securing funding from an Italian Efficiency Fund in June 2023, the project could be completed by 2026. It represents a novel approach to storing excess electricity as compressed air, which can then be used to generate electricity when demand peaks, with the capability to discharge at full capacity for up to 84 hours. The development and diversification of storage technologies in the Netherlands is also demonstrated by the GIGA Buffalo battery project, installed near the Wageningen University Research and Test Center in Lelystad in 2022. With a capacity of 25 MW and 48 MWh, the project is part of Windnet's smart grid and is directly connected to wind farms in the area. It's the first large-scale energy storage project in Europe based on lithium iron phosphate (LFP) chemistry, known for its safety features and sustainable use of resources. The GIGA Buffalo battery employs machine learning and data analytics to optimize its performance and can be activated quickly, making it an agile component in grid stabilization.


ENGIE SOLUTIONS

In the ***Czech Republic***, battery energy storage projects are playing a pivotal role in enhancing grid stability and supporting the nation's transition to clean energy sources. This text combines information about major battery energy storage projects undertaken by different organizations, including CEZ ESCO, SUAS Group, and the DECCI Group. These projects represent significant milestones in the Czech Republic's energy landscape and are all driven by the common goal of bolstering the stability energy grid due to expected reduction of conventional power production and increasing variable renewable generation. CEZ ESCO, a subsidiary of the CEZ Group, is embarking on an ambitious project to build a 10 MW battery in Vítkovice. This battery consists of six battery containers and will contribute to stabilizing the Czech energy grid by providing power balance services, primarily primary frequency control. The project's contractors include CEZ Energetické služby and IBG Cesko, both well experienced in battery systems. This initiative aligns withCEZ's Clean Energy Tomorrow strategy, aiming to construct energy storage facilities with a cumulative capacity of 300 MW by 2030.
SUAS Group, building on its experience with the Sokolovská coal plant, has completed a large battery energy storage facility in the Czech Republic, located near Královský Porící near Sokolov. The facility is divided into two identical branches, each certified for 2.5 MW of power provision for power balance services. Remarkably, the entire process, from selection to network connection, was accomplished within seven months. The DECCI Group, renowned for its commitment to renewable resources, has initiated the construction of a 30-megawatt hybrid power source in Vranany. This hybrid resource combines a 20 MW battery storage system and 30 MW combustion turbines derived from aircraft engines that have the potential to utilize green hydrogen as a future fuel source. This innovative project showcases the DECCI Group's dedication to supporting national climate goals and advancing the Czech Republic's clean energy agenda.

The storage project European Large Scale Energy Accumulation (ELSEA) aims to create a battery-type energy storage installation in ***Slovakia***, with a maximal capacity of 384 MW, enabling an annual electricity generation of 252 GWh. Comprising a system of 12 interconnected sites, it is set to become one of Europe's largest battery installations. This design adapts to the regional energy market's needs, contributing significantly to system operation, reducing grid congestion, and enhancing electricity supply reliability. ZSE Energia, a.s., in Slovakia, serves as the project promoter, with a projected commissioning year in Q4-2035. The storage project PHS Cierny Váh refurbishment involves upgrading an existing pumped hydro storage (PHS) facility in Slovakia and adding electrochemical storage to the infrastructure. The existing PHS, commissioned in 1982, includes six generators with limited grid regulation capabilities. Upgrades to turbo generators will increase efficiency, while the addition of at least 70 MW and 105 MWh (net) battery storage creates a hybrid system combining pumped and electrochemical storage for fast flexibility (-670 MWto +730 MW). Slovenské Elektrárne is the project promoter.
Both projects are designed to provide critical grid support. ELSEA aims to reduce grid congestion, balance electricity supply, and increase reliability, while the Cierny Váh upgrade offers flexibility through ancillary services like frequency regulation, voltage control, and black start capability. They also share the goal of reducing the environmental impact of CO2-intensive power generation, supporting the transition to cleaner energy sources. Additionally, they have the potential to stabilize the grids of neighbouring countries, with ELSEA's positive influence on renewable energy curtailment and the Cierny Váh refurbishment aiding Hungary, Poland, and the Czech Republic. ELSEA's estimated CAPEX is 190 million Euros, with an annual OPEX of 5.8 million Euros. In contrast, the Cierny Váh refurbishment estimates a CAPEX of 148.8 million Euros and OPEX of 0.63 million Euros per year. The estimated commissioning year for ELSEA is Q4-2035, while the Cierny Váh upgrade is expected to be commissioned in 2031.

Battery energy storage has not played a significant role in ***Poland's*** energy sector, primarily due to high costs compared to conventional units. However, it is expected that the profitability of energy storage projects will grow in line with the volatility of electricity prices. The power company PGE Group has received regulatory approval to construct a substantial 200 MW / 820 MWh battery energy storage system named CHEST (Commercial Hybrid Energy Storage) using lithium-ion batteries. PGE expressed the aim of completing the project by 2030. The CHEST project will integrate seamlessly with the existing 716 MW / 3600 MWh PHES plant at Żarnowiec. This integrated setup shall help to stabilize generation from nearby wind farms. PGE Group holds permission to develop large wind farms near these two sites. A Smart Grid Demonstration Project, located at the 24 MW Bystra wind farm, shall combine high-output lithium-ion batteries with high-capacity lead-acid batteries. This system would not only mitigate the fluctuating output of wind turbines but would also safeguard the electricity network from transmission and distribution line overload problems during grid failures. It could perform various functions, including energy arbitrage, responding to shifting power demand, and providing frequency reserve. Showa Denko Materials supplied 1 MW/ 0.47 MWh of lithium and 5 MW/ 26.9 MWh of lead-acid batteries, while Hitachi provided the distribution control system for the battery energy storage system. Hitachi ABB Power Grids supplied 6 MW of power conversion system (PCS) equipment. Additionally, local project partners, including the transmission system operator Polskie Sieci Elektroenergetyczne (PSE) and electric power distribution company Energa, are actively involved, with PSE overseeing the hybrid system. In a capacity market auction for 2027, conducted by PSE, long-term contracts for energy resources were awarded. For example, battery storage projects from Hynfra Energy Storage and OX2 secured contracts through these energy auctions. The auction awards align with the findings of a new report produced by the Polish Electricity Association and EY titled 'Polish Energy Transition Path.' The report emphasizes that as Poland aims to bring more energy storage online, it is crucial to balance energy demand and supply while maintaining grid stability, especially with the increasing integration of variable renewable resources. The report recommends awarding contracts to energy storage in the capacity market as a way to support the sector.

France remains one of the bigger players in energy storage in the EU27. Of the 5.6 GW of operational energy storage, France depends primarily on PHS for the majority of its capacity (5.1 GW, 91%). However, at least 431 MW electrochemical projects, primarily Li-ion batteries, have been brought online in the past two years. RTE (the French TSO) completed the first automatic large scale management system, RINGO, connecting three substation sites, Vingeanne-Jalacourt (eastern France), Bellac (western France) and Ventavon (Alps) in 2022. The storage capacity of each is 12 MW, 10 MW and 10 MW, respectively. The project is innovative in its ability to capture digital data in real time allowing piloting at a distance, as well as absorbing production surplus and injecting electricity when needed. For the RINGO project in Ventavon electrical substation, Haute Alpes region, Equans and designer Blue Solutions partner to, use a new generation Lithium Metal Polymer batteries, also known as "all solid" batteries. With a capacity of 10 MW for two hours, the battery is non-flammable, mitigating the risk of fire and is therefore a safer option to electrochemical storage. The locations are convergence points of multiple power lines, and act as a funnel concentrating hydroelectric power, wind and photovoltaic production. The experimental framework requires strict neutrality on the functioning of the electricity market, meaning that when one or two sites are charging, the other sites must offload the equivalent capacity to avoid impacting the national supply-demand balance. The project is an interesting design for intelligent and flexibility on the grid. TotalEnergies teamed with Saft to install one of the largest battery projects in France in Dunkirk. The 27-container batter can hold 61 MW of power and 61 MWh of capacity, and functions as a FCR to maintain stability on the grid and stabilise the intermittence of renewables, notably a new offshore wind farm planned for 2026. Using the aggregate approach, NW Groupe installed an estimated 185 JBox containers in France over the past two years, each providing 1 MW of primary reserve storage, able to react within 15 to 30 seconds to disequilibrium and fluctuations in frequency on the grid. These 12 meter long white boxes containers are grid-connected and certified by RTE, and contain recycled or end-of-life li-ion batteries. The aggregate of the installations, along with their disperse placement throughout the country offers regional reserves. Renault group, via their Advanced Battery Storage project, connected its 70 MWh battery energy storage system in France and in multiple European locations using second-life vehicle batteries. When the automotive life of a battery is over, the battery still has residual value and can function as stationary storage. The project provides an innovative approach the repurposing and recycling of batteries. ■

EUROBSERV'ER – THE STATE OF RENEWABLE ENERGIES IN EUROPE – 2023 EDITION

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 2021 and 2022. 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 works in more detail. This paper can be downloaded from the EurObserv'ER project website.

WIND POWER

In 2022, the net wind power capacity connected in the European Union increased by almost 15 GW (14 900 MW), with onshore activity driving most of this growth. The rise in offshore wind capacity in 2022 reached 963 MW, marking a 6.4% rise compared to 2021 figures. These figures led to a notable increase in sector-wide employment. With a total of 273 500 jobs identified for 2022, EurObserv'ER estimates a significant increase in employment for the EU27, with 62 000 more jobs than in 2021. This surge in employment is accompanied by an increase in turnover (€9.2 billion) and gross value added (€3.9 billion). Despite wind energy experiencing a significant decrease in turnover in our 2021 estimates, the sector's increased turnover in 2022 solidifies its position as the second-highest technology in terms of turnover, following heat pumps.

In terms of individual country results, Finland, France, and Sweden stand out for their substantial relative growth in installed capacity. Finland experienced a remarkable 74% increase in its installed onshore wind capacity in 2022, now ranking among the top 10 EU27 countries in installed capacity. This surge is attributable to Finland's firm commitment to clean energy goals, supported by proactive government policies and incentives[1]. France and Sweden also saw significant growth, with respective increases of 12% and 21% in installed capacities in 2022, primarily driven by new onshore installations. Meanwhile, Germany, as the European wind industry leader, saw its employment figures rise from an estimated 69,200 in 2021 to 85 600 in 2022, directly linked to its increased installed capacity and market share of equipment. Spain, the second-largest EU27 country in this technology, also experienced a notable increase in installed capacity, leading to a rise in employment from 23 000 in 2021 to 37 100 jobs in 2022. Overall, none of the EU27 countries reported a considerable decrease in their annual installed capacities in 2022.

This surge in wind energy capacity across Europe underscores the region's collective commitment to transitioning towards renewable energy sources, driving economic growth, and reducing carbon emissions. Importantly, these positive numbers come after the overall decline witnessed in 2021, highlighting the resilience and rebound of the wind energy sector in Europe. ■


Bernard Gaetan - EDF Renouvelables

1. *Symons, A. (2023, January 12). Finland: Wind power increased by 75% last year, boosting energy security and climate goals. Euronews.*

Employment and turnover

	Employment (direct and indirect jobs)		Turnover (in M€)		Direct GVA (in M€)	
	2021	2022	2021	2022	2021	2022
Germany	69 200	85 600	11 710	14 180	5 110	6 220
Spain	23 000	37 100	3 320	4 970	1 440	2 120
France	14 500	36 500	2 460	5 910	970	2 400
Denmark	31 900	22 600	6 670	5 030	2 760	1 990
Sweden	14 100	16 800	2 700	3 220	1 360	1 620
Finland	4 400	13 800	780	2 360	340	1 020
Poland	8 600	13 700	690	1 050	300	460
Netherlands	10 500	11 400	1 670	1 840	680	760
Italy	6 100	9 100	1 050	1 470	450	620
Lithuania	2 200	4 400	110	200	50	100
Portugal	7 200	4 200	570	380	230	160
Belgium	2 000	4 000	440	860	170	330
Ireland	1 600	2 800	310	480	130	200
Austria	2 000	2 600	380	490	160	210
Greece	6 600	2 500	630	290	280	140
Romania	2 000	2 200	170	190	80	80
Czechia	600	800	60	70	20	30
Hungary	700	800	40	60	20	20
Latvia	200	700	10	40	<10	10
Bulgaria	700	600	50	40	20	20
Croatia	2 600	600	160	50	70	20
Estonia	300	200	30	20	10	10
Cyprus	100	100	10	10	<10	<10
Luxembourg	100	100	10	20	<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	**211 500**	**273 500**	**34 060**	**43 260**	**14 710**	**18 590**

Source: EurObserv'ER

PHOTOVOLTAIC

Overall, EurObserv'ER highlights significant socioeconomic impacts of photovoltaic (PV) energy in 2022, with turnover estimated at €40.8 billion (up from €27.6 billion in 2021), gross value added at €17 180 million (compared to €11 480 million in 2021), and employment reaching 346 900 FTE — a notable 48% increase from 2021. This growth is paralleled by a 19% increase in total installed PV capacity in the EU27, reaching 195 GW. The additional 36.5 GW capacity added in 2022 exceeds the 22.0 GW increase observed in 2021, further contributing to the surge in employment figures.

EurObserv'ER's monitoring indicates remarkable PV and related socioeconomic growth across most EU27 countries in 2022, with a substantial increase in turnover (€13.2 billion) and gross value added (€5.5 billion) projected for that year. Germany maintains its position as the leader in PV sector employment within the EU27, with 87 100 jobs (up from 56 000 in 2021), attributable to a significant increase of 36.5 GWp of new installed capacity in 2022—over seven times the 5.0 GWp installed in 2021. Poland emerges as the second-largest employer in the sector in 2022, with 33 400 jobs, marking a remarkable 59% increase in installed capacity to 12.2 GWp, driven by policy shifts and market dynamics. Notably, Poland's transition from net-metering to net-billing in April 2022, coupled with high electricity prices and a burgeoning utility-scale segment, resulted in a sector turnover of €3.1 billion[1]. Several other countries also significantly increased their production capacity, with Portugal notably joining the GW club for the first time, recording a 54% growth and generating an estimated 12 000 jobs. Additionally, countries such as Denmark, Hungary, and Sweden witnessed over 50% growth in production capacity, contributing to a combined total of 34 900 new jobs. This exponential growth in PV capacity underscores Europe's escalating reliance on solar energy amid energy and climate crises, emphasizing the pivotal role of solar energy in fostering a secure, green, and prosperous Europe. ■

1. *Bellini, E. (2022, July 13). Poland's transition from net metering to net billing. PV Magazine International.*

Employment and turnover

	Employment (direct and indirect jobs)		Turnover (in M€)		Direct GVA (in M€)	
	2021	2022	2021	2022	2021	2022
Germany	56 000	87 100	8 440	13 070	3 750	5 810
Poland	35 200	44 100	2 470	3 100	1 000	1 260
Spain	25 400	36 300	2 680	3 830	1 170	1 670
Netherlands	21 700	30 000	3 150	4 340	1 190	1 640
Italy	15 100	26 500	2 170	3 740	830	1 460
France	23 300	20 500	3 350	2 930	1 380	1 200
Hungary	2 300	19 500	140	1 100	50	460
Greece	7 000	12 700	570	1 030	230	410
Portugal	7 200	12 000	390	640	150	250
Denmark	3 500	10 500	700	2 000	280	810
Czechia	2 200	7 700	180	560	60	200
Bulgaria	1 800	7 600	100	380	30	140
Austria	5 000	6 600	880	1 170	380	500
Lithuania	1 500	5 100	70	220	30	110
Sweden	3 100	4 900	530	850	250	400
Finland	2 000	3 500	410	690	160	270
Romania	1 900	2 900	130	200	50	70
Belgium	4 300	2 200	840	430	300	150
Slovenia	100	2 200	10	160	<10	60
Estonia	2 500	1 600	180	120	70	40
Cyprus	600	1 000	50	90	20	30
Croatia	<100	1 000	<10	60	<10	20
Latvia	100	500	<10	30	<10	10
Ireland	300	300	50	40	20	20
Luxembourg	500	300	70	40	30	20
Slovakia	200	200	20	20	10	10
Malta	200	100	10	10	10	<10
Total EU-27	**223 100**	**346 900**	**27 610**	**40 850**	**11 480**	**17 030**

Source: EurObserv'ER

SOLAR THERMAL

The figures here cover both the flat plate solar thermal sector and concentrated solar power (CSP) technologies. The EurObserv'ER modelling estimates the turnover and employment in the solar thermal sector at €3.4 billion and 26 700 jobs for 2022. A considerable decrease in sector turnover of €1.8 billion is estimated for 2022, in contrast to the increase in the turnover for 2021. Employment levels also are estimated to decrease on 11 600 jobs, which also differs from the considerable increase seen in 2021. The majority of the substantial decrease in employment comes from a slowdown in installed capacity growth in Germany, which experienced a relatively small 3% increase in installed capacity throughout 2022, in contrast with a notable 12% increase in 2021. This decrease significantly impacted employment in Germany, resulting in nearly 10 500 fewer estimated jobs, although the country still leads in terms of absolute number of jobs in the solar thermal sector within the EU27. Similarly, this decrease is reflected in turnover (a €1.8 billion decrease compared to 2021) and gross value added (a €790 million decrease). Denmark, another country that saw significant growth in 2021, also experienced a slowdown in progress in 2022, with a decrease of 1 200 jobs.

Among the countries that expanded their solar thermal capacities in 2022, Greece saw the largest relative growth in solar thermal employment, with a 26% increase compared to 2021, totalling 2 900 jobs created. Spain maintained its position as the second-largest European player in the sector, with a total of 6 000 jobs and revenues reaching €900 million, slightly higher than 2021 levels. The increase is driven by a national solar thermal market that start growing again in 2022, after a steep shrunk in 2021.

Besides, Spain is home to the largest CSP power plant fleet in the EU. The operation and maintenance (O&M) services in the CSP sector positively affects the employment estimates for Spain. The concentrated solar power (CSP) market segment stagnated over the last years with little new installation activity in EU Member States. Employment in CSP sector should thus primarily stem from technology providers and EU based manufacturers of components. The actual installation currently mainly takes place outside the European Union. In 2022 there were no new CSP deployments in the EU27. ■

Ritter

Employment and turnover

	Employment (direct and indirect jobs)		Turnover (in M€)		Direct GVA (in M€)	
	2021	2022	2021	2022	2021	2022
Germany	17 000	6 500	2 590	960	1 130	420
Spain	5 400	6 000	840	900	410	430
Greece	2 300	2 900	210	260	80	90
Poland	2 800	2 000	200	140	70	50
Austria	1 900	1 800	360	340	150	150
Italy	1 500	1 800	200	240	80	90
Bulgaria	1 300	1 400	60	70	20	20
France	1 500	1 400	220	210	90	80
Portugal	800	700	40	30	10	10
Denmark	1 500	300	290	60	110	20
Cyprus	300	200	20	20	10	10
Czechia	200	200	10	10	<10	10
Belgium	100	100	10	10	<10	<10
Croatia	100	100	<10	10	<10	<10
Hungary	400	100	20	<10	10	<10
Netherlands	100	100	10	10	<10	<10
Sweden	100	100	10	10	10	<10
Slovakia	100	100	10	10	<10	<10
Estonia	<100	<100	<10	<10	<10	<10
Finland	100	<100	10	10	<10	<10
Ireland	100	<100	10	10	<10	<10
Lithuania	<100	<100	<10	<10	<10	<10
Luxembourg	<100	<100	<10	<10	<10	<10
Latvia	<100	<100	<10	<10	<10	<10
Malta	<100	<100	<10	<10	<10	<10
Romania	<100	<100	<10	<10	<10	<10
Slovenia	<100	<100	<10	<10	<10	<10
Total EU-27	**38 300**	**26 700**	**5 200**	**3 390**	**2 320**	**1 530**

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.

Portugal saw the largest increase in installed capacity in 2021 – around 965 MW of new installed capacity. The substantial increase in installed capacity in Portugal in 2021, can be attributed to the finalization of one of the country's largest hydropower plants. The completion of Iberdrola's 880 MW pumped hydro plant at the Tâmega energy storage complex in northern Portugal played a pivotal role in this increase. The Tâmega energy storage complex, which has been under construction since 2014, recently reached a significant milestone with the connection of the first turbines in 2022[1]. Given the scale and duration of the project, it's reasonable to assume that the peak in the number of jobs, which increased by a significant 37 300 in 2021, is likely to be spread over the last 8 years of construction and development. This can also be applied for the peak in turnover (€2.2 billion) and gross value added (€900 million) in for the Portuguese hydropower.

Other countries with an increase in capacity and job estimates are Austria, Belgium, Italy, and Bulgaria. France, on the other hand, showed a considerable decrease of 11 700 jobs in 2022, due to considerable reduction on its running capacity in 2022 – a decrease of 328 MW compared to 2021. This decrease can be attributed to a 22% fall in hydropower generation, primarily due to a severe drought impacting its power generation, as reported in preliminary 2022 results[2].

The overall employment level increased by 29 800 FTE reaching 78 600 hydropower jobs in the EU27. And a similar increase is observed for the turnover part that is estimated at €7.5 billion. The highest hydro power turnover can be observed in Portugal, Austria, Germany and Italy. 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. ■

1. *Colthorpe, A. (2022, February 3). Iberdrola's 880MW pumped hydro plant in Portugal to go online in mid-2022. Energy-Storage.News.*
2. *EDF's power generation in France reached a record low in 2022. (2023, January 17). Enerdata.*

Employment and turnover

	Employment (direct and indirect jobs)		Turnover (in M€)		Direct GVA (in M€)	
	2021	2022	2021	2022	2021	2022
Portugal	2 700	40 000	160	2 210	60	900
Germany	4 700	7 300	720	1 110	320	490
Italy	6 300	6 700	910	950	350	370
Austria	4 500	6 200	810	1 100	340	470
France	15 500	3 800	2 220	560	920	220
Spain	4 000	3 600	460	420	210	190
Sweden	2 100	2 000	380	380	180	180
Bulgaria	800	1 600	50	90	20	30
Romania	1 400	1 200	110	100	40	30
Greece	900	800	80	80	30	30
Czechia	1 400	700	100	50	40	20
Croatia	600	700	40	50	10	20
Poland	500	700	40	60	20	20
Latvia	500	500	30	30	10	10
Slovakia	500	500	40	40	20	10
Finland	500	400	90	70	40	30
Slovenia	400	400	30	30	10	10
Belgium	200	300	40	70	10	20
Lithuania	300	300	10	10	10	10
Luxembourg	200	200	30	30	10	10
Estonia	<100	100	<10	10	<10	<10
Hungary	200	100	10	<10	<10	<10
Ireland	100	100	10	10	<10	<10
Cyprus	<100	<100	<10	<10	<10	<10
Denmark	<100	<100	<10	<10	<10	<10
Malta	<100	<100	<10	<10	<10	<10
Netherlands	<100	<100	<10	<10	<10	<10
Total EU-27	48 800	78 600	6 420	7 510	2 720	3 140

Source: EurObserv'ER

GEOTHERMAL ENERGY

As in previous years, (deep) geothermal energy represents the smallest sector of renewable energy in the EU – both in terms of turnover and induced employment. According to the modelling results, overall EU sector turnover decreased by €140 million in comparison to last year, reaching €770 million in 2022. Employment also decreased to 6 200 in 2022 (from a previous level of 7 300 jobs).

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 2022, the largest increases in geothermal capacity for heating occurred in France (from 670 to 719 MWth), Italy (from 180 to 200 MWth), and Poland (from 137 MWth to 155 MWth). France leads in employment in the geothermal sector for 2022, with a turnover of €190 million and 1 200 jobs. Italy follows as a historically dominant player with 1 200 jobs and a turnover of €180 million, owing to its significant existing geothermal power and heating capacity.

Germany and the Netherlands rank third and fourth in Europe, both with turnovers of €60 million and employing 400 and 300 workers, respectively. However, in 2022, Poland's geothermal sector experienced an 800-job decrease, marking a significant 66% decrease compared to 2021. ■

Employment and turnover

	Employment (direct and indirect jobs)		Turnover (in M€)		Direct GVA (in M€)	
	2021	2022	2021	2022	2021	2022
France	800	1 200	130	190	50	70
Italy	1 000	1 200	160	180	60	70
Hungary	500	500	30	30	10	10
Germany	700	400	110	60	50	30
Poland	1 200	400	90	30	30	10
Netherlands	1 000	300	170	60	60	20
Portugal	<100	200	<10	10	<10	<10
Austria	100	100	20	20	10	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
Sweden	<100	<100	10	10	<10	<10
Slovenia	<100	<100	<10	<10	<10	<10
Slovakia	<100	<100	<10	<10	<10	<10
Total EU-27	7 300	6 200	910	770	470	420

Source: EurObserv'ER

HEAT PUMPS

After a decrease in industry turnover and EU wide employment in 2021, the heat pump sector in the EU27 is estimated to have experienced a large increase in terms of both estimates in 2022. The modelling resulted in an estimated overall turnover of €57 billion (an increase of €5.2 billion) and a heat pump employment level of 416 200 workers (an increase of 38 900 jobs in comparison with 2021). With those results, heat pumps became the largest renewable energy sector in the EU in terms of employment followed now by PV. 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 2022 than the production capacity – leading to more imports of heat pumps and heat pump parts from outside the EU. However, the average increase of 14% in the number of heat pumps in operation in the EU27 justify such an increase in imports and stimulated the market in 2022. The modelling results reflect this increase in levels of local employment and turnover. The heat pump value chain and creation remain a positive example 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.

The largest increase in the estimate of persons employed is observed for France (€2.5 billion and 15 700 jobs), mainly due to the increase in the number of heat pumps installed in France in 2022 compared to 2021. Other countries with a notable increase in the estimated employment and turnover are Netherlands (€1.1 billion and 7 000 jobs), Germany (€0.7 billion and 4 500 jobs) and Sweden (€0.7 billion and 3 400 jobs).

Even with this large increase in the estimates for 2022, Italy remains the largest in terms of employment (135 400 jobs) and turnover (€19.5 billion) in the heat pump sector (cooling and heating). France, Spain, Portugal and Germany remain large players with over 20 000 persons employed in the sector, now also accompanied by the Netherlands. ■

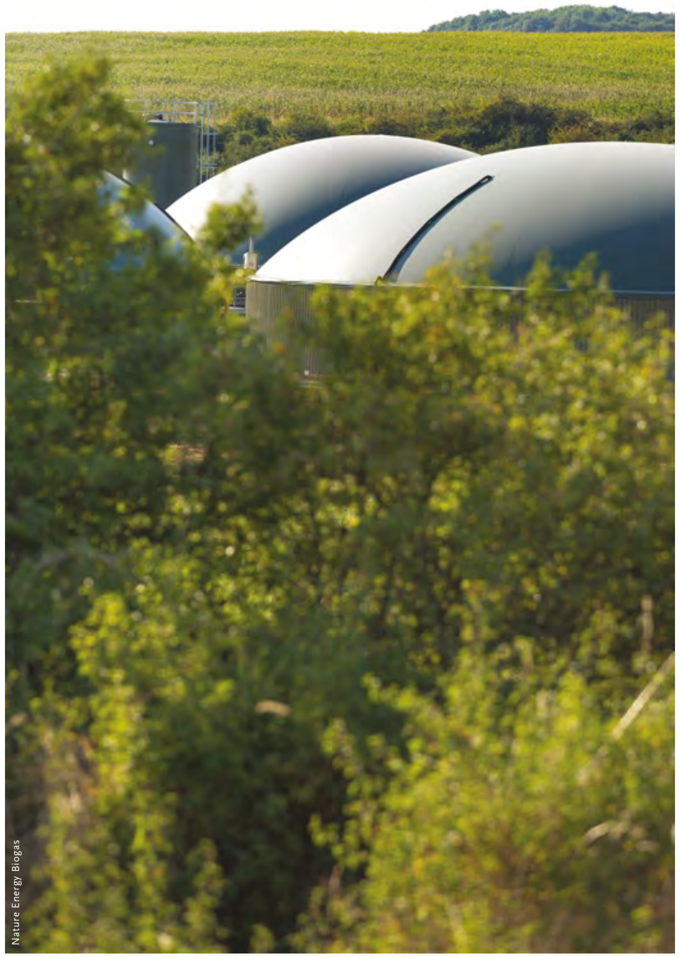
Employment and turnover

	Employment (direct and indirect jobs)		Turnover (in M€)		Direct GVA (in M€)	
	2021	2022	2021	2022	2021	2022
Italy	141 300	135 400	20 650	19 530	7 900	7 530
France	64 600	80 300	9 760	12 250	3 950	4 960
Spain	33 600	32 200	3 860	3 720	1 600	1 540
Germany	27 400	31 900	4 370	5 090	1 890	2 200
Netherlands	20 100	27 100	3 230	4 340	1 180	1 580
Portugal	22 500	24 900	1 290	1 430	480	530
Sweden	15 000	18 300	2 850	3 520	1 260	1 540
Poland	8 200	11 700	580	820	220	320
Finland	7 700	8 900	1 380	1 600	560	640
Greece	5 500	6 000	570	630	220	240
Belgium	4 200	5 100	870	1 050	310	380
Lithuania	2 500	4 500	110	200	60	100
Czechia	1 900	4 200	160	350	50	120
Denmark	3 700	4 200	710	800	290	330
Slovakia	3 100	3 600	240	300	90	110
Austria	2 600	3 100	480	570	200	240
Malta	3 100	3 100	250	250	100	100
Slovenia	2 800	2 600	230	210	90	80
Hungary	1 800	2 500	110	150	40	50
Estonia	2 300	2 400	170	180	60	60
Ireland	1 200	1 700	170	240	70	100
Romania	1 100	1 300	70	80	30	30
Bulgaria	700	800	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	**377 300**	**416 200**	**52 190**	**57 390**	**20 700**	**22 830**

Source: EurObserv'ER

BIOGAS

Following a rapid rise in the first decade of the century, the momentum of biogas development was not sustained over the ten following years in EU Member States. In 2022, primary energy output from biogas in the European Union remained relatively stable compared to 2021. The number of jobs in the biogas sector marginally increased to 49 300 in 2022 – 2 200 full time jobs more than in 2021. The sector produced a turnover of €5.8 billion, a slight growth from €5.5 billion recorded in the previous year. The gross value added for biogas in the EU-27 increased in line with the increase in turnover. Employment estimates for Italy, Greece and France all increased by 900-1400 FTE compared to 2021, but the workforce in Germany remains the largest for the biogas sector, with 23 200 jobs. Sector turnover also shows an increase in all these countries. In the second place, with a turnover of €890 million, comes Italy with 7 700 jobs. ■



Nature Energy Biogas

Employment and turnover

	Employment (direct and indirect jobs)		Turnover (in M€)		Direct GVA (in M€)	
	2021	2022	2021	2022	2021	2022
Germany	24 200	23 200	3 320	3 180	1 500	1 440
Italy	6 300	7 700	690	890	360	440
Czechia	3 400	3 600	230	240	90	100
France	2 600	3 500	350	470	140	200
Poland	2 600	2 300	140	110	50	40
Greece	700	2 000	40	150	20	60
Spain	1 300	1 200	130	130	60	60
Hungary	400	600	20	30	10	10
Croatia	800	500	50	40	20	20
Netherlands	500	500	90	80	40	30
Romania	<100	500	<10	30	<10	10
Austria	400	400	60	60	30	30
Belgium	400	400	100	110	30	40
Latvia	500	400	20	20	10	10
Portugal	500	400	30	20	10	10
Slovakia	500	400	40	40	20	20
Bulgaria	300	300	20	20	10	10
Denmark	300	300	60	60	20	20
Lithuania	300	300	20	10	10	10
Cyprus	100	100	10	10	<10	<10
Finland	300	100	30	20	10	10
Ireland	100	100	20	20	10	10
Luxembourg	100	100	10	<10	<10	<10
Sweden	100	100	10	10	10	<10
Slovenia	100	100	10	10	<10	<10
Estonia	<100	<100	<10	<10	<10	<10
Malta	<100	<100	<10	<10	<10	<10
Total EU-27	47 100	49 300	5 530	5 790	2 520	2 640

Source: EurObserv'ER

BIOFUELS

The methodology used to evaluate the biomass industry covers biomass supply activities, i.e. supply in the agricultural sector. The European biofuels sector (EurObserv'ER subsumes biodiesel, bioethanol and biogas for transport in the biofuels technologies) experienced a modest slowdown in growth during 2022. However, despite this deceleration, the sector still managed to increase its capacity slightly. Overall biofuel consumption increased by 5.2% between 2021 and 2022 to 17 900 ktoe (+ 878 ktoe). Substantial biofuel production capacities remain idle in the EU. According to EurObserv'ER calculations, the entire European Union biofuel-induced industry turnover increased, reaching €11.9 billion in 2022, a decrease of €140 million from 2021. The employment level decreased from 148 300 to 145 700 jobs in 2022. Biofuels remain the fifth largest renewable energy job creator in the EU, following heat pumps, solar PV, solid biofuels, 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. Indeed, Poland (22 100 jobs and €1.01 billion) is the largest in terms of biofuel employment. Romania (16 900 persons employed with a turnover of €700 million) and Hungary (16 100 persons employed and €960 million turnover) follow as third and fourth, closely behind France the second country in job count in the EU in 2022.

In turn, large parts of biofuel value creation occur on the production side of the value chain, which explains why economic turnover is highest in Member States with huge biofuel plants (for example France with €2.3 billion). In 2022, France was the second-largest consumer of biofuel in Europe, behind Germany. It is the second largest market in terms of biofuel jobs with 19 000 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 13 100 jobs. Biofuel-induced turnover remained stable in Germany (€1.8 billion) and correspondingly also saw no changes in job figures with 12 400 persons employed in 2022. ■

Employment and turnover

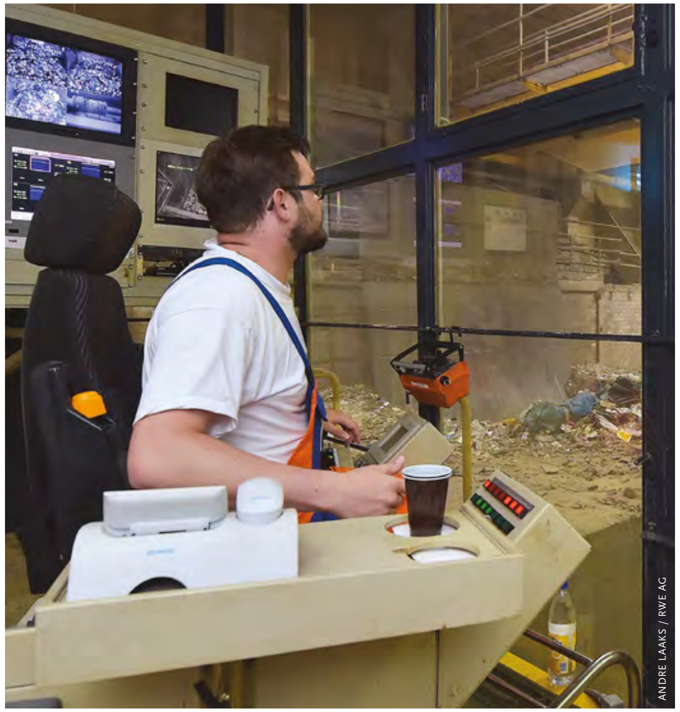
	Employment (direct and indirect jobs)		Turnover (in M€)		Direct GVA (in M€)	
	2021	2022	2021	2022	2021	2022
Poland	21 400	21 500	970	980	370	370
Hungary	17 000	20 400	980	1 180	470	570
France	18 800	19 000	2 250	2 290	950	970
Romania	17 800	16 600	740	690	340	320
Spain	13 500	13 100	1 340	1 300	700	680
Germany	12 400	12 800	1 770	1 820	790	810
Sweden	7 300	7 300	450	450	190	200
Lithuania	7 200	6 800	350	330	150	140
Italy	5 700	5 700	590	590	300	300
Slovakia	4 400	4 300	360	350	160	160
Czechia	4 300	4 200	280	270	110	110
Latvia	3 300	3 100	170	150	50	50
Bulgaria	3 100	3 000	200	190	70	70
Austria	2 600	2 500	390	380	180	170
Greece	2 600	2 300	130	110	60	60
Belgium	1 600	1 700	430	450	160	170
Croatia	1 600	1 500	100	90	50	40
Netherlands	1 200	1 200	270	260	110	110
Finland	1 000	1 000	150	150	60	60
Ireland	300	600	40	90	20	40
Estonia	400	300	20	10	10	<10
Portugal	300	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	**148 300**	**149 700**	**12 070**	**12 220**	**5 360**	**5 470**

Source: EurObserv'ER

RENEWABLE MUNICIPAL WASTE

By definition, municipal waste is considered 50% renewable matter as household waste contains a substantial biodegradable part. Energy production from waste is largely based on incineration in Waste-to-Energy (WtE) plants. This sector is relatively hard to quantify and remains one of the smaller RE sectors in the European Union. EurObserv'ER estimates the RMW sector was worth €2.4 billion in 2021, with €1.1 billion in gross added value. With 13 300 direct and indirect full-time equivalent jobs, a decrease by 1 200 jobs compared to 2021 can be observed. The decrease is explained by a decrease in sector growth, which presented virtually no growth between 2021 and 2022 in capacity. Besides, decreases in capacity were observed among some of the leading countries, such as Germany and Italy, translating into no growth in job to Germany and around 400 fewer jobs in Italy. Poland and Austria are the countries with the largest decrease in jobs, with respectively 1 800 and 1 100 fewer jobs compared to 2021, which can be explained by the slowdown in their capacity growth, after a considerable increase in 2021. Meanwhile, a significant increase can be observed for the estimates for Belgium (+€130 million and 600 jobs).

According to the EurObserv'ER modelling, Germany is the largest MSW member state in terms of socioeconomic impacts, with a turnover of €760 million and 3 900 jobs in the sector. Italy ranks next with an estimated workforce of 1 300 workers and an industry turnover of €230 million in 2022. ■



ANDRE LAAKS / RWE AG

Employment and turnover

	Employment (direct and indirect jobs)		Turnover (in M€)		Direct GVA (in M€)	
	2021	2022	2021	2022	2021	2022
Germany	3 900	3 900	750	760	330	340
Italy	1 700	1 300	300	230	120	90
France	1 300	1 200	240	230	90	90
Sweden	800	1 100	200	270	90	130
Belgium	300	900	70	200	30	80
Netherlands	800	900	160	180	70	80
Portugal	200	600	20	50	10	20
Denmark	300	400	90	100	40	40
Spain	300	400	50	60	20	30
Hungary	100	400	10	30	<10	10
Estonia	<100	300	10	20	<10	10
Austria	1 300	200	240	40	100	20
Finland	200	200	50	60	20	30
Ireland	100	200	20	30	10	20
Lithuania	100	100	<10	10	<10	<10
Poland	1 900	100	130	10	60	10
Bulgaria	<100	<100	<10	<10	<10	<10
Cyprus	<100	<100	<10	<10	<10	<10
Czechia	100	<100	<10	<10	<10	<10
Greece	<100	<100	<10	<10	<10	<10
Croatia	<100	<100	<10	<10	<10	<10
Luxembourg	100	<100	30	<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	14 500	13 300	2 480	2 390	1 130	1 120

Source: EurObserv'ER

SOLID BIOFUELS

Solid biofuels remain an important renewable energy source in terms of energy production and renewable employment in the EU27. The reason for this is that, unlike the other RE giants, wind power, biofuels also make a substantial contribution towards renewable heat generation. Additionally, an important part of employment activities originates from biomass feedstock supply.

The solid biofuels sector comprises different technologies that cover various end-user sectors: energy (biomass CHP, co-firing), industry (boilers), and households (pellet boilers and stoves). Solid biofuels are not only used in the form of wood chips and briquettes, but also includes many other forms such as wood waste, pellets, sawdust, straw, bagasse, animal waste as well as black liquors from the papermaking industry. The energy recovery of this matter is basically channelled into producing heat.

The consumption of solid biofuels energy shows a small decrease in the European Union in 2022, following record growth in 2021. This decrease corresponds to a decrease in consumption of -3.9 Mtoe (from 104.2 to 100.3 Mtoe). The numbers for 2021 were ramped up due to the harsher winter and the rise in fossil fuel prices in the second half of the year, which increased the competitiveness of biomass fuels. Therefore, a small decrease in consumption was to be expected and, even though, the numbers for 2022 are much higher than the ones of 2020 (94.2 Mtoe). Following the same logic, electricity and heat production from solid biofuels increased significantly in 2021, and in 2022 went from 90 to 87.6 GWh (- 2.6%) and from 13.1 to 12.2 Mtoe (- 7%) respectively. These increases have had an impact on the socio-economic results of the sector, with an estimated 331 700 jobs in 2022 (-22 100 compared to 2021) and an estimated turnover of 36.1 billion euros (-2.3 billion compared to 2021). After the large increase in the heat pump and solar sectors in 2022, solid biofuels lost its leading position and is now the third largest renewable energy source in terms of socio-economic indicators in 2021. Regarding turnover, biomass is now the fourth largest sector, behind heat pumps, wind and PV energy. 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 almost 98% of the biomass fuels used in the sector come from EU countries. In 2022, imports from outside the EU accounted for only 2.2% of total consumption.

Regarding the countries, Sweden took the lead and now has the highest solid biofuels turnover (€5.8 billion), but with 29,600 jobs, it is in fourth place in terms of biomass workforce. Germany, previously number one in turnover is now in second place, with €5.8 billion, but is still the first in terms of employment with 40 300 jobs. Poland, one of the most important agricultural countries in EU, represents 33 400 jobs, although the sector turnover is significantly lower at €1.3 billion. The different ratios between employment and turnover are caused by how different types of activity are modelled. ■

Employment and turnover

	Employment (direct and indirect jobs)		Turnover (in M€)		Direct GVA (in M€)	
	2021	2022	2021	2022	2021	2022
Germany	41 300	40 300	5 990	5 650	3 100	2 980
Poland	46 900	33 400	2 160	1 350	910	590
France	24 900	30 500	3 840	4 620	1 810	2 120
Sweden	22 900	29 600	4 590	5 840	1 940	2 490
Spain	17 400	26 400	1 060	2 060	520	930
Italy	21 100	23 600	1 670	2 160	910	1 080
Czechia	15 900	16 400	940	990	340	360
Latvia	17 700	15 000	890	760	340	290
Finland	19 200	14 300	4 560	3 660	2 750	2 310
Portugal	8 700	13 300	790	1 040	460	560
Hungary	12 100	12 300	480	500	190	190
Croatia	10 400	10 100	380	370	190	180
Romania	8 700	10 000	420	520	180	220
Austria	9 800	9 800	2 070	2 080	950	950
Lithuania	9 200	7 900	320	270	150	130
Estonia	8 300	7 700	780	750	300	290
Slovakia	5 400	7 600	340	500	170	230
Netherlands	23 300	6 200	3 610	890	1 440	430
Bulgaria	12 200	6 100	530	250	210	100
Denmark	12 900	5 400	2 180	880	900	360
Belgium	1 000	2 400	400	690	120	230
Ireland	2 100	1 600	200	140	90	60
Slovenia	1 100	900	90	80	50	40
Greece	800	600	90	70	30	30
Cyprus	100	100	<10	<10	<10	<10
Luxembourg	300	100	50	20	20	10
Malta	<100	<100	<10	<10	<10	<10
Total EU-27	353 800	331 700	38 450	36 160	18 090	17 180

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 1.69 million persons are directly or indirectly employed in the European Union renewable energy sector. This represents a gross increase of 222 100 jobs (15%) from 2021 to 2022.
- 20 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 (299 000 jobs, 18% of all EU renewable employment), Italy (219 000 jobs, 13%), France (197 900 jobs, 12%), Spain (156 400 jobs, 9%), and Poland (129 900 jobs, 8%).
- The largest growth in employment estimates were found in Portugal (+46 400 new jobs, equal to +92% - as previously explained mostly due to the large hydro power plant commissioned in 2022), Germany (+42 200, equal to +16%), and Spain (+32 400 jobs, equal to +26%). The greatest decreases were observed in Denmark (-10 400 jobs, equal to -19%), Latvia (- 2 100, -9%) and Croatia (-1 700 jobs, equal to -10%).
- Heat pump (416 200 jobs, 25% of the total EU) once more became the largest sector in terms of renewable energy induced employment, ahead of PV (346 900 jobs, 20%) and solid biomass (331 700 jobs, 20%). The most significant upward jump in employment per technology was in the PV sector with an additional 123 800 jobs (+55%), followed by wind energy that saw an addition of 62 000 new jobs (+29%). Increases were also observed in the hydropower, biofuels, heat pumps and biogas sectors. The increases balance out declines in the solar thermal, geothermal, MSW and solid biofuels sectors.

TURNOVER

- In total the renewable energy related industry turnover in EU-27 Member States in 2022 amounted to around €210 billion, representing a gross growth of around €24.8 billion against 2021 (+13%).
- 22 out of 27 EU Member States either increased or maintained their industrial turnover created by renewable energy sources.
- The top 5 Member States in terms of turnover are Germany (€45.9 billion), Italy (€30.0 billion), France (€29.6 billion), Spain (€17.4 billion), and the Sweden with €14.6 billion. The first four are also the countries where the gross value added is largest, followed by the Netherlands.
- The largest growth in turnover according to the EurObserv'ER modelling was observed in Germany (+€6.1 billion), France (+€4.8 billion), and Spain (+€3.6 billion). The largest dips in turnover occurred in Denmark (-€1.8 billion) and Netherland (-€0.4 billion).
- The largest renewable energy technologies in terms of industry sector turnover were heat pumps with €57.4 billion, followed by wind energy at €43.3 billion and PV at €40.8 billion. The gross value added was also largest for these sectors: €22.8 billion for heat pumps, €18.6 billion for wind energy and €17.2 billion for PV. ■

2021 EMPLOYMENT DISTRIBUTION BY SECTOR

	Total	Heat pumps	Solid biomass	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

2022 EMPLOYMENT DISTRIBUTION BY SECTOR

	Total	Heat pumps	PV	Solid biomass	Wind	Biofuels	Hydro	Biogas	Solar thermal	MSW	Geothermal
Germany	299 000	31 900	87 100	40 300	85 600	12 800	7 300	23 200	6 500	3 900	400
Italy	219 000	135 400	26 500	23 600	9 100	5 700	6 700	7 700	1 800	1 300	1 200
France	197 900	80 300	20 500	30 500	36 500	19 000	3 800	3 500	1 400	1 200	1 200
Spain	156 400	32 200	36 300	26 400	37 100	13 100	3 600	1 200	6 000	400	<100
Poland	129 900	11 700	44 100	33 400	13 700	21 500	700	2 300	2 000	100	400
Portugal	96 600	24 900	12 000	13 300	4 200	300	40 000	400	700	600	200
Sweden	80 300	18 300	4 900	29 600	16 800	7 300	2 000	100	100	1 100	<100
Netherlands	77 800	27 100	30 000	6 200	11 400	1 200	<100	500	100	900	300
Hungary	57 200	2 500	19 500	12 300	800	20 400	100	600	100	400	500
Denmark	44 000	4 200	10 500	5 400	22 600	<100	<100	300	300	400	<100
Finland	42 400	8 900	3 500	14 300	13 800	1 000	400	100	<100	200	<100
Czechia	38 000	4 200	7 700	16 400	800	4 200	700	3 600	200	<100	<100
Romania	35 000	1 300	2 900	10 000	2 200	16 600	1 200	500	<100	<100	100
Austria	33 300	3 100	6 600	9 800	2 600	2 500	6 200	400	1 800	200	100
Greece	30 000	6 000	12 700	600	2 500	2 300	800	2 000	2 900	<100	<100
Lithuania	29 600	4 500	5 100	7 900	4 400	6 800	300	300	<100	100	<100
Bulgaria	21 600	800	7 600	6 100	600	3 000	1 600	300	1 400	<100	<100
Latvia	20 600	<100	500	15 000	700	3 100	500	400	<100	<100	<100
Belgium	17 200	5 100	2 200	2 400	4 000	1 700	300	400	100	900	<100
Slovakia	17 000	3 600	200	7 600	<100	4 300	500	400	100	<100	<100
Croatia	14 800	<100	1 000	10 100	600	1 500	700	500	100	<100	<100
Estonia	12 900	2 400	1 600	7 700	200	300	100	<100	<100	300	<100
Ireland	7 600	1 700	300	1 600	2 800	600	100	100	<100	200	<100
Slovenia	6 700	2 600	2 200	900	<100	<100	400	100	<100	<100	<100
Malta	4 000	3 100	100	<100	<100	<100	<100	<100	<100	<100	<100
Cyprus	2 000	<100	1 000	100	100	<100	<100	100	200	<100	<100
Luxembourg	1 300	<100	300	100	100	<100	200	100	<100	<100	<100
Total EU-27	1 692 100	416 200	346 900	331 700	273 500	149 700	78 600	49 300	26 700	13 300	6 200

Source: EurObserv'ER

2021 TURNOVER BY SECTOR (€M)

	Total	Heat pumps	Solid biomass	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

2022 TURNOVER BY SECTOR (€M)

	Total	Heat pumps	Wind	PV	Solid biomass	Biofuels	Hydro	Biogas	Solar thermal	MSW	Geothermal
Germany	45 880	5 090	14 180	13 070	5 650	1 820	1 110	3 180	960	760	60
Italy	29 980	19 530	1 470	3 740	2 160	590	950	890	240	230	180
France	29 660	12 250	5 910	2 930	4 620	2 290	560	470	210	230	190
Spain	17 400	3 720	4 970	3 830	2 060	1 300	420	130	900	60	<10
Sweden	14 560	3 520	3 220	850	5 840	450	380	10	10	270	10
Netherlands	12 010	4 340	1 840	4 340	890	260	<10	80	10	180	60
Denmark	8 960	800	5 030	2 000	880	10	<10	60	60	100	10
Finland	8 630	1 600	2 360	690	3 660	150	70	20	10	60	<10
Poland	7 650	820	1 050	3 100	1 350	980	60	110	140	10	30
Austria	6 250	570	490	1 170	2 080	380	1 100	60	340	40	20
Portugal	5 850	1 430	380	640	1 040	40	2 210	20	30	50	10
Belgium	3 880	1 050	860	430	690	450	70	110	10	200	<10
Hungary	3 100	150	60	1 100	500	1 180	<10	30	<10	30	30
Greece	2 640	630	290	1 030	70	110	80	150	260	<10	<10
Czechia	2 560	350	70	560	990	270	50	240	10	<10	<10
Romania	1 840	80	190	200	520	690	100	30	<10	<10	10
Slovakia	1 290	300	<10	20	500	350	40	40	10	<10	<10
Lithuania	1 270	200	200	220	270	330	10	10	<10	10	<10
Estonia	1 140	180	20	120	750	10	10	<10	<10	20	<10
Bulgaria	1 100	40	40	380	250	190	90	20	70	<10	<10
Ireland	1 070	240	480	40	140	90	10	20	10	30	<10
Latvia	1 070	<10	40	30	760	150	30	20	<10	<10	<10
Croatia	700	<10	50	60	370	90	50	40	10	<10	<10
Slovenia	540	210	<10	160	80	<10	30	10	<10	<10	<10
Malta	340	250	<10	10	<10	<10	<10	<10	<10	<10	<10
Cyprus	190	<10	10	90	<10	<10	<10	10	20	<10	<10
Luxembourg	170	10	20	40	20	<10	30	<10	<10	<10	<10
Total EU-27	209 730	57 390	43 260	40 850	36 160	12 220	7 510	5 790	3 390	2 390	770

Source: EurObserv'ER

2021 GROSS VALUE ADDED BY SECTOR (€M)

	Country total	Heat pumps	Solid biomass	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

2022 GROSS VALUE ADDED BY SECTOR (€M)

	Country total	Heat pumps	Wind	Solid biomass	PV	Biofuels	Hydro	Biogas	Solar thermal	MSW	Geothermal
Germany	20 740	2 200	6 220	2 980	5 810	810	490	1 440	420	340	30
France	12 310	4 960	2 400	2 120	1 200	970	220	200	80	90	70
Italy	12 050	7 530	620	1 080	1 460	300	370	440	90	90	70
Spain	7 660	1 540	2 120	930	1 670	680	190	60	430	30	<10
Sweden	6 590	1 540	1 620	2 490	400	200	180	<10	<10	130	<10
Netherlands	4 670	1 580	760	430	1 640	110	<10	30	<10	80	20
Finland	4 390	640	1 020	2 310	270	60	30	10	<10	30	<10
Denmark	3 600	330	1 990	360	810	<10	<10	20	20	40	<10
Poland	3 130	320	460	590	1 260	370	20	40	50	10	10
Austria	2 750	240	210	950	500	170	470	30	150	20	10
Portugal	2 460	530	160	560	250	10	900	10	10	20	<10
Belgium	1 420	380	330	230	150	170	20	40	<10	80	<10
Hungary	1 340	50	20	190	460	570	<10	10	<10	10	10
Greece	1 080	240	140	30	410	60	30	60	90	<10	<10
Czechia	970	120	30	360	200	110	20	100	10	<10	<10
Romania	790	30	80	220	70	320	30	10	<10	<10	<10
Lithuania	630	100	100	130	110	140	10	10	<10	<10	<10
Slovakia	580	110	<10	230	10	160	10	20	<10	<10	<10
Ireland	480	100	200	60	20	40	<10	10	<10	20	<10
Estonia	460	60	10	290	40	<10	<10	<10	<10	10	<10
Bulgaria	420	10	20	100	140	70	30	10	20	<10	<10
Latvia	420	<10	10	290	10	50	10	10	<10	<10	<10
Croatia	340	<10	20	180	20	40	20	20	<10	<10	<10
Slovenia	250	80	<10	40	60	<10	10	<10	<10	<10	<10
Malta	190	100	<10	<10	<10	<10	<10	<10	<10	<10	<10
Cyprus	120	<10	<10	<10	30	<10	<10	<10	10	<10	<10
Luxembourg	110	<10	10	10	20	<10	10	<10	<10	<10	<10
Total EU-27	89 950	22 830	18 590	17 180	17 030	5 470	3 140	2 640	1 530	1 120	420

Source: EurObserv'ER

EUROBSERV'ER – THE STATE OF RENEWABLE ENERGIES IN EUROPE – 2023 EDITION

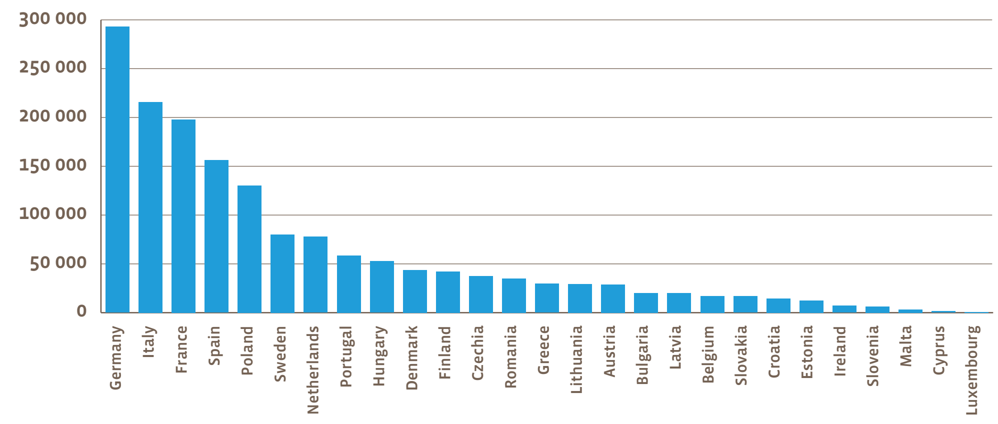
RENEWABLE ENERGY DEVELOPMENT AND ITS INFLUENCE ON FOSSIL FUEL SECTORS

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 2023 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 2022. The effect is estimated for the following six subsectors: power generation, mining, oil for power generation, refining, heat production and extraction and supply of crude oil and fossil gas. The evaluation has been conducted in terms of direct jobs. Our approach only covers the effects on operation and maintenance (O&M) and fuel production activities (effects on O&M are assumed to be proportional to the displaced production). It must be noted that reduced construction activities of new conventional plants are not considered, but at the same time that opposite effects are not considered: effects that influence the fossil sectors through other mechanisms (for example the impact of gas increase on the coal sector). Establishing a full reference picture is outside the scope of this analysis, so the presented indicator for equivalent replaced fossil employment does not give the full spectrum of effects. The figures show that the effects in the fossil fuel sector vary significantly between Member States. The relative impact on the fossil sector, when compared to the gross renewable employment, is for example of a completely different nature in Hungary than it is in Romania. The reason for this lies in the difference in composition of the fossil fuel sector and in the type of renewable technology that is deployed. Countries that have coal mining activities are more sensitive to the influence of renewables development than countries that import coal for power generation. This has been described in the JRC-report 'EU coal regions: opportunities and challenges ahead'. In our methodology, the employment affected by reduced use of fossil gas in gas extraction, gas conversion and gas transport is assumed to be close to zero, while in the power sector there is an effect.

The type of renewable technology deployed is also an important factor. Technologies that use feedstock (biogas, solid biomass, biofuels and MSW) generate a relatively high amount of jobs per MW. Therefore, development of employment in the production of feedstock for such renewable technologies results in a proportionally smaller impact on the fossil fuel sector than the development of, for example, the wind industry. ■

1

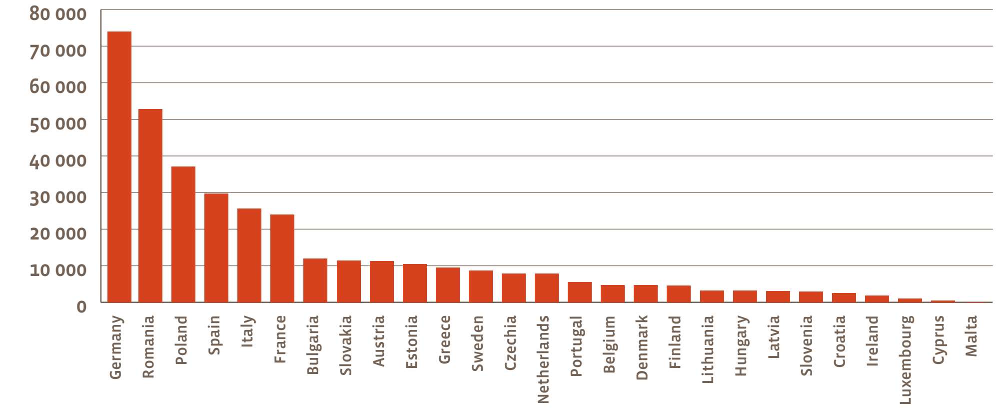
Gross renewable employment from previous sections (data for 2022)



Source: EurObserv'ER

2

Indicator for equivalent replaced fossil employment, looking at operation, maintenance, and fuel production activities only (data for 2022)



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 due to limited resources. 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 off-shore 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 2023 reports an investment in the energy transition of $180 billion in EU Member States in 2022, retaining 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, hydrogen, CCS and sustainable materials. Among all EU Member States, Germany, France, Spain and Italy invested $55 billion, $29 billion, $17 billion and $16 billion respectively in these low-carbon fields. A lot of momentum has been observed in the electric vehicle market, which compensated for the deceleration in renewables. Especially in Germany and France, more than half of the investment volume was spent on electrified transport. Nevertheless, a substantial volume has been invested in renewable energy in Germany, while France invested more in electric heat than renewables. In Italy, the investment volume was distributed quite evenly among electrified transport, renewable energy and electrified heat, while the investment in Spain focused mainly on renewable energy.

The following sections analyse in detail the investments in onshore wind, offshore wind and solar photovoltaic in the EU Member States, with a focus on the asset finance and associated capacity added in 2021 and 2022.

EUROBSERV'ER – THE STATE OF RENEWABLE ENERGIES IN EUROPE – 2023 EDITION

WIND POWER

Investments in wind power have been strongly influenced by the difficult macroeconomic circumstances, which led to rising costs and an insecure investment environment. Investments in new capacity in 2022 have dropped substantially in both onshore and offshore wind sectors and reached the lowest since 2009. Total investments in wind capacity in the EU reduced by 48% from € 28.2 billion in 2021 to € 14.7 billion in 2022. Correspondingly, the associated capacity added dropped by 42% from 18 GW to 11 GW.

Most Member States downsized their investments in wind capacity in 2022 compared to 2021. Despite a reduction of investment volume by 70%, Germany continued to lead in wind investment with € 2.4 billion in 2022. Finland invested the second most in the wind sector with € 2.1 billion in 2022, while France moved from second place in 2021 to fifth place in 2022 with € 1.6 billion. Only Poland and Italy have slightly increased their investments as well as associated capacities in the wind sector from 2021 to 2022, while the investments in Ireland remained at the same level.

1

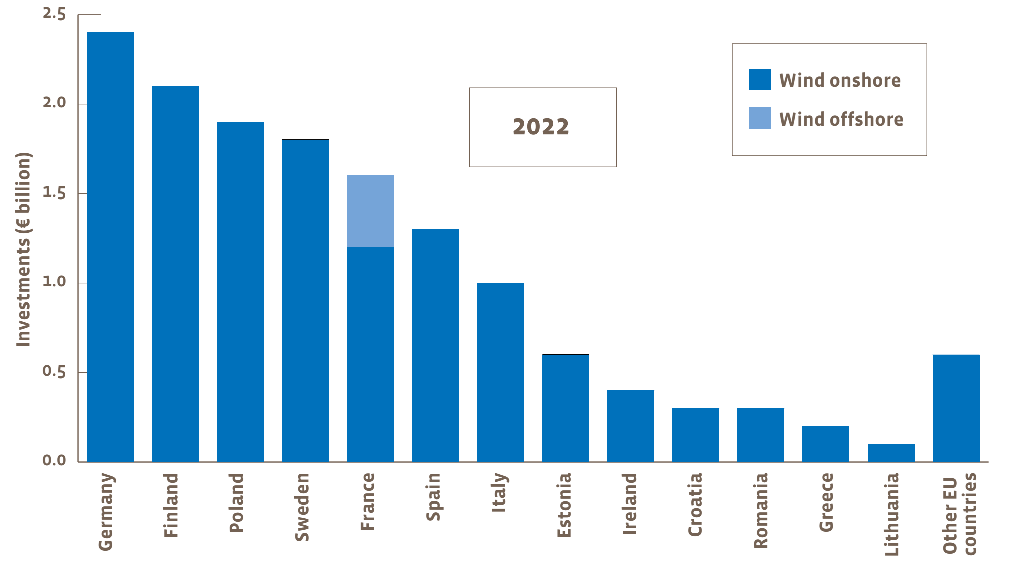
Overview of asset finance in the wind power sector (onshore + offshore) in the EU Member States in 2021 and 2022

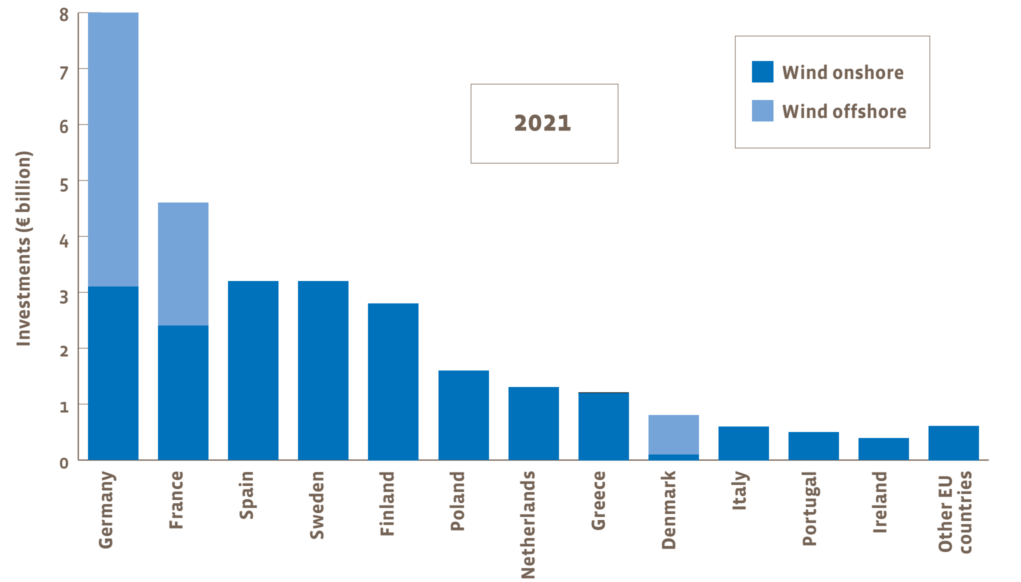
	2021		2022	
	Asset finance - newly built (€ bn)	Associated capacity added (GW)	Asset finance - newly built (€ bn)	Associated capacity added (GW)
Germany	8.0	3.5	2.4	1.7
Finland	2.8	2.5	2.1	1.5
Poland	1.6	1.3	1.9	1.5
Sweden	3.2	2.6	1.8	1.4
France	4.6	2.2	1.6	0.9
Spain	3.2	2.9	1.3	1.1
Italy	0.6	0.5	1.0	0.7
Estonia	NA	NA	0.6	0.4
Ireland	0.4	0.3	0.4	0.3
Croatia	NA	NA	0.3	0.2
Romania	NA	NA	0.3	0.3
Greece	1.2	0.7	0.2	0.2
Lithuania	NA	NA	0.1	0.1
Other EU countries	2.6	1.8	0.6	0.3
Total EU-27	28.2	18.3	14.7	10.5

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

2

Asset finance in the wind power sector in the EU Member States in 2021 and 2022





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

WIND INVESTMENTS SHRANK AND CONCENTRATED IN ONSHORE

The investments have been shifted from offshore to onshore wind investments in 2021 and even more in 2022. In addition, the investments in wind capacity shrink in 2022, especially in off-shore wind sector. Although onshore wind investments in the EU decreased from € 21 billion in 2021 by 32% to € 14.3 billion in 2022, accounting for 97% of the total wind investments in 2022. As for offshore wind sector, there was a lack of large-scale investment and only two floating demonstration projects were invested in 2022. The investments in offshore wind plants decreased by 95% from € 7.8 billion in 2021 to only € 0.4 billion in 2022.

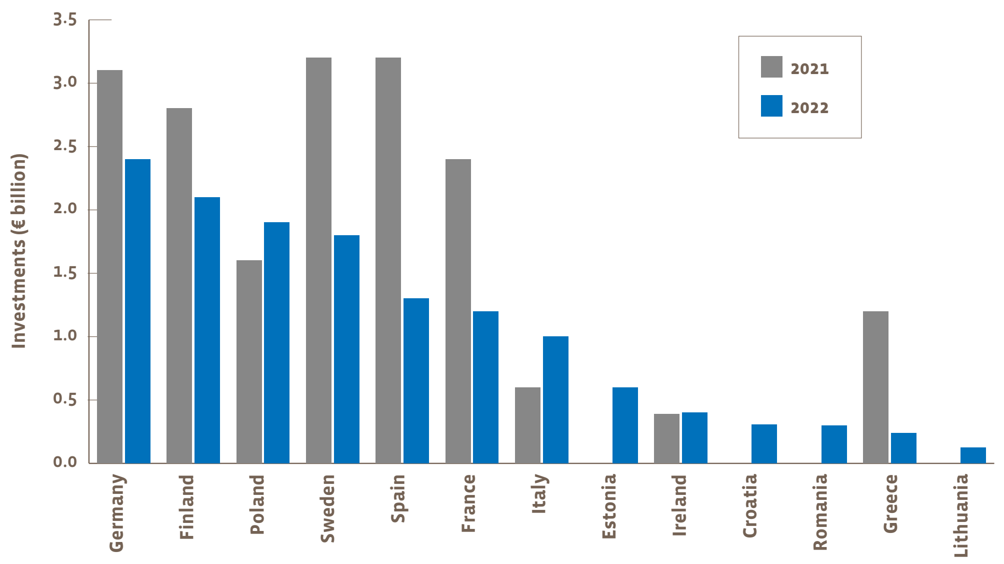
Consequently, the capacity added associated to the wind investments reduced. The associated onshore wind capacity added dropped from 16.1 GW in 2021 by 35% to 10.4 GW in 2022, while the associated capacity added for offshore wind decreased by 97% from 2.2 GW in 2021 to 0.1 GW in 2022.

GERMANY LED IN ONSHORE WIND

Similar to the investment trend observed in the total wind investments, most Member States stepped back their investments in onshore wind capacity. Germany led with around € 2.4 billion in onshore wind investments again in 2022, although more investments of € 3.1 billion were made in 2021. Finland was the only other Member State to invest over € 2 billion in 2022. The Member States invested the most in 2021, Spain and Sweden, have cut around half of their investments in onshore wind plants in 2022 and moved therefore to the fourth and fifth places of Member States investing the most in the onshore wind sector in 2022.

3

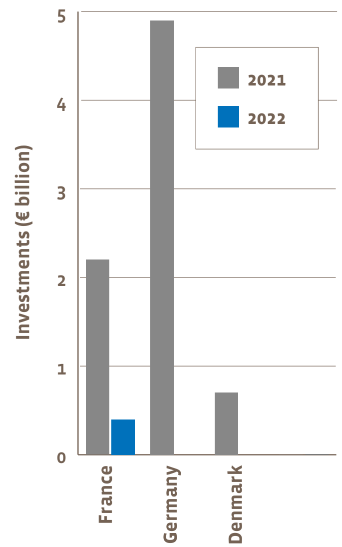
Asset finance in the onshore wind sector in the EU Member States in 2021 and 2022



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

4

Asset finance in the offshore wind sector in the EU Member States in 2021 and 2022



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

Among all 27 EU Member States, Spain, Sweden and Poland have relatively large onshore markets and low investment costs at the same time in 2022. With the similar level of investment costs, Croatia and Romania only invested a few onshore projects, summing up to € 0.3 billion for each country in 2022.

As for associated capacity added, Spain led with 2.9 GW in 2021 and Germany took over the first place with 1.7 GW in 2022. Finland and Poland ranked second in 2022 with 1.5 GW each, who ranked third with 2.5 GW and sixth with 1.3 GW respectively in 2021. Corresponding to the asset finance, the associated capacity added in most Member States reduced from 2021 to 2022. Among all Member States, higher associated capacity added were only observed in Poland and Italy.

Overall, a slight rise in investment costs in the onshore wind sector was observed, from € 1.3 million per MW in 2021 to €1.4 million per MW in 2022. However, the investment costs lowered if inflation were taken into account.

OFFSHORE WIND INVESTMENTS ONLY IN FRANCE

There are only a few players in the offshore wind sector. The Netherlands has stepped down since it made enormous investments in 2020, and so have Germany and Denmark since their investments of € 4.9 billion and € 0.7 billion respectively in 2021. The special macroeconomic circumstances have been influencing the offshore wind sector further, which led to only investment decisions being made in France in 2022. Specifically, only two offshore demonstration projects in France were invested, summing up to € 0.4 billion and associated with 60 MW.

Due to the lack of investments, no conclusive observation can be made on the development of investment costs in the offshore wind sector. The substantially increased investment costs in France, from € 3.7 million per MW in 2021 to € 6.7 million per MW in 2022, do not represent the development in the EU. Nevertheless, rising investment costs for offshore wind technology have been observed globally according to the recently published Renewable power generation costs in 2022 from the International Renewable Energy Agency.

5

Overview of asset finance in the onshore wind sector in the EU Member States in 2021 and 2022

	2021		2022	
	Asset finance - newly built (€ bn)	Associated capacity added (GW)	Asset finance - newly built (€ bn)	Associated capacity added (GW)
Germany	3.1	2.1	2.4	1.7
Finland	2.8	2.5	2.1	1.5
Poland	1.6	1.3	1.9	1.5
Sweden	3.2	2.6	1.8	1.4
Spain	3.2	2.9	1.3	1.1
France	2.4	1.6	1.2	0.8
Italy	0.6	0.5	1.0	0.7
Estonia	NA	NA	0.6	0.4
Ireland	0.4	0.3	0.4	0.3
Croatia	NA	NA	0.3	0.2
Romania	NA	NA	0.3	0.3
Greece	1.2	0.7	0.2	0.2
Lithuania	NA	NA	0.1	0.1
Other EU countries	2.5	1.6	0.6	0.3
Total EU-27	21.0	16.1	14.3	10.4

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

Overall, investments in wind power, especially offshore wind plants, are largely induced by auctions, which focus on low bidding prices in order to minimise the support costs (or increase paybacks in the case of Contracts for Difference). However, this does not reflect the economic reality of rising costs and inflation caused by special macroeconomic circumstances. The difficult economic and financing conditions have increased the risks for projects, which led to delays or even failure of projects meeting final investment decision. To restore the confidence of investors and adapt to the new reality, auction design might be adjusted, for instance by introducing non-price criteria as in Germany, the Netherlands and France[1]. Successful offshore auctions and positive developments have been observed in 2023, as reported by WindEurope.[2] ■

1. *https://www.euractiv.com/section/energy-environment/opinion/the-growing-role-of-non-price-criteria-in-offshore-wind-auctions/*
2. *https://windeurope.org/newsroom/press-releases/lots-of-good-news-and-good-numbers-again-in-offshore-wind/*

6

Overview of asset finance in the offshore wind sector in the EU Member States in 2021 and 2022

	2021		2022	
	Asset finance - newly built (€ bn)	Associated capacity added (GW)	Asset finance - newly built (€ bn)	Associated capacity added (GW)
France	2.2	0.6	0.4	0.1
Germany	4.9	1.4	-	-
Denmark	0.7	0.2	-	-
Total EU-27	7.8	2.2	0.4	0.1

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

C.Beyssier

PHOTOVOLTAIC

When analysing investments in solar PV, two points are particularly important to be kept in mind. First of all, asset financing in the EurObserv'ER report before the edition 2019 only contains utility-scale investments. Starting from the EurObserv'ER report edition 2022, the estimated investment data includes not only utility-scale PV investments but also small-scale investments, i.e. PV installations with capacities below 1 MW, which make up the largest share in PV installations in most of the EU countries.
Overall, the total investment in solar PV in the EU-27 Member States was estimated to reach € 33.2 billion in 2021, double the investments in 2020. The estimated investment volume in 2021 was associated with a capacity added of 27 GW. Slightly less than half of the investments result-ed in plant size between 20 kW and 1 MW, while a bit over one-third of them were invested in utility-scale installations over 1 MW. Due to the limited availability of investment information for the year 2022, no estimation for the total investment in all Member States is made. Nevertheless, a detailed analysis of Member States with available information in 2022 is shown in the following sections.

GERMANY AND SPAIN LED THE PV MARKET

Among all EU Member States, Germany continued to lead the investment volume in solar PV, with € 8.5 billion in 2021 and € 9.4 billion in 2022. With an investment volume of € 6.4 billion in 2022, Spain took over second place from the Netherlands, which invested € 5.4 billion in 2021. As for the associated capacity added, Germany ranked first in 2021 with 5.8 GW, followed by Spain with 4.9 GW. Thanks to the high cost-competitiveness, Spain invested in more capacity with less expenditure and surpassed Germany in associated capacity added with 8.6 GW,

1

Overview of estimated investment in the solar photovoltaic sector (residential + commercial) in the EU Member States in 2021

	2021	
	Estimated investment (€bn)	Associated capacity added (MW)
Germany	8.5	5760
Spain	3.6	4900
Netherlands	5.4	3632
Poland	4.3	2900
France	3.3	3351
Hungary	1.1	837
Denmark	1.1	718
Italy	1.1	938
Greece	1.0	990
Portugal	0.8	571
Belgium	0.7	440
Sweden	0.6	500
Austria	0.3	740
Bulgaria	0.3	175
Estonia	0.2	187
Lithuania	0.2	91
Finland	0.1	100
Luxembourg	0.1	91
Cyprus	0.1	85
Ireland	0.1	45
Other EU countries	0.3	228.5
Total EU-27	33.2	27 278

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

2

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

	2022	
	Estimated investment (€ m)	Associated capacity added (MW)
Germany	9.4	7193
Spain	6.4	8621
Netherlands	5.1	3900
Poland	4.7	3630
Italy	2.9	2490
France	2.6	2966
Denmark	2.1	1573
Austria	1.8	1009
Portugal	1.2	890
Sweden	1.1	798
Finland	0.4	274

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

while the investments in Germany were associated with 7.2 GW. The second highest investor in 2021, the Netherlands, ranked third in 2022 in terms of investment volume (€ 5.1 billion) as well as associated capacity added (3.9 GW). The highest relative increase of investment from 2021 to 2022 is expected to be in Austria, by 5 times from € 0.2 billion to € 1.8 billion.

Overall, the observation suggests the investment costs of PV dropped slightly between 2021 and 2022. Nevertheless, the special macroeconomic circumstances have influenced each Member State to a different extent. Italy and Sweden, for instance, have experienced higher investment costs of PV in 2022 compared to 2021.

GROWING MARKET FOR DISTRIBUTED PV SYSTEMS IN MANY MEMBER STATES

The distribution of EU PV investments varies considerably across Member States, which also changed year by year. Spain, as an example, shifted the investment from focusing on grid-connected centralised power plants in 2020 to even distribution between grid-connected distributed and grid-connected centralised installations in 2022. France, as another example, concentrated with 62% of the investment in distributed installations in 2022. Even more extreme is the distribution of investment in Sweden, where distributed PV systems have a large and continuously growing market share. In 2022, distributed solar PV systems made up to 97% of the total PV investment in Sweden, with the average power plant size decreased from 18.7 kW in 2021 to 14.4 kW in 2022. ■

RENEWABLE ENERGY COSTS AND PRICES

One of the important drivers in renewables' deployment is their competitiveness. Energy from renewable technologies comes at a cost of the energy, and it competes with conventional energy carriers: fossil fuels and electricity generated from fossil fuels. Through deployment and technology learning the costs of renewable energy may go down, whereas fossil fuels have become more expensive because of geopolitical developments influencing security of supply and thus energy prices. Additionally, we see fluctuations in conventional energy prices because of market effects (demand versus supply). This section focuses on renewable energy costs and conventional energy prices.

In order to calculate the levelized cost of energy (LCoE) for renewables we present renewable technology investment costs based on literature, an approach to estimate the weighted average cost of capital (WACC) and then the resulting LCoE values. Finally, EU (weighted) average prices for electricity and gas are presented for households and non-households, including their breakdown in price components. These complete the picture of competitiveness: renewable energy costs in the first sections versus actual energy prices in the closing section.

Investment cost data for Europe

INVESTMENT COSTS

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

Challenging macroeconomic circumstances in the years 2021 and 2022 made it difficult to generalise the situation to a continuing cost reduction or, on the opposite, a cost increase.

Due to the rise of this uncertain situation, the previous EurObserv'ER Barometer (Edition 2022) accepted the methodology to keep the investment cost estimates similar as the year before. As a result, the 2021 estimates in that Barometer assumed the same costs as reported in the previous Barometer for 2020. In the current Barometer we'll base the investment cost estimate on a range from literature, with 2023 as a reference year. Source is JRC (2018).

In the IRENA (2023) report 'Renewable power generation costs in 2022' renewable costs have been assessed and cost reductions from 2021 to 2022 were found for most technologies (utility scale solar PV, onshore wind, bioenergy power and geothermal power). The report found two technologies where investment costs increased: offshore wind and hydropower.

For utility scale solar PV investment costs IRENA recorded a decline of 4% from 2021 to 2022, but at the same time it stresses that there is not a consistent trend across all markets. Some markets (France, Germany, Greece) showed strong cost increases, which is partly a result of the variation in observed costs as projects always differ. Furthermore, to a large extent this is a result of material and labour cost inflation. And in other markets investment costs came down, together resulting in the above-mentioned decline.

For residential solar PV the investment costs haven't been assessed, so no trends can be deduced. However, as the cost components for residential PV are similar to the components of utility scale solar PV, a similar trend may be applicable, with some differences in the weight of the various components.

As an illustration of the observed price peak during 2022 we zoom into solar pv module costs. The module is an important component in the total solar PV plant costs. The remaining cost components (inverter, construction, installation, grid connection) play an important role as well, but for these costs no detailed data are available. For modules, we refer to the price index that is being published on a monthly basis by the internet platform pvxchange.com. The data are presented in Figure 1. In the year 2020 the observed module price first dropped from around 250 to 200 €/kWp in summer, to slightly increase towards the end of the year. During 2021 and 2022 prices increased linearly to a maximum value of nominal 350 €/kWp (around 300 €/kWp real) in October 2022. After this price peak at the end of 2022 prices regained a strong downward trend, which still holds throughout December 2023. It can be concluded that in the second half of 2023 the module prices have left the price peak behind and the downward trend from the first semester of 2020 is picked up again.

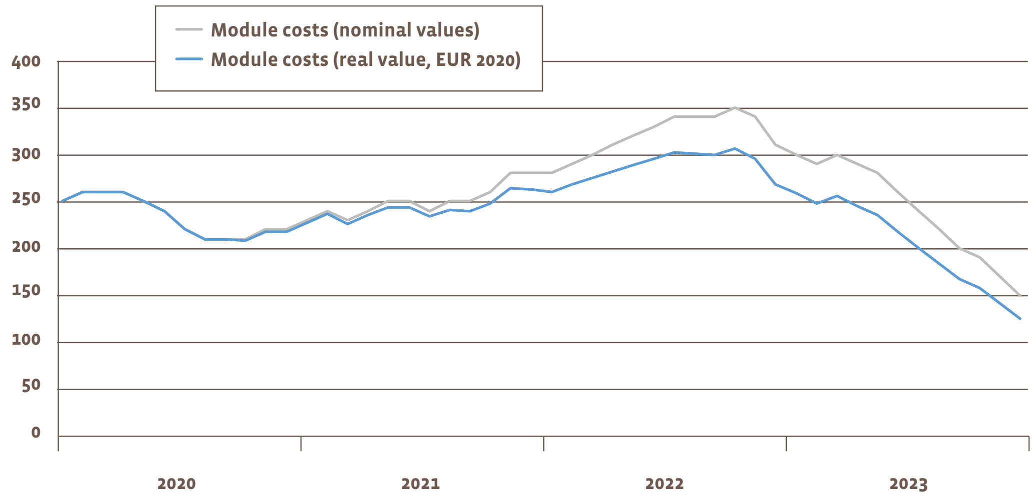
This effect is illustrative in understanding technology markets, but it cannot easily be translated to other cost components of solar PV installations, let alone to other technologies such as wind power or bioenergy. But it may be assumed that the driving factors such as increased worldwide material and labour costs also have occurred in the markets of other sectors. For bioenergy, IRENA sees an investment cost reduction, which is mainly a result of low-cost plants in Brazil and China. IRENA reports an investment cost increase from 2021 to 2022 for offshore wind of 13%, which could be a result of the relatively high construction, material and energy costs during 2022. For onshore wind there is an investment cost reduction of 10%, which is mainly driven by developments in China.

In the investment cost approach based on the data from JRC (2015) data ranges are defined, which are fed into a Monte Carlo analysis (more info in the section on the levelized cost of energy). We performed an analysis in which the new 2022 estimates from IRENA were compared to the extrapolated JRC investment cost estimates, and we found that the ranges used in our approach fully enclose the four IRENA estimates discussed above, except for onshore wind power. However, as the cost reduction for onshore wind power is mainly a result of cost decreases observed in China, we think that the JRC data ranges are still applicable and can be used for the purpose of the EurObserv'ER analysis. In the analysis in the current section we opt for investment costs that are projected for the year 2023, based on JRC (2018). This in order to avoid any confusion regarding the year 2022 in which the developments are difficult to generalize. For O&M-costs we equally refer to the data from JRC (2018).

It can be observed from Figure 2 that the data ranges are larger for certain technologies compared to others. Wider ranges occur for the innovative technologies such as offshore wind, for which multiple countries are developing farms. Furthermore, local, national and regional circumstances also influence the project investment cost level. Onshore wind power has a narrow bandwidth, but surely projects will exist that fall outside the depicted range. For solar PV two variants are depicted: large scale commercial PV and residential PV. Economies of scale determine the lower investment costs for large PV project, whereas residen-

1

Monthly price index for mainstream solar pv modules for the period 2020-2023



Source: pvxchange.com both in nominal and real values

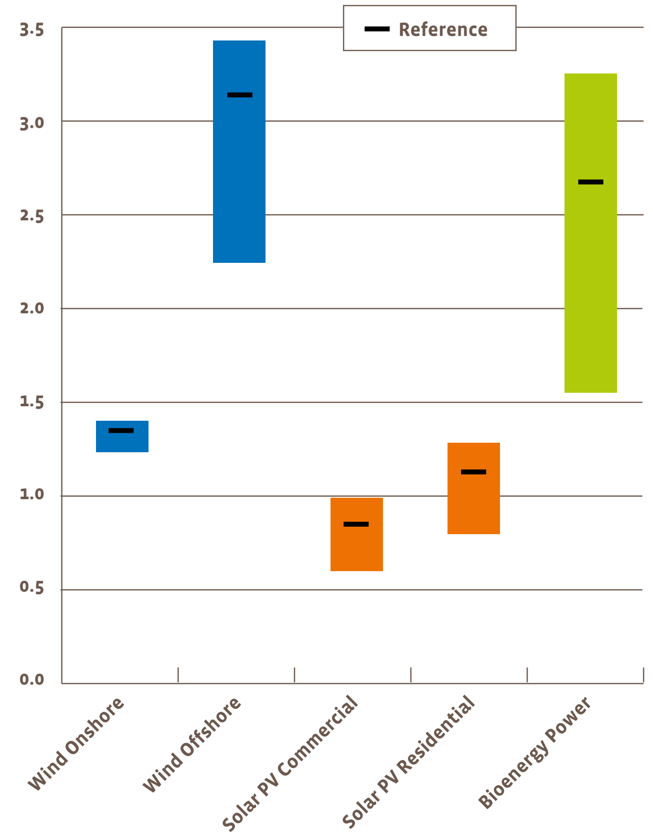
EUROBSERV'ER – THE STATE OF RENEWABLE ENERGIES IN EUROPE – 2023 EDITION

tial PV has, considered over time, seen important investment cost decreases. The ranges in investment costs are relatively narrow for both solar PV categories. For bioenergy power generation a fluidised bed boiler is taken as a reference, which burns biomass feedstock and provides steam to a steam turbine, and for which investment costs vary considerably.

Another parameter that influences the resulting energy generation costs is the way financing is organised. For calculating the levelized cost of energy (LCoE), project financing is assumed. Project financing is a possible way in which renewable energy technologies are set up: a loan from a bank and own funds (equity) are applied to develop the project and start producing renewable energy. The sales of the renewable electricity, heat or bio-based energy carriers generate income that is used to pay back the loan and to give a reasonable financial return to the investors. The conditions against which loans can be obtained differs from country to country, and differs between different technologies. The weighted average cost of capital (WACC) is a parameter that describes this, and it is introduced in the next section. ■

2

Renewable energy investments costs estimated for the year 2023 (M€/MW)



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

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Weighted average cost of capital (WACC)

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

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

Methodology breakdown

We collect data for bottom-up parameters to build the debt and equity components of the cost of capital. The debt interest rate[1], corporate tax rate[2] and the debt share[3] are 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. 2023. Euro area statistics. Averaged bank lending rates over small and large loans*
2. *PWC. 2023. Worldwide Tax Summaries. https://taxsummaries.pwc.com*
3. *Source: Eindadvies basisbedragen SDE++ 2023, PBL, 2023, https://www.pbl.nl/publicaties/eindadvies-basisbedragen-sde-plus-plus-2023. Debt shares of low, medium and high risk technologies.*
4. *Source: Netherlands Enterprise Agency (RVO), Stimulation of sustainable energy production and climate transition (SDE++).*
5. *Source: Eindadvies basisbedragen SDE++ 2023, PBL, 2023, https://www.pbl.nl/publicaties/eindadvies-basisbedragen-sde-plus-plus-2023. Cost of equity of low, medium and high risk technologies.*
6. *Body of European Regulators for Electronic Communications (BEREC), 2023. BEREC Report on WACC parameter calculations according to the European Commission's WACC Notice of 6th November 2019 (WACC parameters report 2023). European Commission. Risk free rates for all EU27 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 a medium risk (e.g. hydropower, solar thermal) are well developed but can be deployed to a limited extent or only on a small scale, making project risks higher. For offshore wind, no financing parameters are set within the SDE++. As indicated below, the risk of offshore wind is considered to be low to medium, but on reflection we assume medium rather than low risk for this technology. This is because larger and more technologically innovative wind turbines are installed offshore in comparison to onshore. More innovative turbines entail greater risks, and the marine environment increases the risk of failure. The higher the risks, the higher the required return, and this is reflected in our cost of equity calculations for offshore wind.

1

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

	Wind onshore	Solar PV	Wind offshore	Hydropower	Bioenergy and other technologies
Technology risk	Low	Low	Average	Average	High
Cost of equity	8%	8%	9%	10%	11.5%
Debt to equity ratio					
minimum	*70/30*	*75/25*	*65/35*	*60/40*	*50/50*
average	*80/20*	*85/15*	*75/25*	*70/30*	*60/40*
maximum	*90/10*	*95/5*	*85/15*	*80/20*	*70/30*

Source: EurObserv'ER

DISCUSSION ON 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

The level and volatility of interest rates has increased sharply over the past 12 months. Therefore, the average interest rate over the past 5 years is not representative of the rates at which project developers borrowed in the year 2022. As a result, the cost of equity and cost of debt have also risen sharply in 2022. To reflect these changing financial market conditions, the WACC values shown in this report are calculated using the most current data available. The methodology uses consistent data and calculations, and provides a more up-to-date, representative overview of the WACC for the EU27 Member States.

The return on equity has increased due to higher return expectations of equity investors, and an increase in the risk-free rate. The return on equity for medium-risk projects is now 10 percent. From 2022, this includes the technology categories of CCU and industrial heat pump due to higher deployment rates and experience with these technologies. For technology categories with higher operational risk or policy risk, the return on equity is unchanged at 11.5 percent. This is consistent with the calculations from previous years where no adjustment for changes in the risk-free rate has been applied. This is because there is a strong dependence on third parties and at the same time a scarcity of supply, such as in the procurement of raw materials like biomass. Innovative technologies such as the CO2-reducing categories of waste heat, hydrogen via electrolysis and CCS face higher risks because deployment of these technologies is not yet at scale.

In contrast, wind energy and solar PV technologies are more advanced than other technologies and deployed on a larger scale. They can be considered mainstream technologies, where operational and policy risks are significantly lower than for the other technologies. This is evidenced in part by the availability of guarantees that are issued by technology suppliers for wind energy and solar PV. Returns on equity for solar PV and wind energy increased to 8 and 9 percent, respectively. The return for wind offshore is somewhat higher than for solar PV because of the higher mark-up for preparation costs of wind offshore projects that are not included in the cash flows generated. Over the past year, due to rising interest rates project developers have had to pay higher interest and loan repayments and can no longer meet the Debt Service Coverage Ratio (DSCR) requirements of banks. To address this, project developers have been trying to extend loan terms to e.g. 20 years. Some developers realise the benefit of higher electricity prices for the first few years after project realisation and only then allow the SDE++ decision to take effect. Nevertheless, for new solar PV projects, a debt to equity ratio of 90 percent to 10 percent is typically no longer feasible. Developers have been forced to bring in more equity and leverage has been adjusted to 85 percent debt. For the other technology categories that have been financed with a smaller proportion of debt, the current debt-equity ratio is adequate and has not been changed.

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

The financing conditions are most favourable for onshore wind and solar PV in western European Member States, such as 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 Eastern European Member States, in particular in Greece, Poland and Romania, and especially for technologies that are considered riskier to deploy. In conclusion, the final WACC values have increased across all technologies and Member States in 2023. The cost of equity and the cost of debt have risen. This effect can be explained mainly by the fact that central banks have increased their base interest rates to dampen inflationary pressures, and commercial debt interest rates have followed. Furthermore, return expectations of equity providers have risen sharply, and thus the cost of equity for project developers has increased. 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. ■

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	Average estimate	High estimate	Low estimate	Average estimate	High estimate	Low estimate	Average estimate	High estimate	Low estimate	Average estimate	High estimate	Low estimate	Average estimate	High estimate
Austria	4.2%	4.6%	5.1%	NA	NA	NA	4.0%	4.4%	4.8%	5.0%	5.7%	6.3%	6.1%	6.9%	7.7%
Belgium	4.4%	4.8%	5.3%	4.8%	5.3%	5.8%	4.2%	4.6%	5.0%	5.2%	5.9%	6.5%	6.3%	7.1%	7.9%
Bulgaria	5.5%	5.8%	6.2%	NA	NA	NA	5.3%	5.7%	6.0%	6.2%	6.8%	7.3%	7.2%	7.9%	8.6%
Croatia	4.5%	5.1%	5.6%	NA	NA	NA	4.3%	4.8%	5.3%	5.5%	6.2%	6.9%	6.6%	7.5%	8.4%
Cyprus	5.3%	5.7%	6.2%	NA	NA	NA	5.1%	5.5%	5.9%	6.1%	6.8%	7.4%	7.2%	8.0%	8.8%
Czech Republic	5.2%	5.7%	6.3%	NA	NA	NA	4.9%	5.5%	6.0%	6.1%	6.9%	7.6%	7.3%	8.2%	9.1%
Denmark	4.4%	4.8%	5.2%	4.8%	5.3%	5.8%	4.2%	4.6%	5.0%	5.2%	5.8%	6.4%	6.3%	7.0%	7.8%
Estonia	5.3%	5.7%	6.0%	NA	NA	NA	5.1%	5.5%	5.9%	6.1%	6.6%	7.2%	7.1%	7.8%	8.5%
Finland	4.7%	5.1%	5.5%	5.0%	5.5%	6.0%	4.5%	4.9%	5.3%	5.5%	6.1%	6.6%	6.5%	7.2%	8.0%
France	3.9%	4.4%	4.9%	4.3%	4.9%	5.5%	3.7%	4.2%	4.6%	4.8%	5.5%	6.2%	5.9%	6.8%	7.6%
Germany	4.0%	4.5%	4.9%	4.4%	4.9%	5.4%	3.8%	4.2%	4.7%	4.9%	5.5%	6.1%	5.9%	6.7%	7.5%
Greece	5.2%	5.8%	6.3%	NA	NA	NA	5.0%	5.5%	6.1%	6.2%	6.9%	7.7%	7.4%	8.3%	9.2%
Hungary	5.9%	6.5%	7.2%	NA	NA	NA	5.6%	6.2%	6.8%	6.9%	7.8%	8.6%	8.2%	9.2%	10.2%
Ireland	5.3%	5.6%	6.0%	5.6%	6.1%	6.5%	5.1%	5.5%	5.8%	6.0%	6.6%	7.1%	7.0%	7.7%	8.4%
Italy	4.6%	5.2%	5.8%	5.1%	5.7%	6.4%	4.3%	4.9%	5.5%	5.6%	6.4%	7.1%	6.8%	7.7%	8.6%
Latvia	5.3%	5.6%	6.0%	NA	NA	NA	5.1%	5.4%	5.8%	6.0%	6.6%	7.1%	7.0%	7.7%	8.5%
Lithuania	5.7%	6.0%	6.3%	NA	NA	NA	5.6%	5.9%	6.1%	6.4%	6.9%	7.3%	7.3%	7.9%	8.5%
Luxembourg	3.3%	3.9%	4.4%	NA	NA	NA	3.1%	3.6%	4.1%	4.3%	5.0%	5.7%	5.4%	6.3%	7.2%
Malta	3.0%	3.7%	4.3%	NA	NA	NA	2.7%	3.4%	4.0%	4.1%	4.9%	5.8%	5.4%	6.4%	7.4%
Netherlands	3.7%	4.2%	4.7%	4.1%	4.7%	5.2%	3.5%	3.9%	4.4%	4.6%	5.3%	5.9%	5.7%	6.5%	7.4%
Poland	5.3%	5.9%	6.5%	NA	NA	NA	5.0%	5.6%	6.2%	6.3%	7.1%	7.9%	7.6%	8.5%	9.5%
Portugal	5.0%	5.4%	5.9%	5.4%	5.9%	6.4%	4.8%	5.2%	5.6%	5.8%	6.5%	7.1%	6.9%	7.7%	8.5%
Romania	5.2%	6.0%	6.9%	NA	NA	NA	4.8%	5.6%	6.5%	6.4%	7.5%	8.5%	7.9%	9.1%	10.3%
Slovakia	4.9%	5.3%	5.7%	NA	NA	NA	4.7%	5.1%	5.5%	5.7%	6.3%	6.9%	6.8%	7.5%	8.2%
Slovenia	4.7%	5.1%	5.5%	NA	NA	NA	4.4%	4.9%	5.3%	5.5%	6.1%	6.7%	6.5%	7.3%	8.1%
Spain	4.2%	4.7%	5.2%	4.6%	5.2%	5.8%	4.0%	4.5%	5.0%	5.1%	5.8%	6.5%	6.3%	7.1%	8.0%
Sweden	4.6%	5.0%	5.4%	5.0%	5.5%	6.0%	4.4%	4.8%	5.2%	5.4%	6.0%	6.6%	6.5%	7.2%	8.0%

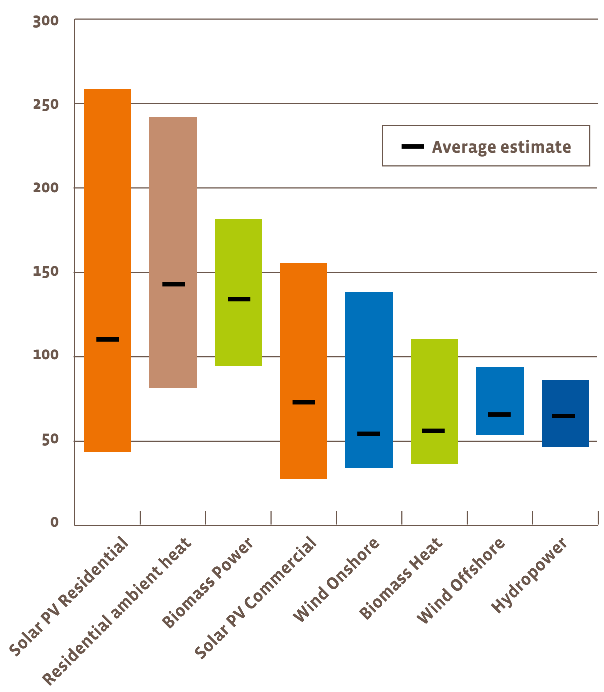
Other technologies include geothermal, biogas and solid biomass.* ***Source: EurObserv'ER

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 cost ranges and WACC estimates presented in the previous sections. In addition to the WACC estimates and the investment costs, the renewable energy technology LCoE analysis requires a significant amount of data and assumptions on operational expenditures, fuel costs (for biomass technologies), economic life, 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 2014 and 2018), fuel price assumptions were borrowed from (Elbersen et al, 2016) and interpolated from modelled data. Due attention is paid to the monetary year of the cost data: the LCoE is expressed in euro's of 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 investment costs, but higher electricity production, hence lower values for the LCoE.
The technologies addressed are: residential ambient heat from heat pumps (an average of ground source, air source and water source heat pumps), bioenergy (power and heat derived from solid biomass), hydropower, solar photovoltaics (PV, commercial and residential), and wind energy (both onshore and offshore). The data ranges for the calculated levelised cost of renewable energy for the European Union are depicted in Figure 1. The technologies generating renewable electricity are solar PV, biomass and wind power and hydropower. Heat generating technologies are biomass heat and ambient heat. Note that the auxiliary electricity used for heat pumps has been kept unaltered from the assumptions in earlier barometers in order to make the LCoE's better comparable. The same holds for the biomass prices. This means that the changes in LCoE are driven by two effects: technology progress resulting in investment cost changes and macro-economic changes resulting is updated WACC values.

1

Levelised cost of energy in the European Union (EUR/MWh)



Note: based on investment cost estimates for 2023 and WACC data for 2023.
Source: EurObserv'ER

Changes in investment cost estimates and updated WACC values have two effects: lower investment costs result in lower LCoE outcomes, whereas higher WACC estimates increase the LCoE outcomes. Both opposite effects have a combined effect on the LCoE estimates and this results in some values to increase, while others decrease. When the new estimates for the investment costs are declining sharply (for all technologies less than 5%) this also pulls down LCoE values (this is the case for the new average estimates for solar PV residential, residential ambient heat and biomass power), while moderate investment reductions cannot outweigh higher investment costs (valid for solar PV commercial, wind onshore, biomass heat, wind offshore and hydropower). In relative terms, the resulting LCoE values deviate up to plus or minus 10%.

RENEWABLE ELECTRICITY

Over the past few years, the LCoE from solar PV has continued to decrease, which has been demonstrated in previous versions of 'The State of Renewable Energies in Europe'. In the updated data (see Figure 1) residential solar pv shows lower LCoE values, while commercial solar pv an increase is found. Solar PV in the residential sector is small in system size (it should fit on rooftops) and therefore is relatively expensive. There are less benefits from economies of scale for modules and inverters, and in relative terms, more labour is involved to install the PV system. Although all cost components in a PV system have seen significant cost reductions over the past decades, it remains the most expensive renewable technology, although that varies strongly from country to country. The average estimated cost level is 110 EUR/MWh for residential solar PV and 72 EUR/MWh for commercial solar PV. From the calculations it follows that bioenergy power generation is roughly between 95 and 181 EUR/MWh across Europe. The average costs for onshore wind power are lower than for commercial PV, with a comparable cost bandwidth. It is clear that Denmark is the country with the lowest costs of electricity for onshore wind. Offshore wind has a smaller range because not all 27 Member States have projects in place. Hydropower traditionally has been a cost competitive technology for many years in many countries. As it is capital intensive, the higher WACC rates result in increased values for the LCoE. but due to the usually high number of running hours, the produced electricity can in our estimates be found between 48 and 87 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 show aggregate values for the European Union (EU27) as a whole.

RENEWABLE HEAT

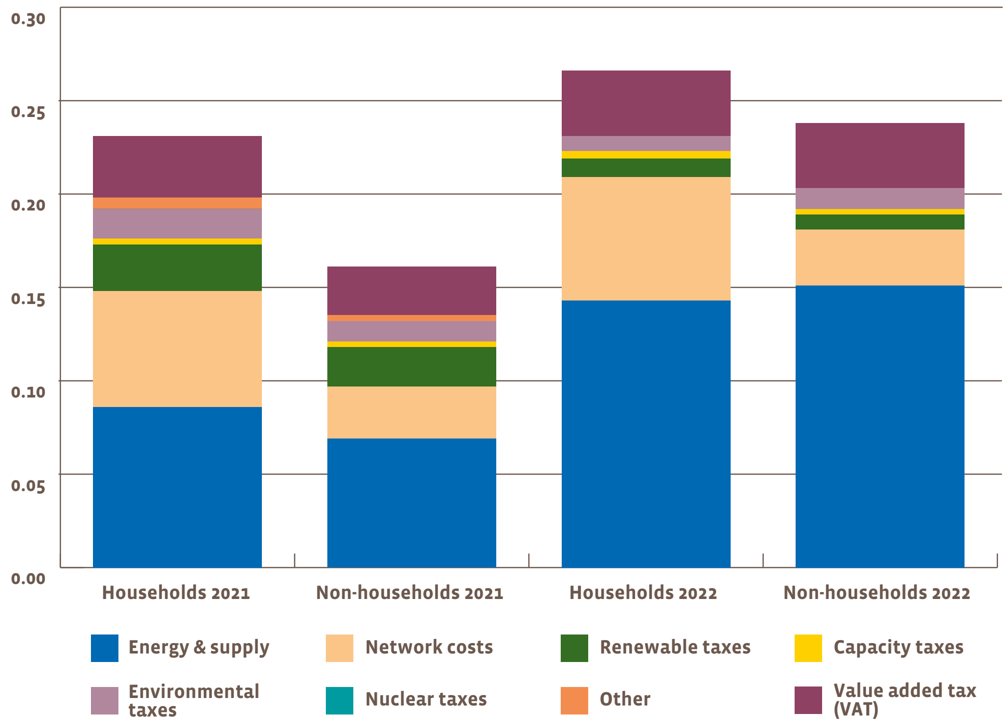
For the technologies producing heat, bioenergy heat LCoE is relatively low, indicating it is competitive in many countries. According to the analysis, heat captured from ambient heat via heat pumps (through small-scale equipment) shows relatively high LCoE levels. Scaling up to collective systems, possibly in combination with district heating, may decrease the costs further. ■

Prices of energy

For the European Union Member States the prices for electricity and natural gas are monitored by Eurostat. These prices are listed in Figures 1 and 2 here for the years 2021 and 2022. Geopolitical developments, notably the Russian invasion of Ukraine and consequently the reduction of energy imports from Russia, have influenced the energy markets in 2022 and prices for natural gas increased strongly. 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. During 2022 several countries introduced policy measures to alleviate the impact of increased energy prices, mostly for households. On average across the European Union Member States the natural gas supply costs for households nearly doubled (+95%) but as tax reductions and energy subsidies were introduced the overall effect in household natural gas prices was an increase of 40%. Average prices for electricity in households increased similarly (+67% on electricity supply costs) but price compensation measures were mostly implemented on the electricity bill, resulting in an EU-average electricity price of +13%. Of course in individual countries the effect may have been more (or less) pronounced. For non-household energy carriers the price increase effect was more important: +141% for natural gas supply costs, resulting in +101% higher natural gas prices at the customer. For electricity the effect on supply costs for non-households was +120%, resulting in a +47% price increase on customer prices..

1

Weighted average electricity prices observed in the European Member States in 2021 and 2022 (€/kWh)



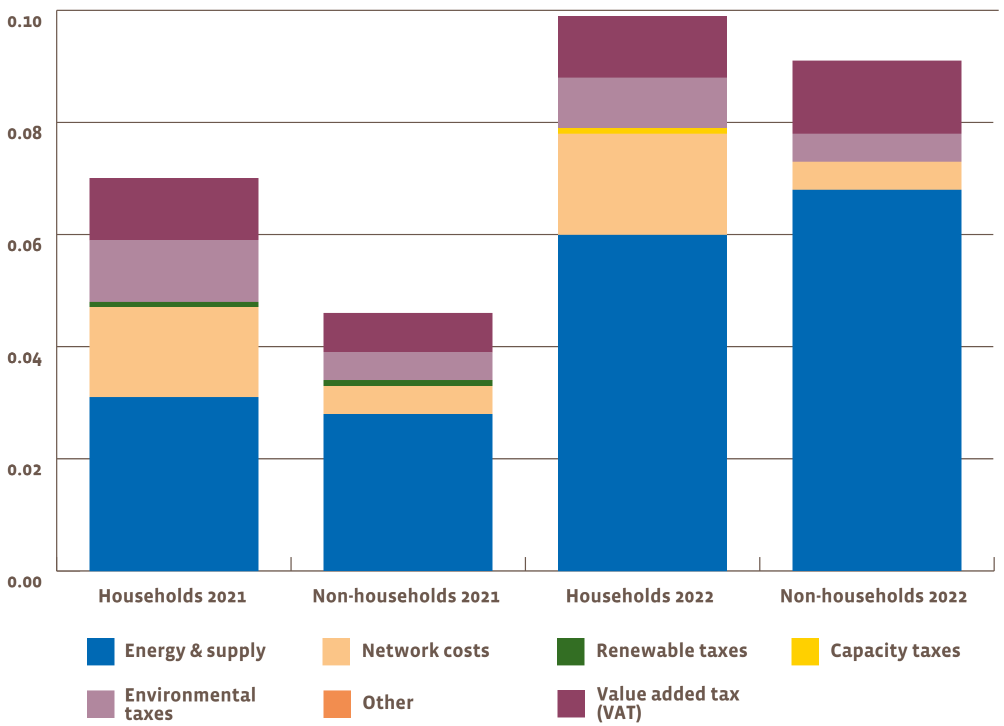
Note: the electricity price components [EUR/kWh] are based of an average of all electricity consumption bands. ***Source: Eurostat***

MULTIPLE COMPONENTS IN ENERGY PRICES

For both electricity and natural gas, several price add-ons are imposed on the energy price. Costs related to the network are imposed by the transmission and distribution companies, and represent the upkeep costs for delivering electricity and natural gas to consumers. Taxes, fees, charges and levies are charged by the authorities, which can have different purposes. For example, renewable taxes are imposed on consumers to acquire funds to be redistributed among developers of renewable energy in the form of subsidies. Environmental taxes are usually policy 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. 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 natural gas prices observed in the European Member States in 2021 and 2022 are depicted in Figure 1 and Figure 2 respectively. ■

2

- Weighted average natural gas prices observed in the European Member States in 2021 and 2022 (€/kWh)



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

AVOIDED FOSSIL FUEL USE AND RESULTING AVOIDED COSTS AND GHG EMISSIONS

MORE RENEWABLE ENERGY MEANS LESS FOSSIL FUELS AND ASSOCIATED COSTS

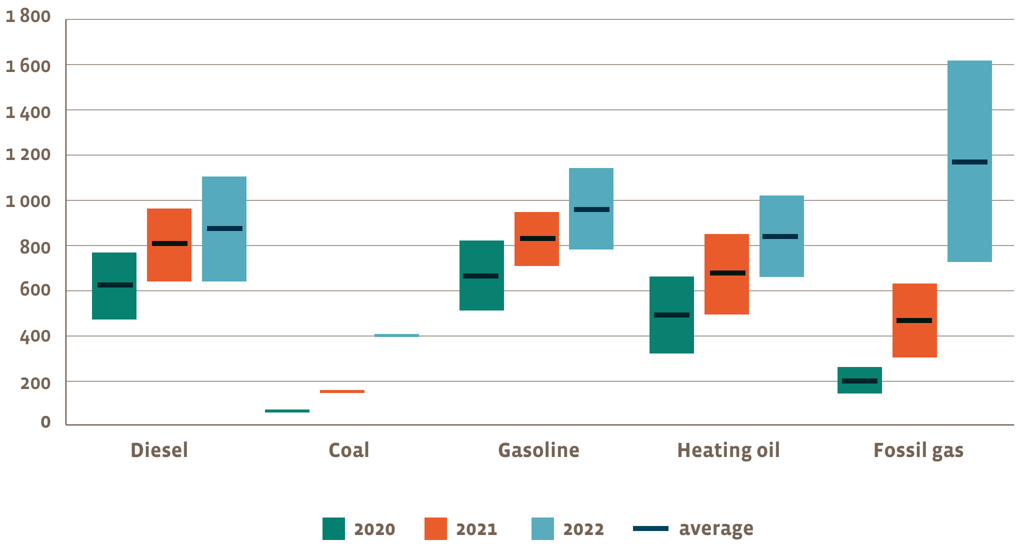
Progress achieved in EU-wide renewable energy deployment since 2005 is largely attributed to the presence of mandatory national targets for 2020, first set under the Renewable Energy Directive, or RED (Directive 2009/28/EC) which has been recast under the 'Clean Energy for all Europeans' package: REDII (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 did set a binding EU-wide target of 32 % RES in gross final energy consumption. Member States had to propose an indicative level of effort contributing to the EU binding target for renewables in their first NECPs[1], due by the end of 2019. However, mid 2021 the European Commission adopted the 'fit for 55' package, which adapts existing climate and energy legislation to meet the new EU objective of a minimum 55% reduction in greenhouse gas (GHG) emissions by 2030. A key element in the 'fit for 55' package is the revision of the Renewable Energy Directive (RED II) and sets a new EU target of a minimum 40 % share of RES in final energy consumption by 2030, accompanied by new sectoral targets. As part of the REPowerEU plan (May 2022), the Commission proposed to further raise this RES target to a 45 % share by 2030. After Trilogue negotiations between the Parliament, the Council and the Commission during 2023, the revised Directive EU/2023/2413 ente-

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

red into force on 18 October 2023. The next 18-month period most of the directive's provisions will be transposed into national law, with a shorter deadline of July 2024 for some provisions related to permitting for renewables. It sets an overall renewable energy target of at least 42.5% binding at EU level by 2030 - but aiming for 45% and aiming for innovative renewable energy technology of at least 5 % of newly installed renewable energy capacity by 2030.

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

The amount of avoided fossil fuels is annually analysed by the European Environment Agency (*'Renewable energy in Europe 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). The figure below highlights the fuel price ranges observed in the 27 EU Member States for 2020, 2021 and 2022 for five energy carriers: coal, diesel, gasoline, natural gas and oil. Prices for coal refer to wholesale prices. For coal no country specific prices are available from the consulted sources and therefore the European price has been taken. Wholesale prices for gas are not available in a continuous timeseries and therefore approximated by prices for band I5[2] for non-household consumers. For transport and heating fuels wholesale prices aren't available, therefore end-user prices are applied as a proxy. These five fuels are assumed to reasonably cover the fuels reported in (EEA, 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.

Looking at the individual energy carriers and their ratios, it can be seen that all fossil fuel end user prices in 2021 increased significantly due to the economic recovery after the COVID-crisis of 2020. This has tightened commodity markets and put upward pressure on prices across the board. In 2022 prices were pushed even further upward by the Russian invasion in Ukraine. 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 since 2021[3].

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

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

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Methodological note

- *The focus of the analysis is on the national level, quantifying the avoided costs in the case where all fossil energy carriers are being purchased abroad. As a consequence, all fuel prices considered exclude taxes and levies. Moreover, we do not differentiate caloric values of the fuels to their origin or quality.*
- *For countries producing their own fossil fuels the analysis is similar and no correction is made for the indigenous resources.*
- *The reference is the year 2005. Since progress achieved in EU-wide renewable energy deployment since 2005 is largely attributed to the presence of mandatory national targets for 2020 and for 2030. This is in line with the progress reported by the European Environment Agency (EEA 2023).*
- *The avoided costs through the substitution of natural gas by synthetic natural gas (SNG) is not quantified explicitly.*
- *Only the impact on fossil fuel displacement is being addressed: in the electricity mix nuclear energy is not considered.*
- *Pricing non-renewable waste is not straightforward; therefore, this impact is not quantified in monetary terms.*
- *For liquid biofuels only the biofuels compliant with the Directive 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 based on the type of fuel used to produce electricity in each country, on an annual basis. For this the next technologies/fuels are excluded: nuclear (usually operated as must-run capacity); renewable electricity generation (currently it is unlikely that renewable energy plants are to be displaced by new renewable capacity); blast furnace gas (considered a residue that can be utilised or flared). All other technologies and fuels are included*
  - *For RES-H/C, country-specific emission factors for heat (EFh) are calculated similarly to the approach applied to determine the reference values for the initial energy carrier electricity, so as to reflect the differences in the fuel mix between Member States.*
  - *For RES-T, the assumption is straightforward that renewable transport fuels (essentially biodiesel and bioethanol) replace the conventional transport fuels petrol and diesel on a one-to-one basis, according to their specific energy content.*
- *In the absence of specific information on current bioenergy systems, 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).*

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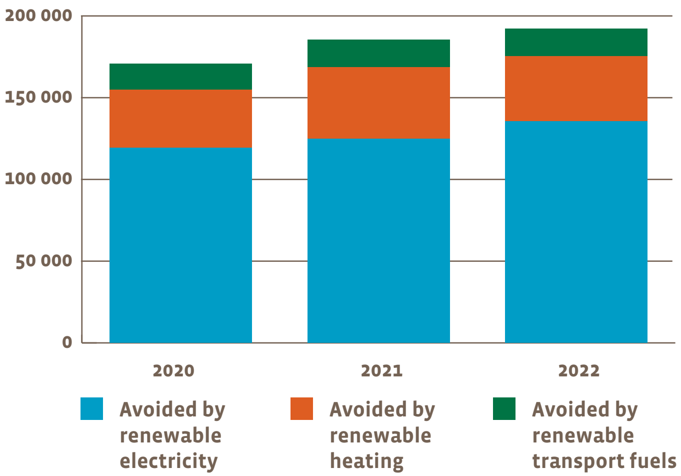
1. *RES-E: Renewable electricity; RES-H/C: Renewable heating and cooling; RES-T: Renewable energy consumed in transport*
2. *Renewable energy in Europe —approximated recent growth and knock-on effects, EEA Technical report No 1/2015, Renewable energy in Europe - Approximated recent growth and knock-on effects — European Environment Agency (europa.eu)*

In 2022 and 2021 the use of renewable energy substituted respectively around 192 Mtoe and 185 Mtoe of fossil fuels, compared to the level of use of renewable energy in 2005. These figures correspond to an avoided annual cost of €74 billion for EU27 collectively in 2021, increasing to €220 billion in 2022. In 2021 the largest financial contributions derive from renewable electricity and renewable heat at approximately equal contributions together representing about 91% of the avoided expenses. For 2022 the picture is similar.

2

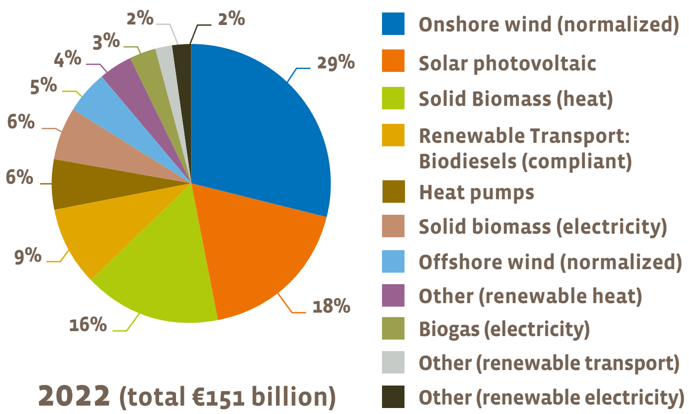
EU27 avoided fossils fuels per sector (ktoe)



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

3

EU27 avoided expenses through renewables



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

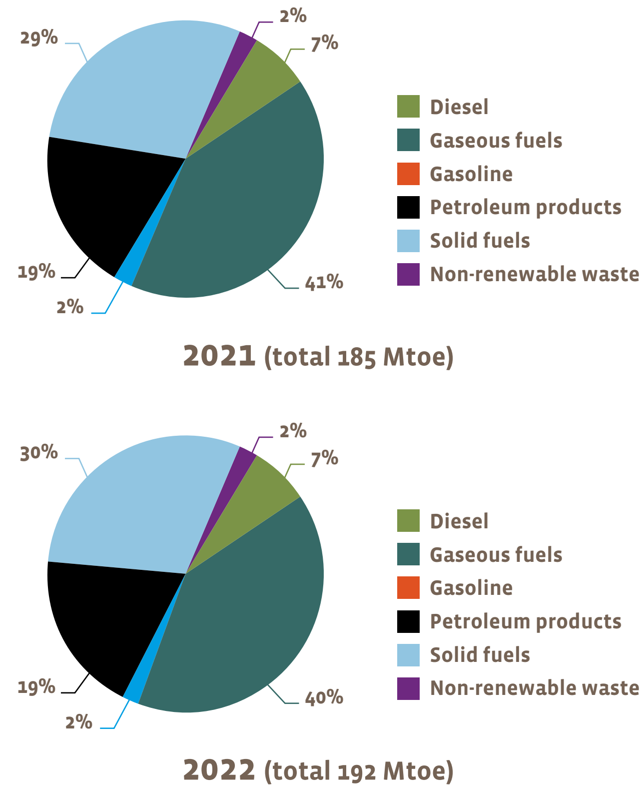
AVOIDED FOSSIL FUEL USE & AVOIDED COSTS PER TECHNOLOGY

The use of renewable electricity contributed to 70% of the total avoided fossil fuels in 2022 (in terms of energy). This is followed by renewables in the heating and cooling sector contributing to 21% 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 40.3 billion in 2021 and EUR 95.1 billion in 2022 in the electricity sector. Second, renewable heat contributed to avoided costs reaching to EUR 20.6 billion in 2021 while in 2022 this increased to EUR 39.1 billion. Third is renewable transport which contributed to avoided costs of EUR 13.1 billion in 2021 and EUR 16.9 billion in 2022. For correctly interpreting these results it is important to take into account a number of methodological notes, see the text box in the beginning of this chapter. While the penetration of renewable energy (expressed in avoided fossil fuels) expanded by approximately 4% from 2021 to 2022, the effect of the avoided fossil fuel expenses is, with a 204% increase (from EUR 74 billion to EUR 151 billion) tremendously more pronounced than the growth in renewable energy. Reason for this is the strong increase in fossil fuel prices in 2022 compared to 2021.

Among the RES technologies, onshore wind avoided the purchase of fossil fuels at an amount of EUR 44.3 billion in 2022 (EUR 19.6 billion in 2021, both for normalised production) compared to the level in 2005.

4

EU27 substituted fossil fuels during 2021 and 2022



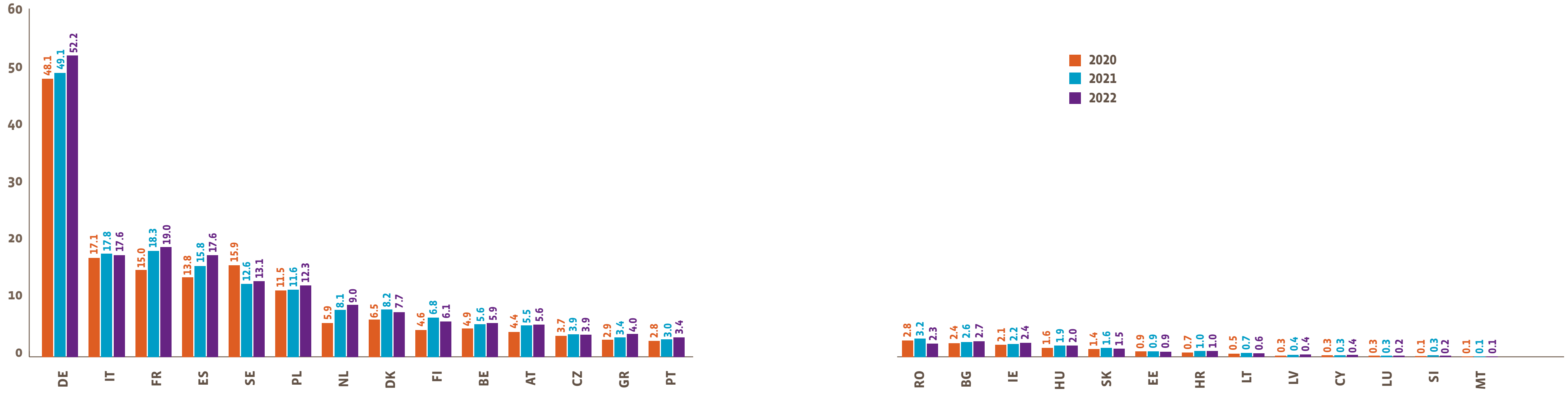
Note : reference year 2005. ***Source: EurObserv'ER based on EEA data.***

Next solar photovoltaic has been responsible for EUR 44.2 billion in 2022 (EUR 13.5 billion in 2021). Solid biomass for heat purposes is third in the row with EUR 28.5 billion in 2022 (EUR 14.3 billion in 2021).
The pie chart shows how each technology contributes to the total avoided expenses in 2022.

The largest share of avoided fossil fuels comes from natural gas (respectively 41% and 40% in 2021 and 2022), followed by solid fuels (mainly coal, respectively 29% and 30% for 2021 and 2022). Next are oil products, with a contribution of respectively 19% in both 2021 and 2022. The remaining fuels (transport fuels and non-renewable waste) cover the remaining share (11% in 2021 and in 2022).

5

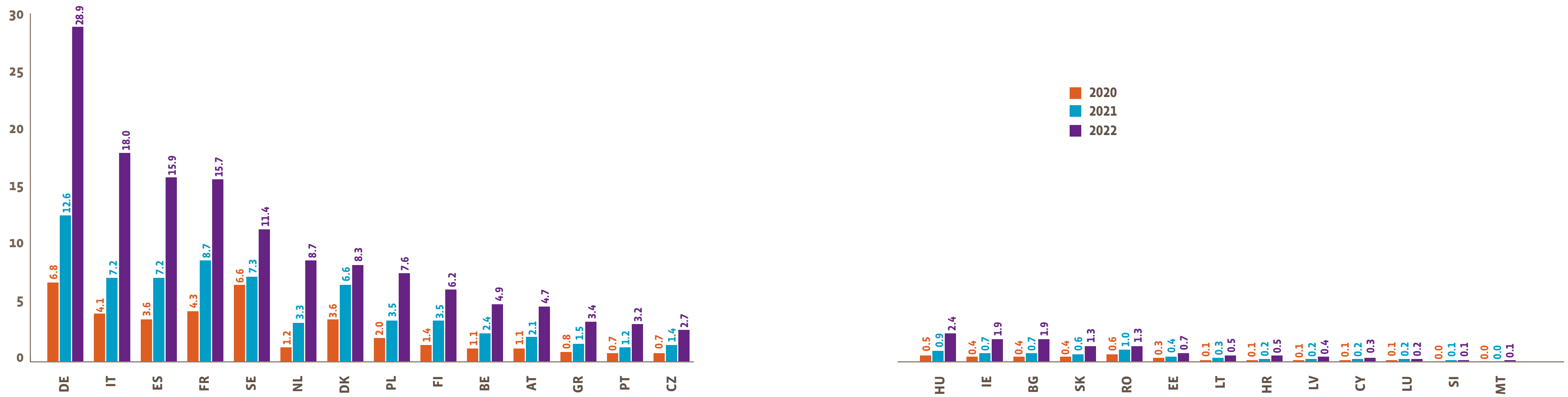
Avoided fossil fuels per country (Mtoe)



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

6

Avoided expenses per country (€ billion)



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

AVOIDED FOSSIL FUELS & EXPENSES PER MEMBER STATE

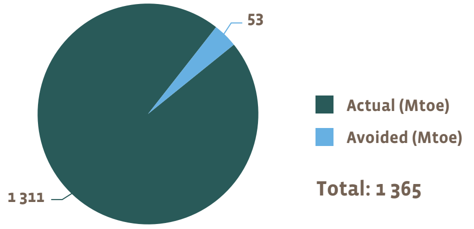
At Member State level, the amount of avoided fossil fuels and the avoided costs have been estimated as described in the methodological notes. Note that there is a strong correlation between the avoided amount and the size of a country. As can be expected, the avoided cost follows the fuel price development with fossil fuel prices higher in 2022 compared to 2021.
It can be observed from the results that countries with higher avoided fossil fuels figures not necessarily end up with higher avoided expenses, which is because these countries usually show a relatively lower growth in biogenic transport fuels which displace expensive fossil fuels, such as diesel and gasoline.

The data have been displayed graphically in the figures 6 and 7.

Next, the figures 8 and 9 indicate how the amounts of estimated avoided fuel due to increased RES consumption since 2005 relate to the total EU27 primary energy consumption. The relevant parameter for comparing the avoided fuel use with is the primary energy consumption, which indicates the gross inland consumption excluding all non-energy use of energy carriers (e.g. natural gas used not for combustion but for producing chemicals).

7

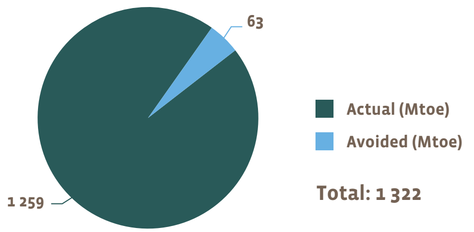
Effect on primary energy consumption (Mtoe) in 2021



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

8

Effect on primary energy consumption (Mtoe) in 2022



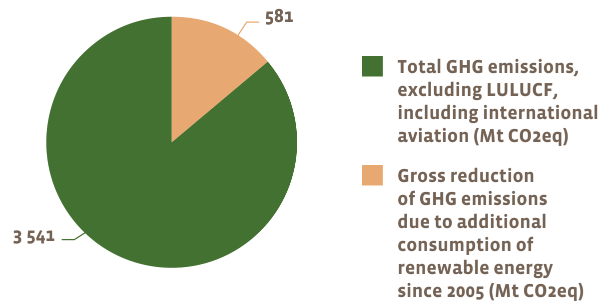
Note: reference year 2005. ***Source: Eurostat, EurObserv'ER based on EEA data.***

AVOIDED GHG EMISSIONS IN EU27 AND PER MEMBER STATE

Finally, the figures 10 to 12 indicate the estimated savings in GHG emissions in 2021 and 2022 due to increased RES consumption since 2005, for the EU as a whole and per Member State.
In 2022, for the EU27 a gross reduction of 604 Mt CO_2eq of GHG emissions has been realised due to the additional consumption of renewable energy. While total EU27 GHG emissions were approximately 3491 Mt CO_2eq in 2022, the additional uptake of renewable energy has led to a gross reduction of GHG emissions of 14.8% 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 581 Mt CO_2eq in 2021 to approximately 604 Mt CO_2eq in 2022.

9

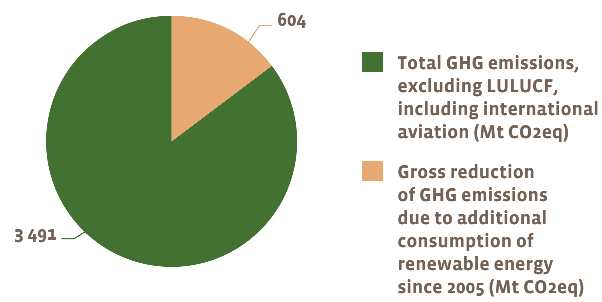
Effect on GHG emissions in EU27 in 2021



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 EU27 in 2022



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

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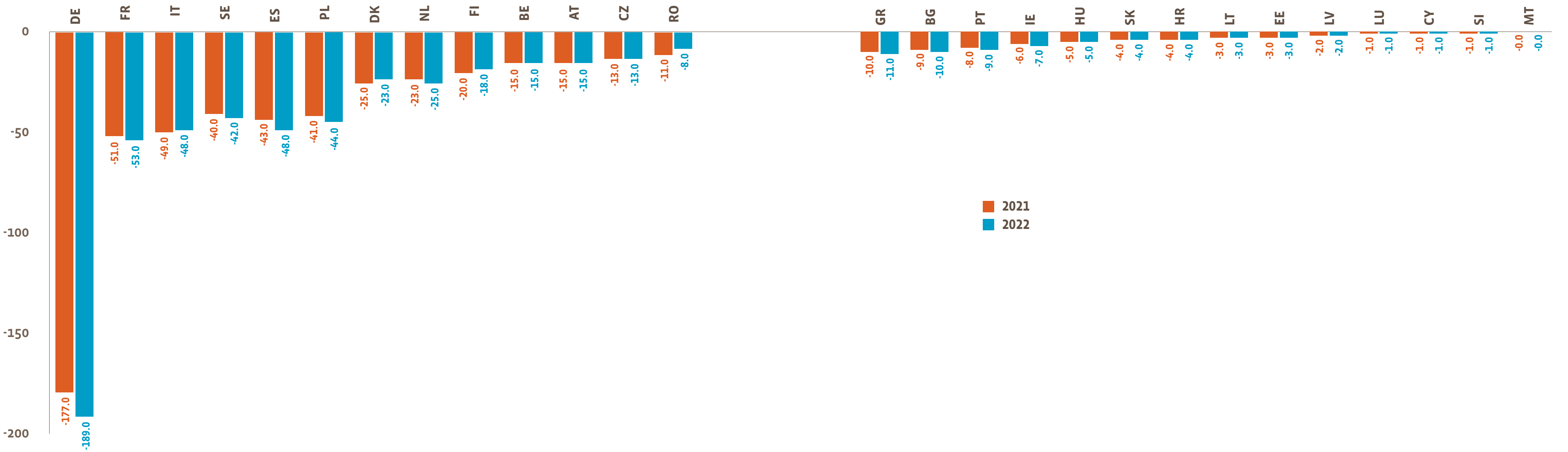
11

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



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

In terms of gross avoided GHG emissions in 2022, the countries with the largest estimated gross reductions were Germany (189 Mt CO_2), France (53 Mt CO_2), Italy and Sweden (48 and 42 Mt CO_2 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.

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R&D Investments

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

Methodological approach

Overall, R&D expenditures are financed by private and public resources, while R&D is performed by both private (business) and public (government and higher education) sectors. This differentiation into financing (gray area) and performing (white area) is depicted in Figure 1. In this section, we will analyze public and private R&D expenditures of a selected set of countries regarding renewable energy technologies, i.e., research investments originating from the public sector (see light gray). For this report, the data on public and private R&D investment were provided by JRC SETIS. Its R&D data rely on IEA statistics, which collects and depicts national R&D investments. They address 20 of the EU Member States with varying regularity and granularity of technology detail. Furthermore, the European Commission has a separate budget for spending on R&D, this is indicated as a separate 'country', which has no correlation with the EU27 totals. However, there is a 2-year time delay in reporting for most Member States, thus data for 2020 is by and large complete, while the data

Sectors by financing and performing of R&D

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

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 area in Figure 1) as well as from the private sector are considered (see dark gray area in Figure 1). R&D investments from the public sector are supposed to boost innovation in the private sector. Although the specific returns to public sector R&D investments are largely unknown, the basic idea is to create follow-up investments from the private sector and generate spill-over effects. For this report, the data on public and private R&D investment were provided by JRC SETIS. Its R&D data rely on IEA statistics.1, which collects and depicts national R&D investments. They address the EU Member States with varying regularity and granularity of technology detail (for public R&D, 19 Member States have data, and data is available with various degrees of regularity for the other indicators (the same holds for private R&D, where all EU Member States have some data: note that private R&D data is only available for EU Member States)). Furthermore, the European Commission has a separate budget for spending on R&D, this is indicated as a separate 'country', which has no correlation with the EU27 totals (when reporting the European Commission's activity relative to GDP, we used the GDP of the EU, which is the sum of the GDPs of its Member States).
There is also some reporting delay that varies per member state. As such, we have chosen the most recent years with the most available data. These years are 2020 and 2021 for public R&D, and 2019 and 2020 for private R&D and patent indicators (note that the data is provisional).
The methodology is described in more detail in the JRC Science for Policy Report "Monitoring R&D in Low Carbon Energy Technologies: Methodology for the R&I indicators in the State of the Energy Union Report, - 2016 Edition".
2 Data gaps are supplemented by the Member States through the SET Plan Steering Group or through targeted data mining.
Besides providing absolute figures for R&D expenditures (Euro) of the given countries, the share of R&D expenditures by GDP (%) is calculated to get an impression of the relative size of a country's investments in RET technologies. For the GDP, we used data from the World Bank.3 (both values in current US$ and average yearly conversion rates from US$ to €).

1. *IEA. International Energy Agency RD&D Online Data Service. Available from: http://www.iea.org/statistics/RDDonlinedataservice/*
2. *A. Fiorini, A. Georgakaki, F. Pasimeni, E. Tzimas, "Monitoring R&I in Low-Carbon Energy Technologies", EUR 28446 EN (2017), doi: 10.2760/447418. Available from: https:// setis.ec.europa.eu/related-jrc-activities/jrc-setis-reports/ monitoring-ri-low-carbon-energy-technologies*
3. *https://data.worldbank.org/ via the API: https://pypi.org/project/wbgapi/ https://blogs.worldbank.org/opendata/introducing-wbgapi-new-python-package-accessing-world-bank-data*

PUBLIC R&D INVESTMENTS

Public R&D investments are split by RE technologies for 2020 and 2021.

PRIVATE R&D INVESTMENTS

Private R&D investments are split by RE technologies for 2019 and 2020 and are only available for EU Member States..

PUBLIC R&D INVESTMENTS
SOLAR ENERGY

		Public R&D Exp. (in € m)		Share of Public R&D Exp. by GDP	
		2020	2021	2020	2021
EU27	Germany	107.98	109.51	0.0032%	0.0030%
	France	80.98	78.79	0.0035%	0.0031%
	Spain	12.74	41.95	0.0011%	0.0034%
	Netherlands	19.68	22.40	0.0025%	0.0026%
	Sweden	9.33	11.90	0.0019%	0.0022%
	Poland	7.32	9.18	0.0014%	0.0016%
	Hungary	0.27	7.27	0.0002%	0.0047%
	Austria	6.47	5.05	0.0017%	0.0012%
	Finland	5.50	4.68	0.0023%	0.0019%
	Denmark	2.07	3.31	0.0007%	0.0010%
	Lithuania	0.44	1.20	0.0009%	0.0021%
	Czechia	1.36	1.07	0.0006%	0.0004%
	Ireland	0.41	0.72	0.0001%	0.0002%
	Belgium	10.35	0.38	0.0022%	0.0001%
	Slovakia	0.24	0.32	0.0003%	0.0003%
	Estonia	0.05	0.30	0.0002%	0.0010%
	Italy	29.59	n.a.	0.0018%	n.a.
	European Union	294.78	298.02	0.0022%	0.0020%
	EU Commission	67.69	118.71	0.0005%	0.0008%
Other Countries	United States	245.50	236.88	0.0013%	0.0012%
	Korea	57.48	64.05	0.0040%	0.0042%
	Switzerland	39.96	38.68	0.0062%	0.0056%
	Canada	19.80	35.91	0.0014%	0.0021%
	United Kingdom	46.31	29.63	0.0020%	0.0011%
	Japan	30.21	27.66	0.0007%	0.0007%
	Australia	13.18	25.80	0.0011%	0.0020%
	Norway	10.33	13.73	0.0032%	0.0033%
	Turkey	4.14	10.71	0.0007%	0.0015%
	New Zealand	0.54	0.44	0.0003%	0.0002%

Source: JRC SETIS, World Bank (WBGAPI)

In the field of solar energy, the largest player in terms of public R&D investment is the EU (as sum of its members). They are followed by the USA, with the investments by the European Commission coming in third place. This holds both for 2020 and 2021. Korea follows, ahead of a group including Switzerland, Canada, the United Kingdom, Japan, and Australia. Within the EU27, the biggest players are Germany and France, followed by Spain. For most countries, the 2020 and 2021 figures are relatively close, with a few exceptions, with Spain, Hungary, Canada, the EU Commission, Canada, and Australia with the biggest increases, and Belgium, and the UK with the biggest decreases.

In terms of public investment relative to GDP, Switzerland comes on top. It is followed by Hungary and Kore in 2021, while the runners-up in 2020 were Korea and France. The relative values to GDP also show that solar is one of the three main public investment sectors. Figures for China as well as some other countries are not available. ■

PUBLIC R&D INVESTMENTS
GEOTHERMAL ENERGY

		Public R&D Exp. (in € m)		Share of Public R&D Exp. by GDP	
		2020	2021	2020	2021
EU27	Germany	16.68	26.24	0.0005%	0.0007%
	France	13.74	10.57	0.0006%	0.0004%
	Netherlands	3.89	4.97	0.0005%	0.0006%
	Ireland	0.39	1.24	0.0001%	0.0003%
	Czechia	0.18	0.81	0.0001%	0.0003%
	Finland	n.a.	0.70	n.a.	0.0003%
	Austria	0.56	0.60	0.0001%	0.0001%
	Poland	0.36	0.58	0.0001%	0.0001%
	Hungary	1.40	0.35	0.0010%	0.0002%
	Spain	0.30	0.33	0.0000%	0.0000%
	Sweden	2.60	0.25	0.0005%	0.0000%
	Belgium	0.41	0.00	0.0001%	0.0000%
	Denmark	n.a.	0.00	n.a.	0.0000%
	Estonia	0.00	0.00	0.0000%	0.0000%
	Italy	6.88	n.a.	0.0004%	n.a.
	Slovakia	0.23	n.a.	0.0002%	n.a.
	European Union	47.63	46.66	0.0004%	0.0003%
	EU Commission	17.49	13.80	0.0001%	0.0001%
Other Countries	United States	96.45	89.68	0.0005%	0.0005%
	Japan	17.41	16.37	0.0004%	0.0004%
	Switzerland	18.53	8.70	0.0029%	0.0013%
	Canada	6.78	4.60	0.0005%	0.0003%
	New Zealand	3.60	3.74	0.0019%	0.0017%
	Korea	1.63	3.28	0.0001%	0.0002%
	Norway	1.79	1.71	0.0006%	0.0004%
	United Kingdom	1.88	1.09	0.0001%	0.0000%
	Turkey	0.00	0.16	0.0000%	0.0000%
	Australia	0.09	0.07	0.0000%	0.0000%

Source: JRC SETIS, World Bank (WBGAPI)

In the field of geothermal energy, the largest player in terms of public R&D investment is the USA. They are followed by the EU (as sum of its members), both for 2020 and 2021. For the third place, the picture changes between 2020 and 2021, with Switzerland coming just ahead of the European Commission and Japan in 2020. For 2020, Germany gets third place, followed by Japan and the European Commission.

For most countries, the 2020 and 2021 figures are relatively close, with a few exceptions, with Germany having the most notable increases, Switzerland (and Sweden and Canada to a lesser extent) with the most notable decrease. In terms of public investment relative to GDP, New Zealand comes ahead of Switzerland and Germany in 2021, while Switzerland was ahead of New Zealand and Hungary in 2020. The relative values to GDP also show that geothermal is a minor public investment sector. Figures for China as well as some other countries are not available. ■

PUBLIC R&D INVESTMENTS

HYDRO ENERGY

		Public R&D Exp. (in € m)		Share of Public R&D Exp. by GDP	
		2020	2021	2020	2021
EU27	France	3.53	3.70	0.0002%	0.0001%
	Sweden	2.47	3.68	0.0005%	0.0007%
	Austria	3.40	2.50	0.0009%	0.0006%
	Spain	0.44	2.36	0.0000%	0.0002%
	Germany	2.45	0.98	0.0001%	0.0000%
	Poland	0.27	0.77	0.0001%	0.0001%
	Czechia	0.07	0.66	0.0000%	0.0003%
	Finland	0.06	0.24	0.0000%	0.0001%
	Belgium	0.00	0.00	0.0000%	0.0000%
	Denmark	n.a.	0.00	n.a.	0.0000%
	Estonia	0.00	0.00	0.0000%	0.0000%
	Netherlands	0.00	0.00	0.0000%	0.0000%
	Hungary	0.00	n.a.	0.0000%	n.a.
	Slovakia	0.00	n.a.	0.0000%	n.a.
	European Union	12.69	14.90	0.0001%	0.0001%
	EU Commission	10.80	1.02	0.0001%	0.0000%
Other Countries	United States	134.24	115.83	0.0007%	0.0006%
	Canada	15.01	15.97	0.0010%	0.0009%
	Switzerland	15.56	12.48	0.0024%	0.0018%
	Norway	7.90	10.04	0.0025%	0.0024%
	Turkey	13.19	7.04	0.0021%	0.0010%
	Korea	0.60	4.33	0.0000%	0.0003%
	United Kingdom	0.28	0.12	0.0000%	0.0000%
	Australia	0.13	0.07	0.0000%	0.0000%
	New Zealand	0.01	0.03	0.0000%	0.0000%

Source: JRC SETIS, World Bank (WBGAPI)

In the field of hydro energy, the largest player in terms of public R&D investment is the USA, by a very wide margin. They are followed by Canada and the European Union in 2020, and Switzerland and Canada in 2020. Within the EU, France remains the country with the highest public expenditure for hydro energy, followed by Sweden. For most countries, the 2020 and 2021 figures are relatively close, with a few exceptions, with Spain, Norway, and Korea with the biggest increases, and the European Commission, Germany, and Turkey with the biggest decreases. In terms of public investment relative to GDP, Norway is on top, followed by Switzerland and Turkey both in 2020 and 2021. The relative values to GDP also show that hydro energy is a minor public investment sector. Figures for China as well as some other countries are not available. ■

PUBLIC R&D INVESTMENTS

BIOFUELS

		Public R&D Exp. (in € m)		Share of Public R&D Exp. by GDP	
		2020	2021	2020	2021
EU27	Germany	53.58	68.46	0.0016%	0.0019%
	France	67.73	64.54	0.0029%	0.0026%
	Denmark	13.87	24.97	0.0045%	0.0073%
	Sweden	19.63	23.23	0.0041%	0.0043%
	Spain	7.35	16.71	0.0007%	0.0014%
	Netherlands	7.80	14.03	0.0010%	0.0016%
	Finland	11.83	9.89	0.0050%	0.0039%
	Austria	10.97	8.97	0.0029%	0.0022%
	Czechia	8.14	6.77	0.0038%	0.0028%
	Hungary	0.37	5.66	0.0003%	0.0037%
	Ireland	2.49	3.00	0.0007%	0.0007%
	Poland	1.90	2.23	0.0004%	0.0004%
	Lithuania	2.06	1.05	0.0041%	0.0019%
	Belgium	3.77	0.12	0.0008%	0.0000%
	Estonia	0.14	0.00	0.0005%	0.0000%
	Italy	9.13	n.a.	0.0005%	n.a.
	Malta	0.00	n.a.	0.0000%	n.a.
	Romania	0.01	n.a.	0.0000%	n.a.
	Slovakia	0.01	n.a.	0.0000%	n.a.
	European Union	220.76	249.62	0.0016%	0.0017%
	EU Commission	95.55	61.23	0.0007%	0.0004%
Other Countries	United States	227.53	215.73	0.0012%	0.0011%
	Japan	83.30	69.53	0.0019%	0.0016%
	Canada	47.76	49.04	0.0033%	0.0029%
	United Kingdom	14.16	32.13	0.0006%	0.0012%
	Norway	35.92	25.99	0.0112%	0.0063%
	Switzerland	24.46	19.96	0.0038%	0.0029%
	Korea	28.81	17.81	0.0020%	0.0012%
	Australia	4.00	5.35	0.0003%	0.0004%
	New Zealand	2.01	1.81	0.0011%	0.0008%
	Turkey	0.60	0.38	0.0001%	0.0001%

Source: JRC SETIS, World Bank (WBGAPI)

For biofuels, the largest player in terms of public R&D investment in 2021 is the EU (with Germany and France as main players), followed by the USA, with Japan being a distant third, closely followed by Germany, France, and the European Commission. In 2020, the USA are ahead of the EU, with the European Commission coming in third. There are two big groups of movers between 2020 and 2021. The growers are EU members states (Germany, Denmark, Spain, The Netherlands, Hungary) and the UK. The decreases are most notable for Japan, Norway, Switzerland, Korea, and Belgium. In terms of public investment relative to GDP, 2021 sees Denmark ahead of Norway and Sweden, while Norway comes ahead of Finland and Denmark in 2020. The relative values to GDP also show that biofuels are one of the three main public investment sectors. Figures for China as well as some other countries are not available. ■

PUBLIC R&D INVESTMENTS
WIND ENERGY

		Public R&D Exp. (in € m)		Share of Public R&D Exp. by GDP	
		2020	2021	2020	2021
EU27	Germany	82.53	87.36	0.0024%	0.0024%
	France	18.63	31.59	0.0008%	0.0013%
	Denmark	23.00	18.57	0.0074%	0.0054%
	Netherlands	16.86	14.95	0.0021%	0.0017%
	Spain	15.83	12.51	0.0014%	0.0010%
	Belgium	6.19	7.32	0.0013%	0.0014%
	Sweden	5.36	4.19	0.0011%	0.0008%
	Ireland	1.12	2.63	0.0003%	0.0006%
	Austria	1.03	2.51	0.0003%	0.0006%
	Finland	1.86	2.17	0.0008%	0.0009%
	Poland	0.27	0.59	0.0001%	0.0001%
	Lithuania	0.12	0.39	0.0002%	0.0007%
	Czechia	0.28	0.15	0.0001%	0.0001%
	Hungary	0.00	0.01	0.0000%	0.0000%
	Estonia	0.00	0.00	0.0000%	0.0000%
	Italy	0.69	n.a.	0.0000%	n.a.
	Slovakia	0.00	n.a.	0.0000%	n.a.
	European Union	173.77	184.94	0.0013%	0.0013%
	EU Commission	50.74	93.13	0.0004%	0.0006%
Other Countries	Japan	161.34	171.24	0.0037%	0.0040%
	United States	91.19	93.06	0.0005%	0.0005%
	Korea	67.05	57.93	0.0047%	0.0038%
	United Kingdom	32.31	45.74	0.0014%	0.0017%
	Norway	7.79	27.37	0.0024%	0.0066%
	Switzerland	6.32	9.27	0.0010%	0.0013%
	Canada	5.10	7.00	0.0004%	0.0004%
	Turkey	1.19	0.86	0.0002%	0.0001%
	Australia	0.30	0.58	0.0000%	0.0000%
	New Zealand	0.00	0.00	0.0000%	0.0000%

Source: JRC SETIS, World Bank (WBGAPI)

In the field of wind energy, the largest player in terms of public R&D investment is the EU (as sum of its members, with Germany counting for about half). They are followed by Japan, the USA, and the European Commission in 2021. For 2020, the EU is followed by the USA, Japan, and Korea. There are two big groups of movers between 2020 and 2021. The growers are France, the European Commission, Japan, the UK, and Norway. The decreases are most notable for Denmark and Korea. In terms of public investment relative to GDP, Norway is on top, followed by Denmark and Japan in 2021. In 2020, the top three was Denmark, ahead of Korea and Japan. The relative values to GDP also show that wind is one of the three main public investment sectors. ■

PUBLIC R&D INVESTMENTS
OCEAN ENERGY

		Public R&D Exp. (in € m)		Share of Public R&D Exp. by GDP	
		2020	2021	2020	2021
EU27	France	8.32	12.62	0.0004%	0.0005%
	Sweden	5.89	4.78	0.0012%	0.0009%
	Spain	0.95	3.51	0.0001%	0.0003%
	Ireland	3.20	2.38	0.0009%	0.0005%
	Denmark	6.40	0.03	0.0021%	0.0000%
	Poland	0.08	0.02	0.0000%	0.0000%
	Belgium	0.23	0.00	0.0001%	0.0000%
	Germany	0.00	0.00	0.0000%	0.0000%
	Estonia	0.00	0.00	0.0000%	0.0000%
	Netherlands	0.00	0.00	0.0000%	0.0000%
	Finland	n.a.	0.00	n.a.	0.0000%
	Hungary	0.00	n.a.	0.0000%	n.a.
	Slovakia	0.00	n.a.	0.0000%	n.a.
	European Union	25.07	23.35	0.0002%	0.0002%
	EU Commission	38.33	12.20	0.0003%	0.0001%
Other Countries	United Kingdom	14.92	20.33	0.0006%	0.0008%
	Canada	4.14	8.83	0.0003%	0.0005%
	Japan	6.17	3.18	0.0001%	0.0001%
	Australia	0.15	0.15	0.0000%	0.0000%
	Norway	0.14	0.13	0.0000%	0.0000%
	Turkey	0.11	0.09	0.0000%	0.0000%
	United States	0.00	0.00	0.0000%	0.0000%
	New Zealand	0.00	0.00	0.0000%	0.0000%
	Korea	1.27	n.a.	0.0001%	n.a.
	Switzerland	0.00	n.a.	0.0000%	n.a.

Source: JRC SETIS, World Bank (WBGAPI)

In the field of ocean energy, the largest player in terms of public R&D investment is the EU (as sum of its members, with France counting for about half). They are followed by the UK and by the European Commission in 2021. For 2020, the European Commission is ahead of the EU and the UK. There are two big groups of movers between 2020 and 2021. The growers are France, Spain, the UK, and Canada. The decreases are most notable for the European Commission, Denmark, and Japan. In terms of public investment relative to GDP, Sweden is on top, followed by UK and Ireland in 2021. In 2020, the top three was Denmark, ahead of Sweden and Ireland. The relative values to GDP also show that ocean energy is a minor public investment sector. ■

PUBLIC R&D INVESTMENTS

RENEWABLE ENERGY TECHNOLOGIES IN TOTAL

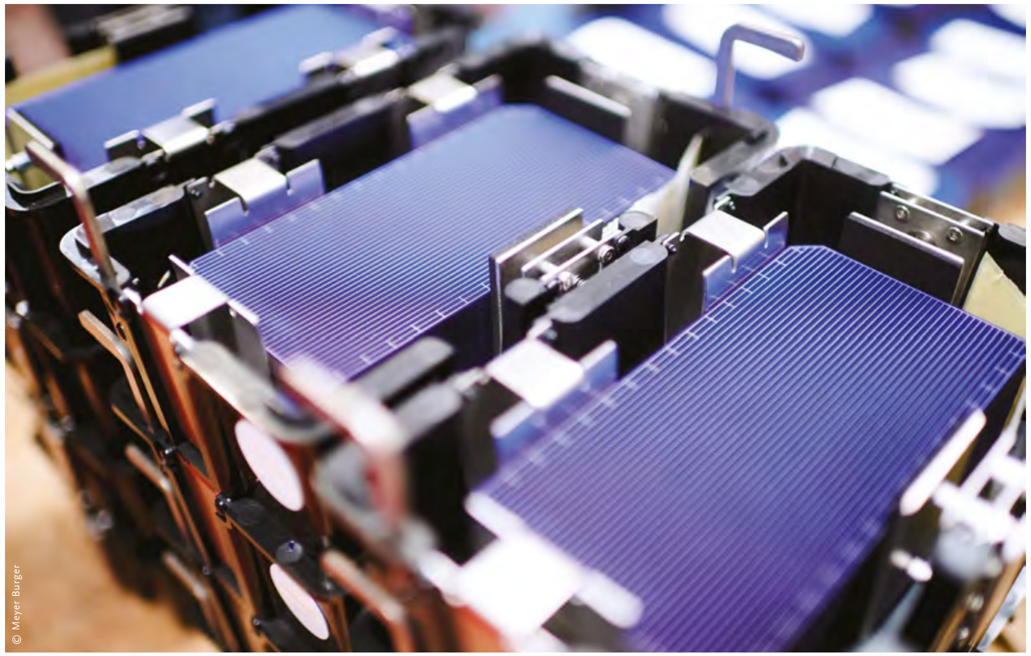
		Public R&D Exp. (in € m)		Share of Public R&D Exp. by GDP	
		2020	2021	2020	2021
EU27	Germany	263.22	292.55	0.0077%	0.0081%
	France	192.93	201.82	0.0083%	0.0081%
	Spain	37.61	77.37	0.0034%	0.0063%
	Netherlands	48.23	56.35	0.0061%	0.0065%
	Sweden	45.28	48.03	0.0095%	0.0089%
	Denmark	45.34	46.87	0.0146%	0.0137%
	Austria	22.43	19.64	0.0059%	0.0048%
	Finland	19.25	17.68	0.0081%	0.0070%
	Poland	10.19	13.38	0.0019%	0.0023%
	Hungary	2.04	13.30	0.0015%	0.0086%
	Ireland	7.61	9.98	0.0020%	0.0023%
	Czechia	10.02	9.45	0.0047%	0.0040%
	Belgium	20.95	7.82	0.0045%	0.0015%
	Lithuania	2.62	2.63	0.0052%	0.0047%
	Slovakia	0.48	0.32	0.0005%	0.0003%
	Estonia	0.19	0.30	0.0007%	0.0010%
	Bulgaria	0.00	0.00	0.0000%	0.0000%
	Greece	0.00	0.00	0.0000%	0.0000%
	Croatia	0.00	0.00	0.0000%	0.0000%
	Italy	46.29	0.00	0.0028%	0.0000%
	Cyprus	0.00	0.00	0.0000%	0.0000%
	Latvia	0.00	0.00	0.0000%	0.0000%
	Luxembourg	0.00	0.00	0.0000%	0.0000%
	Malta	0.00	0.00	0.0000%	0.0000%
	Portugal	0.00	0.00	0.0000%	0.0000%
	Romania	0.01	0.00	0.0000%	0.0000%
	Slovenia	0.00	0.00	0.0000%	0.0000%
	European Union	774.70	817.49	0.0058%	0.0056%
	EU Commission	280.60	300.08	0.0021%	0.0020%
Other Countries	United States	794.91	751.18	0.0043%	0.0038%
	Japan	298.43	287.98	0.0068%	0.0068%
	Korea	156.84	147.40	0.0109%	0.0096%
	United Kingdom	109.85	129.05	0.0047%	0.0049%
	Canada	98.59	121.35	0.0068%	0.0072%
	Switzerland	104.83	89.09	0.0161%	0.0130%
	Norway	63.87	78.96	0.0198%	0.0190%
	Australia	17.86	32.01	0.0015%	0.0024%
	Turkey	19.23	19.24	0.0030%	0.0028%
	New Zealand	6.15	6.02	0.0033%	0.0028%

Source: JRC SETIS, World Bank (WBGAPI).

Continues overleaf

For the total, we set the non-available values to zero to sum the values to avoid having only countries that invested in all technologies showing up in the totals. This means that some of the numbers can be underestimates. For example, Italy shows up with a zero total for 2021 (compared to €46 million in 2020). This does not indicate a decrease but is a consequence of the unavailability of data for Italy in 2021.

The aggregated results of public R&D investments for all renewable energy technologies shows the European Union (with Germany and France being the most prominent contributors) ahead of the USA in 2021, followed by the European Commission and Japan. In 2020, The USA are just ahead of the EU, with Japan and the European Commission following. Note that the 2021 figures for the EU are likely to be an underestimate, due to the lack of availability of data for Italy. The countries whose public investments grew the most are Germany, Spain, the Netherlands, Hungary, the European Commission, the UK, Canada, Norway, and Australia. The countries whose public investments decreased the most are Belgium, Austria, Finland, the USA, and Switzerland. In terms of public investment relative to GDP Norway is ahead of Switzerland and Denmark in 2021, with the latter two being flipped in 2020. The major contributors to public investment are solar, biofuels, and wind, while geothermal, hydro, and ocean have a minor role. ■



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PRIVATE R&D INVESTMENTS

SOLAR ENERGY

		Private R&D Exp. (in € m)		Share of Private R&D Exp. by GDP	
		2019	2020	2019	2020
EU27	Germany	397.47	459.13	0.0114%	0.0135%
	France	107.26	103.31	0.0044%	0.0045%
	Austria	27.40	40.96	0.0069%	0.0108%
	Italy	40.75	36.79	0.0023%	0.0022%
	Sweden	13.33	35.49	0.0028%	0.0074%
	Spain	19.14	29.00	0.0015%	0.0026%
	Netherlands	55.17	23.31	0.0068%	0.0029%
	Belgium	13.01	11.04	0.0027%	0.0024%
	Denmark	19.22	10.03	0.0062%	0.0032%
	Poland	9.07	9.35	0.0017%	0.0018%
	Finland	10.61	3.80	0.0044%	0.0016%
	Estonia	n.a.	1.90	n.a.	0.0069%
	Greece	n.a.	1.90	n.a.	0.0012%
	Czechia	3.51	1.27	0.0016%	0.0006%
	Ireland	4.34	n.a.	0.0012%	n.a.
	Croatia	1.75	n.a.	0.0032%	n.a.
	Cyprus	7.02	n.a.	0.0303%	n.a.
	Luxembourg	4.68	n.a.	0.0075%	n.a.
	Hungary	1.75	n.a.	0.0012%	n.a.
	Portugal	29.83	n.a.	0.0139%	n.a.
	Romania	1.75	n.a.	0.0008%	n.a.
	Slovenia	0.48	n.a.	0.0010%	n.a.
	Total EU27	767.55	767.27	0.0055%	0.0057%

Source: JRC SETIS, World Bank (WBGAPI)

In terms of private investments in R&D for solar energy, Germany is far ahead of all other countries, accounting for more than half of the investments made by EU members states. France is the runner-up, with a group of nine to eleven countries following (Portugal and Cyprus are in that group in 2019 but have no data for 2020).

Germany, Austria, Sweden, and Spain considerably increased their private investments between 2019 and 2020. Italy, the Netherlands, and Denmark considerably reduced their private investments between 2019 and 2020.

In terms, of private investment per GDP, Germany comes ahead of Austria and Sweden in 2020. In 2019, Cyprus is ahead of Portugal and Germany. Given the lack of data for Cyprus and Portugal in 2020, it cannot be directly concluded that the 2020 ranking in terms of private investment per GDP would hold or if it would be like 2019. The relative values to GDP also show that solar is one of the three main private investment sectors. ■

PRIVATE R&D INVESTMENTS

GEOTHERMAL ENERGY

		Private R&D Exp. (in € m)		Share of Private R&D Exp. by GDP	
		2019	2020	2019	2020
EU27	Germany	4.25	1.30	0.0001%	0.0000%
	Netherlands	1.28	1.09	0.0002%	0.0001%
	Finland	3.43	0.87	0.0014%	0.0004%
	France	2.48	0.22	0.0001%	0.0000%
	Italy	2.28	n.a.	0.0001%	n.a.
	Hungary	4.57	n.a.	0.0031%	n.a.
	Austria	4.57	n.a.	0.0011%	n.a.
	Slovakia	2.28	n.a.	0.0024%	n.a.
	Sweden	1.04	n.a.	0.0002%	n.a.
	Total EU27	26.17	3.48	0.0002%	0.0000%

Source: JRC SETIS, World Bank (WBGAPI)

In terms of private investments in R&D for geothermal energy, Germany is ahead of the Netherlands and Finland in 2020. In 2019, Hungary and Austria are ahead of Germany (Hungary and Austria do not have data for 2020, so it is unclear if the 2020 data would still hold, or if it due to a lack of data).

All countries that have data for 2020 show a decrease in private investments, but the lack of data for 2020 for many countries that do have data in 2019 does not allow us to draw solid conclusions on the matter.

In terms of private investment per GDP, Finland comes ahead of the Netherlands and Germany in 2020. In 2019, Hungary is ahead of Slovakia and Finland. Given the lack of data for Slovakia and Hungary in 2020, we cannot say if the 2020 ranking in terms of private investment per GDP would hold or if it would be like 2019. The relative values to GDP also show that geothermal is a minor private investment sector. ■

PRIVATE R&D INVESTMENTS

HYDRO ENERGY

		Private R&D Exp. (in € m)		Share of Private R&D Exp. by GDP	
		2019	2020	2019	2020
EU27	Germany	31.20	16.31	0.0009%	0.0005%
	France	13.57	3.73	0.0006%	0.0002%
	Italy	2.77	1.91	0.0002%	0.0001%
	Poland	2.77	1.91	0.0005%	0.0004%
	Sweden	1.35	1.24	0.0003%	0.0003%
	Netherlands	0.92	0.25	0.0001%	0.0000%
	Spain	0.92	n.a.	0.0001%	n.a.
	Austria	0.61	n.a.	0.0002%	n.a.
	Slovenia	0.92	n.a.	0.0019%	n.a.
	Finland	0.92	n.a.	0.0004%	n.a.
	Total EU27	55.96	25.35	0.0004%	0.0002%

Source: JRC SETIS, World Bank (WBGAPI)

In terms of private investments in R&D for hydro energy, Germany is ahead of France and Italy and Poland in 2019 and 2020. All countries that have data for 2020 show a decrease in private investments, and this is especially large for the two major players Germany and France. In terms of private investment per GDP, Germany comes ahead of Poland and Sweden in 2020. In 2019, Slovenia is ahead of Germany and France. Given the lack of data for Slovenia in 2020, we cannot say if the 2020 ranking in terms of private investment per GDP would hold or if it would be like 2019. The relative values to GDP also show that hydro energy is a minor private investment sector. ■

PRIVATE R&D INVESTMENTS

BIOFUELS

		Private R&D Exp. (in € m)		Share of Private R&D Exp. by GDP	
		2019	2020	2019	2020
EU27	Denmark	103.48	66.88	0.0334%	0.0215%
	France	22.61	58.62	0.0009%	0.0025%
	Finland	41.56	29.45	0.0173%	0.0124%
	Germany	36.24	26.42	0.0010%	0.0008%
	Sweden	24.09	25.05	0.0051%	0.0052%
	Hungary	4.81	22.34	0.0033%	0.0162%
	Netherlands	43.07	20.99	0.0053%	0.0026%
	Italy	25.87	14.56	0.0014%	0.0009%
	Austria	18.99	13.20	0.0048%	0.0035%
	Spain	2.84	10.01	0.0002%	0.0009%
	Czechia	0.65	4.74	0.0003%	0.0022%
	Belgium	7.65	3.60	0.0016%	0.0008%
	Cyprus	n.a.	2.03	n.a.	0.0092%
	Latvia	5.18	n.a.	0.0169%	n.a.
	Luxembourg	9.98	n.a.	0.0160%	n.a.
	Portugal	5.18	n.a.	0.0024%	n.a.
	Romania	5.18	n.a.	0.0023%	n.a.
	Total EU27	357.38	297.90	0.0025%	0.0022%

Source: JRC SETIS, World Bank (WBGAPI)

In terms of private investments in R&D for biofuels, Denmark is ahead of France in 2020. They are followed by a group of five countries. In 2019, Denmark is far ahead of The Netherlands and Finland. Germany is ahead of France and Italy and Poland in 2019 and 2020. The countries that considerably increased their investment between 2019 and 2020 are: France, Hungary, and Spain. The countries that considerably decreased their investment between 2019 and 2020 are: Denmark, Finland, Germany, the Netherlands, Italy, and Austria. In terms of private investment per GDP, Denmark comes ahead of Hungary and Finland in 2020. In 2019, Denmark is ahead of Finland and Latvia (note that Lavia does not have data for 2020). The relative values to GDP also show that biofuels are one of the three main private investment sectors. ■

PRIVATE R&D INVESTMENTS

WIND ENERGY

		Private R&D Exp. (in € m)		Share of Private R&D Exp. by GDP	
		2019	2020	2019	2020
EU27	Denmark	741.44	609.76	0.2395%	0.1963%
	Germany	351.41	238.52	0.0101%	0.0070%
	Spain	71.67	114.49	0.0058%	0.0102%
	Austria	30.67	36.43	0.0077%	0.0096%
	Sweden	11.95	29.09	0.0025%	0.0061%
	Netherlands	25.56	26.25	0.0031%	0.0033%
	France	25.41	17.64	0.0010%	0.0008%
	Belgium	3.32	13.49	0.0007%	0.0029%
	Poland	1.30	3.49	0.0002%	0.0007%
	Finland	4.34	2.66	0.0018%	0.0011%
	Italy	7.54	2.44	0.0004%	0.0001%
	Latvia	1.30	1.79	0.0043%	0.0060%
	Cyprus	2.60	1.59	0.0112%	0.0072%
	Greece	n.a.	1.20	n.a.	0.0007%
	Romania	n.a.	1.20	n.a.	0.0005%
	Portugal	0.87	n.a.	0.0004%	n.a.
	Total EU27	1279.38	1100.04	0.0091%	0.0082%

Source: JRC SETIS, World Bank (WBGAPI)

In terms of private investments in R&D for wind energy, Denmark is far ahead of Germany and Spain (with the other countries far behind) in 2019 and 2020 (though Spain is a step back behind Germany in 2019).
The countries that considerably increased their investment between 2019 and 2020 are: Spain, Austria, Sweden, and Belgium. The countries that considerably decreased their investment between 2019 and 2020 are: Denmark, Germany, France, and Italy.
In terms of private investment per GDP, Denmark comes far ahead (and far ahead of any values for any RET in any country) of Spain and Austria 2020. In 2019, Denmark is even further ahead of Cyprus and Germany. The relative values to GDP also show that wind energy is one of the three main private investment sectors. ■

PRIVATE R&D INVESTMENTS

OCEAN ENERGY

		Private R&D Exp. (in € m)		Share of Private R&D Exp. by GDP	
		2019	2020	2019	2020
EU27	France	1.87	8.60	0.0001%	0.0004%
	Sweden	9.17	8.19	0.0019%	0.0017%
	Finland	1.41	3.09	0.0006%	0.0013%
	Netherlands	2.81	2.78	0.0003%	0.0003%
	Denmark	n.a.	1.97	n.a.	0.0006%
	Germany	2.11	0.93	0.0001%	0.0000%
	Italy	8.63	0.93	0.0005%	0.0001%
	Ireland	1.41	n.a.	0.0004%	n.a.
	Austria	1.41	n.a.	0.0004%	n.a.
	Slovenia	1.41	n.a.	0.0029%	n.a.
	Total EU27	30.21	26.49	0.0002%	0.0002%

Source: JRC SETIS, World Bank (WBGAPI)

In terms of private investments in R&D for ocean energy, France and Sweden are ahead of Finland and the Netherlands in 2020. In 2019, Sweden and Italy are far ahead of a group of seven countries. France has a considerable increase in investment between 2019 and 2020, while Finland has a lower increase. Italy (and Sweden and Germany to a lesser extent) shows a decrease in private investment.
In terms of private investment per GDP, Sweden comes ahead of Finland and Denmark in 2020. In 2019, Slovenia is ahead of Sweden and Italy. Given the lack of data for Slovenia in 2020, we cannot say if the 2020 ranking in terms of private investment per GDP would hold or if it would be like 2019. The relative values to GDP also show that ocean energy is a minor private investment sector. ■

PRIVATE R&D INVESTMENTS

RENEWABLE ENERGY TECHNOLOGIES IN TOTAL

	Private R&D Exp. (in € m)		Share of Private R&D Exp. by GDP	
	2019	2020	2019	2020
Germany	822.68	742.62	0.0237%	0.0218%
Denmark	864.14	688.64	0.2792%	0.2217%
France	173.20	192.11	0.0071%	0.0083%
Spain	94.57	153.50	0.0076%	0.0137%
Sweden	60.94	99.06	0.0128%	0.0207%
Austria	83.66	90.59	0.0211%	0.0238%
Netherlands	128.81	74.66	0.0158%	0.0094%
Italy	87.84	56.63	0.0049%	0.0034%
Finland	62.26	39.87	0.0260%	0.0168%
Belgium	23.98	28.13	0.0050%	0.0061%
Hungary	11.13	22.34	0.0076%	0.0162%
Poland	13.13	14.75	0.0025%	0.0028%
Czechia	4.16	6.01	0.0018%	0.0028%
Cyprus	9.62	3.63	0.0415%	0.0164%
Greece	0.00	3.10	0.0000%	0.0019%
Estonia	0.00	1.90	0.0000%	0.0069%
Latvia	6.48	1.79	0.0212%	0.0060%
Romania	6.93	1.20	0.0031%	0.0005%
Bulgaria	0.00	0.00	0.0000%	0.0000%
Ireland	5.75	0.00	0.0016%	0.0000%
Croatia	1.75	0.00	0.0032%	0.0000%
Lithuania	0.00	0.00	0.0000%	0.0000%
Luxembourg	14.66	0.00	0.0235%	0.0000%
Malta	0.00	0.00	0.0000%	0.0000%
Portugal	35.87	0.00	0.0167%	0.0000%
Slovenia	2.81	0.00	0.0058%	0.0000%
Slovakia	2.28	0.00	0.0024%	0.0000%
Total EU27	2516.66	2220.53	0.0180%	0.0165%

Source: JRC SETIS, World Bank (WBGAPI)

Looking at total private investments, we see Denmark and Germany far ahead of the rest of the countries. Germany is ahead of Denmark in 2020, while the reverse is true in 2019. The following range of countries in 2020 includes France, Spain, Sweden, and Austria. In 2019, this range includes France, the Netherlands, Spain, and Austria. Germany, Denmark, the Netherlands, Italy, and Finland significantly decreased their total investment between 2019 and 2020 (Portugal and Luxembourg have no data for 2020, so we cannot say which way they went). Spain and Sweden (and France, Belgium, and Hungary to a lesser extent) increased their private investment between 2019 and 2020. In terms of investments per GDP, Denmark is an order of magnitude ahead of all other countries, with Austria, Germany, and Sweden leading the other countries (Cyprus is ahead of them in 2019, but not in 2020: that might come from the lack of data for solar in 2020 for Cyprus). Due to missing data for non-EU27 countries, the investments cannot be compared to the rest of the world. ■

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PUBLIC AND PRIVATE R&D CONCLUSIONS

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

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

- For solar energy, the EU27 (2020/2021) and the US are the frontrunners in public R&D spending, followed by the European Commission and Korea (data for China is not available). Within the EU27, the largest investments in 2020 are due to Germany, France, and Spain. For private R&D investments within the EU27, Germany, France, and Austria are the leading countries (2020).
- Regarding geothermal energy, the U.S. ranks first with a substantial difference from the EU (mostly through Germany and France), followed by Japan. Private R&D expenditures in the EU27 are highest in Germany, the Netherlands, and Finland.
- In hydro energy, the U.S. dominates in public R&D investments, followed by Canada and the EU27. Within the EU27, France is in the lead, followed by Sweden and Austria. As for the private R&D investments in the EU27, the largest values are noted for Germany, France, and Italy.
- Within biofuels, the EU is in the head position regarding public R&D investments, followed by the USA and Japan (2021). Within the EU27, the largest contributions are due to Germany and France. As for the private R&D investments within the EU27, Denmark, France, and Finland are in the lead (2020).
- In wind energy, the EU27 shows the largest public R&D spending in 2021, followed by the USA and the European Commission. Within the EU27, the largest contributions come mainly from Germany, followed by France and Denmark. Regarding private R&D spending in the EU27 (2020), Germany and Denmark are by far on the top of the list.
- In ocean energy – 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 EU27, the largest contributions are provided by France and Sweden. Concerning private R&D investments within the EU27, France, Sweden, and Finland are the most committed countries in 2020.
- Regarding the total public R&D expenditures the EU27 and the US are clearly the two most significant among the assessed regions worldwide. With some distance behind, Japan, Korea, and the UK follow outside of the EU27. Germany and France clearly show the highest expenditures of public R&D within the EU27.
- Overall, this analysis shows that private R&D financing by far exceeds public R&D financing. Within the EU27, Germany and Denmark are leading, followed by France, Spain, and Sweden (2020). ■


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EUROBSERV'ER – THE STATE OF RENEWABLE ENERGIES IN EUROPE – 2023 EDITION

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 2019 and 2020. 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	
	2019	2020	2019	2020	2019	2020
EU27						
Germany	162.0	188.7	0.4	0.6	46.6	55.4
France	100.2	90.2	0.7	0.9	41.1	38.9
Spain	36.5	45.7	2.1	2.3	29.3	40.8
Italy	27.9	31.6	0.9	1.1	15.5	19.0
Netherlands	39.6	28.8	1.2	1.0	48.7	36.2
Poland	30.2	21.9	1.9	1.7	56.7	41.8
Austria	12.9	15.8	0.6	0.8	32.4	41.4
Sweden	8.1	11.8	0.3	0.5	17.0	24.5
Belgium	6.8	9.1	0.6	0.8	14.1	19.7
Denmark	7.7	5.2	0.2	0.2	24.8	16.6
Romania	4.5	4.3	1.2	1.6	20.1	19.3
Greece	0.9	4.0	1.4	2.7	5.0	24.2
Finland	5.9	3.0	0.4	0.2	24.4	12.6
Ireland	2.4	2.5	0.4	0.5	6.6	6.7
Slovakia	1.3	2.1	1.7	3.4	14.1	22.7
Czechia	1.7	1.8	0.4	0.5	7.4	8.5
Portugal	9.3	1.5	3.5	0.6	43.4	7.5
Cyprus	2.0	1.0	4.4	2.1	86.3	45.3
Lithuania	0.4	1.0	0.6	2.1	7.9	20.1
Luxembourg	1.4	1.0	0.6	0.5	22.7	15.5
Estonia	n.a.	0.5	0.0	1.0	n.a.	18.2
Bulgaria	n.a.	n.a.	0.0	0.0	n.a.	n.a.
Croatia	0.5	n.a.	1.9	0.0	9.1	n.a.
Latvia	n.a.	n.a.	0.0	0.0	n.a.	n.a.
Hungary	0.5	n.a.	0.4	0.0	3.4	n.a.
Malta	n.a.	n.a.	0.0	0.0	n.a.	n.a.
Slovenia	0.3	n.a.	0.3	0.0	5.6	n.a.
Total EU27	462.6	471.4	0.6	0.8	33.0	35.0

Continues overleaf

Other Countries						
China	5 564.7	5 937.9	1.1	1.1	436.2	461.8
Korea	1 412.7	1 214.6	1.5	1.3	957.7	843.7
Japan	663.9	425.6	0.6	0.6	145.2	96.3
United States	385.7	364.0	0.6	0.7	20.2	19.7
Rest of the world*	376.7	366.4	1.0	1.1	14.2	15.3
out of which United Kingdom	*26.4*	*20.4*	*0.4*	*0.4*	*10.4*	*8.6*

** 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, World Bank (WBGAPI).***

In the field of solar energy, China is the uncontested frontrunner in terms of patents (filed domestically or internationally), although Korea has higher levels of patents per trillion of GDP. China is followed in number of patents by Korea and Japan and then the EU27 and the US. Within the EU27, Germany has filed the largest number of patents, followed by France, Spain, Italy, the Netherlands, and Poland (in 2020). Among the more significant patent filing countries, Germany, Austria, Poland, Spain, and France are scoring highest in terms of patents per GDP within the EU27, but they lag very far behind Korea and China (and are behind Japan). Countries with significant patent filing levels showed little variation in their specialization index between 2019 and 2020, with Spain and Poland showing the highest specialization indices amongst EU27 countries. Similarly to investment levels, the patent filing levels show that solar is one of the three major RETs. ■

GEOTHERMAL ENERGY

	Number of patent families		Patent specialization		Patents per € trillion GDP	
	2019	2020	2019	2020	2019	2020
EU27						
Netherlands	0.6	3.8	0.7	4.4	0.8	4.8
Germany	5.7	3.8	0.5	0.4	1.7	1.1
Poland	1.0	1.5	2.3	3.8	1.9	2.9
France	1.1	1.2	0.3	0.4	0.5	0.5
Denmark	n.a.	1.0	0.0	1.0	n.a.	3.2
Finland	2.0	1.0	4.9	2.4	8.3	4.2
Portugal	n.a.	0.5	0.0	6.2	n.a.	2.5
Sweden	0.3	0.3	0.5	0.4	0.7	0.7
Belgium	n.a.	n.a.	0.0	0.0	n.a.	n.a.
Spain	n.a.	n.a.	0.0	0.0	n.a.	n.a.
Italy	2.0	n.a.	2.3	0.0	1.1	n.a.
Hungary	2.0	n.a.	54.7	0.0	13.7	n.a.
Austria	2.0	n.a.	3.4	0.0	5.0	n.a.
Slovenia	n.a.	n.a.	0.0	0.0	n.a.	n.a.
Slovakia	1.0	n.a.	48.0	0.0	10.6	n.a.
EU27	19.8	17.9	1.3	0.9	1.5	1.3
Other Countries						
China	142.5	184.5	1.0	1.0	11.2	14.3
Korea	41.6	33.8	1.7	1.1	28.2	23.5
Japan	14.8	7.5	0.5	0.3	3.2	1.7
United States	7.5	13.5	0.4	0.8	0.4	0.7
Rest of the world*	13.9	22.2	1.3	2.1	0.5	0.9
out of which United Kingdom	*1.0*	*4.0*	*0.5*	*2.4*	*0.4*	*1.7*

** 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 geothermal energy, China is the uncontested frontrunner in terms of patents (filed domestically or internationally), although Korea has higher levels of patents per trillion of GDP. China is followed in number of patents by Korea and The USA and the EU. Within the EU, Germany and the Netherlands have filed the largest number of patents, followed by Poland, France, Denmark, and Finland (in 2020). The Netherlands saw an increase between 2019 and 2020, leading to a relatively large patent specialization index. It is important to keep in mind that this jump occurs at relatively low levels (from 0.6 to 3.8), so it might be a one-time event. This also shows the Netherlands as the leader with the EU in terms of patents per GDP (though it might once again be an artefact of low numbers). Korea and China are once again very far ahead in terms of patents per GDP. Similarly to investment levels, the patent filing levels show that geothermal is a minor RET in terms of patent focus. ■

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EUROBSERV'ER – THE STATE OF RENEWABLE ENERGIES IN EUROPE – 2023 EDITION

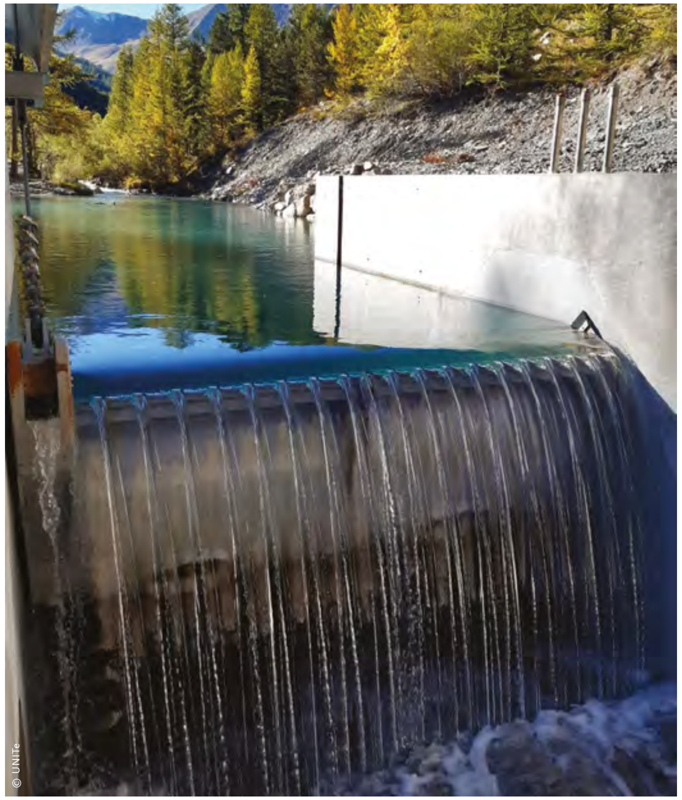
HYDROENERGY

	Number of patent families		Patent specialization		Patents per € trillion GDP	
	2019	2020	2019	2020	2019	2020
EU27						
Germany	19.7	12.3	0.7	0.4	5.7	3.6
Italy	3.8	8.8	1.6	3.3	2.1	5.3
Poland	6.3	5.8	5.5	4.9	11.9	11.1
France	8.9	5.0	0.9	0.6	3.7	2.2
Sweden	0.7	4.0	0.3	1.8	1.4	8.4
Spain	1.0	2.3	0.8	1.3	0.8	2.1
Austria	0.3	2.2	0.2	1.2	0.8	5.7
Greece	1.0	1.5	21.5	10.7	5.5	9.1
Finland	1.0	1.5	0.9	1.2	4.2	6.3
Netherlands	0.5	1.5	0.2	0.5	0.6	1.8
Lithuania	0.2	1.3	5.8	30.4	5.1	26.7
Romania	1.6	0.8	5.7	3.1	7.0	3.4
Estonia	n.a.	0.5	0.0	10.5	n.a.	18.2
Belgium	n.a.	n.a.	0.0	0.0	n.a.	n.a.
Bulgaria	n.a.	n.a.	0.0	0.0	n.a.	n.a.
Czechia	n.a.	n.a.	0.0	0.0	n.a.	n.a.
Denmark	n.a.	n.a.	0.0	0.0	n.a.	n.a.
Ireland	1.0	n.a.	2.4	0.0	2.8	n.a.
Croatia	n.a.	n.a.	0.0	0.0	n.a.	n.a.
Cyprus	n.a.	n.a.	0.0	0.0	n.a.	n.a.
Hungary	n.a.	n.a.	0.0	0.0	n.a.	n.a.
Malta	n.a.	n.a.	0.0	0.0	n.a.	n.a.
Portugal	n.a.	n.a.	0.0	0.0	n.a.	n.a.
Slovenia	0.5	n.a.	7.2	0.0	10.3	n.a.
Slovakia	n.a.	n.a.	0.0	0.0	n.a.	n.a.
EU27	**46.5**	**47.6**	**0.8**	**0.8**	**3.3**	**3.5**
Other Countries						
China	424.6	612.3	1.2	1.2	33.3	47.6
Japan	55.3	37.2	0.7	0.6	12.1	8.4
Korea	50.1	47.0	0.7	0.5	33.9	32.7
United States	9.0	19.0	0.2	0.4	0.5	1.0
Rest of the world*	51.6	64.4	1.9	2.0	1.9	2.7
out of which United Kingdom	*3.2*	*5.5*	*0.6*	*1.1*	*1.2*	*2.3*

** 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.***

Continues overleaf

In the field of hydro energy, China is the uncontested frontrunner in terms of patents (filed domestically or internationally). It also has the highest levels of patents per trillion of GDP. China is followed in number of patents by the EU, Korea, and Japan. Within the EU, Germany is ahead of Italy and Poland, (in 2020). China saw considerable growth in terms of patents (and a resulting patents per GDP growth) between 2019 and 2020. Some EU country such as Poland and Italy show a higher-than-average patent specialization index, but this might be more linked to a low number of patents. Similarly to investment levels, the patent filing levels show that hydro energy is a minor RET in terms of patent focus. ■



BIOFUELS

	Number of patent families		Patent specialization		Patents per € trillion GDP	
	2019	2020	2019	2020	2019	2020
EU27						
France	33.2	44.3	1.6	3.1	13.6	19.1
Germany	22.6	20.7	0.4	0.5	6.5	6.1
Poland	7.3	19.8	3.0	10.4	13.8	37.6
Denmark	10.7	10.3	2.0	2.1	34.4	33.0
Finland	11.7	10.0	5.0	5.1	48.7	42.0
Netherlands	13.0	9.9	2.6	2.4	16.0	12.4
Sweden	6.8	7.2	1.6	2.0	14.2	15.0
Spain	4.2	6.7	1.6	2.3	3.4	6.0
Italy	7.5	6.7	1.5	1.6	4.2	4.0
Hungary	0.9	5.5	4.4	30.8	6.3	40.0
Austria	4.2	4.8	1.2	1.6	10.5	12.5
Belgium	2.7	4.5	1.6	2.7	5.6	9.8
Romania	4.0	2.0	6.7	5.2	17.8	9.1
Portugal	2.0	1.8	4.8	4.7	9.3	9.1
Bulgaria	n.a.	1.5	0.0	16.5	n.a.	24.3
Czechia	0.4	1.4	0.6	2.6	1.7	6.6
Greece	0.4	0.6	3.7	2.7	2.0	3.6
Cyprus	n.a.	0.5	0.0	7.1	n.a.	22.6
Ireland	n.a.	0.0	0.0	0.1	n.a.	0.1
Estonia	n.a.	n.a.	0.0	0.0	n.a.	n.a.
Latvia	1.0	n.a.	8.8	0.0	32.7	n.a.
Lithuania	n.a.	n.a.	0.0	0.0	n.a.	n.a.
Luxembourg	1.0	n.a.	2.6	0.0	16.0	n.a.
Slovenia	n.a.	n.a.	0.0	0.0	n.a.	n.a.
Slovakia	n.a.	n.a.	0.0	0.0	n.a.	n.a.
EU27	**133.5**	**158.2**	**1.1**	**1.7**	**9.5**	**11.7**

Continues overleaf

Other Countries						
China	836.0	745.1	1.1	0.9	65.5	57.9
Korea	123.5	112.4	0.9	0.8	83.7	78.1
Japan	98.4	92.0	0.6	0.9	21.5	20.8
United States	74.7	84.9	0.8	1.1	3.9	4.6
Rest of the world*	95.9	115.7	1.6	2.3	3.6	4.8
out of which United Kingdom	*10.3*	*18.5*	*1.0*	*2.3*	*4.0*	*7.8*

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

In the field of biofuels, China is the uncontested frontrunner in terms of patents (filed domestically or internationally), although Korea has higher levels of patents per trillion of GDP. China is followed in number of patents by the EU and Korea. Within the EU27, France has filed the largest number of patents, followed by Germany, and Poland (in 2020). Among the more significant patent filing countries, France, Poland, Finland, and Denmark are scoring highest in terms of patents per GDP within the EU27, but they lag very far behind Korea and China. Countries with significant patent filing levels showed little variation in their specialization index between 2019 and 2020, with France and Poland showing the highest specialization indices amongst EU27 countries. Similarly to investment levels, the patent filing levels show that biofuels are one of the three major RETs. ■

WIND ENERGY

	Number of patent families		Patent specialization		Patents per € trillion GDP	
	2019	2020	2019	2020	2019	2020
EU27						
Denmark	297.6	273.4	26.3	23.0	961.5	880.2
Germany	171.1	131.1	1.2	1.2	49.2	38.5
Spain	42.0	67.0	7.4	9.2	33.7	59.9
France	24.8	29.1	0.6	0.8	10.2	12.5
Netherlands	20.0	26.3	1.9	2.5	24.6	33.0
Poland	12.8	16.1	2.4	3.4	23.9	30.7
Austria	15.3	14.7	2.2	2.0	38.6	38.6
Sweden	7.1	13.1	0.8	1.5	15.0	27.3
Italy	6.7	8.6	0.6	0.8	3.7	5.2
Belgium	1.3	7.7	0.4	1.8	2.7	16.6
Finland	1.4	4.6	0.3	0.9	5.8	19.4
Romania	5.0	4.6	3.9	4.8	22.3	20.8
Latvia	2.5	2.2	10.3	7.1	81.8	74.7
Greece	n.a.	2.0	0.0	3.6	n.a.	12.1
Portugal	0.3	1.5	0.4	1.6	1.6	7.5
Cyprus	1.0	1.4	6.8	8.1	43.1	64.1
Bulgaria	n.a.	1.0	0.0	4.4	n.a.	16.2
Hungary	n.a.	1.0	0.0	2.3	n.a.	7.3
Ireland	0.5	0.2	0.3	0.1	1.4	0.7
Czechia	n.a.	n.a.	0.0	0.0	n.a.	n.a.
Estonia	n.a.	n.a.	0.0	0.0	n.a.	n.a.
Lithuania	0.8	n.a.	4.2	0.0	17.0	n.a.
Luxembourg	n.a.	n.a.	0.0	0.0	n.a.	n.a.
Malta	0.3	n.a.	3.5	0.0	23.3	n.a.
Slovenia	n.a.	n.a.	0.0	0.0	n.a.	n.a.
Slovakia	n.a.	n.a.	0.0	0.0	n.a.	n.a.
EU27	**610.6**	**605.7**	**2.4**	**2.7**	**43.6**	**45.0**
Other Countries						
China	1 795.3	2 137.0	1.1	1.0	140.7	166.2
United States	140.8	111.1	0.7	0.6	7.4	6.0
Korea	129.1	145.0	0.4	0.4	87.5	100.8
Japan	108.1	85.1	0.3	0.3	23.7	19.3
Rest of the world*	118.1	160.9	0.9	1.3	4.5	6.7
out of which United Kingdom	*16.9*	*26.9*	*0.7*	*1.4*	*6.6*	*11.4*

** 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.***

Continues overleaf

In the field of wind energy, China is the uncontested frontrunner in terms of patents (filed domestically or internationally), though Denmark is far ahead in terms of levels of patents per trillion of GDP. China is followed in number of patents by the EU and Korea. Within the EU27, Denmark has filed the largest number of patents by far (and is even ahead of Korea), followed by Germany (with similar patent filings to Korea) and Spain (in 2020). In terms of patents per GDP, Denmark is far ahead of China and Korea. Denmark (and Spain to a lesser extent) has a very significant degree of patent specialization. Similarly to investment levels, the patent filing levels show that wind energy is one of the three major RETs. ■

OCEAN ENERGY

	Number of patent families		Patent specialization		Patents per € trillion GDP	
	2019	2020	2019	2020	2019	2020
EU27						
France	8.2	10.7	1.3	1.9	3.4	4.6
Sweden	3.8	3.0	3.0	2.2	8.0	6.3
Italy	3.5	2.5	2.4	1.5	1.9	1.5
Germany	2.2	2.3	0.1	0.1	0.6	0.7
Denmark	n.a.	2.3	0.0	1.2	n.a.	7.2
Netherlands	1.0	2.0	0.7	1.2	1.2	2.5
Finland	0.5	1.6	0.7	2.1	2.1	6.8
Poland	1.0	1.5	1.4	2.0	1.9	2.9
Spain	2.5	1.0	3.2	0.9	2.0	0.9
Luxembourg	n.a.	1.0	0.0	8.4	n.a.	15.5
Romania	1.0	0.8	5.7	5.0	4.5	3.4
Belgium	n.a.	n.a.	0.0	0.0	n.a.	n.a.
Bulgaria	n.a.	n.a.	0.0	0.0	n.a.	n.a.
Ireland	0.5	n.a.	1.9	0.0	1.4	n.a.
Croatia	n.a.	n.a.	0.0	0.0	n.a.	n.a.
Hungary	n.a.	n.a.	0.0	0.0	n.a.	n.a.
Malta	n.a.	n.a.	0.0	0.0	n.a.	n.a.
Austria	0.5	n.a.	0.5	0.0	1.3	n.a.
Portugal	2.0	n.a.	16.5	0.0	9.3	n.a.
Slovenia	0.5	n.a.	11.4	0.0	10.3	n.a.
Slovakia	n.a.	n.a.	0.0	0.0	n.a.	n.a.
EU27	**27.3**	**28.6**	**0.8**	**0.8**	**1.9**	**2.1**
Other Countries						
China	292.0	387.6	1.3	1.2	22.9	30.1
Korea	18.4	16.5	0.4	0.3	12.4	11.4
United States	33.2	46.2	1.9	2.4	1.3	1.9
Japan	11.8	8.4	0.2	0.2	2.6	1.9
Rest of the world*	33.2	46.2	1.9	2.4	1.3	1.9
out of which United Kingdom	*11.4*	*16.6*	*3.7*	*5.4*	*4.5*	*7.0*

** 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.***

Continues overleaf

In the field of ocean energy, China is the uncontested frontrunner in terms of patents (filed domestically or internationally). It also has the highest levels of patents per trillion of GDP. China is followed in number of patents by the EU, and the USA Within the EU, France is ahead of a pack of 10 countries. China saw some growth in terms of patents (and a resulting patents per GDP growth) between 2019 and 2020. The specialization index is relatively low across the board, with some exceptions for countries with a low number of patents (though the UK has average levels of both). Similarly to investment levels, the patent filing levels show that ocean energy is a minor RET in terms of patent focus. ■

RENEWABLE ENERGY TECHNOLOGIES IN TOTAL

	Number of patent families		Patents per € trillion GDP	
	2019	2020	2019	2020
EU27				
Germany	383.3	358.9	110.3	105.5
Denmark	315.9	292.0	1020.7	940.3
France	176.5	180.5	72.4	77.9
Spain	86.2	122.8	69.2	109.7
Netherlands	74.7	72.3	91.9	90.8
Poland	58.6	66.6	110.0	126.9
Italy	51.3	58.2	28.6	35.1
Sweden	26.9	39.3	56.3	82.1
Austria	35.2	37.4	88.6	98.1
Finland	22.4	21.7	93.5	91.3
Belgium	10.8	21.3	22.5	46.2
Romania	16.1	12.3	71.7	56.0
Greece	2.3	8.1	12.5	49.1
Hungary	3.4	6.5	23.4	47.2
Portugal	13.6	5.3	63.6	26.6
Czechia	2.0	3.3	9.1	15.1
Cyprus	3.0	2.9	129.4	132.1
Ireland	4.4	2.8	12.2	7.4
Bulgaria	0.0	2.5	0.0	40.6
Lithuania	1.5	2.3	30.1	46.8
Latvia	3.5	2.2	114.5	74.7
Slovakia	2.3	2.1	24.7	22.7
Luxembourg	2.4	2.0	38.7	31.0
Estonia	0.0	1.0	0.0	36.4
Croatia	0.5	0.0	9.1	0.0
Malta	0.3	0.0	23.3	0.0
Slovenia	1.3	0.0	26.2	0.0
EU27	**1 298.4**	**1 324.6**	**92.6**	**98.4**

Continues overleaf

Other Countries				
China	9 055.1	10 004.4	709.9	778.0
Korea	1 775.3	1 569.3	1 203.5	1 090.1
Japan	952.3	655.7	208.3	148.3
United States	635.8	613.2	33.3	33.3
Rest of the world*	689.4	775.7	26.0	32.3
out of which United Kingdom	*69.2*	*91.8*	*27.2*	*38.9*

** 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 2020, followed by Korea, the EU27, Japan, and the US. Within the EU27, 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 countries such as Cyprus and Poland. This high level for Denmark is boosted by its leadership position in wind energy and pushes it ahead of China and close to Korea in terms of patents per GDP in all RETs. ■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CONCLUSIONS

Across nearly all fields in renewable energies technologies, the Asian countries, in particular China, display the highest patenting activities in absolute and relative (GDP) numbers when including patent filings that refer only to the domestic market (singletons). The EU27 is in a good position behind the Asian countries but ahead of the US. Within the EU27, 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 EU27, wind energy ranks highest in number of patent filings. In contrast to the large R&D investments into biofuels, the patent statistics show relatively modest results for biofuels, i.e., it is the third largest field behind solar energy and wind energy. Regarding ocean energy, in terms of patents and R&D spending it is less significant, albeit its resource and technological development potentials. ■

References:
*Joint Research Centre (JRC) based on data from the European Patent Office (EPO)**
• Patent data based on PATSTAT database 2021 spring version (JRC update: May 2021). The methodology behind the indicators is provided in Fiorini et al. (2017), Pasimeni et al. (2019), Pasimeni (2019), and Pasimeni et al. (2021)

International Trade

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

Methodological approach

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

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

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 2021and 2022. 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 (854142 and 854143), wind energy (850231) and hydroelectricity (841011, 841012, 841013, 841090). For biofuels, the codes (220710, 220720) are based on the classification by JRC SETIS in Pasimeni F., EU energy technology trade: Import and export, EUR 28652 EN, Publications Office of the European Union, Luxembourg, 2017, ISBN 978-92-79-69670-1, doi:10.2760/607980, JRC107048.*

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

ALL RES

EU27 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	-1014	4,6%	16
Poland	1 420	229	-1190	0,3%	-61
Greece	1 378	170	-1208	0,2%	-30
Total EU27	21 166	16 132	-5034	21%	-16

Main EU partners' trade with the rest of the world (including EU27). 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

In 2021, the largest importers of photovoltaics, wind energy equipment, biofuels, and hydropower equipment in the EU27 were the Netherlands (€4 659 million), Germany (€4 301 million) and Spain (€1 682 million). Germany and the Netherlands were also the two main exporters of RET in 2021 with €5 080 million and €3 645 million respectively. From the main trading partners, China is the largest by far with €8 265 million in imports and €29 744 million in exports in 2021.

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, Belgium and Japan. Since these countries exported more RET goods than they imported in 2021, 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, the U.K., Brazil, Greece, Poland and Canada.

When looking at the export shares in all four selected renewable energy technologies, it can be observed China has the largest values in 2021 with 38%. The EU27 follows with export shares of 21% in 2021. 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

EU27 trade (incl. intra-EU trade). 2022 - all RES

	Imports (in € m)	Exports (in € m)	Net exports (in € m)	Share of global exports	Exports specialisation (RCA)
Denmark	629	1 309	680	1,6%	42
Hungary	447	670	223	0,8%	10
Slovakia	102	127	25	0,2%	-45
Malta	4	0	-4	0,0%	-100
Luxembourg	63	52	-11	0,1%	-6
Cyprus	48	0	-47	0,0%	-95
Latvia	62	11	-51	0,0%	-71
Slovenia	178	126	-52	0,2%	-19
Estonia	59	5	-54	0,0%	-83
Croatia	155	52	-104	0,1%	-24
Belgium	808	691	-117	0,8%	-36
Lithuania	188	57	-131	0,1%	-43
Ireland	282	5	-277	0,0%	-97
Austria	764	433	-331	0,5%	-23
Finland	350	5	-344	0,0%	-94
Czechia	633	282	-351	0,3%	-45
Bulgaria	494	130	-365	0,2%	-14
Portugal	1 231	735	-495	0,9%	38
Romania	568	13	-554	0,0%	-89
Sweden	920	243	-677	0,3%	-43
Greece	1 347	367	-980	0,5%	25
Poland	1 446	317	-1 129	0,4%	-53
France	2 277	891	-1 385	1,1%	-37
Italy	1 921	239	-1 682	0,3%	-76
Germany	5 865	3 512	-2 353	4,3%	-23
Netherlands	6 306	3 624	-2 682	4,4%	12
Spain	3 603	773	-2 830	0,9%	-28
Total EU27	29 625	14 607	-15 018	18%	-21

Note: Photovoltaic trade data for Poland in 2022 has not been updated in the Comtrade database.
For this table, data from 2021 are reported for 2022, as photovoltaic exports are negligible in the total RES figures

Main EU partners' trade with the rest of the world (including EU27). 2022 - all RES

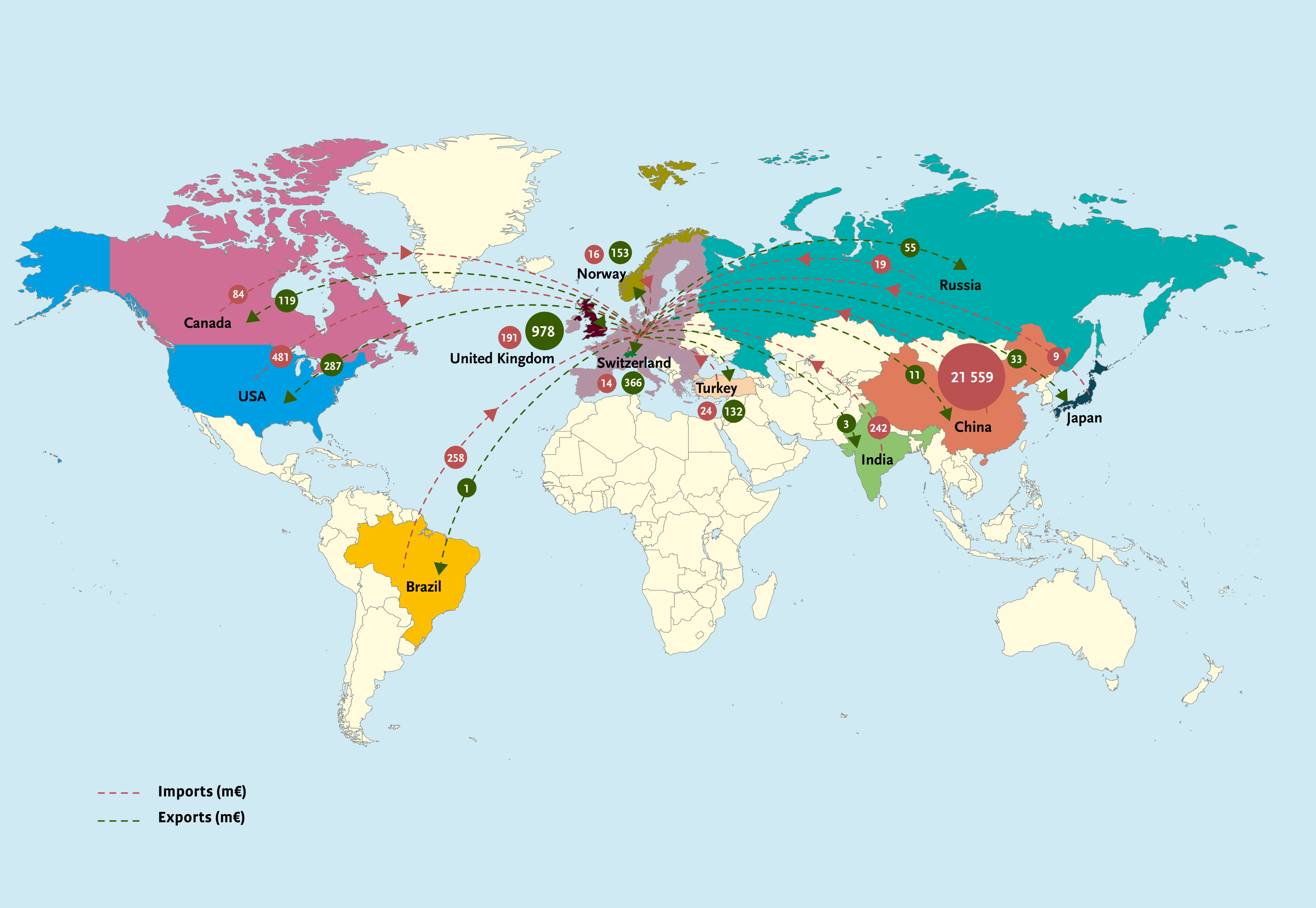
	Imports (in € m)	Exports (in € m)	Net exports (in € m)	Share of global exports	Exports specialisation (RCA)
China	1 473	43 890	42 417	53,9%	49
Russia	-	-	-	0,0%	N/A*
Norway	209	1	-208	0,0%	-99
India	1 458	1 003	-455	1,2%	-20
Switzerland	652	18	-634	0,0%	-96
Turkey	1 362	244	-1 118	0,3%	-51
United Kingdom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

**Data not available*

scores ahead of the remaining countries, i.e. goods related to RET technologies have a large weight in Denmark's export portfolio. Positive specialisation values can also be found for 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 2021.

Both the total RET import values for the EU27 increased significantly in 2022 compared to 2021, by approximately €8 500 million. The total RET export values have decreased by 13% (€1 525 million. The most significant relative increases in imports can be observed for Spain (€1 921 million), the Netherlands (€1 645 million), Germany (€1 565 million) and Portugal (€701 million). The exports in Germany decreased most of all the EU27 (€1 568 million). A few other countries also show large relative decreases in export, most notably France, Denmark and Italy. Other large relative increases in imports can be seen in Bulgaria, Czechia, Romania and Belgium, together accounting for export volumes of around €1 100 million. Net exports declined significantly in the Netherlands, due to an increase in PV imports and a decrease in wind energy exports. Spain, Germany, Italy and France also showed significant decreases in net exports, mainly as a result of increase in PV imports and a decrease in wind energy exports. When looking at the main trading partners we see a large increase in imports in the USA (€2 499 million) and Brazil (€1 235 million) in 2022 compared to 2021. Large decreases in imports can be seen for China (€6 791 million), India (€2 339 million), the UK (€585 million) and Japan (€271 million). For exports we see the largest shift in China (€14 146 million increase), followed by Japan (€3 167 million decrease) and the U.S.A. (€737 million decrease). The trade balances follow these trends, with China showing the largest increase in the

EU27 trade with its main trading partners. 2022 - all RES



Source: EurObserv'ER

trade balance. The U.S.A. has a large negative trade balance in 2022 compared to 2021. Brazil, Turkey, Norway and Russia still have a negative trade balance, have worsened their positions between 2021 and 2022.
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 2022 with 54%. For the EU27, we see a decrease in export shares from 21% in 2021 to 18% in 2022.

Note that the PV data for 2022 of Poland has not been updated in the Comtrade database, at the time of publishing this report. For this dataset, data from 2021 was assumed the same for 2022. This may yield slight differences in expectations for the total numbers.

The trade in RET between the EU27 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 EU27 than the reverse. Imports from China increased by almost €12 000 billion in 2022 compared to 2021. The EU27 also has a negative RET trade balance with Brazil, India, and the U.S.A. in 2022. On the other hand, the EU27 has a significant positive RET trade balance with the U.K., Switzerland, Norway and Turkey. Trade balance with Russia has significantly increased by around €16 million from 2021 to 2022. ■

1. *UN Comtrade: International Trade Statistics*

WIND ENERGY

EU27 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%	N/A*
Luxembourg	0	-	0	0,0%	N/A*
Malta	0	-	0	0,0%	N/A*
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 EU27	1 489	4 387	2 898	72%	37

Main EU partners' trade with the rest of the world (including EU27). 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 wind power, Germany (34%) and Denmark (27%) are the major players in terms of export shares. They are followed by Spain, which also shows large export shares in wind energy of more than 8%. The Netherlands has significantly decreased its exports by almost €400 million, leading to an export share lower than 1%. Around 72% of worldwide exports in wind technologies originate from these three countries. Chinese export shares have increased from 7.5% in 2017 to 20% in 2021, showing an increasingly large role for China in global wind energy exports. India follows at quite some distance with 4.1% 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 and Spain. In terms of export specialisation (RCA), Denmark is the most highly specialised in trade of wind technology related goods. Germany and Spain are also highly specialised in wind technology exports. China's export specialisation in wind technology increased from -52 in 2017 to 11 in 2021, again showcasing the rapidly changing position of China in the global trade of wind technology goods.

EU27 trade (incl. intra-EU trade). 2022 - wind energy

	Imports (in € m)	Exports (in € m)	Net exports (in € m)	Share of global exports	Exports specia-lisation (RCA)
Germany	127	1 483	1 356	31.2%	56
Denmark	55	1 274	1 219	26.8%	93
Spain	99	273	174	5.8%	46
Hungary	0	2	1	0.0%	-86
Slovakia	0	1	0	0.0%	-93
Portugal	20	21	0	0.4%	9
Luxembourg	0	0	0	0.0%	N/A*
Cyprus	0	0	0	0.0%	N/A*
Latvia	0	0	0	0.0%	N/A*
Slovenia	0	0	0	0.0%	N/A*
Malta	0	0	0	0.0%	N/A*
Croatia	0	0	0	0.0%	-96
Bulgaria	0	0	0	0.0%	-94
Czechia	2	1	-1	0.0%	-92
Romania	1	0	-1	0.0%	-100
Estonia	9	0	-8	0.0%	-79
Lithuania	26	12	-14	0.2%	8
Ireland	25	3	-23	0.1%	-83
Belgium	26	1	-25	0.0%	-96
Austria	26	1	-25	0.0%	-94
Greece	91	25	-66	0.5%	32
Italy	93	1	-93	0.0%	-98
Poland	143	2	-141	0.0%	-92
France	158	2	-156	0.0%	-94
Finland	161	0	-161	0.0%	-93
Sweden	181	0	-181	0.0%	-96
Netherlands	322	35	-287	0.7%	-57
Total EU27	**1 569**	**3 139**	**1570**	**66%**	**34**

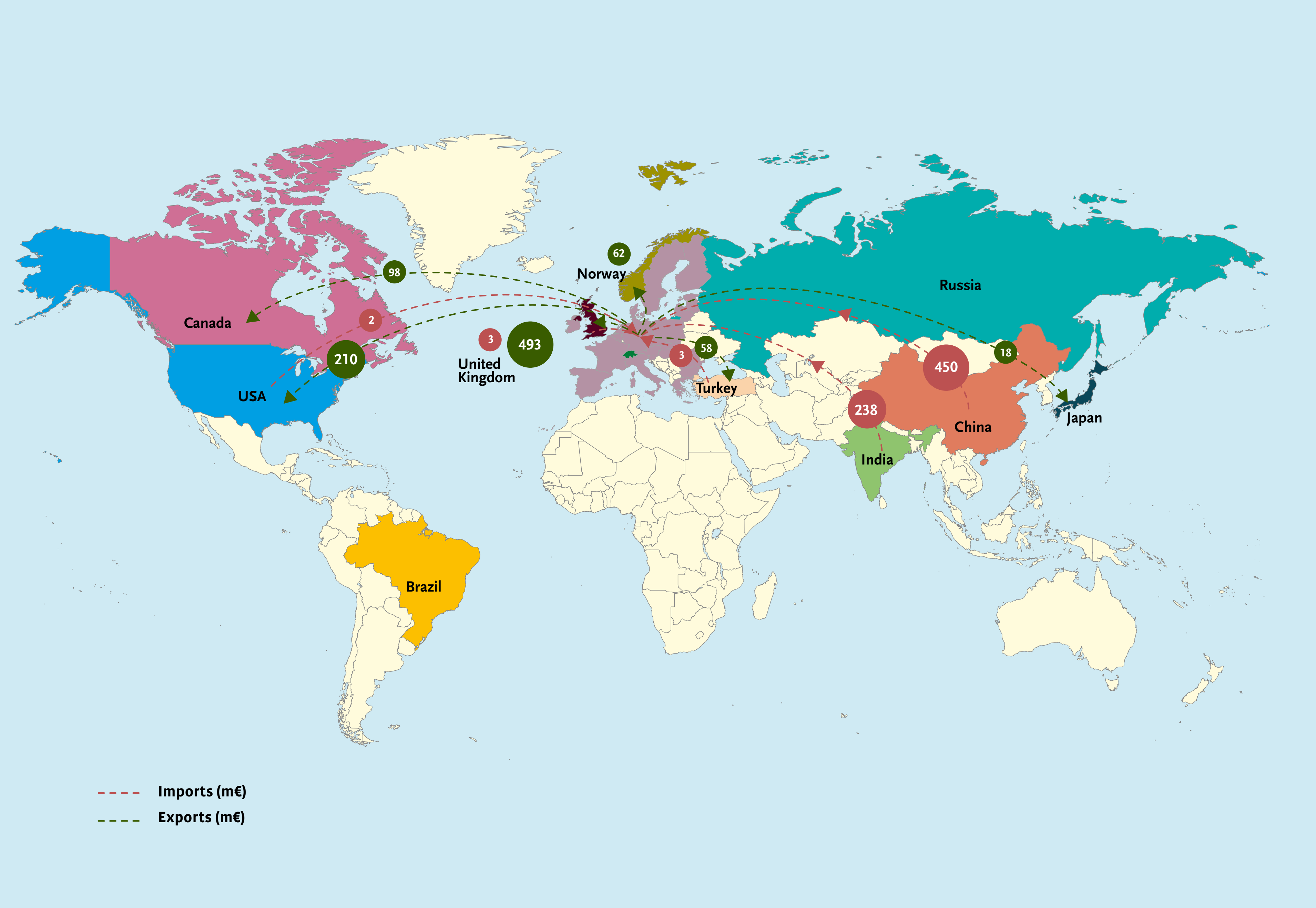
Main EU partners' trade with the rest of the world (including EU27). 2022 - wind energy

	Imports (in € m)	Exports (in € m)	Net exports (in € m)	Share of global exports	Exports specia-lisation (RCA)
China	3	921	918	19.4%	9
India	3	339	336	7.1%	51
Russia	0	0	0	0.0%	N/A*
Switzerland	0	0	0	0.0%	-100
Norway	62	0	-62	0.0%	-100
Brazil	143	67	-76	1.4%	-1
Turkey	99	1	-98	0.0%	-92
Japan	174	1	-173	0.0%	-98
USA	408	162	-246	3.4%	-40
United Kingdom	387	112	-275	2.4%	1
Canada	455	1	-454	0.0%	-98
Rest of the world	2 462	5	-2 663	0.1%	-99

Source: EurObserv'ER

In 2022, Germany (31%) and Denmark (27%) remain major players in terms of export shares, despite the decrease in exports from Germany compared to 2021. Spain showed a decrease in export share to 6%. In total, the net exports of the EU27 decreased in 2022. Even with the decreased exports from Denmark, more than 65% of worldwide exports in wind technologies originate from the EU27. Chinese export shares have decreased slightly to 19% in 2022, stabilizing the growth of the role China has in global wind energy exports. Exports from the India and U.S. have increased significantly to 7.1% and 3.4%, while exports from Brazil decreased slightly in 2022.
In 2022, neither Germany nor Denmark reached the €1.5 billion mark of positive trade balance. China followed at €0.9 billion in net exports. The Netherlands and Spain showed further decreases in net exports to €287 million and €174 million respectively in 2022.
Denmark remains the most specialised wind energy exporter, followed by Germany, India and Spain. China's export specialisation in wind technology remained positive (9) in 2021. In 2022 we also observe a positive RCA in wind energy for the U.K.

EU27 trade with its main trading partners. 2022 - wind energy



Source: EurObserv'ER

In terms of trade balance, we observe a positive trade balance for the EU with most of the main trading partners, including the U.K., the U.S., Turkey, Norway, and Japan. Net exports to Norway, Turkey, the U.K. and the U.S.A decreased significantly. The total exports from wind energy to countries outside the EU27 was lower than €1 billion.

The EU was a net importer from China and India in 2022. Net imports from China and India increased by about €48 million and € 11 million compared to 2021, respectively. ■

PHOTOVOLTAIC

EU27 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	-1 063	0.1%	-83
Netherlands	3 375	2 250	-1125	3.6%	5
Spain	1 511	141	-1 370	0.2%	-72
Total EU27	**15 231**	**7 189**	**-8 042**	**11%**	**-39**

Main EU partners' trade with the rest of the world (including EU27). 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	-2 301	0.0%	-99
India	3 524	139	-3 384	0.2%	-72
USA	8 080	2 076	-6 005	3.3%	-37
Rest of the world	20 057	20 906	1 004	33.4%	6

Source: EurObserv'ER

In photovoltaics, China remains the largest player with almost 45% of global exports. They are followed at quite some distance by Japan (5%), Germany (4%) and the Netherlands (4%). In total, the EU27 reach a 11% share in 2021. The share of the «rest of the world» category is also very high (33% in 2021), showing that there are large exporters not included in the above list.

Regarding net exports in PV, only China has a significant positive balance. All other countries in this comparison have a negative trade balance, i.e. they are importing more PV technologies than they export. The most negative one can be found for the U.S., followed by the EU27, 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 the Netherlands have a positive RCA.

EU27 trade (incl. intra-EU trade). 2022 - photovoltaic

	Imports (in € m)	Exports (in € m)	Net exports (in € m)	Share of global exports	Exports specia-lisation (RCA)
Malta	4	0	-4	0,0%	-100
Luxembourg	59	52	-7	0,1%	5
Latvia	33	4	-30	0,0%	-84
Estonia	44	4	-39	0,0%	-82
Cyprus	46	0	-46	0,0%	-94
Slovakia	66	8	-57	0,0%	-91
Slovenia	161	89	-72	0,1%	-23
Lithuania	91	10	-81	0,0%	-80
Finland	90	1	-89	0,0%	-98
Croatia	140	49	-91	0,1%	-15
Ireland	187	1	-186	0,0%	-100
Sweden	265	9	-256	0,0%	-95
Denmark	319	14	-305	0,0%	-89
Czechia	551	218	-333	0,3%	-45
Romania	380	12	-368	0,0%	-88
Hungary	413	19	-394	0,0%	-87
Belgium	583	172	-411	0,3%	-70
Bulgaria	484	21	-463	0,0%	-67
Portugal	1 176	706	-470	1,1%	46
Austria	651	104	-547	0,2%	-63
Greece	1 082	342	-741	0,5%	32
France	1 262	211	-1 050	0,3%	-72
Poland	1 125	62	-1 063	0,1%	-83
Italy	1 534	84	-1 450	0,1%	-87
Netherlands	3 966	1 752	-2 214	2,8%	-8
Germany	4 194	1 448	-2 746	2,3%	-47
Spain	3 329	155	-3 174	0,2%	-70
Total EU27	**21 108**	**5 485**	**-15 624**	**9%**	**-49**

Note: Photovoltaic trade data for Poland in 2022 has not been updated in the Comtrade database. For this table, data from 2021 are reported for 2022, as photovoltaic exports are negligible in the total RES figures

Main EU partners' trade with the rest of the world (including EU27). 2022 - photovoltaic

	Imports (in € m)	Exports (in € m)	Net exports (in € m)	Share of global exports	Exports specia-lisation (RCA)
China	1 466	42 796	41 330	67.9%	56
Russia	0	0	0	0.0%	N/A*
Norway	73	0	-72	0.0%	-100
Canada	395	179	-216	0.3%	-75
Switzerland	454	5	-450	0.0%	-98
United Kingdom	638	23	-616	0.0%	-95
India	1 231	528	-702	0.8%	-36
Turkey	1 161	221	-940	0.4%	-46
Japan	2 108	58	-2 050	0.1%	-91
Brazil	3 673	0	-3 672	0.0%	-100
USA	10 130	44	-10 086	0.1%	-97
Rest of the world	8 215	13 658	5 899	21.7%	-14

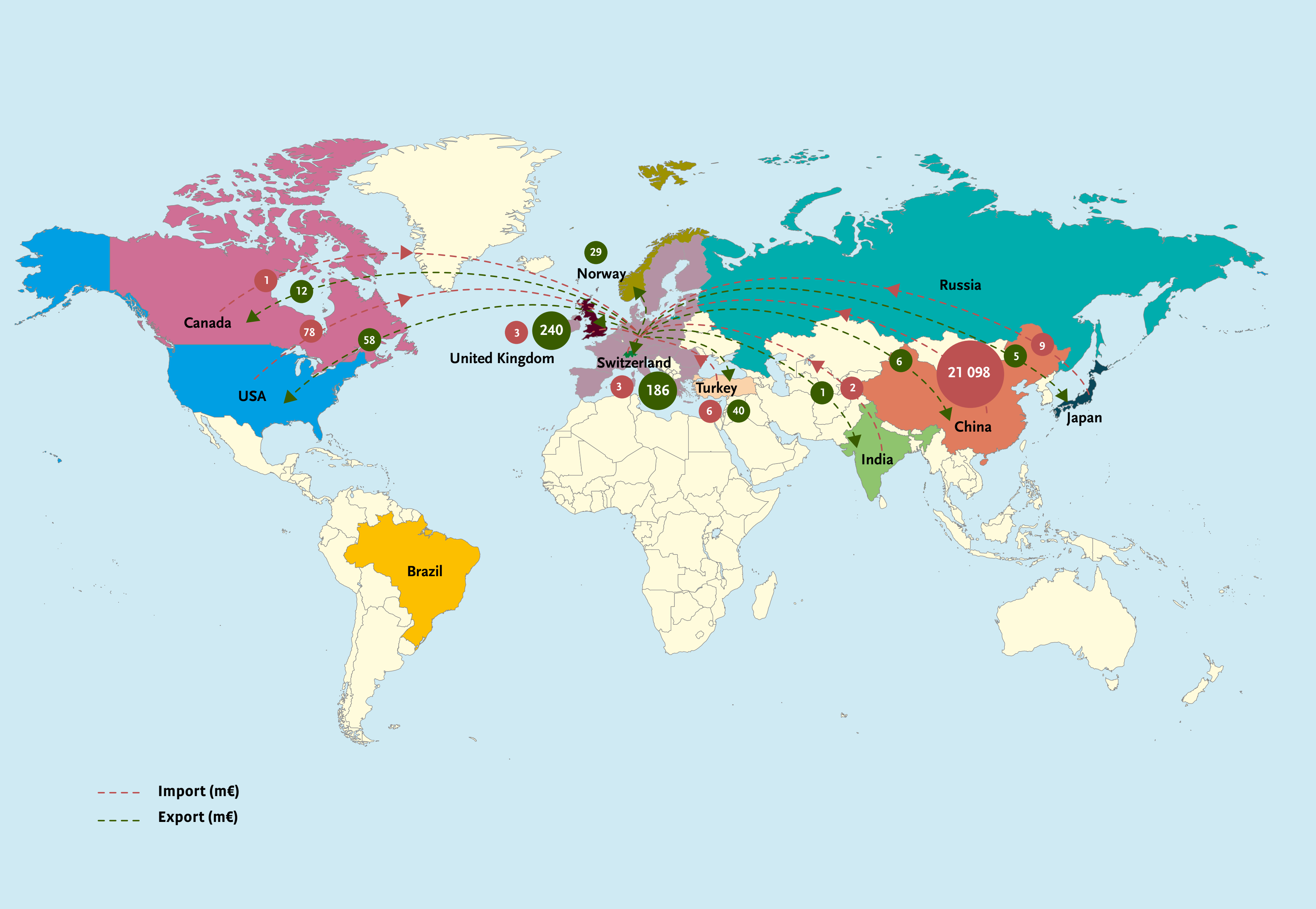
Source: EurObserv'ER

The top position of China can be confirmed again in 2022, with a big increase to a total of 68% of worldwide exports in PV originating from China. They are once more followed by the Netherlands (2.8%), Germany (2.3%) and Portugal (1.1%). The EU27 decreased its share of exports to 9% in 2022. Regarding net exports in PV, China remains the only net exporter, at a significant positive value. All other countries, including countries in the EU in this comparison have a negative trade balance. India and the U.S. decreased net imports by over €3 billion and €2 billion respectively. Net imports increased significantly for the EU27 and in many countries, such as Brazil and the U.S.A. China remains the most highly specialised in goods related to PV, followed by India. Portugal significantly increased its positive RCA, while the Netherlands decreased its RCA to the negative. Luxembourg is the only other country with a positive RCA.

Note that the PV data for 2022 of Poland has not been updated in the Comtrade[1] database, at the time of publishing this report. For this dataset, data from 2021 was assumed the same for 2022. This may yield slight differences in expectations for the total numbers.

1. *UN Comtrade: International Trade Statistics*

EU27 trade with its main trading partners. 2022 – 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 €19 billion compared to 2021. The EU also has a negative trade balance in PV with Japan and the U.S.A. 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.K., Switzerland, Turkey and Norway. ■

BIOFUELS

EU27 trade (incl. intra-EU trade). 2021 - Biofuels

	Imports (in € m)	Exports (in € m)	Net exports (in € m)	Share of global exports	Exports specialisation (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	1368	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	0	-50	0.0%	N/A*
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 EU27	**4 318**	**4 190**	**-128**	**46%**	**19**

Main EU partners' trade with the rest of the world (including EU27). 2021 - Biofuels

	Imports (in € m)	Exports (in € m)	Net exports (in € m)	Share of global exports	Exports specialisation (RCA)
USA	378	2 421	2 043	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 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 EU27, the U.S. and Brazil score the top positions when looking at the shares on global exports. More than 80% of worldwide exports in biofuels originate from these three regions (2021 as well as 2022). 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, Canada, Japan 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, the U.S.A., Bulgaria and Belgium.

EU27 trade (incl. intra-EU trade). 2022 - Biofuels

	Imports (in € m)	Exports (in € m)	Net exports (in € m)	Share of global exports	Exports specia-lisation (RCA)
Hungary	30	648	617	5.0%	71
Belgium	199	517	318	4.0%	29
Austria	51	212	162	1.6%	25
Spain	167	327	160	2.5%	13
Bulgaria	9	105	96	0.8%	51
Slovakia	36	118	82	0.9%	28
Poland	177	251	74	1.9%	11
Malta	0	0	0	0.0%	-100
Cyprus	1	0	-1	0.0%	-100
Luxembourg	3	0	-3	0.0%	-97
Estonia	7	0	-6	0.0%	-90
Slovenia	8	1	-7	0.0%	-94
Croatia	14	0	-14	0.0%	-94
Latvia	28	7	-21	0.1%	-26
Portugal	34	4	-29	0.0%	-77
Lithuania	71	35	-36	0.3%	13
Czechia	78	30	-47	0.2%	-57
Ireland	69	2	-68	0.0%	-95
Finland	96	0	-96	0.0%	N/A*
Greece	171	0	-170	0.0%	-98
Netherlands	2 018	1 834	-184	14.2%	56
Romania	186	1	-184	0.0%	-93
Italy	279	90	-188	0.7%	-55
France	843	654	-189	5.0%	27
Denmark	254	20	-234	0.2%	-51
Sweden	470	231	-240	1.8%	30
Germany	1 525	513	-1 012	4.0%	-26
Total EU27	**6 824**	**5 601**	**-1 223**	**43%**	**16**

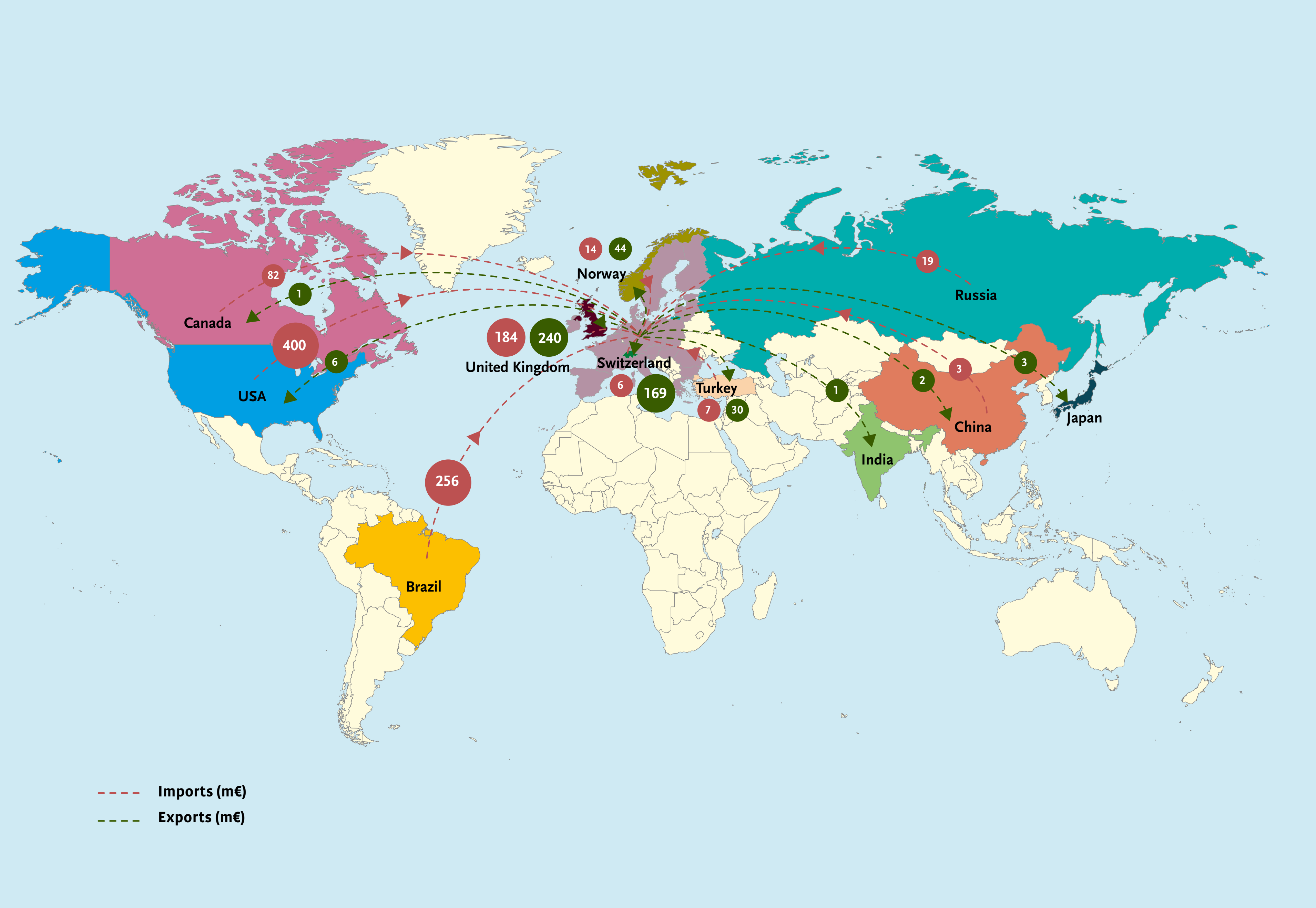
Main EU partners' trade with the rest of the world (including EU27). 2022 - Biofuels

	Imports (in € m)	Exports (in € m)	Net exports (in € m)	Share of global exports	Exports specia-lisation (RCA)
USA	564	3 576	3 012	27.6%	45
Brazil	202	1 622	1 420	12.5%	73
China	3	11	8	0.1%	-98
Russia	0	0	0	0.0%	N/A*
Norway	53	0	-53	0.0%	-100
Turkey	94	11	-84	0.1%	-81
India	221	91	-130	0.7%	-42
Switzerland	175	7	-169	0.1%	-91
Japan	649	1	-648	0.0%	-99
United Kingdom	1 019	184	-834	1.4%	-21
Canada	1 364	197	-1 168	1.5%	-23
Rest of the world	2 218	1 656	-561	12.8%	-35

Source: EurObserv'ER

In 2021, both imports and exports of biofuels increased in the EU, yet net imports increased to €1 223 million. The share of global exports decreased from 46% in 2021 to 43% in 2022. The U.S., the Netherlands and Brazil remain the largest biofuel exporters. Brazil's net exports increased to €1 420 million, compared to around €700 million in 2020. Brazil remains the most specialised in biofuels trade.

EU27 trade with its main trading partners. 2022 – 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.S., Brazil and Canada. The EU also has a positive trade balance with the U.S. and Brazil. ■

HYDROELECTRICITY

EU27 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
Italy	16	51	35	5.7%	35
Czechia	4	44	39	4.8%	62
Slovenia	8	34	27	3.8%	87
France	15	27	12	3.0%	12
Spain	6	25	18	2.7%	24
Bulgaria	2	5	4	0.6%	50
Netherlands	1	4	3	0.4%	-68
Poland	1	3	3	0.4%	-47
Hungary	0	3	3	0.4%	-19
Portugal	4	3	-2	0.3%	-1
Sweden	6	2	-4	0.2%	-49
Croatia	0	2	1	0.2%	37
Finland	4	2	-2	0.2%	-26
Romania	1	1	0	0.1%	-52
Denmark	0	0	0	0.1%	-75
Greece	7	0	-6	0.0%	-74
Lithuania	0	0	0	0.0%	-66
Belgium	1	0	0	0.0%	-95
Slovakia	1	0	-1	0.0%	-95
Luxembourg	2	0	-2	0.0%	-78
Ireland	0	0	0	0.0%	-97
Estonia	0	0	0	0.0%	N/A*
Malta	0	0	0	0.0%	N/A*
Cyprus	0	0	0	0.0%	N/A*
Latvia	3	0	-3	0.0%	N/A*
Total EU27	**127**	**366**	**239**	**40%**	**20**

Main EU partners' trade with the rest of the world (including EU27). 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 hydropower, we can see a more balanced picture than in the case of PV and wind energy. Within the EU27, the largest export shares can be found for Austria (11%), Germany (7%), Italy (6%), Czechia (5%), Slovenia (4%) and France (3%). In sum, the EU27 is responsible for more than 40% of the worldwide exports within hydropower. As a single country, China also shows a large value of 18%. China is followed by Brazil at 6.6%. The U.S.A. and India follow with export shares of 4.7%. The largest positive net export values within the EU27 are displayed for Austria, Germany, Czechia, Italy, Slovenia, Spain, and France. Yet, the largest value globally can be found for China. Russia, Switzerland, Japan and Norway display a negative trade balance. The specialisation values in hydroelectricity show a rather positive picture for Europe, with eight EU27 members having a positive RCA value. Slovenia and Austria are most highly specialised in the export of hydropower goods, followed by Brazil, Turkey and India. China also shows positive RCA values, but its specialisation in PV is still higher than it is in hydroelectricity.

EU27 trade (incl. intra-EU trade). 2022 - hydroelectricity

	Imports (in € m)	Exports (in € m)	Net exports (in € m)	Share of global exports	Exports specia-lisation (RCA)
Austria	36	116	79	15.3%	84
Italy	15	64	49	8.5%	44
Germany	18	67	49	8.9%	8
Czechia	3	33	30	4.3%	54
Slovenia	9	36	27	4.8%	86
France	14	24	10	3.2%	7
Spain	8	17	9	2.3%	9
Portugal	0	4	4	0.5%	17
Bulgaria	1	3	3	0.4%	30
Netherlands	0	3	2	0.4%	-73
Croatia	0	2	2	0.3%	42
Finland	2	4	1	0.5%	10
Poland	1	2	1	0.3%	-62
Belgium	0	1	1	0.1%	-82
Malta	0	0	0	0.0%	N/A*
Lithuania	0	0	0	0.0%	-98
Denmark	0	0	0	0.0%	-79
Cyprus	0	0	0	0.0%	N/A*
Slovakia	0	0	0	0.0%	-93
Estonia	0	0	0	0.0%	-100
Ireland	1	0	-1	0.0%	-93
Latvia	1	0	-1	0.0%	-87
Sweden	4	3	-1	0.4%	-35
Romania	2	1	-1	0.1%	-58
Luxembourg	1	0	-1	0.0%	-92
Hungary	3	2	-2	0.2%	-43
Greece	3	0	-3	0.0%	-99
Total EU27	124	382	258	50%	23

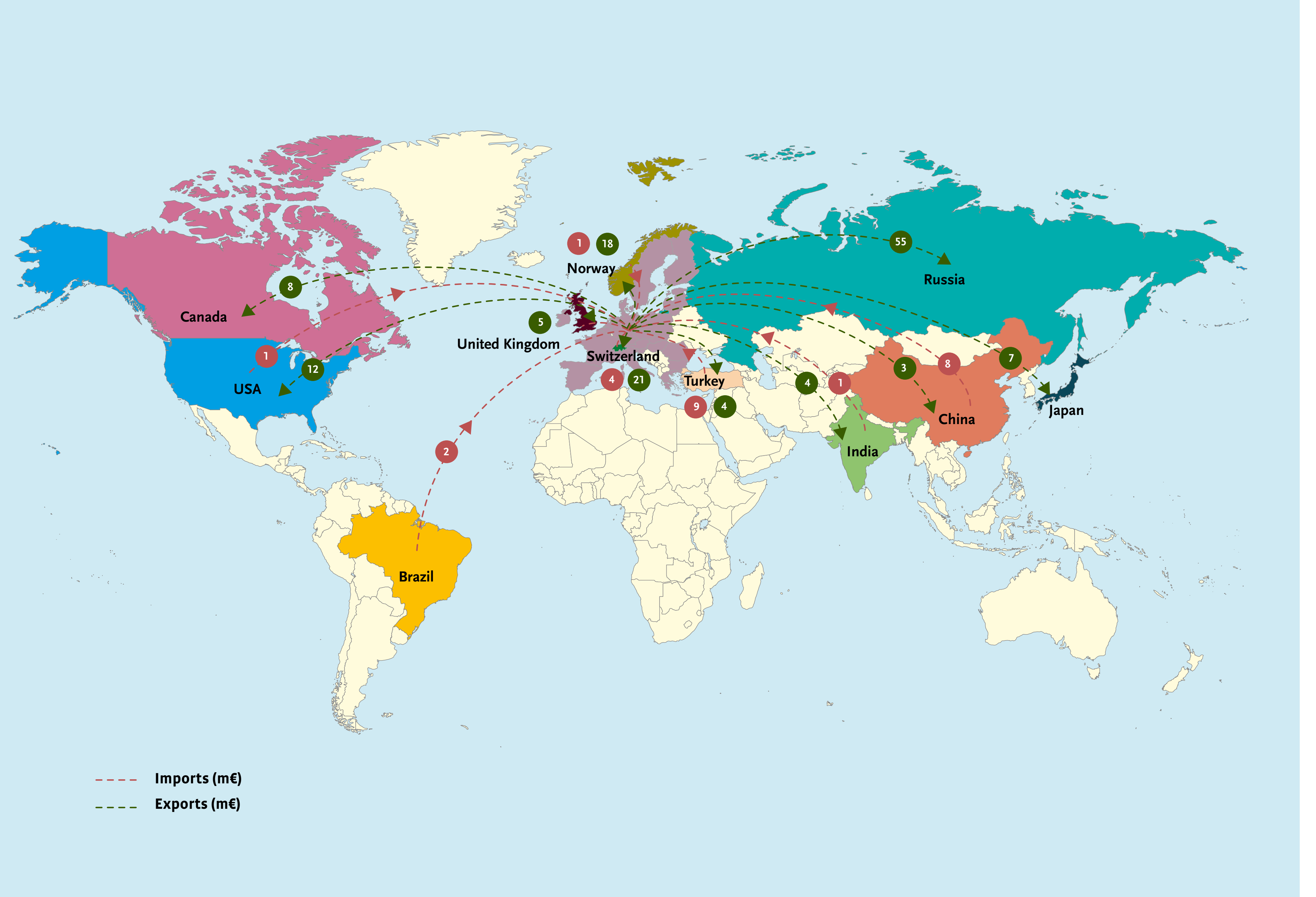
Main EU partners' trade with the rest of the world (including EU27). 2022 - hydroelectricity

	Imports (in € m)	Exports (in € m)	Net exports (in € m)	Share of global exports	Exports specia-lisation (RCA)
China	2	162	161	19.8%	14
India	4	45	41	5.5%	44
Brazil	4	45	41	5.5%	54
Turkey	8	11	3	1.3%	10
United Kingdom	15	17	1	2.0%	-2
Russia	0	0	0	0.0%	N/A*
Japan	14	7	-7	0.8%	-52
USA	39	24	-15	3.0%	-42
Switzerland	22	7	-15	0.8%	-29
Canada	32	16	-16	1.9%	-9
Norway	21	1	-20	0.2%	-69
Rest of the world	333	40	-293	4.9%	-64

Source: EurObserv'ER

In 2022, net exports of hydropower goods in the EU27 increased compared to 2021. The export share of the EU increased to 50% of global exports. The largest increase in exports is observed for Austria, to 15% of the total export. China's and India's exports also increased, as did its share of global exports. Brazil and the U.S.A., on the other hand, decreased their export and export shares. Germany and Slovenia showed increases of their share of exports. Furthermore, there are no large shifts in net exports.
When it comes to export specialisation, two countries in EU27 stand out with the highest RCAs: Slovenia and Austria. Other countries that show high specialisation indices are Brazil and India.

EU27 trade with its main trading partners. 2022 – 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 Canada, Norway, Switzerland, and the U.S.A. Negative trade balances for hydropower are observed with China, India 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 and to a lesser extent hydropower. China is also the country the EU27 imports the largest amount of RET from, led by large imports of photovoltaics. When it comes to photovoltaics, the EU27 share in world exports is small (9%) compared to China's share (68%). In wind energy, especially Germany and Denmark, but also Spain and India can be seen as strong competitive countries, with large roles in the worldwide export markets. These four 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 almost 20% in 2022, ranking third in net exports behind Germany and Denmark.

The EU is a large player in the biofuels market, with a 43% share in global exports. The U.S. and Brazil are responsible for another 40% of global exports, showing the large role of these countries and the EU. In the EU, the Netherlands, Hungary and France are the largest exporters. They are followed by Belgium, Germany and Spain. Germany, however, imports much more biofuels than they export and therefore has a large negative trade balance. Apart from France, the other three EU countries have a positive trade balance.

In hydroelectricity, the picture is very balanced. Several European countries are active on worldwide export markets, while also China is responsible for comparably large shares. The EU's share in global exports increased significantly to just over 50% in 2022, with the biggest share coming from Austria. Overall, the EU displays a strong competitiveness in all RET fields, yet the total export share decreased to 18% in 2022, from 21% 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. China's exports increased significantly, exporting more than 50% of the total RET exports in 2022. ■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- European Alternative Fuels Observatory *https://alternative-fuels-observatory.ec.europa.eu*
- EBA – European Biogas Association *(www.european-biogas.eu)*
- EBB – European Biodiesel Board *(www.ebb-eu.org)*
- EGEC – European Geothermal Energy Council *(www.egec.org)*
- EHPA – European Heat Pump Association *(www.ehpa.org)*
- Ocean Energy Europe *(www.oceanenergy-europe.eu)*
- Eurostat – Statistique européenne/European Statistics *(www.ec.europa.eu/eurostat/fr)*
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AUSTRIA

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BELGIUM

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CYPRUS

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- Cyprus Union of Solar Thermal Industrialists (EBHEK) *(www.ebhek.org.cy)*

CROATIA

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DENMARK

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ESTONIA

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FINLAND

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

FRANCE

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- UNICLIMA – Syndicat des industries thermiques, aérauliques et frigorifiques *(www.uniclima.fr/)*

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)*
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GREECE
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- Ministry of Environment and Energy and Climate Change *(https://ypen.gov.gr/)*

IRELAND
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- IWEA – Irish Wind Energy Association *(www.iwea.com)*
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- SEAI – Sustainable Energy Authority of Ireland *(www.seai.ie)*

ITALY
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- 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
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- 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
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ROMANIA
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SPAIN
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SLOVENIA
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SWEDEN
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- SCB – Statistics Sweden *(www.scb.se)*
- Svensk Solenergi – Swedish Solar Energy Industry Association *(www.svensksolenergi.se)*
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Wind power	**>> March 2024**
Photovoltaic	**>> April 2024**
Solar thermal	**>> June 2024**
Heat pumps	**>> October 2024**
Renewables in transport	**>> November 2024**
Solid biofuels	**>> December 2024**

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