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Review article

Renewable energy transition in Europe in the context of renewable energy transition processes in the world. A review

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ABSTRACT

Both the global and European energy sectors have been undergoing a deep transition for several years, associated with a reduction in the overall share of conventional coal-based energy in favor of new technologies, especially energy from renewable sources (RES). This transition is moving from centralized production towards distributed technologies and from providing only energy to end users towards combining innovative products and services with it. Electricity consumers are becoming prosumers connected to the grid and generating an increasing amount of energy. The original goal of decision-makers was to stop global warming and improve air quality. After Russia's aggression of Ukraine in 2022, the EU transition efforts accelerated, and concerns about the climate were joined by issues related to energy security. After the painful experiences of the last several months, Europe wants to become independent from energy raw materials and their unstable suppliers as soon as possible, securing markets against price fluctuations, blackmail and unfair practices of some sellers. The aim of the article is to describe the current situation of energy and heat production from RES in selected countries in the aspect of contemporary energy transition (ET) processes. The achievement of the goal made it possible to present the European RES market in 2022, discuss the actions taken by European countries towards decarbonization and propose recommendations for the further development of the renewable energy market. The ET in Europe has been going on for over a dozen years, although there are countries, such as Norway, that use almost 100 % of renewable energy, as well as those that still largely use conventional fuels, such as Poland. In European countries, the energy mix of renewable energy, energy storage and green hydrogen should be developed. Green hydrogen produced in the electrolysis process

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from surplus renewable energy is an energy carrier with versatile applications both in the energy sector and in European industry.

1. Introduction

Energy transition (ET) is currently taking place not only in the energy sector, but in all economies of the world [1–4]. The systematic and dynamic development of these processes is a consequence of world globalization [5,6], which has resulted in an increase in interdependence between all markets [7–9], the institutional development of markets and the socio-economic growth of most countries [10]. Globalization processes have also influenced the functioning of the labor market and changes in consumption patterns, both of individual consumers, households and business entities [11,12]. Undoubtedly, the functioning of modern economies depends to a high extent on energy, especially electricity. It can be stated that an additional measure of the economic development of individual countries or regions is the amount of electricity produced and consumed [13]. This means that within the developing ET processes, processes related to the production of energy and heat, including processes related to RES, energy mix and energy security are extremely important [14–19].

In the last century, fossil fuels have enabled a very rapid economic development in recent decades. However, fossil fuel deposits are limited, their extraction is becoming more and more expensive, and combustion causes deterioration of environmental quality and climate change [20–22]. The environmental costs of coal combustion are also very high: from carbon dioxide emissions, through emissions of sulfur oxides, nitrogen oxides, heavy metals (lead, arsenic, cadmium, mercury, etc.), chlorine, fluorine, methane, and radioactive elements. aerosols, dust, dioxins, furans, carcinogenic organic compounds, mining waste in the form of ashes, slags and sewage, as well as problems with mining sinkholes [23]. Particularly toxic is mercury - an extremely toxic metal, causing damage to the nervous and hormonal systems, and threatening intellectual impairment in children [23,24].

The fact that burning fossil fuels must be abandoned due to the negative environmental consequences is already clear, and the ongoing discussion around the world is increasingly focused on whether to do it, but how to do it [25,26]. The shrinking time horizon of fossil fuel availability results from both the increase in consumption and the systematic decline in the volume of reserves. It turns out that there are not as many fossil fuels as previously thought, and the 21st century is the last century of fossil fuels. A natural solution is the availability of energy and heat from RES before fossil fuels run out. Additionally, the conflict in Ukraine has made Europe, and especially the EU member states, realize how dependent they are on imports of energy fuels from Russia. It was realized that full economic sanctions could not be imposed on Russia "right away" or excluded from the global financial circulation, because doing so would cause a massive energy crisis in Europe [27]. Therefore, the European Union as a community of 27 member countries has decided to accelerate the ET, which is expressed in the adopted strategies, regulations, created institutions, law and actions on socio-economic levels [28–30].

The innovative economy has been an important element of European prosperity for generations. Competition in this field is very strong and maintaining Europe's position requires a favorable systemic environment, including regulation, financing, business viability, education and social attitudes that stimulate future solutions and industries. Effective long-term policy and responsible risk management require systemic thinking to respond to challenges in a coherent manner. In the case of Europe, this means policy orientation towards moving away from fossil fuels, efficient exploit of energy and resources, and protection of natural capital and environmental services, as well as implemented in a way that stimulates the creation of innovative jobs and improves the quality of life [31].

The aim of the article is to describe the current situation of energy and heat production from RES in selected European countries in the aspect of contemporary ET processes. The achievement of the goal made it possible to present the European energy market in 2022 within the use of RES, discuss the actions taken by European countries towards decarbonization and propose recommendations for the future of the RES market.

2. Energy transition processes regarding the exploit of renewable energy sources – a literature review

ET is dynamic processes at the national or global level that, through changes in energy production processes and used, influence the sustainable development of economies and societies [32]. This means that the economy is switching from sources such as coal, oil or gas to RES such as solar, wind or geothermal energy [4]. The ET concerns not only enterprises, but also individual energy consumers or local governments, which all play a key role in counteracting the negative effects of the functioning of the world economies on the environment [33,34].

ET is possible with currently available technologies and it is worth doing it as soon as possible [35,36]. The barriers to transition do not lie in physical, technical or economic limitations, but primarily in "accustomation" to conventional sources. People do not like change, especially something new in their area (e.g. a biogas plant), which they consider to be lowering the quality of their life. When representatives of an energy company wanting to build wind turbines or biogas plants come to the village, local communities often protest, fearing the ugly sight, noise or smell. The NIMBY (Not In My Back Yard) effect (syndrome) [37] is solved when local communities are the owners and/or shareholders of these installations. Shares can be purchased for just a few hundred euros, so anyone who wants can be the (co-)owner of the installation. And since it is profitable and simple, there is great interest [38,39].

The heart of the energy revolution is a decline in resource use and energy consumption - so fast that the economy will not face shortages. At the same time, it is a huge investment program with the prospect of creating numerous jobs that will ensure a healthy economic situation. The ET should be linked to energy efficiency and energy saving [40]. The question arises about the sufficiency of resources for the massive expansion of the RES installation. It is true that not all hard-to-reach raw materials can be eliminated from specific technologies, but the range of different solutions is so wide that in most other RES installations all hard-to-reach raw materials can be replaced, especially by developing these technologies, e.g. wind turbines or energy storage, which rely only on abundantly available materials, or recycle them effectively [41].

In many countries, vertical axis wind turbines (VAWT) are in operation (Fig. 1). This turbine, also called the Darrieus turbine, usually has 2 or 3 long C-shaped loops that are connected at the bottom and top. The Darrieus turbine works regardless of the wind direction - it does not need to be adjusted to the wind. The horizontal cross-section of the rotor of this Savonius turbine is similar to the letter "S". The difference in the forces of the wind on the concave and convex sides of the blades causes the rotor to rotate, unfortunately, the turbine rotates slowly and therefore has little use for generating electricity. It is used for pumping water, anemometers, powering deep-sea buoys. It is used when reliability and costs are more important than efficiency [42,43].

The possibility of using earth's raw materials is visible in the case of photovoltaics (PV), where the vast majority (over 90 %) of PV cells use almost exclusively silicon and aluminum, abundant in the earth's crust and easily available. The only element with limited availability used in these cells is silver, but it can be eliminated from the structure with almost no loss of efficiency [44]. Also, the consumption of materials for silicon PV cells in the last decade, as a result of improved efficiency and lower material consumption, has dropped from about 16 g to about 5 g per W of installed power. Improved silicon wafer production processes are already in the implementation phase, allowing further reduction of material consumption by half and energy consumption by 80 %. Moreover, once produced, PV modules age very slowly - for example, in 14 German PV farms with silicon panels, a power decrease of 0.1 % per year for the entire power plant was found [45]. New generations of wind turbines based on easily available superconductors have also appeared, they will be much lighter, simpler to build, cheaper and made of fully recycled materials [46].

2.1. Exploit of RES in energy transition

RES sources are large: biomass, wind energy, solar energy (in various variants), water energy, waste energy and many others. Different energy sources work in different ways, produce energy in different forms and times, so they should complement each other. In an energy system powered by RES, much more attention should be paid to when energy is available, in what form, how to store it and how to match it all with the demand for various energy carriers (this demand will also need to be managed) [47]. The answer to this is the dynamic progress in various electricity storage technologies, stimulated by mobile device batteries and the growing electric car market, which can be compared to the pace of development of PV. The potential applications of graphene also look very promising, both in energy production and storage [48].

As part of the ET processes taking place, a key element is the proper management of the power system. For example, hydroelectric power plants can very quickly and easily adjust their power to the needs. When plenty of wind and solar power is available, hydroelectric plants can be shut down and store water upstream of the dam; and they will be activated when there is no wind and solar energy. Additionally, if a hydropower plant has two reservoirs - upper and lower - it can operate as a pumped-storage power plant. This is a perfect solution for cooperation with wind and PV farms. When they produce surplus electricity, they can be used to pump water

Fig. 1. Darrieus turbine (photo: Aarchiba).

from the lower reservoir to the upper one, and then (when there is no energy from wind and sun) use this water to drive turbines [49].

Biomass can also be used to produce stable energy. It seems necessary to use local sources of waste biomass, e.g. from sawmills or furniture companies. On poorer quality soils, energy crops (such as miscanthus or willow) should be grown, and plantations should be fertilized with sewage sludge or ash from biomass combustion [50]. Additionally, ash from burning wood is a rich fertilizer that is easily absorbed by plants. It contains potassium, sodium, phosphorus, calcium, magnesium and many other trace elements, for example silicon, iron, sulfur, boron and manganese. It is even called “fertilizer concentrate”. Ash also improves the soil structure and promotes the development of microflora, especially nitrogen-fixing bacteria, although it does not contain nitrogen itself. It is especially suitable for lawns, for growing vegetables and plants that like alkaline soil. It is alkaline, so it should not be used when growing acid-loving plants - rhododendron, azaleas or blueberries. The components contained in the ash after biomass combustion should be reused as a valuable agricultural fertilizer. Previous studies indicate the appropriate content of micro- and macroelements, thanks to which the fertilizing effect of phytoash is similar to that of commercial mineral fertilizers [51].

A stable source of gas/electricity/heat is also provided by a biogas plant [52]. Carbon dioxide must be removed from biogas to obtain practically pure methane (biomethane) [53]. Carbon dioxide from biogas can be used, solving the problem of using unnecessary (and therefore cheap) surplus electricity from wind and solar power plants at the peak of their production. These surpluses can be used for water electrolysis [54]. The hydrogen produced in this way can be combined with carbon dioxide from biogas, thus obtaining methane (the process also produces heat that can be used to heat buildings or for industrial purposes):

$$CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O \tag{1}$$

Biomethane can be easily stored in natural gas tanks; it can therefore be used for energy purposes in another place and time (when there is less energy production from wind and sun) [55]. This means that gas storage is not problematic from the point of view of the functioning of the economy and households. It turns out that storing heat is also not problematic. Small home heat accumulators (with a capacity of e.g. 1–2 m^3) can provide hot water for several days, with additional water heating in the accumulators when energy is easily available (i.e. cheap). Large batteries will be able to store heat seasonally - solar collectors will supply heat to them mainly in summer, biogas plants during operation, and wind and PV power plants during periods of excess electricity supply [56].

It should also be emphasized that biogas plants basically have no external costs (eliminating waste, which becomes an energy input and provides benefits to local communities). The construction of a rural heating network using heat from a biogas plant may bring additional benefits by eliminating the burdensome burning of coal and garbage and the resulting air pollution [57].

All the issues described above can be used in the construction of new intelligent energy systems. These systems can be expanded to include new issues, for example, there is a place for electric car batteries, the use of which can actively contribute to the stabilization of a network powered by sources that produce electricity intermittently, just like the use of stationary batteries in homes and companies. The battery of an electric car can be charged with the owner’s own electricity - a prosumer - or with electricity purchased from the network (when it is cheap). When you don’t need the car and electricity is expensive, you can sell the electricity stored in the battery as electricity. Similarly, using this mechanism, cities can expand networks of rented small urban electric cars [58].

It is worth emphasizing that the ET will be particularly beneficial for rural areas. First of all, part of the energy production will move there (biomass, biogas, wind, sun, etc.), which will result in economic benefits. In the new model, it is farmers who will gain the most – wind and solar farms and agricultural biogas plants will be built on their land. It is farmers who will supply materials to operate RES installations, some will find work there, and additionally they will benefit from taxes. Farmers’ income will be diversified [59].

2.2. *Energy security in energy transition*

An important issue within the ongoing ET processes is energy security [59]. Distributed, RES forming the energy mix guarantee the security of energy supplies and the use of the network by final consumers. The centralized energy system, based on several dozen large power plants, is exposed to serious failures, whether “natural” or deliberate physical or IT attacks. The distributed energy system, based on millions of diversified, dispersed and independent RES, creating energy clusters that can operate independently (e.g. biogas plant + wind turbine + PV), is similar in its resistance to the Internet network, which was designed at the time as a resistant structure to attacks that destroy its fragments. In a distributed energy system, a total blackout scenario will not occur [60]. Integration of the energy systems of European countries is also an important solution to increase energy security. The south of Europe has very good conditions for solar energy, the northern region - hydro energy, the western region - wind energy, and the eastern region - biomass. This makes it possible to create synergies between different energy sources and regions. Yes, creating an integrated market and transmission networks on a continental scale is a challenge, not so much technical, but rather political and business [61].

2.3. *Use of energy and heat cogeneration*

The next important step will be a large-scale transition to heat production in cogeneration. In a thermal power plant (e.g. coal or gas), only 30–50 % of the energy of the fuel burned in the power plant is converted into electricity. The rest is released as waste heat and usually heats the air, a nearby river or lake. This heat should be captured and distributed through the heating network to consumers - the power plant turns into a combined heat and power plant. In turn, small local coal-fired heating plants should be converted into CHP plants using biomass and biogas. The advantage of small power units is the ability to quickly turn them on and off, depending on needs. We do not have this option in the case of large fossil fuel units, which take many hours to turn on and off and also cause their accelerated wear. For this reason, flexible adjustment of the power of large units to the needs is basically impossible, and we should have sources that can dynamically adjust their power to the needs and thus supplement the generation of electricity from unstable energy sources, such as wind or sun [62]. Heat pumps can act as air conditioners, cooling water as needed (e.g. storing it in the form of ice) in the cold storage tank (this is the second smaller tank next to the heat storage tank) - depending on the needs, water from the heating network can be directed to the coil in the heat storage tank (so that radiators provide heat) or in a cold store (to cool them on hot days, which are becoming more and more frequent as the inevitable climate change progresses) [63].

2.4. *Potential of RES*

To sum up, it can be said that the potential to obtain energy from the natural environment is enormous. Based on a sustainable approach to the use of natural forces and environmental resources, electricity and heat/cold can be produced ecologically and at acceptable costs. For example, it is possible to use heat from industry, heat from sewage (thanks to heat pumps), traditional chimney losses through the technology of condensing water vapor from exhaust gases, thanks to which we recover an additional 35 % of heat from exhaust gases. Waste incineration plants, small hydroelectric power plants, heat pumps where the lower heat source is the Baltic Sea, rivers, lakes, air and even sewage play an important role. Numerous biogas plants produce electricity and heat or biomethane in cogeneration, which powers cars, buses and even trains [64].

The fact that the ET is “accelerating” is undeniably proven by the fact that within a few years the RES capacity in the world has increased from about 1200 MW to about 3100 MW (Fig. 2). Currently, photovoltaics and wind energy are mainly responsible for the increase in power [63,64].

2.5. *New jobs in energy transition*

ET means the development of new technologies, and therefore new, well-paid jobs. In the years 2010–2023, year by year, employment in the RES sector increased by several hundred thousand new jobs per year, and their total amounted to almost 13 million jobs worldwide (Fig. 3). Most people work in PV, biofuels and hydropower [67].

The RES installation is of course new sources of work, but also many financial benefits, such as VAT, corporate and personal income tax, as well as various types of fees related to the operation of the plant. The owners of RES installations often support local sports, local culture, and organize pro-ecological events. The local community, the commune and the State Treasury benefit from this [68]. Therefore, the overriding social interest is the construction and development of RES installations throughout the country. The development of RES installations results in an increase in taxes paid to local governments, which in turn can use them for specific purposes, e.g. construction of roads, kindergartens, playgrounds, etc. If the development of RES is relatively even, almost all municipalities in Poland will benefit. Most importantly, each renewable energy sector is “renewable”, so profits will be generated without time limits (fixed revenues) [69].

ET is not only about improving competitiveness by creating “flywheels” of the economy. Those countries that neglect energy efficiency (and, more broadly, the efficiency of resource use) and stubbornly stick to fossil fuels, especially imports of natural gas and crude oil, will in the next dozen or so years expose themselves to the threat of rising prices of fossil fuels and loss of competitiveness compared to economies based on their own RES. The ET guarantees lasting access to own sustainable energy sources and lack of sensitivity (also of a geopolitical nature) to oil and energy shocks, and therefore stable and competitive economic conditions [70].

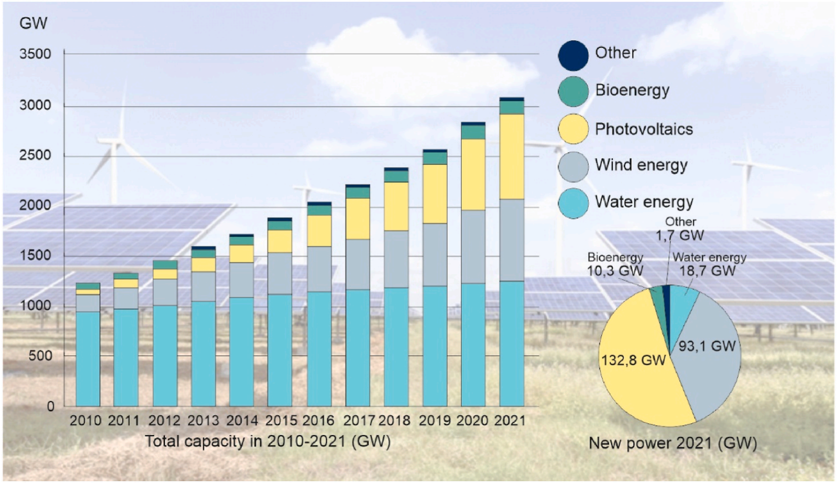

Fig. 2. Cumulative capacity of renewable energy in 2010–2021 (own elaboration based on [65,66]).

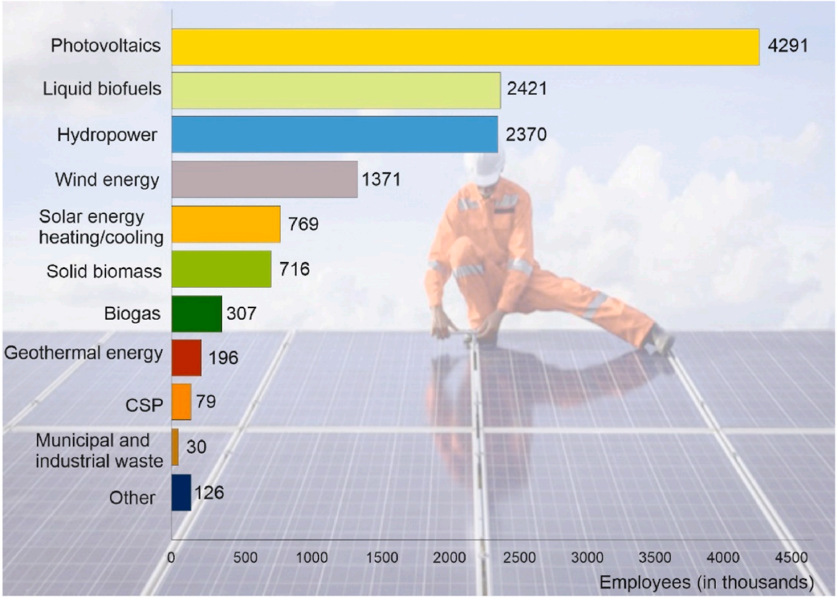

Fig. 3. Jobs in renewable energy in the world (own elaboration based on [67]).

2.6. *RES and green hydrogen in transition processes*

Green hydrogen can accelerate ET, as it can be used to store energy from RES, which will stabilize the power grid. Green hydrogen plays an important role in the transformation of industry - it will be a source of fuel, a source of energy, and in the chemical industry it will also be an important reaction raw material. Green hydrogen can also be used in the production of green methanol and green ammonia, which will allow a move away from natural gas. In the case of the transport market, green hydrogen can be used as a stand-alone fuel or for fuel cells, which are an alternative to combustion engines in vehicles [71].

3. The current course of energy transition processes in the world and Europe

The use of RES has become widespread around the world. In 2022, China's installed renewable capacity increased to 1.32 TW. Thus, RES has surpassed coal in China's generation mix in this respect. This means that China will most likely, within the next few months, achieve the 2025 goal of rebalancing the power system in such a way that the renewable sources park is larger than the capacity park installed in fossil fuels [66].

China leads the world in renewable energy (Table 1). Germany is in the top "5" in the world, and Spain is also in the "5" of aeroenergy, Turkey is in the top "5" of solar heating, and Turkey and Iceland are in the top "5" of geothermal heating [66].

Europe is leading in pro-environmental activities, undergoing ET, implementing sustainable development goals [72]. This is caused by falling RES prices, the desire to reduce greenhouse gas emissions, and the energy crisis following Russia's aggression against Ukraine [73]. These activities are also dictated by the agreement that European countries concluded in the Paris Agreement [74]. Gradual decarbonization and basing on own RES sources is the way to achieve energy independence for Europe [75]. Europe can

Table 1
Total power capacity as of end 2022 [62].

Power					
	1	2	3	4	5
Total RES capacity	China	United States	Brazil	India	Germany
Total RES capacity (no hydro)	China	United States	Germany	India	Japan
Total RES capacity per capita (no hydro)	Iceland	Denmark	Finland	Belgium	Greece
Biopower	China	Brazil	United States	India	Germany
Hydropower	China	Brazil	Canada	United States	Russian Federation
Solar PV	China	United States	Japan	Germany	India
Wind	China	United States	Germany	India	Spain
Geothermal	United States	Indonesia	Philippines	Turkey	New Zealand
Heat					
Solar water heating collector capacity	China	Turkey	United States	Germany	Brazil
Geothermal heat output	China	Turkey	Iceland	Japan	New Zealand

complete the energy transition by 2035; without additional costs above specified plans and without compromising security of supply. Further development of RES will "boost" the European economy, strengthen Europe's position as a leader in climate protection and pro-ecological actions and send an important signal to other world economies that ET is possible and environmentally and economically beneficial [76].

The EU aims to achieve climate neutrality by 2050, and this goal, as well as an interim 55 % emission reduction target by 2030, are enshrined in European climate law. Among the various initiatives taken by the EU to achieve these goals is the "Effort Sharing Regulation" [77], which is being updated as part of the "Ready for 55″ legislative package [78].

Further decarbonization of the energy system is crucial to achieving the climate goals for 2030 and 2050. About 75 % of greenhouse gas emissions in Europe come from the production and use of energy in various economic sectors. Energy efficiency must become a priority. We need to create an energy sector based largely on RES, while rapidly phasing out coal and reducing the emission intensity of the gas sector. In Europe, energy supply must be both secure and affordable for consumers and businesses. To this end, the full integration, interconnection and digitization of the European energy market should be ensured, while respecting technological neutrality [31].

The advantages of RES include high employment in this sector of the economy. For example, per 1 GW of wind energy, approximately 5000 jobs are created directly in the production, installation and maintenance of wind turbines, and the same number in supporting sectors of the economy [77].

Green hydrogen, direct electrification is difficult (for now) achievable here: cement production, metallurgy and steel production, maritime shipping, aviation, armed forces. Their decarbonization can be achieved with the help of hydrogen - both as a power source (directly or as a substrate for the production of e-fuels) and for industrial processes [80].

The clean ET should engage and benefit consumers. In cooperation with individual Member States, the production of energy from offshore should be increased. Sustainable development of RES, increased energy efficiency and implementation of pro-ecological activities will reduce greenhouse gas emissions at the lowest cost. Today, energy bills paid by households using RES are already lower than before [81,82]

In November 2019, the European Parliament declared a climate crisis, asking the European Commission to ensure that all its legislative proposals are consistent with the goal of limiting global warming to below 1.5 °C. In response, the European Commission presented the Green Deal Strategy - an action plan for Europe enabling it to become a climate neutral continent by 2050, which is understood as zero net emissions of greenhouse gases into the atmosphere: small residual emissions of greenhouse gases are to be compensated by absorbing an adequate amount of carbon dioxide (Fig. 4) [31,82].

The European Union has recently adopted an increase in the emission reduction target from the originally proposed 40 % emission reduction compared to 1990 to at least 55 %, preparing the Fit for 55 climate regulation package for this purpose. The key actions include:

- maximizing the benefits of energy efficiency, with particular emphasis on zero-energy buildings,
- implementing RES and using electricity to completely abandon the burning of fossil fuels,

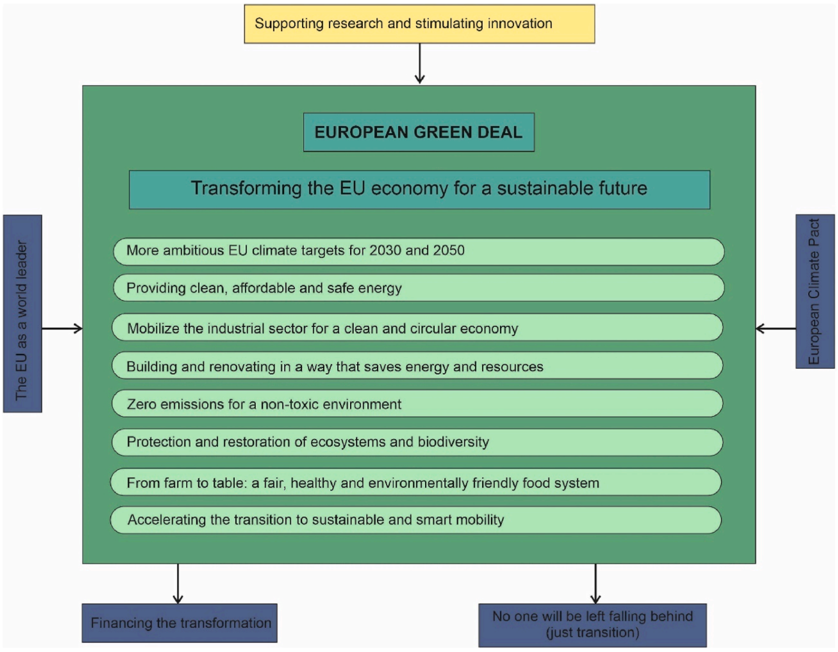

Fig. 4. European Grean Deal (own elaboration based on [31,82]).

- electromobility combined with systemic changes in transport,
- integration of the following sectors: electricity, transport, construction, industry and others, using digitalization,
- circular economy and the efficiency and competitiveness of the industry, efficient, sustainable and CO_2-absorbing use of biomass [31,82].

Firstly, it is proposed to recognize the development of RES as a matter of “overriding public interest”, enabling Europe to achieve climate neutrality. This could significantly speed up permitting, helping to more quickly resolve legal issues surrounding new RES installations. All administrative steps, network construction permits and environmental impact assessments (EIA) will have to be finalized within the specified deadlines. Achieving transparency on the procedural side is key to accelerating investment, as it removes developer uncertainty about the interpretation of Europe’s rules in EU-27 national, regional and local jurisdictions. European law states that the development of RES is possible only if the protection of biodiversity is taken into account. The development of RES is possible in a sustainable, ecosystem-friendly way, while contributing to Europe’s achievement of climate and energy security goals [31,82].

European governments have stated that RES are projects of “overriding public interest”, of course taking into account the appropriate location, not negatively affecting biodiversity. Necessary permits, which must be issued within the deadlines for permits for new and modernized projects. In the case of repowering, simplified EIAs have been introduced, which only take into account the additional effects related to the expansion of wind farms [31,82].

Europe is constantly developing and strengthening its leading role in the ET. There is extensive research and innovation in the field of RES and modern energy technologies in heating and cooling [74]. Progressing climate change and the conflict in Ukraine have made Europe “accelerate” the development of RES [28]. The RES target has been raised to at least 42.5 % by 2030, taking into account climate and biodiversity sustainability [31].

4. Electricity production from renewable sources in the world and in Europe

4.1. Development of PV in the world and in Europe

Due to the level of market commercialization in the form of availability and affordable price, PV is the most widespread source of RES in the world, especially in the individual consumer segment. The PV market in the world systematically continues its dynamic growth, where in 2022 the market increased by 243 GW of new PV, i.e. 61 GW more than year ago. This was the largest increase in annual capacity in recent years and contributed to raising the cumulative total PV capacity to 1185 GW. PV was estimated to account for 6.2 % of global electricity production in 2022, up from 5 % in 2021. By the end of 2022, at least 9 countries had enough installed solar PV capacity to meet at least 10 % of their electricity demand, and an additional 22 countries had enough installed PV capacity to meet about 5 % of their electricity demand [83–85].

In terms of spatial variation in PV energy production, Asia dominates the region in terms of new PV installations for the tenth year

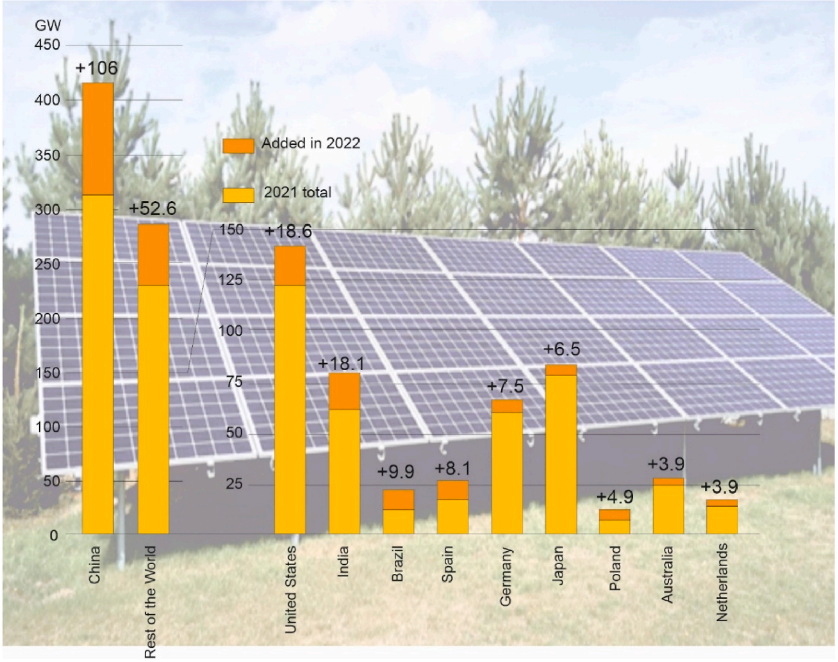

Fig. 5. PV capacity in top 10 countries (own elaboration based on [66]).

in a row, followed by both continents of the Americas, which are ahead of Europe. The top five countries in terms of added capacity were China, the United States, India, Brazil and Spain, which together account for about 65 % of newly installed capacity in 2022 (up from about 60 % in 2021) (Fig. 5) [66].

China's PV saw a huge growth in 2022, with around 105 GW added, which is around 90 % more than the previous year. Nearly 60 % of the new capacity came from distributed (mainly prosumer) PV (over 60 GW), while over 44 GW was centralized PV. Overall, the Chinese market grew by over 35 % in 2022, reaching a total PV capacity of over 414.5 GW [66,86].

China's market for centralized PV plants grew by about 20 %, while distributed PV grew by almost 50 %. The domestic rooftop installation market was driven mainly by a three-year support scheme that launched in early 2021 and contributed to twice as many new installations in 2022 compared to 2021. Total electricity production (from all sources) increased by 3.6 % in China, while PV electricity increased by about 28 % [78,87].

India was once again in 2022 the second largest PV market in Asia (after China) and the third largest in the world. The country added about 18 GW in 2022, more than the year before, accounting for about 80 % of all new capacity. New installation capacity included approximately 15.7 GW of utility-scale solar (87 %) and 2.4 GW of rooftop solar (13 %). The total cumulative solar PV capacity in India is approximately [79] GW. However, this was still below India's target of 100 GW of PV in 2022. The shortfall can be attributed to a number of factors including net metering caps, tariffs that came into force in April 2022, and unsigned RES supply contracts that were submitted to the tender but were not signed by the distribution companies, and banking restrictions (with higher bank fees and banking where the period for RES was changed from annual to monthly) [66,88,89].

The US solar market decreased in 2022 relative to 2021. The country added more than 18 GW in 2022 year, a 16 % decrease compared to 2021. Cumulative solar PV capacity at the end of 2022 was 141.6 GW. For the fourth year in a row, PV was the leading new source of electricity in the US. The following states added the most solar: California (4.7 GW), Texas (3.3 GW) and Florida (1.7 GW). Electricity production from PV in the USA totaled 201 TWh; in total, PV allowed the production of 4.7 % of electricity in the USA in 2022 [66,87].

Compared to all continents, Europe added 40.5 GW of PV capacity in 2022, reaching a total of 206 GW. New installations in the 27 EU-27 member states reached a capacity of 38.9 GW, which is 63 % more than the 25.9 GW added in 2021 [66]. Europe that as part of a plan to reduce imports from Russian fossil fuels and accelerate the use of RES, the EU announced in early 2022 an acceleration of more than 20 % to achieve a target of 420 GW PV by 2030. The largest increases in 2022 in the EU took place in Spain (8.1 GW), Germany (7.5 GW), Poland (4.9 GW), the Netherlands (3.9 GW) and France (2.9 GW). Italy added 2.6 GW, an increase of 174 %, and Portugal added 2.5 GW, an increase of 250 % year-on-year. The largest total PV capacity is in Germany, Spain, Italy, France and the Netherlands. In Germany, PV growth increased by almost 50 % in 2022, well above the 8 % growth rate recorded in 2021, and the total installation capacity reached 67 GW. This translated into the fact that in 2022, PV provided a record 12 % of electricity production in Germany, compared to about 10 % in 2021 [66,89,90].

Further institutional changes are being introduced in other countries, where in France regulations impose the obligation to install PV systems in parking lots with at least 80 spaces within the next 3–5 years [66,91]. In Greece, a regulation entered into force in 2023 requiring the installation of PV in all new buildings, at least 50 % of which are intended for non-residential purposes and with an area exceeding 500 m^2. In turn, in January 2022, 9 out of 16 federal states in Germany introduced requirements for installing PV panels on roofs [66].

It is also worth emphasizing the importance of the conflict in Ukraine, which has caused disruptions on the German energy market, forcing the government to issue amendments supporting RES in 2022 to improve energy security and increase climate neutrality. Germany adopted an Easter package that reviewed energy regulations and proposed new measures, including higher feed-in tariff (FIT) rates, the abolition of the FIT surcharge or 10–30 kW self-consumption systems, and an increase in the auction threshold to 1 MW [66].

In 2022, the Netherlands was the second country to advance to the top 10 PV installers in the world, adding 4 GW of PV in 2022. Nearly 50 % of new installations (1.8 GW) are rooftop PV. The Netherlands could boast the highest share of PV in the energy generation mix in Europe - 14 % (up from 12 % in 2021) [92].

Also in 2022, Austria installed for the first time over 1 GW of PV, installing 1009 MW (in 2021 it was 740 MW, and in 2020–341 MW). The Austrian government wants to achieve 100 % by 2030. covering energy consumption with RES. Austria is also focusing on the development of energy batteries; over 520 MWh of battery systems will be installed in Austria by 2025. This would be a more than threefold increase compared to 2020 (161 MWh) [66].

The next very dynamically developing countries in the field of PV are Spain and Poland [93]. Spain added 8.1 GW of PV in 2022, up 65 % from the previous year (4.9 GW). The total Spanish capacity increased to nearly 27 GW. Installations included 4.3 GW of large-scale PV systems and 2.7 GW of distributed prosumer PV systems. In 2022, the Spanish utility-scale PV market continued to be driven by unsubsidized PPAs, while the prosumer PV market grew at a steady rate of around 102 %, driven by high electricity prices. Spain is currently facing a major challenge related to excess production capacity (mainly PV), investments are necessary in network expansion, energy storage and green hydrogen [93].

In the case of Poland, in 2022 the country will become one of the 10 largest PV installers in the world. The Polish PV market added 4.9 GW of new capacity, which is almost 50 % more than in 2021 (3.3 GW) [94]. Data for 2023 indicate as much as 7 GW of new PV capacity in Poland. The decisive group with PV are energy consumers (nearly 1.5 million people and approximately 80 % of PV capacity), which was motivated by an attractive net metering system and rising electricity prices [94].

When it comes to the popularization of PV among individual consumers, it should be emphasized that European households have invested in rooftop PV, increasing their capacity by 25 GW in 2022, 8 GW more than in 2021. Rooftop PV panels currently account for 66 % of the EU's total installed PV capacity of 209 GW. New initiatives have helped accelerate the introduction of PV, for example some German states have introduced mandatory PV for new homes, while less well-off Belgians can count on free PV panels. Without the record solar production of 203 TWh, the EU would need an additional 35 bcm of imported gas to generate electricity. This is equivalent to about a quarter of Russian gas imports to the EU in 2021. Assuming an average European TTF gas reference price for 2022 of 121 EUR/MWh, this means 49 billion EUR in avoided natural gas costs [66].

The process of developing PV in Europe is progressing systematically and dynamically (Fig. 6) [95]. In 2018, 103 GW of PV capacity was installed and in just four years this number has doubled, reaching 209 GW at the end of 2022. It is very likely that in four years PV capacity will triple again - to around 600 GW. The latest forecast [66] predicts an increase in installed PV capacity by approximately 50 GW in 2023 (medium scenario) and up to 70 GW (high scenario). This is 30–65 % more than the record 41 GW installed in 2022. A highly probable scenario is that by 2026 the annual capacity increase will amount to 85 GW (medium) and 120 GW (high). In the case of EU member states, institutional issues are important, as they significantly support the development of both the PV market and the entire RES market. The European Commission is currently implementing the REPowerEU plan, which aims to accelerate the development of the RES market and replace fossil fuels, and has set PV capacity targets of 400 GW by 2025 and 740 GW by 2030 [89,95].

4.1.1. Further development of PV - recommendations

The PV market has the greatest development potential in Europe in the coming years or even decades. PV panels and power plants enjoy great social support and can operate as large power plants and as prosumer micro-installations.

Many research centers conduct extensive research on the development of new and improvement of existing PV materials. Perovskites may soon revolutionize PV in Europe and the world. Perovskites are characterized by lightness and flexibility. PV cells can be used to cover various materials – from thin foils, through roof tiles and walls, to even clothes [96].

The price of PV cells is systematically falling - from over 70 USD/W in the 1970s to a dozen or so cents/W today (and this with less money). Falling prices of PV cells mean that energy from PV is already cheaper than energy from fossil fuels [84].

Over the last 30–40 years, the decline in the prices of PV cells has been accompanied by a significant increase in their efficiency to about 20–25 %, and in the case of cells obtained in laboratory conditions it is approaching 50 % [97].

The development of agrophotovoltaics (or agrovoltaics) should be supported [98]. Agrophotovoltaics is the combined use of a given area of land both for agricultural production as a primary use and the production of electricity from an installed PV installation as a secondary use. This structure is based on PV installations, which consist of light-transmitting modules placed on structures higher than those commonly used on land. Thanks to this, you can farm, grow flowers, vegetables, fruit and cereals under the panels. This use of land is more effective both economically and ecologically.

The advantages of agrophotovoltaics include:

- availability of technology and ease of installation – the agroPV design is simple and easy to implement,
- protection for plants and animals - the panels can act as a shield against excessive sunlight and reduce heat stress of plants and prevent them from overheating. During periods of heavy rainfall, hailstorms or strong winds, the mounting structures of the panels can protect plants from mechanical damage
- environmental protection - photovoltaics in agriculture do not generate any pollution or noise, and at the same time reduce CO_2 emissions into the atmosphere – by replacing conventional fossil fuels with green energy
- additional source of income - agricultural land can earn twice as much. The farmer gains not only by selling his crops, but also by selling the energy generated by the agrovoltaic installation [99,100].

Recommendations:

- greater financial support for PV micro-installations,
- construction of energy batteries,

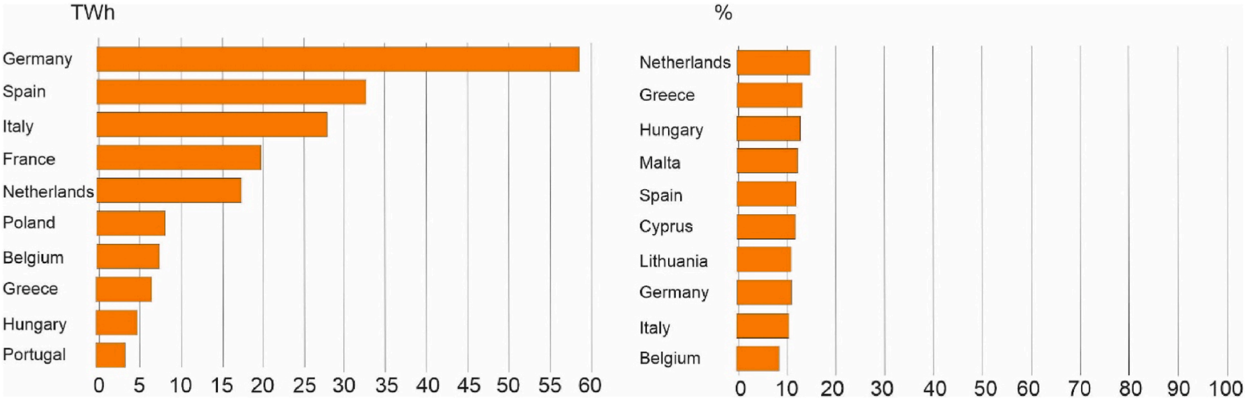

Fig. 6. Larger solar generators (on the left) and highest shares of solar powers (on the right) (own elaboration based on [95]).

- development of new PV materials, including perovskites,
- development of agrophotovoltaics

4.2. Development of wind energy in the world and in Europe

Wind energy is undoubtedly as popular as energy obtained from PV, and its development is also included in many ET processes (Fig. 7). The attractiveness of aeroenergy is determined by high and volatile fossil fuel prices, geopolitical pressure and increasingly higher greenhouse gas emissions. Wind energy creates new, well-paid jobs. Onshore and offshore development can be a kind of "catalyst" for further investments in various sectors of the economy [66,101].

Globally, over 77 GW of new wind capacity was added in 2022, including 68.4 GW of onshore capacity and almost 8.8 GW of offshore capacity. The cumulative capacity of aeroenergy in 2022 increased by nearly 10 % to 906 GW. 2022 was the third largest year on record for new installations. The world leaders include European countries: Germany, Finland, France, Sweden, Great Britain and Spain (Fig. 8) [66,102].

China installed more than half of the world's new wind power capacity - nearly 38 GW of wind power in 2022, including more than 32 GW onshore and more than 5 GW offshore. The total wind power capacity in China is more than 365 GW, including 334 GW onshore and about 31 GW offshore. Power production increased by more than 16 % and accounted for more than 9 % of China's electricity production. In late December 2022, the Chinese government announced, among other things, a target of achieving 430 GW of wind power capacity by the end of 2023 [66,102].

China continues to dominate wind turbine production and is the most important global supplier of critical components and raw materials (China has a 70 % share of the global market). About 60 % of the world's turbine production capacity is also located in China. Although most Chinese turbines are still built in the country, the decline in demand and fierce competition have sparked price wars and pushed manufacturers to invest in other countries. Competitive prices and technological innovations introduced in Chinese turbines are causing increasing interest from other customers. In 2022, 6 of the world's top 10 turbine manufacturers were based in China; the remaining 4 are: Vestas (Denmark), followed by Siemens Gamesa (Spain), GE (USA) and Nordex Group (Germany) [66,102].

The US still ranks second in both new and cumulative aeropower capacity at the end of 2022. US investment in 2022 decreased by 37 % compared to 2021, reaching a total of 8.6 GW (all onshore). Both the nascent US offshore sector and the 10 GW of onshore capacity planned for 2022 have been delayed due to supply chain constraints and interconnection issues. At the end of 2022, the US had 144.2 GW of wind farm capacity. Wind energy accounted for over 10 % of electricity production in the US in 2022 - an increase from 9 % compared to 2021. At the end of 2022, over 26.7 GW in the US was in the advanced phase of construction, with of which 16.7 GW at sea [66,102].

The third country in terms of new capacity and for the third time in a row was Brazil. Wind in 2022 accounted for almost half of the country's new capacity, with a record increase of almost 4.1 GW - it was almost 80 % of the new capacity of South America and the

Fig. 7. Wind energy capacity in the world in 2012–2022 (own elaboration based on [66]).

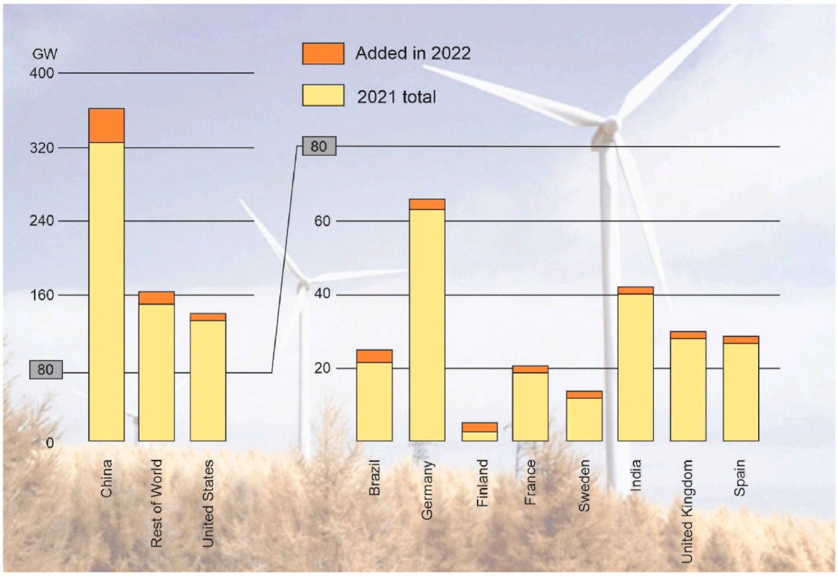

Fig. 8. Wind capacity in top 10 countries (own elaboration based on [66]).

Caribbean. In Brazil, wind energy is experiencing record growth thanks to public auctions. Wind energy is very competitive - electricity from wind turbines had the lowest free market price in Brazil. At the end of 2022, Brazil had over 25.6 GW of operational wind power capacity - it was the second largest source of electricity in Brazil (after hydroelectricity), and electricity from wind turbines provided 13.6 % of the country's energy in 2022 [103].

It should be emphasized that the wind energy market is experiencing very dynamic development also in Europe [104–107]. In 2022, Europe added a record 17.9 GW of wind capacity, most of which was installed onshore (86.2 %), bringing the total capacity to 242.4 GW at the end of the year (212.1 GW onshore and 30.3 GW offshore). Despite record investments in Europe in 2022, it should be emphasized that at the end of the same year in the EU and Norway, 80 GW of new turbines were "stuck" in permitting procedures at the level. Due to the energy crisis caused by the conflict in Ukraine, many European countries have taken steps to simplify the procedures for issuing permits for wind energy (both onshore and offshore). At the end of 2022, the EU adopted emergency measures to solve permitting problems and not block the development of the European aeroenergy market [66].

In 2022, Germany strengthened its position as the European leader (production of over 120 TWh of electricity), followed by Spain (over 60 TWh) and France (nearly 40 TWh) (Fig.). Wind energy plays the main role in Denmark's energy mix (over 55 % share), Lithuania (almost 40 % share) and Ireland (almost 35 % share) (Fig. 9) [95].

The last two decades in Europe have seen a successive increase in power and an increase in electricity production from wind energy, especially in EU member states. In 2022, wind energy production in the EU and UK combined increased by almost 10 % thanks to new installations and strong winds in many countries, and covered approximately 17.3 % of electricity demand (14.1 % onshore turbines, 3,2 % offshore turbines). In Europe, aeroenergy had the highest share in the energy mix in Denmark (55 %) and Ireland (34 %). Wind energy also had a significant share in Great Britain (28 %), Germany (26 %), Portugal (26 %), Spain (25 %) and Sweden (25 %). At the end of 2022, Germany ranked first in Europe in terms of total wind power capacity (66.3 GW), followed by Spain (29.8 GW), Great

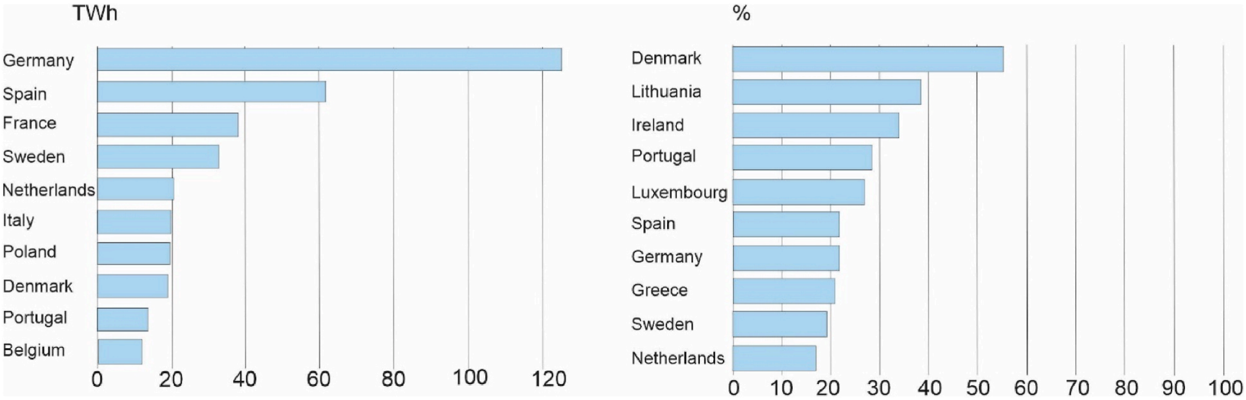

Fig. 9. Largest wind generators (on the left) and highest shares of wind power (on the right) (own elaboration based on [95]).

Britain (28.5 GW), France (21.1 GW) and Sweden (14.2 GW). These countries accounted for over 65 % of the total capacity in Europe [107–110].

Offshore, six European and three Asian countries added almost 9 GW of new capacity in 2022, bringing the global total to 65 GW. Offshore wind accounted for almost 11.5 % of new grid-connected wind capacity in 2022 and accounted for more than 7 % of total capacity at year-end. China continued to lead the offshore industry for the fifth year in a row, with almost 60 % of new capacity, with almost all the rest installed in Europe and Chinese Taipei [102].

In 2022, Europe connected approximately 2.5 GW of new offshore capacity to the grid. Great Britain connected almost half of European capacities (1.2 GW). The world's largest offshore project, "Hornsea Two", with a total capacity of 1.4 GW was commissioned in Great Britain [102].

The countries where wind energy was developing at the highest level in Europe were Germany, Finland, France, Sweden, Great Britain and Spain. These six countries account for almost 60 % of the annual number of wind installations in Europe and all of these countries are among the top ten in the world. In 2022, in four of this group of countries, with the exception of Great Britain and Sweden, the growth of aeroenergy power increased significantly [66,102].

Looking at other European countries, Germany ranked first in terms of new production capacity in 2022 and fourth in the world. The country added over 2.7 GW (2.4 MW onshore, 0.3 GW offshore) and retired almost 0.3 GW. At the end of 2022, the total capacity of German wind energy was 66.3 GW (almost 58.3 GW on land, 8.1 GW at sea). In Germany, the production of electricity from wind increased by nearly 10 % in 2022, to over 125 TWh. To accelerate ET, Germany plans to install 10 GW of wind power per year [108].

In Finland, which had a record year, 2.4 GW of capacity was added (all onshore), taking the country to second place in Europe and fifth globally. Total operational aeropower capacity in Finland increased by over 74 % to 5.7 GW. In 2022, Finland covered approximately 14 % of its electricity demand with aeroenergy. Finland wants to continue its ET to achieve net zero emissions in 2035 and become independent from energy and fuel imports [107].

For the French wind power industry, 2022 was also a record year, with France taking third place in Europe and sixth place in the world, respectively. Wind power capacity increased by over 2 GW of new installations, bringing the cumulative wind power capacity to over 21 GW. Moreover, the first commercial offshore installation was implemented in 2022. The French wind power industry generated an estimated 8 % of electricity in 2022 [107].

In the case of Sweden, the number of new installations in 2022 decreased slightly (all installations on land), giving a total of 14.2 GW (including 0.2 GW offshore). In terms of new capacity, the country ranks seventh in the world and fourth in Europe. Wind energy production compensated for a 6 % decline in hydroelectric production in 2022 [109].

The UK continues to be one of the leading countries in the world when it comes to aeroenergy (ninth) and in Europe (fifth). In 2022, 0.5 GW of new onshore capacity and approximately 1.2 GW of new offshore capacity were installed. At the end of 2022, the total aeropower capacity in the UK was almost 28.5 GW, of which 14.6 GW on land and 13.9 GW offshore. Thanks to the growing power of aeroenergy and good wind conditions, British aeroenergy produced a record amount of electricity in 2022: 74 TWh, which allowed to power over 19 million British homes and reduced the import of natural gas [66].

In 2022, Spain added almost 1.7 GW onshore, more than twice as much as last year, bringing the total capacity to nearly 30 GW. In terms of new aeroenergy installations, the country ranks tenth in the world and sixth in Europe. Year-on-year, electricity production from wind turbines increased slightly to approximately 61 TWh. Spain has launched a program to modernize old turbines, which should allow for greater electricity yields [107].

In the case of the development of maritime aeroenergy, it is visible that more countries obtain energy from this source. As already mentioned, France has launched its first commercial offshore wind farm (0.5 GW), while the Netherlands is producing electricity from its first "subsidized" wind farm "Hollandse Kust Zuid" with a total capacity of 1.5 GW. Norway has launched a 60 MW floating offshore project "Hywind Tampen" (total 95 MW). Italy has also launched its first offshore project (30 MW), the first offshore farm in the Mediterranean Sea. Germany, in turn, has increased its offshore capacity by another 0.3 GW. At the end of 2022, the cumulative offshore capacity in Europe amounted to over 30 GW in 13 countries. The EU Member States have committed to achieving a total

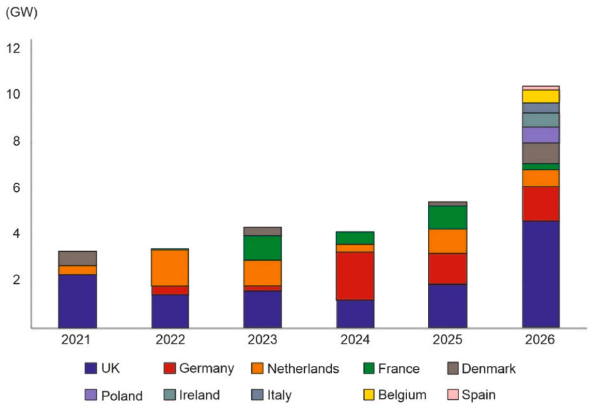

Fig. 10. New offshore installations per country, realistic expectations (own elaboration based on [107]).

capacity of 111 GW from offshore wind farms by 2030, and the United Kingdom alone – 50 GW (including 10 GW from floating wind energy) [107].

The Polish Energy Policy until 2040 assumes that offshore capacity will reach nearly 6 GW in 2030 and about 11 GW in 2040 [110]. In 2022, Germany, Belgium, Denmark and the Netherlands jointly committed to increase the capacity of offshore wind farms tenfold by 2050 at the latest. In turn, Germany, in accordance with the Offshore Wind Energy Act, updated its target for offshore wind capacity from 40 GW to 70 GW by 2040. In 2023, nine countries (France, Great Britain, Germany, Belgium, Denmark, Ireland, Luxembourg, the Netherlands, Norway) agreed on common future targets for offshore wind capacity, the aim of which is to achieve at least 120 GW offshore by 2030 and 300 GW offshore by 2050 [107].

In many European countries, offshore projects are at various stages of advancement. Offshore capacity will start to grow significantly from 2025. Investors will be countries that already have offshore facilities (e.g. the UK), as well as those countries that will build the first turbines at sea (e.g. Poland) (Fig. 10) [107].

4.2.1. Further development of wind energy - recommendations

In the coming years, aeroenergy will develop in Europe, both on land and at sea. Wind energy, next to PV and hydropower, will be the main source of electricity. Green hydrogen will be produced from surplus wind energy.

Large-scale scientific and scientific-technical research is underway all over the world on new types of turbines and/or the optimization of existing ones. New turbines have fewer and fewer disadvantages - they are energy efficient and their negative impact on the environment is negligible.

The development of wind energy is also a great stimulus for economic development. Countries with access to the sea can use shipyards to build offshore equipment and turbines.

Recommendations:

- simplification of legal regulations for investments in aeroenergy,
- placing turbines in places where they pose a threat to fauna (mainly birds) and do not interfere too much with the landscape,
- educating the public about aeroenergy.

4.3. Development of hydropower in the world and in Europe

Another extremely important source of renewable energy is water and hydroelectric power plants using the power of nature [111]. Global hydropower installed at least 22.2 GW of new capacity in 2022, bringing the total installed capacity to 1220 GW (Fig. 11). Electricity production increased by 5 % compared to 2021, reaching 4429 TWh. In 2022, hydroenergy accounted for 37 % of the world's total installed RES capacity and added 2 % to the total capacity of all RES [66].

China extended its hydroenergy capacity advantage by adding 13 GW in 2022, bringing its total installed capacity to 368 GW. The world's largest hydroelectric power plants operate in China; in 2022, several mega-projects were completed, including six hydroelectric plants on the Yangtze River, and the last turbines were installed at the 16 GW Baihetan power plant. Heavy rains increased hydropower production in southern China by approximately 18 % in the first half of 2022 - bringing the country's total annual production to 1352 TWh. In the years 2001–2020, China invested in hydroenergy in many countries around the world, which enabled the launch of at least 38 GW in total, with another 11 GW planned [112].

Brazil ranked second in the world in terms of total installed hydropower capacity and energy production. In 2022, it launched just over 300 MW of new capacity, and heavy rains increased electricity production by 17 %. Overall, during the year, the country generated 92 % of its total electricity from RES, and hydropower accounted for 78 % of renewables [66,113].

Canada currently ranks third in terms of total hydropower capacity and electricity production from it. In 2022, Canada

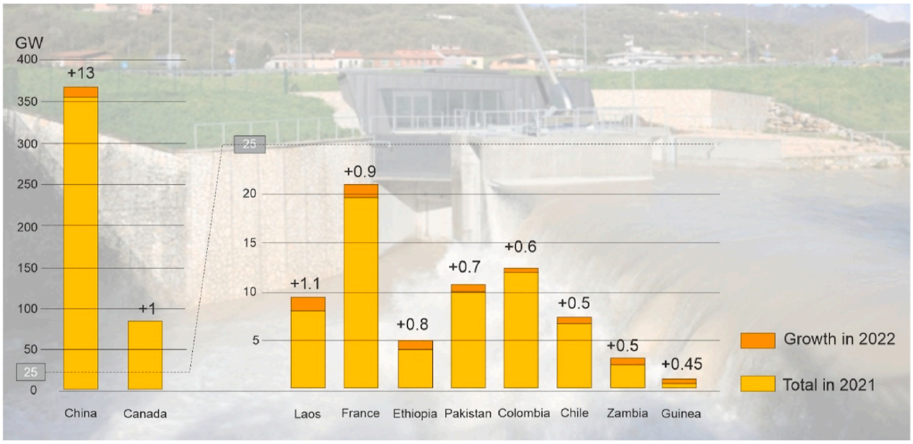

Fig. 11. Hydropower capacity in the world (own elaboration based on [66]).

commissioned 1 GW of new capacity, the Romaine 4 hydroelectric power plant in Quebec [66].

In the USA, in 2022, hydropower production of approximately 80 GW increased by 4 % year-on-year, reaching 262 GWh, which represented about 6 % of the country's energy mix. A decades-long drought in the American West has resulted in the Western Energy Administration, which has approximately 10 GW of installed hydroenergy capacity, recording only about 66 % of its average electric generation. In turn, the rest of the USA experienced heavy rainfall or snowfall in the second half of 2022. The states of California, Oregon and Washington grew 14.2 % in 2022 (129,918 TWh), accounting for 49.6 % of U.S. hydropower. In 2022, 14.2 MW of small hydropower plants were launched in the USA [66].

Hydropower accounted for 10 % (283 TWh) of European electricity production in 2022. Sweden is in the lead (69 TWh), followed by France (46 TWh) and Austria (36 TWh). Together, these countries account for more than half of the continent's hydroelectricity production. In Sweden, Austria, Latvia and Croatia, hydroenergy accounted for over 30 % of the total energy mix [95].

In Europe, the most electricity from hydropower plants is produced by Norway (130 TWh), Sweden (almost 70 TWh) and France (over 45 TWh). Hydropower has the largest share in the energy mix of Norway (95 %), Austria (55 %) and Lithuania (over 50 %) (Fig. 12) [95].

Hydroelectric power plants at the European level account for about 17 % of total capacity. It should also be remembered that reservoirs or pumped storage systems also account for 90 % of electricity storage capacity in the EU [66].

On the European continent, hydropower plants play an important role in creating the RES market and in balancing the power system (pumped storage plants). Negative climate change is also becoming more and more visible in Europe, where in 2022 the t drought led to almost 20 % decline in electricity production [66].

Energy technologies using sea and ocean energy constitute the smallest share of the RES sector in Europe, although there are huge resources of this type of energy. It is predicted that Europe must spend EUR 1.2 billion by 2030 to commercialize technologies using ocean energy [114].

A French company launched a 1 MW tidal turbine in Brittany [66]. Its implementation is part of the PHARES project, which aims to combine solar, wind, tidal and storage energy to meet most of the electricity needs of Ushant Island, which is an "energy island". A small electrolyzer was also launched to produce green hydrogen.

In France, a prototype of an 800 kW wave energy converter was installed in the port of Sainte Anne du Portzic. A Waveswing test device was launched in Scotland with a power of over 10 kW and a peak power of 80 kW for moderate waves. In Belgium, work is underway on a 3.5 kW wave power plant in Oostende [66].

The 300 kW Mutriku Wave power plant in Spain has produced 3 GWh over the last decade. The installation, integrated with the Biscay Sea breakwater, will be used to test, among others, air turbines and electric generators [66].

4.3.1. *Further development of hydropower – recommendations*

In Europe, the development of large hydropower plants in the future will be rather slow. This involves dividing rivers and building dams, which have a negative impact on the ecosystem and require the resettlement of people.

In Europe, small hydropower generation may continue to develop on existing dams, such as locks or weirs. For example, Poland has over 16,000 dams [115]. Small hydropower plants (SHP) fit into the distributed energy scheme. An opportunity for new direction of SHP is the use of waste water. The greatest opportunities for using utility water occur in the energy industry, for example in the cooling systems of power plants or in sewage treatment plants [115].

Recommendations:

- simplification of legal regulations,
- construction of SHP on already existing dammings,
- construction of fish passes.

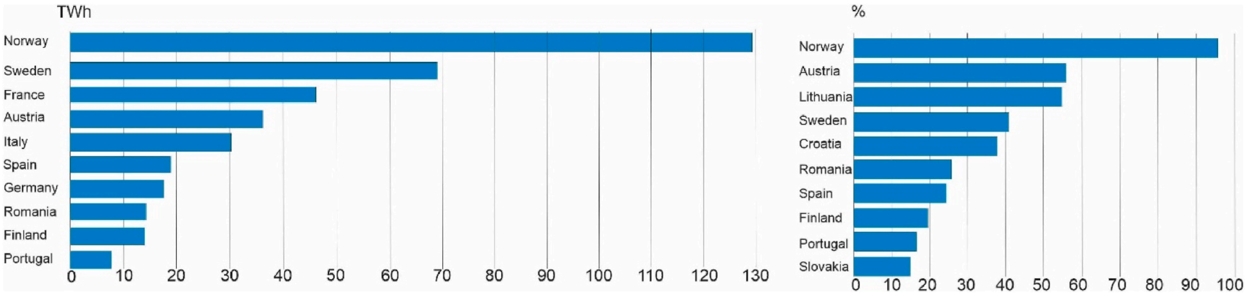

Fig. 12. Largest hydro generators (on the left) and highest shares of hydro power (on the right) (own elaboration based on [95]).

5. Heat production from renewable sources in the world and in Europe

5.1. Solar heating

The global solar thermal market grew by an estimated 22.8 GW in 2022 (Fig. 13). In several cases, sales grew at double-digit rates, including Italy (43 %), France (29 %), Greece (almost 17 %), and Germany and Poland (11 % each); in addition, South Africa, the most important market in the sub-Saharan region of Africa, recorded a growth of 9 % compared to 2021 [66].

Small solar installations and combi systems still accounted for around 60 % of annual installations, but have lost market share in recent years in much of Europe and China. Demand is growing for large-scale, multi-megawatt facilities that were under construction in 2022 and signaled a new era for solar installations in these regions. There is also a growing interest in hybrid systems, especially combined with PV systems and with heat pumps [66].

After stabilizing in 2021, solar panel sales in China declined, impacted by the pandemic and a slowdown in construction. However, the country still accounted for the largest share of global annual sales at almost 70 %. China added an estimated 15 GW. Most new installations were commissioned by industry (83 %) [66].

Among households in European countries, solar heating has gained similar popularity to the production of electricity from PV. In 2022, the growth of the global solar thermal heating market amounted to nearly 23 GW, and in Europe to approximately 3 GW (Fig. 8). In Europe, the payback periods for solar collectors among Mediterranean countries are quite short due to high irradiation and good matching of hot water demand. As a result, the amount of collected heat has increased at double-digit rates in several solar energy markets, including Italy (43 %), France (29 %), Greece (almost 17 %) and additionally in Germany and Poland (both 11 %) [116].

Europe is taking significant steps towards developing RES-based heating and cooling, mainly in the field of solar thermal energy. “The Fit for 55” package aims to accelerate the implementation of RES by setting higher overall targets for 2030. RE is to be introduced in heating and cooling, construction and industry [116]. Under the Green Deal [117], solar thermal is recognized as a strategic net-zero emissions industry. It is estimated that this sector can meet at least 90 % of Europe’s heat demand.

Germany has created a special fund worth EUR 3 billion to support decarbonization of the heating sector and to finance the construction of new heating networks based on RES. In turn, Denmark has introduced new regulations that allow heating companies to negotiate prices with geothermal energy operators in order to set an upper limit on the costs borne by consumers. The British “Net Zero” strategy assumes the allocation of GBP 338 million for the “Heat Network Transformation Program”, with particular emphasis on renewable and low-emission technologies. Germany was also the sixth largest solar collector market in the world in 2022. Annual sales in this country increased by 11 % and amounted to over 91,000 solar collectors with a total capacity of 496 MW. 2022 was the third year of market growth in Germany after several years of recession. Growth was achieved despite weakening demand in the construction industry due to economic uncertainty and rising fuel prices. By the end of the year, Germany had reached over 15 GW of production capacity [66].

Greece was the second largest European market for solar collectors in 2022, adding a record capacity of 293 MW. This translated into an increase of 17 % compared to the previous year and gave a total capacity of 3.8 GW. The Greek solar collector market was mainly driven by high electricity and heat prices and the decarbonization of the Greek economy. In 2022, sales increased by 19.4 % and exports mainly to European countries by 21 % [66].

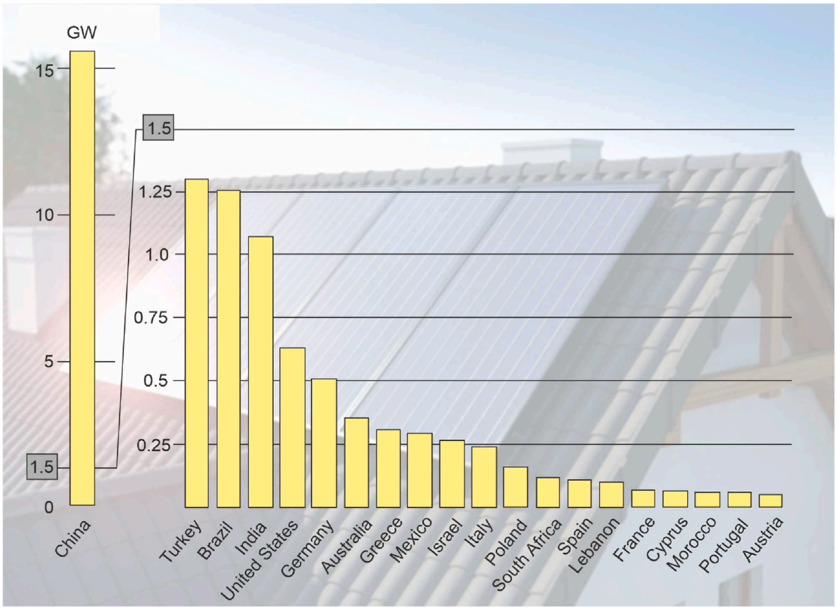

Fig. 13. Solar water heating collector additions in 2022 (own elaboration based on [66]).

In the case of Italy, 225 MW of new solar collector capacity was created in 2022, which means an increase of 43 % year on year. Moreover, this followed a record growth of 83 % in 2021. The development of the Italian collector market was mainly due to the "Super Bonus", a 110 % tax reduction for energy efficiency, which also includes the replacement of fossil fuel boilers with RES heating systems [66].

However, in Poland, 11 % more solar collectors were installed in 2022 compared to 2021. The capacity of the new collectors was 147 MW, with flat-plate collectors dominating the Polish market (over 99 %). The growth of the solar collector market in Poland was caused primarily by the sharp increase in hard coal prices and its shortages in fuel warehouses. At the end of 2022, there were over 2.4 GW of solar collectors in Poland (3.4 million m^2) [1].

In Spain, the installation of solar collectors in 2022 translated into 102 MW of new capacity (145,500 m^2). The Spanish solar market is dominated by PV, which is heavily promoted. This means that it is sometimes difficult to find solar installers. Perhaps government incentives and subsidies of up to 60 % for some apartments will change the situation.

5.2. *Geothermal heating*

Geothermal heat is being used worldwide for direct heating applications, with a total capacity estimated at 38 GW in 2022. As of 2019, the average annual growth is 2.7 GW. It is estimated that in 2022, heat production increased by 14 TWh to approximately 155 TWh (560 PJ) (Fig. 14) [66].

The use of geothermal heat depends on the temperature of the thermal water, its availability and local needs. In China, almost half of the produced geothermal heat is used for district heating and for heating swimming pools. In Iceland, more than 70 % of the heat is used for heating apartments, schools, offices, etc. In Turkey, thermal water mainly heats swimming pools, and to a lesser extent, rooms. In Japan, geothermal heat is mostly used for heating bathing areas and swimming pools located near geothermal sources [66].

China is the fastest growing geothermal heat market in the world, with annual growth exceeding 20 % between 2015 and 2022. In 2022 alone, the increase in geothermal heat production amounted to approximately 355 PJ. In 2022, China's 14th Five-Year Plan for Energy Efficiency and Green Construction Development was being implemented and placed great emphasis on the continuous expansion of the use of geothermal energy for space heating [118].

The development of geothermal heating in continental Europe is concentrated in several areas where there are deep heat reservoirs. These include primarily the Paris region in France, Bavaria in Germany, and various locations in Hungary, Italy, Poland and the Netherlands. These locations are the focus of geothermal exploration and development work in Europe [66].

It is important to emphasize here the geographical location of Island, which ranks third in the world in terms of the use of geothermal heat. The annual geothermal heat consumption in Iceland was approximately 35 PJ thanks to a capacity of approximately 2.5 GW. Geothermal heat covers 90 % of the demand for space heating in Iceland, and the resources are still much greater than the needs. Activities in the following years should focus on gradually replacing fossil fuels with electricity from geothermal and hydroelectric power plants, as well as geothermal heat [66].

The development of geothermal heating plants in France is mainly concentrated around Paris, as well as in the southwest in Aquitaine and in the east in Alsace. In 2021, three new geothermal installations were made available in the suburbs of Paris, and in

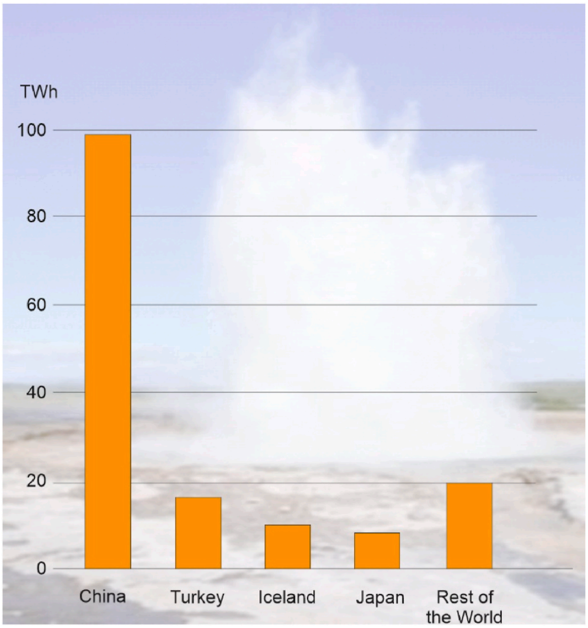

Fig. 14. Geothermal heat production in selected countries in the world in 2022 (own elaboration based on [66]).

2022 the construction of a heating plant for the commune of Meudon began. This heating plant will heat nearly 8000 houses by 2026 at the latest. In order to increase efficiency and adapt to the lower temperatures of geothermal energy supply, the local distribution network will also be modernized [66].

In Germany, the heat production plan has been institutionalized, where the government presented an action plan to achieve a 10-fold increase in the use of geothermal heat by 2030 (10 TWh per year). This means the construction of 100 additional geothermal installations. Bavaria wants to cover 25 % with geothermal heat by 2050, while expanding its networks. Continuing research indicates that the geothermal potential is about 20 % greater than previously expected [119].

In turn, in Austria, large-scale exploration of geothermal water deposits near Vienna began in 2023. Investors predict that the first geothermal heating plant will be completed in 2026. The installation's capacity is estimated at 20 MW, which will provide heat to 125,000 households [66].

In Switzerland, geothermal drilling began in Lavey-les-Bains and in early 2022, with the hope of completing the country's first geothermal power plant by 2023 [66].

Geothermal energy is also being developed in Poland. In 2022, "Geotermia Toruń" was opened in Poland, in Toruń, with a capacity of 18 MW. Geothermal energy is a renewable heat source independent of turmoil on raw material markets and supply chains, therefore it is an important element in diversifying and increasing the security of heat supplies for residents. Thanks to this, Toruń already more than meets the EU requirements regarding energy efficiency, which will come into force only in four years [120].

In the Netherlands, geothermal heat production increased by 6 % in 2022. In total, research was carried out in 31 geothermal project locations with an annual production capacity of 6.4 PJ. Although new wells are launched every year, investors believe that progress is too slow. The main problems are the significant number of permits needed (bureaucracy), the drastic rigors of the drilling process, the lack of appropriate heat distribution networks to households and greenhouses, and financial, political and social barriers. Currently, about 70 projects are at various stages of development, including 19 of them in the initial phase of starting heat production [66].

5.3. *Heat pumps*

The use of heat pumps has been used in Europe for a long time. The heat pump was used on an industrial scale in Switzerland in 1914. It was used from a dyeing plant to concentrate soda lye. In 1928, Haldane built an installation with a heat pump to heat the house. In recent years, the heat pump market has been developing systematically and now heat pumps are increasingly used by households in Europe. It should be emphasized that heat pumps have a wide range of applications for heating and cooling in commercial, residential and industrial buildings. Heat pumps also provide heat energy to district heating networks [121].

The global heat pump market is mainly concentrated in countries with colder climates such as China, Japan, the US and some European countries. However, countries with warmer climates are also installing heat pumps, given that the units can operate reversibly, also transferring heat from the inside of the building to the outside. The global heat pump market grew by approximately 11 % in 2022 compared to 2021, the second consecutive year of double-digit growth [66].

China is long-standing the world's leading installer of heat pumps. Ground pumps are increasingly used there to replace coal-fired furnaces [66].

The US is also a large heat pump market, in 2022 it increased by 11 % compared to last year to a record level of 4.3 million operating units (Fig. 15). For the first time, annual sales of heat pumps in the US exceeded annual sales of gas boilers. State and local policies promoting the purchase of heat pumps before federal regulations came into force [66] contributed to this.

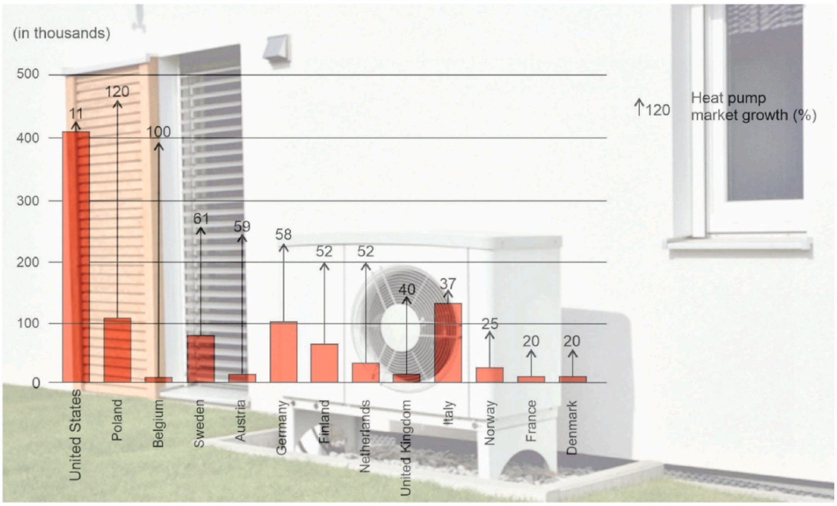

Fig. 15. Heat pump market grown (own elaboration based on [66]).

In Europe, one of the main factors for the increase in heat pump sales in 2022 was the armed conflict in Ukraine. This conflict resulted in an increase in energy and fuel prices, in particular natural gas for heating purposes. It turned out that Europe is heavily dependent on Russian fossil fuels. To remedy this, alternative sources of fossil fuels were launched, and above all, the focus was on own, RES and fuels [66].

The sales dynamics of heat pumps in Europe is very high. In 2022, sales increased by almost 40 %, reaching a record 3 million new installs. Air-to-water heat pumps are the most popular in Europe and account for over 50 % of devices sold. When it comes to sales of heat pumps in individual countries, most heat pumps are installed in France - approximately 600,000 units. Sales also increased in other countries: by 58 % in Germany and by 37 % in Italy [122].

In 2022, large-scale heat pumps were developed in Finland (wastewater and seawater), Austria (wastewater-based) and Germany (Rhine river water; it is also the largest heat pump in terms of power (40 MW) in Europe), the Netherlands (wastewater), Serbia (wastewater) and Sweden [66].

The rapid development of heat pump technology also occurred in European "emerging" markets. Poland has experienced the fastest growth of heat pumps in the world – an increase of 120 % – over 200 thousand units were sold in 2022. Sales also doubled in the Czech Republic and Belgium [122,123].

The investment and operating costs of heat pumps vary depending on the country, and their competitiveness compared to technologies using fossil fuels depends on a number of factors. Heat pumps "win" over gas and hard coal if electricity is not too expensive. This situation is often exacerbated by energy taxation systems that impose high taxes on electricity. One of the solutions, which is becoming more and more common, e.g. in Poland, is the installation of a PV installation, which provides almost "free" electricity, and therefore almost "free heat and cold" from the heat pump. The UK, Germany, Denmark, and the Netherlands have started reforming their tax systems to favor electric (zero-emission) heating, especially the use of heat pumps. Other European countries have also reformed taxes and tariffs to further encourage the use of heat pumps [122,123].

The RePowerEU strategy assumes the installation of at least 20 million heat pumps in the EU by 2026 and approximately 60 million by 2030 [115]. The EU wants to reduce the import of heat pumps from outside Europe by increasing their production in its own territory. In France, at the beginning of 2023, the subsidy for the installation of ground heat pumps was increased to EUR 5000. In turn, Germany has introduced discounts of up to 40 % for home owners for installing heat pumps. In Poland, you can obtain financing for a heat pump from several sources. Financial support exceeds even PLN 40,000. zloty (EUR 9000) [124].

5.4. *Heat from renewable sources – further development and recommendations*

Obtaining heat in Europe from RES will increase because these sources are increasingly cheaper and generate virtually no waste and greenhouse gases. Cities will develop a heating network, while solar collectors and heat pumps will dominate in villages. Waste heat (e.g. heat from sewage or biogas plants) will be used to a greater extent. Heat storage facilities will be built on a larger scale [66].

Recommendations:

- financial support of individual investors,
- investments in geothermal energy, thermal baths and balneology,
- effective policy promoting heat pumps,
- educating the public about ecological heat sources.

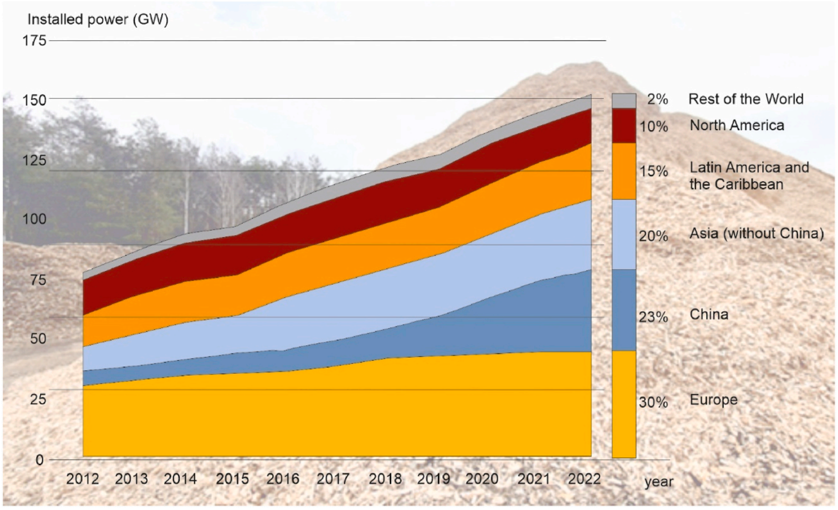

Fig. 16. Growth and cumulative power of biomass power plants in the world (own elaboration based on [66]).

6. The use of biomass as a source of renewable energy in the world and in Europe

6.1. Bioenergy

Fig. 16 shows the growth and cumulative capacity of power plants and combined heat and power plants burning biomass around the world. The installed cumulative "bioenergy" capacity in 2022 reached approximately 150 GW, representing over 4 % of the total renewable energy capacity. Biopower capacity increased by 5 % in 2022. China has the largest installed capacity: 34 GW, Brazil 17 GW, the US 11 GW and India 10 GW [66].

Over 670 TWh of electricity was generated from a wide range of biomass feedstocks in 2022. The production of electricity from biomass increased slightly by 0.8 %, while the share in total electricity production remained unchanged (2.4 %) [66].

Another important renewable heat source is biomass, which is commonly produced in the economy as part of agricultural processes, food processing and selected production processes. Biomass is a natural raw material for the production of biofuels, which in turn are the basis for the production of bioheat. Europe produces about 90 % of the heat generated from solid biofuels, municipal waste and biogas. In 2021, 0.55 EJ of bioheat from solid biofuels was produced in European countries; 61 % of this was in high-efficiency thermal power plants and the rest in district heating plants. Municipal waste produced 0.13 EJ of heat, mainly in thermal power plants, with Sweden and Germany accounting for about half of this production. In the case of biogas, heat production was 0.04 EJ, with Italy and Germany accounting for more than 60 % of the heat from biogas [66].

The most electricity from biomass is produced by Germany (almost 45 TWh), Italy (nearly 20 TWh) and Finland (about 15 TWh). Bioenergy has the largest share in the energy mix of Estonia (30 %), Denmark (over 20 %) and Finland (around 20 %) (Fig. 17) [95].

In European countries, the share of bioethanol in transport in 2021 was 6.8 % by volume, with E5 accounting for the majority of the gasoline market (although E10 is also gradually increasing). The main barriers to the expansion of liquid biofuels on the continent include discussions about phasing out internal combustion engines, falling demand for gasoline, and legal regulations limiting the qualification of crop biofuels for RES purposes [66].

In 2021, energy production from solid biofuels (excluding charcoal) in Europe increased by 12 %, generating 93 TWh. It is worth emphasizing that nearly 90 % of the energy was produced in accordance with the sustainable development criteria specified in EU regulations. Moreover, most of the solid biomass used (96.5 %) came from the EU. In 2021, the top producers in the region were Finland, Sweden and Germany, accounting for 37 % of production [66].

6.1.1. Bioenergy – further development and recommendations

In Europe, energy crops, fallow land and wasteland should be used to a greater extent for bioenergy production. Energy management of fallow and wasteland will result in an increase in farmers' incomes [24,125].

The development of RES based on agricultural biomass will increase the income of rural residents - they will be the ones to grow biomass and deliver it to boiler houses or power plants. Farmers' incomes will therefore be diversified. Extensive research is being conducted worldwide, both on a laboratory and technical scale, on the optimization of the biogas production process. The number of scientific articles on biogas technology is growing year by year [24,125].

In many countries, for example in Poland, biogas is burned in cogeneration at biogas plants and electricity and heat are produced. In Germany, biomethane is used as a substitute for natural gas in the gas network. In other countries, biomethane is used as a fuel, for example in Sweden, buses, cars and even trains run on this biofuel.

Recommendations:

- long-term farmer-power plant contracts,
- fixed price of biomass, greater degree of use of solid forest and agricultural waste for energy purposes,
- greater financial support for agricultural (recycling) biogas plants,

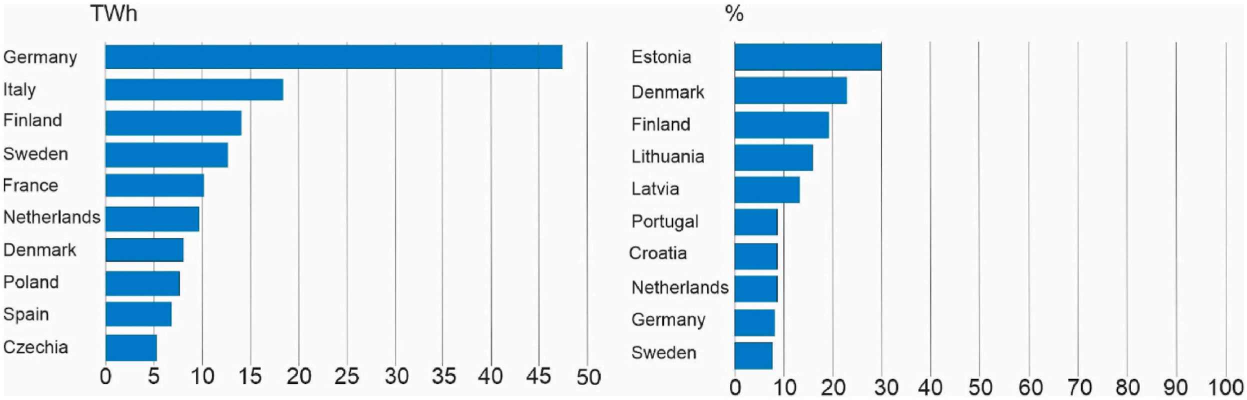

Fig. 17. Largest biomass generators (on the left) and highest shares of hydro power (on the right) (own elaboration based on [95]).

- simplifying the necessary documentation,
- long-term contracts for the supply of feedstock,
- economic use of heat.

7. Development of green hydrogen technology in the world and in Europe

Green hydrogen (GH) production is a natural response to the oversupply of electricity production from RES [126]. Undoubtedly, the development of the production and use of GH in the economy is an opportunity for European countries to accelerate the ET process. At the turn of 2022 and 2023, the UK, Slovakia and Turkey announced national GH strategies and action plans, meaning that almost 50 countries worldwide have such strategies. As part of the functioning of the community of EU countries, the European Commission in 2020 adopted an overarching the “hydrogen strategy for a climate-neutral Europe” project [66]. The strategy aims to support the implementation of GH in multiple areas, including energy production, transport and industry. GH is intended to help the EU achieve climate neutrality by 2050. GH aims to help the EU achieve climate neutrality by 2050. The EU aims to consolidate efforts to develop hydrogen technology by using partnerships and cooperation at regional and global levels. Examples of this are the Mediterranean Hydrogen Pipeline project and the EU-Japan cooperation for cooperation and research. In 2023, the EU (28 %) and Japan (24 %) are the world leaders in the number of patent applications related to hydrogen [66].

In line with the EU’s overarching GH strategy, additional countries have launched national strategies. In Germany, a National Hydrogen Strategy has been introduced, which assumes increasing the role of hydrogen in order to reduce the country’s dependence on coal [66]. The German government wants to invest $7.5 billion to achieve a hydrogen production capacity of 5 GW by 2030. Germany signed an extremely important agreement with Denmark for construction in Denmark electrolyzer with a capacity of 1 GW, which will produce GH using offshore wind energy [127].

In 2020, France announced its new clean hydrogen development strategy, which assumes investing approximately USD 7.5 billion in hydrogen production and the construction of GH infrastructure, which will reduce greenhouse gas emissions by 6 about million tons by 2030. In France, nuclear power dominates the energy mix and the country urges the EU to also include low-emission hydrogen produced from nuclear energy in its RES rules. Some EU Member States are opposed to this because they fear it will undermine efforts to rapidly increase the use of wind and solar energy [66].

In turn, Spain presented in 2020 a strategy to create a favorable economic environment for the supply and demand of GH. The milestones of this project are the launch of electrolysers with a capacity of up to 600 MW by 2024 and 4 GW by 2030, which will reduce CO_2 emissions by 4.6 million. Spain, with large solar energy resources for GH production [66].

Japan is probably the most advanced green hydrogen market in the world. It was the first to approve the Basic Hydrogen Strategy. It assumes diversification of hydrogen sources, playing a leading role in the development of hydrogen technologies, educating society, strengthening regional cooperation, as well as investing in the development of the international supply chain, which results from the country’s small raw material resources [66].

China wants to double its hydrogen production by 2050. It turns out that GH occupies an important place in the 14th national 5-year plan (2021–2025) in China. The two main goals are the production of gas and fuel cell vehicles. As for the former, at the end of 2025, the annual total production of GH should be between 100,000 and 200,000. In the case of fuel cell vehicles, there will be up to 50,000 of them in China in 2025. and will be accompanied by an extensive network of stations for filling cells with hydrogen. The world’s first hydrogen-powered city train runs in Chengdu. It can carry up to 1500 passengers, reaches a speed of up to 160 km/h and has a range of up to 600 km on a single charge. In turn, a hydrogen locomotive is being tested in Inner Mongolia. It can travel at speeds of up to 80 km/h for 24.5 h on a single charge and tow loads weighing up to 5000 tons. On the water, China is testing hydrogen-powered inland shipping vessels, and two companies recently announced that they are working on installing fuel cells in yachts [66,128].

8. Summary

Both the global and European energy sectors have been undergoing a deep transition for several years, associated with a reduction in the overall share of conventional coal-based energy in favor of new technologies, especially energy from RES. This transition is moving from centralized production towards distributed technologies and from providing only energy to end users towards combining innovative products and services with it. Electricity consumers are becoming prosumers connected to the grid and generating an increasing amount of energy.

The current energy crisis has shown how sensitive we are to price fluctuations and problems with the supply of fossil raw materials. Faster implementation of low-emission sources and technologies could mitigate the effects of the crisis on the raw materials market and better protect consumers against high prices. The development of RES means the development of the entire economy through the development and implementation of modern, cheap and environmentally friendly technologies.

The development of RES helps strengthen communities and local economies through the development of community and distributed energy, powered by a network of smaller and safer power plants. A significant part of energy production will move to agricultural areas (biomass, biogas, biomethane, bio-LNG, windmill and PV installations. The development of RES means that the inhabitants of the countries, especially the inhabitants of the countryside, will be the beneficiaries - they will deliver waste to biogas plants, and solar farms and windmills will operate in their areas. The development of RES technologies can have a positive impact on the development of the entire society and the entire economy, including GDP growth and the labor market.

ET means the development of new technologies, and therefore new, well-paid jobs. In recent years, employment in renewable energy has been increasing year by year by several hundred thousand new positions, and their total amounts to almost 13 million positions worldwide. Most people work in PV, biofuels and hydropower. Renewable energy power plants provide not only jobs, but also significant financial benefits for the local government unit and the local community, as they generate various types of taxes and operating fees. In this way, the local economy develops, and also the economy of a given country and the entire global economy. The development of RES will ensure a civilizational and economic leap for all economies in the world.

Worth highlighting is that the ET processes also include research on the production of green hydrogen and its use in the economy, including in sectors that are difficult to decarbonize, such as steel production. This direction of ET, including the use of RES and green hydrogen, is important because it will allow countries to fulfill their obligations regarding the transition of their economies to sustainable development and their decarbonization. Global challenges related to climate change and environmental degradation determine trends in ET processes. More countries are implementing ambitious environmental, climate and energy policies around the world. European countries, including EU member states, are in the lead in this matter. These countries are developing their economies in the scope of the Green Deal, where particular attention is focused on achieving the sustainable development goals. By setting a credible example and then conducting appropriate diplomatic actions, trade policy, supporting development and implementing other external policy strategies, the EU can be an effective implementer and advocate of the assumptions of the Green Deal.

It should be emphasized that in the group of world economies, member countries have moved from the planning phase to the implementation phase of transition projects. By 2050, the EU is to be carbon neutral. The original goal of decision-makers was to stop global warming and improve air quality. After 2022, the EU's transition efforts accelerated, and security concerns were added to climate concerns. After the painful experiences of the last several months, Europe wants to become independent from energy raw materials and their unstable suppliers as soon as possible, securing markets against price fluctuations, blackmail and unfair practices of some sellers.

CRediT authorship contribution statement

Bartłomiej Igliński: Writing – original draft, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Urszula Kiełkowska:** Supervision, Software, Resources, Formal analysis. **Krzysztof Mazurek:** Validation, Resources, Data curation. **Sebsstian Drużyński:** Visualization, Validation, Software, Resources. **Michał B. Pietrzak:** Software, Resources, Formal analysis, Conceptualization. **Gopalakrishnan Kumar:** Software, Formal analysis, Data curation. **Ashokkumar Veeramuthu:** Software, Resources, Formal analysis. **Mateusz Skrzatek:** Visualization, Validation. **Marek Zinecker:** Software, Resources, Formal analysis. **Grzegorz Piechota:** Writing – review & editing, Supervision, Project administration, Formal analysis, Data curation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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