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Review

Review of PV Solar Energy Development 2011–2021 in Central European Countries

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Abstract: According to the data collected in 2022 during 5th International Off-Grid Renewable Energy Conference organized in Abu Dhabi by the International Renewable Energy Agency, the global energy requirements show a negative impact on approximately 785 million people facing energy poverty. The long-term energy sustainability solutions should consider off-grid solutions in the planning of an energy mix and be considered as interim both in remote and already urbanized areas. These measures require integrated planning and partnering with local distribution networks. The review presents the development of photovoltaic installations in Central European countries. For more than 40 years, this area belonged to different regimes and joined the European Union at various dates. Hence, the development of energy policies and cultural and social expectations differ even when based on the Green Deal presented by the European Union in 2020. The outcomes prove that even with a variety of policy measures, the strongest boost can be given only by a set of national rules and financial incentives supporting the stakeholders. It should be noted that the advancement of PV often does not rely on climatic conditions, but more on the level of incentives undertaken by each country, as well as the general policy measures undertaken on the EU level.

Keywords: solar energy; PV installations; Central European countries; energy crisis

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1. Introduction

According to the International Renewable Energy Agency (IRENA), in 2021 [1], the aggregate electricity consumption in the European Union (EU) increased by 4.3%, with production rising at a similar pace, almost reaching prepandemic levels. In turn, in 2022, a reversal was noted where the coal-to-gas substitution trend of previous years was concerned, with gas-to-coal substitution becoming dominant as gas prices escalated.

Since April 2022, the EU has been proposing several measures to solve the ongoing energy crisis. The measures have been announced in the wake of additional factors that have made the crisis worse, including a severe drought that reduced the EU's hydropower by over a quarter and the current shortage of nuclear power. The measures included a mandatory target for reducing energy usage at peak hours and a price cap on excessive profits made by energy companies. The measures build on previous plans under REPowerEU [2] that include a gas demand reduction target of 15% for all Member States by the end of March 2023 and an increase in the binding energy efficiency target (from 9 to 13%) and in the installation rates of heat pumps and rooftop solar panels.

Countries across Europe have introduced a range of measures to combat the ongoing energy crisis. For example, in Germany, the key actions include (1) a EUR 65 bn package of measures including extra payments to the country's most vulnerable citizen, funded by a tax on electric companies and (2) a much quicker procedure for the country's implementation concerning the planned 15% global minimum corporation tax [3].

Solar energy is used worldwide both for generating electricity and heating. Power may be generated by photovoltaic panels (PV), electronic devices that convert sunlight directly into electricity and presently are one of the fastest-growing renewable energy technologies.

There is a wide range of data published on PV technologies in EU countries. The review proved that PV data are available for all EU countries and may be checked in a variety of publications presented by the International Renewable Energy Agency (IRENA) and European Commission publications [4]. Data may be also found through a webpage tool called Photovoltaic Geographical Information System (PVGIS) providing information about photovoltaic (PV) system performance for any location in Europe and Africa, as well as a large part of Asia and America [5]. There are also policy and statistical reports for each of EU countries provided on the EurObserv'ER webpage [6]. For European Union countries, a comparison analysis was found for the Baltic countries [7], Mediterranean area [8], and a comparison of six sites located in the Nordic countries [9]. A paper concerning a comparison made between Germany and the Czech Republic [10] to a certain extent covers the issue pf PV installations in the Central European zone. There are several papers dedicated to a particular area in Europe, i.e., Iberian Peninsula [11] Poland [12], Germany [13] Sweden [14], Spain [15], or the United Kingdom [16].

Additionally, data may be found in a variety of official national documents prepared by adequate stakeholders representing each of the EU countries but with data relating only to each country or an area within that country.

The literature review included all relevant European Union documents, which were used, with certain modifications in all EU countries and included policy documents, guidance notes, and directives concerning energy development and climate change issued during 2010–2021. The review was prepared chronologically. Due to the large waste potential of PV installations, the review included Directive 2012/19/EU of the European Parliament and of the Council of 4 July 2012 on waste electrical and electronic equipment (WEEE) (recast) text with the EEA [17], which, together with the RoHS Directive 2011/65/EU [18], became European law in February 2003. With effect from 1 January 2019, these regulations were modified according to the appearance of new technologies, which also had to be covered by the Directive. The next document of major importance is the Policy Document 7th Environment Action Programme, Decision No 1386/2013/EU of the European Parliament and of the Council of 20 November 2013 on a General Union Environment Action Programme to 2020 "Living well, within the limits of our planet" [19]. This document relates to the general EU aims, including becoming a smart, sustainable, and inclusive economy by 2020 and the provision of policies and actions aimed at making the economy low-carbon and resource-efficient leading to the reduction of at least 20% of greenhouse gas (GHG) emissions by 2020. In the following years, the EU issued Decision (EU) 2022/591 of the European Parliament and of the Council of 6 April 2022 on a General Union Environment Action Programme to 2030 Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee, and the Committee of the Regions Closing the loop [20]. One of the first documents of importance directly relating to the development of solar energy technologies is Directive (EU) 2018/2001 of the European Parliament and of the Council of 11 December 2018 on the promotion of the use of energy from renewable sources (recast) [21]. A Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee, and the Committee of the Regions, published in 2018 A European Strategy for Plastics in a Circular Economy presenting a strategy for a new plastics economy, where the design and production of plastics and plastic products fully respect reuse, repair, and recycling requirements [22]. Since some of the leading manufacturing companies have introduced PV cells in plastic frames, this strategy should also be applied in future. There are two documents of major importance, which have been introduced lately by the EU. The first one is The European Green Deal—a roadmap for making the EU's economy sustainable by turning climate and environmental challenges into opportunities—published in December 2019 [23]. The other, the Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee, and the Committee of the Regions for A New Circular Economy Action Plan for a Cleaner and More Competitive Europe, published in 2020 [24]. They both contain general aims for a more sustainable future and are directly involved with the intensification of renewable resources within every sphere of life. There are also some documents of lesser importance, such as the Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee; the Committee of the Regions REPowerEU Plan-2020 [25]; and guidance notes published to help EU countries to transpose fully the different elements of the 2012 Directive into national law [26,27]. As EU members have been accepted into the European Union at various dates and from different policy backgrounds, the EU directives are of a more general nature with the hopes that the governments of each of the countries will modify their own legislative documents in order to comply with the general stated aims.

The key segments of this paper include the methodological approach and a reference to general climatic data for the region, which have not yet been compared where PV installation development is concerned. The chosen countries are presented as case studies containing a brief summary of their development and current status and potential barriers. This section is followed by the Discussion and Conclusion sections.

2. Methodology

This study was based on an extensive literature review. In addition, a content analysis of the literature on the PV market and industry reports as well as trends applicable in the studied countries were mentioned. Although the topic addressed in this paper is quite important and relevant, there are different models in the scientific and journalistic literature for the introduction of PV and its participation in the overall energy market. There is a limited number of national studies devoted to analyzing the prospects of the domestic photovoltaic industry from the perspective of a group energy transition and development.

The first criteria for the analysis were the geographical delimitations of the study of the chosen countries located in a single region with similar climatic characteristics. Since the Mediterranean, Baltic, and Nordic regions are described in detail, Central European countries were chosen. These comprise Austria, Germany, Hungary, Poland, Slovakia, and Slovenia because they have similar ambient temperatures and a similar annual number of solar days (Table 1). A single initial starting date could not be established for all seven countries; therefore, the goal was to briefly analyze the beginnings of solar energy in each country and prepare a development analysis for the past decade. Both technical and nontechnical aspects are considered within this paper. Among the technical aspects, the focus is on the adoption of PV installations and an estimation of their potential and foreseen development barriers. Regarding the nontechnical aspects, the focus is on identifying barriers and challenges in relation to national and local legislation.

Table 1. Climate characteristics for the capital cities based on https://en.climate-data.org/europe (accessed on 10 September 2022).

Country	Climate	Precipitation [mm]	Average Ambient Temperature [°C]	Number of Solar Hours [Annual]
Austria, Vienna	Warm and temperate	703	10.9	2802.41
Czech Republic, Prague	Warm and temperate	687	9.8	2575.33
Germany, Berlin	Warm and temperate	669	10.1	2479.08
Hungary, Budapest	Warm and temperate	661	11.1	2964.21
Poland, Warsaw	Warm and temperate	695	9.3	2467.91
Slovakia, Bratislava	Warm and temperate	683	10.8	2825.28
Slovenia, Ljubljana	Warm and temperate	1224	10,2	2505.02

Therefore, this study presents the PV installation development in the Central European area during 2011–2021, including a prediction for future solar photovoltaic power generation. The main contributions of this paper can be stated as follows:

1. Presentation of countries that belong to the same warm temperate zone (Table 1) but have followed a variety of development routes

2. The outcomes of the former decade of development and measures undertaken in each of the countries to manage the ongoing crisis
3. A list of potential barriers and foreseen future development

The literature review included relevant European Union documents issued during 2010–2021, described in the Introduction section. In addition, important national laws concerning renewable energy requirements, climatic mitigation regulations and procedures in the seven countries belonging to the Central European area, scientific papers and other published materials written during 2014–2022 concerning the same region, and relevant documents published by the International Renewable Energy Agency (IRENA)

3. Case Studies

3.1. Case Study: Austria

At of the end of 2014, solar power in Austria amounted to 766 megawatts (MWs) of cumulative photovoltaic (PV) capacity. Solar PV generated 766 gigawatts (GWs) or about 1.4% of the country's final electricity consumption [27]. As in other European countries, the Austrian solar market is reviving, and the installed solar capacity is expected to register a compound annual growth rate (CAGR) of over 12% during the forecast period (2022–2027). All EU countries reported a slowdown in installations during the COVID-19 outbreak, but in Austria, the recovery was quicker. In 2020, the solar energy capacity accounted for around 10% of the total renewable capacity. The primary drivers of the market included the growing demand for more clean energy, distinct efforts to lower greenhouse gas (GHG) emissions, and government policies stimulating solar panel use. A new renewable energy law supports the replacement of fossil fuels with solar power. According to Austria's National Energy and Climate Plan (NECP), the Austrian government is committed to installing 1 million PV systems by 2030. The forthcoming renewable energy generation is likely to become a significant share of the country's market during the forecast for the next 10-year period [28].

Austria's solar photovoltaic industry is already one of the significant segments in the power generation industry, with an installed capacity of approximately 2.2 GW in 2020. Growing concerns regarding climatic change and rising air pollution were the main reasons to prepare a national roadmap, which includes aims to increase the share of solar energy. According to the National Energy and Climate Plan, Austria's power production target from solar photovoltaic is expected to be 2 terawatt hours (TWh) in 2030, 3 TWh in 2040, and 5 TWh in 2050. The proposed 1 million photovoltaic roofing program is the key factor assisting the nation in achieving climate neutrality by 2040. Furthermore, the Erneuerbaren-Ausbaugesetz—The Renewable Energy Extension Act—[29] proposed by the government is designed to support renewable energy projects to achieve the 2030 target, according to which an electricity generation of 11 TWh is required from solar power production. Austria's last coal power plant was closed in April 2020. This choice will support the further growth of solar energy in the country in the coming years.

The total renewable energy generation in Austria reached 13.6 TWh in 2020, and the total installed capacity of renewables was 21,842 MW in the same year. The new national target is restricting the use of natural gas for heating in new buildings from 2025 onward, and the shutdown of all heating systems powered by nonrenewable energy resources by 2035. In August 2021, the Bundesministerium für Klimaschutz, Umwelt, Energie, Mobilität, Innovation und Technologie—The Austrian Ministry for Climate Protection—approved a budget of EUR 20 million to construct residential and commercial solar projects. The Ministry has also raised a funding budget for small-scale systems. The subsidy is geared to households and small-scale enterprises with an output not exceeding 50 kW [29,30].

In 2020, the Österreichische Mineralölverwaltung (OMV), an integrated oil and gas company, and Verbundgesellschaft (VERBUND), Austria's leading electricity provider, initiated construction of the country's largest ground-mounted photovoltaic plant in Schönkirchen, Lower Austria with a capacity of 11.4 megawatt-peak (MWp). In addition, in October 2021, Austria revealed a plan to build its largest solar PV plant at Vienna's international airport. This solar project covers 24 ha with approximately 55,000 panels. The Vienna International Airport plans to invest EUR 33 million in the project that is expected to support one third of its annual electricity consumption [27]. The PV market is not a key sector where already installed capacity is concerned. However, the steady increase in installations has made an influence for the end-of-life (EOL) sector. Where PV waste prognosis is concerned, Austria proves to be more advanced than other European countries. The transposition of the European Waste from Electrical and Electronic Equipment (WEEE) Directive [17] was achieved on the national level by the update to the 2014 Elektroaltgeräteverordnung und dem Abfallwirtschaftsgesetz—Ordinance Regulating the Handling of Waste Electrical Equipment and the Waste Management Act (EAG-VO). In general, PV installation purchases can be classified as business-to-consumer (B2C) or business-to-business (B2B) products. The B2C classification applies also to equipment intended to be used in areas other than private ones but with a similar capacity. All PV panels offered on the Austrian market are always classified as part of professional waste. This contrasts with most EU member states. Austria has implemented an adaptation of the six modified WEEE categories. PV panels are a separate "collection and treatment category" and have specific recycling targets, although the expected values are equal to those expected for large equipment, according with the WEEE Directive classification [17].

3.2. Czech Republic

The Czech Republic's solar energy market is expected to grow at a CAGR of around 2.5% during the next 10 years. The primary driver for the market includes government initiatives and investments into clean and alternative sources of energy. However, a lack of precise regulations and the limitations of the existing electricity transmission and distribution structures might not be favorable for the expected market growth. Growing carbon emissions and an increase in renewable energy in total electricity production is expected. In 2019, the renewable share in electricity generation was 15%, and the estimated output increase is expected to achieve nearly 22% by 2030. Additionally, the calculations prove that renewable energy consumption will increase to nearly 230 petajoules (PJ) by 2030 [31].

In 2018, approximately 88 TWh of electricity was generated, of which 29.9 TWh was from nuclear power plants, 45.07 TWh from thermal power plants, 4.9 TWh from renewables, 3.68 TWh from natural gas power plants, and approximately 4.4 TWh from others. Nearly 25.48 TWh of the electricity was exported during 2018. Austria was the highest importer of electricity from the Czech Republic, followed by Slovakia and Germany [32]. This changed as early as 2019, when the Czech Republic installed a solar power installation of approximately 2071 MW, with an electricity generation capacity of 2.3 TWh. The Czech Republic's renewable energy shares amount to approximately 12% of the total electricity generation in the country. Moreover, the country's demand for electricity is expected to be approximately 83 terawatt hours (TWh) by 2025. The target to reduce carbon emissions with the use of other alternative energy sources can further support growth of this sector. Innovations in the solar sector have also reduced the global average selling prices of solar PV. The anticipated new and more advanced technologies and increased manufacturing of PV installations will allow for a stabilization of the capital costs at lower levels [33,34].

3.3. Case Study: Germany

After 1945, Germany, like many other countries, based its energy sector on mining resources. The approach changed gradually, and in 2018, black coal mining was halted. Lignite extraction is still under reduction, and in keeping with the EU recommendations, Germany hopes to reduce CO2 emissions by 55% before 2030. After the introduction of PV cells in 1991, many local firms achieved the status of leaders where new technologies were concerned. By 2012, this status was lost due to the market collapse. Nevertheless, Germany's power production levels allow it to remain one of the world leaders where solar installations are concerned. Economic trends show that the next development wave is approaching. Presently, the main aims are to integrate all renewable resources [35]. Solar power's global share in power generation surpassed two percent for the first time in 2019, according to the IEA [20] Researchers from the Fraunhofer ISE estimate that 1030 full-load hours are possible, but this level is still far below the nearly 6600 full-load hours that German lignite plants ran in 2016. Germany added about 5.3 GW of solar power capacity in 2021, this being 10% more than the year before but still much less in comparison with the initial years of development. The aim to reach a better energy independence is becoming the key factor and to make the PV system the key component within the presented energy strategy. The forecast is to achieve 80% of renewables in 2030 and 100% in 2035. This requires investments to quadruple annual expansion in order to reach 215 GW assumed to be installed by 2030. In 2022, the first two German states implemented a solar PV obligation for construction projects, and others are expected to introduce similar measures. In addition, the national government proposed to make rooftop solar panels mandatory for new commercial buildings and new private buildings. A new law was proposed to use a larger share of agricultural and moorland areas to be partially used for solar PV farms. These assumptions support investor confidence, and the first auction in early 2022 received more bids than it could award. A shortage of skilled labor for installing panels may become a hindrance to Germany's faster pursuit toward energy independence. Additionally, German solar power companies have to compete with foreign manufacturers, even if they still remain in the light when providing module system integration and implementing innovative applications.

Despite being among the countries with the least hours of sunshine, Germany is one of the largest solar power producers in the world. In 2019, total solar energy reached 4 GW. It is a lower value than that connected in 2010, but it is higher in comparison with the previous 5 years. In 2020, the sum of installed power exceeded 50 GW. With an installed capacity of nearly 60 gigawatts (GW) in 2021, the country ranked 4th globally after leading the field for several years, according to the International Renewable Energy Agency (IRENA). For 2030, solar power is estimated at 98 GWp [17]. The German solar landscape includes both large stakeholders and small private owners, who also play an important role in the overall output amounting to nearly 10% of the total produced solar energy. Nevertheless, the observers of the German energy policy state that this level is not sufficient to achieve the national aim of 6.5% of renewable energy resources. More than likely, the German solar power capacity should be tripled to meet the 2030 targets. It should be noted that one of the reasons for this rapid growth is the 2019 close-down of the coal mines and nuclear power plants, giving space to new developments. In addition, financial incentives proved to be advantageous [36].

Currently, according to research from the Fraunhofer Institute for Solar Energy Systems (ISE) [36], solar power has become the cheapest mode of power generation in Germany. Between 2010 and 2021, the costs for new panels fell by about 90 percent. However, financial incentives for existing and new solar power installations still have to cover substantial costs for German power customers, amounting to over EUR 10.3 billion in 2018 alone, according to the economy and the Bundesministerium für Wirtschaft und Energie (BMWi—The Federal Ministry for Economic Affairs and Energy). In contrast to conventional energy systems, an important part of the German energy system is formed by thousands of small solar panel operators. In 2021, solar operators accounted for about 10% of the country's net power consumption, with the renewables share of approximately 46%, according to research from the Fraunhofer ISE [37]. Many solar power users install their panels without participating in auctions. According to the Bundesnetzagentur (BNetzA—Federal Network Agency for Electricity, Gas, Telecommunications, Post and Railway), in 2021, just under 73% was installed outside of the tendering process. Regardless of the awaited advanced solar technologies, German citizens already accept PV installations as the best form of renewable energy generation. Solar power ranked first in a survey by the pollster Allensbach [38,39] on what Germans believe to be the most important power source in the future. Eighty percent of respondents expected solar power to take a greater lead. According to the Renewable

Energy Agency (AEE) in 2021, one in three households had considered PV installations. BSW Solar confirms that this trend had amplified since the April 2022.

3.4. Case Study: Hungary

Hungary has run out of available grid connection capacity to connect weather-dependent power plants, disappointing solar power developers and investors. No new connection requests can be accepted under the tender procedure, and investors are required to bear the costs of grid connection. Over the last decade, production capacities and consumer demands within the Hungarian electricity system have changed fundamentally [40].

There has also been a change from the typical few large generators to a highly decentralized production. The steadily improving returns on PV installations increased the demand for grid connection capacity. The Hungarian electricity system currently has around 3000 MW of industrial and domestic solar capacity. The former has increased tenfold over the last five years, and a further expansion on the household scale is expected. This means that the Hungarian electricity system has at least another 5000 MW of renewable connection needs [41].

The share of solar power plants in the total output was 11.1% percent during 2021, the highest in the EU-27, according to a report of the Hungarian Energy and Utility Regulatory Office (MEKH). This rapid expansion of domestic solar capacity allowed Hungary to take the lead in solar power, ahead of Mediterranean countries, such as Spain and Greece [42].

Hungary did not follow the 2022 EU trend with gas-to-coal substitution as gas prices escalated, and as lignite-based generation continued to decline, the share of solar power plants grew [43]. The forecast is that the primary RES energy consumption in Hungary will be 21% by the year 2030; this means approximately 4000 MW in the coming decade. The production capacity is estimated to exceed 6500 GWh, more than 70% of which will be delivered through photovoltaics [44]. Essential for the long-term energy-independence goals of Hungary are security, energy saving, and environmental protection [43].

3.5. Case Study: Poland

According to the first report on the PV market in Poland published in 2012, installation power was estimated at 7.9 MW with most of the installations being off-grid. Initial estimations for the following years proved to be wrong, and in 2020, the production already exceeded that proposed for 2030. Nevertheless, Poland had to wait until 2019 in order to pass the barrier of 1 GWp of installed power. The year 2021 brought a new definition of “small RS installations”, accepting sources from 50 kW (prior limit was 500 kW) and giving the status of “micro-installations” to those not exceeding this level, but having an 80% share in the total PV production in Poland. This situation was due to many incentive programs and a harbinger of the system’s change from net metering, where overcapacity was stored in the grid, to net billing, where overcapacity is sold at wholesale prices. Hence, local energy storage solutions have become one of the most important future developments. At the end of 2021, the power installed in EU countries approached 158 GW, which meant a yearly increase of 21.4 GW. Poland was just behind Germany where PV cells gains were concerned. The year 2022 might have been similar, except for the new challenges due to the supply chain disruptions and rising component prices [45].

The presented scenarios contain legal and financial incentives that supported and shaped the market development in this country. “My electricity” program and advantageous ecobanking loans brought in many off-grid private investments [46].

There is a variety of financial support incentives also for photovoltaic installations. These include:

- My Electricity—cofinancing PV installations with a capacity of 2–10 kW and energy, heat, and cold storage facilities [47];
- Thermomodernization tax relief—allowing to deduct the costs incurred for insulation up-grades, including PV installations, in the annual tax declaration;

– Agroenergy Program—dedicated to individual farmers, cofinancing capacities of 10–30 kW;
– Energy Plus—a program for entrepreneurs that includes nonreturnable subsidies of 50% of eligible costs;
– Regional programs—subsidies for photovoltaics are granted to municipalities, which also determine the conditions and their level.

Poland receives solar radiation of 1000 kWh/m^2/year, ranking this country as having a lower solar power capacity. Therefore, several studies were conducted to understand potential solar energy technology (SET) utilization, according to EU directives. The results suggest that innovative SET applications with rotating solar towers and artificial photosynthesis could be developed to enhance possible development [48].

Environmental awareness remains one of the strongest factors influencing the choice of PV technology; factors related to the environment vary among countries [49,50]. This significant influence of environmental factors is linked to the European decarbonization policy and may be interpreted as the internalization of ecological values within Polish society [51].

Moreover, the growing power production where renewable energy sources are concerned strengthens the country's energy balance. Furthermore, this development ensures higher energy security, reduces dependence on energy imports, and limits the use of fossil fuel resources [52].

3.6. Case Study: Slovakia

Even though the irradiance conditions are comparable with those countries with strongly developed PV, the Slovak market for electric power generation is small compared to that of other Central European areas. The developments were low for many years prior to 2005, and PV installations were mentioned only marginally as part of a wider energy strategy. State barriers resulted from technological, economical, and regulatory causes.

In 2019, approximately 54.7% of the total production of 27,149 GWh of electricity was obtained from nuclear power stations, 21% from conventional power stations, 14.4% from hydro stations, and only 8.9% from renewable sources. Slovakia plans to utilize its approximately 27,000 GWh per year sourced from renewable resources. This includes available and affordable innovative technologies. Renewable sources will include biomass, bio-gas, landfill gas, wastewater gas, photovoltaics, wind, water, and geothermal sources [53].

For Slovakia, biomass has the largest technical potential of 11,200 GWh per year, covering 40% of the total in-house energy production. The solar radiation flux achieves a maximum of 1100 kWh/m^2, which estimates the technical potential of solar energy at 5200 GWh per annum. Moreover, this provision allows for 20% of the total technical potential of renewable power sources in the country. As in many other countries, the demand for the supply of PV power plants and the installation of solar panels on rooftops is steadily growing [1,30]. Solar power plants scattered across the country currently produce approximately 550 megawatts of electricity. It is unfortunate that the development of solar energy has been influenced by controversial subsidies allocated by the previous Slovakian government. A technical development issue was the destabilization of power grids due to the solar energy characteristics. Therefore, for several years, solar panels were installed only as off-grid on rooftops [1].

The electricity production from RES was supported by the annual feed-in tariff scheme, under which RES producers sold electricity for fixed prices that were higher than those for conventionally produced electricity. Although, in theory, all RES producers are entitled to preferential access to the distribution and transmission systems, the reality has proved otherwise. In the last 5 years, distribution companies have been hesitant to connect new solar installations. The main argument was that the existing national grid had insufficient capacity [54]. The Slovakian amendment to the Act on Support of Renewable Energy Sources and High Efficiency Combined Heat and Power adopted a new clean energy and cogeneration support scheme [55]. Presently, the Slovak Ministry of Economy is soliciting bids for new producers of renewable energy. The Economy Ministry will accept bids for photovoltaic facilities with an installed capacity from 100 KW to 2 MW, while the installed capacity for renewables including solar energy can range from 500 KW to 10 MW [1,30].

On the level of national investments, it was announced that a solar park will be built by the state nuclear energy company in the vicinity of the existing nuclear power plant Jaslovenské Bohunic and completed by 2025. This plant will cover 105 hectares, and provide 58 MGW, this being more than one tenth of the current production from all Slovakian solar power plants [56].

In June 2020, the Slovak Regulatory Office for Network Industries published statistical data disclosing that in 2019, the electricity consumed from renewable energy sources (RES) constituted approximately 17.48% of the Slovak Republic's energy mix, and solar energy represented only 1.8% of the total production. Without strong support schemes, Slovakian innovative energy installations are unable to challenge the status of conventionally powered power plants. Therefore, future decisions should include stronger support from the state [56].

On 1 January 2021, a significant amendment to the Renewable Energy Sources Act was adopted that dealt with the promotion of renewable energy sources and high efficiency cogeneration solutions [57]. The amendment was intended to lead to extensive reform concerning the support of electricity production from RES. This document was prepared in line with the EU directives. The introduced rules include a new feed-in premium tariff that guarantees a premium above the market price and auctions for solar installations above 100 kW. For smaller installations, the feed-in tariff is still available, but it is not as generous as it was during 2009–2010. The amendment also introduced a rule that the distribution companies could connect locally installed sources to the national grid. The condition was that 90% of the electricity would be consumed in situ. The noteworthy update included the introduction of green auctions for new installations to be organized in accordance with EU guidelines. In February 2020, the first green auction was announced for new installations with a capacity up to 30 MW with a guaranteed feed-in premium tariff for 15 years. The auction conditions for the solar installations included a maximum installed capacity of 100 kW−2 MW and installations on rooftops, façades of buildings, or nonarable land [57]. When discussing solar power solutions, overcompensation is one of the problems that Slovakia is currently facing. After recent scrutiny of the finalized investments, the Slovak Regulatory Office for Network Industries recognized that over 90% was overcompensated. There are still no definite plans for legal sanctions, but much stricter measures are expected in the near future. The new government elected in 2020 has approved a National Energy and Climate Plan, setting a target of 19.2% of all energy to come from RES by 2030 [57].

3.7. Case Study: Slovenia

In February 2020, the Slovenian government adopted the National Energy and Climate Plan (NECP), setting the energy strategy targets for 2030 and expectations for 2040. By 2030, Slovenia aims to have renewable energy (RES) account for at least 27% of the total energy usage. It is also expected that two thirds of the energy consumption in buildings will be sourced from RES [30]. It is expected that decarbonization will be achieved mainly through the reduction of fossil fuel, incentives, and subsidies for nonconventional energy sources. Foreseen steps are a 30% reduction of coal in electricity production by 2030 and phasing it out by 2050 at the latest, including reducing lignite excavation and dependence on imported fossil fuels. The NECP offers worthy incentives for decarbonization and a further reduction of fossil fuels. Other targets are of lesser importance, with a 1% reduction of greenhouse gas emissions in agriculture and low targets for public passenger transport. Slovenia is preparing the Spatial Development Strategy of Slovenia 2050, which includes the impact of RES on the environment [30]. The strategy prohibits the installation of wind power farms in various areas, i.e., near historic sites or in valuable landscape conditions, and restricts the distance from settlements. This bears high resemblance to the Landscape Act passed in 2015 in Poland [58]. The use of solar power is currently foreseen only in urbanized areas in the vicinity of infrastructural facilities and "brownfields". As in other countries, the investment in the renewables sector is dependent on the availability and level of financing incentives. Power plant operators, awarded by public tender, may choose between a guaranteed purchase and an operating premium when installing power plants with a capacity not exceeding 10 MW.

In May 2020, the Slovenian government adopted amendments to the Rules on Support for Electricity Generated from Renewable Energy Sources and from High Efficiency Cogeneration, introducing the obligation for investors to provide adequate insurance for the performance of installations. The insurance amount could be up to 5% of the investment value of the project, with the exact amount, type and the validity of the insurance determined by the Slovenian Energy Agency. In 2019, the electricity production within the subsidies scheme—in the 3858 power plants with a nominal power of 417 MW—amounted to 947.5 GW, which is 1% more than in 2018. In March 2020, the Slovenian government adopted the Decree on Small Installations for the Production of Electricity from Renewable Energy Sources or Through High-Efficiency Cogeneration. The types of installations for energy production from renewable energy sources and high-efficiency cogeneration that do not require a building permit were specified as solar power plants with a maximum power of up to 1 MW. The Decree simplifies investing in renewables and is a welcome change [1,30].

The potential to increase renewable energy in Slovenia is significant as the country has a high number of solar hours. Slovenia is also in the final stages of adopting the Energy Efficiency Act, which sets out measures to promote and increase energy efficiency with a particular focus on buildings. In addition to tenders for the feed-in support scheme, which are published around twice a year, additional cofinancing mechanisms are available [59]. The performance ratio of PV systems in Slovenia is higher than that in Switzerland and Spain. The mean value is 68.84%, which indicates that PV systems are producing annual energy that is 23.20% less than the reference conditions [60]. The PR of 106 PV systems in Germany varied between 42% and 85% with a mean value of 67%. In addition, Austria reported a mean performance ratio related to 22 PV systems to be in the order of 63%. The majority of these PV systems are rooftop residential systems and often are installed regardless of the required inclination and azimuth [61].

Slovenia plans to set up giant solar power plants to supply households in the next three years, which shows plans for a significant increase in solar capacity. Currently, the Infrastructure Ministry is preparing a plan to increase the photovoltaic capacity by 1000 megawatts by 2025. The plan is being drawn up in cooperation with the national grid operator ELES and the distribution system operator SODO [62].

4. Discussion

The EU regulations have changed throughout the last years. The 2017 Winter Package [63] introduced new stakeholders, the prosumers, who are important where PV solutions are concerned, as they include private stakeholders within the circular flow of solar power. Additionally, the manufacturing costs per unit have dropped in the last decade making this system affordable. Solar panels have a lifespan of 30 years; therefore a lot of attention is given to the classification of waste and the reuse of components [64]. In 2019, the total installed PV capacity in the EU and United Kingdom exceeded 134 gigawatt-peak (GWp). The increase was mainly caused by residential, commercial, and rooftop developments accounting for more than 60% of the cumulative installed capacity [65]. The development trend reversed in 2018 after six years of stagnation. In 2019, the five leading countries were the United Kingdom, Spain, Germany, the Netherlands, and Poland. The next four runner-ups producing more than 500 megawatt-peak (MWp) were Belgium, France, Hungary, and Italy. This rapid progress was the outcome of technological advancements making PV one the most cost-effective power generation technologies [66]. During 2020, the cost of most bifacial modules in the EU became cheaper by 15.4% and the mainstream modules by 12%. PV cells currently play an important role in the European

Green Deal Policy [65]. The European Commission (EC) has named 2050 as the threshold for climatic neutrality and 55% GHG reductions by 2030. This document also corresponds with the European Climate Law [67] proposal and Impact Assessment providing future projections for the EU energy system. Where PV cells are concerned, the scenarios presented in the Impact Assessment [68] are shown in Table 2 [65]. Regardless if it is the base line or a more advanced scenario, in 2030, the share of PV in electricity generation is estimated at 12–14% of total production.

Table 2. Energy model projections for solar PV capacity deployment in EU 27 [65].

Scenario	Solar PV Generation Capacity (GWac)			2030 PV Share in Electricity Generation [%]
	2018	2030	2050	
Base Line Scenario (BSL)	104	311	465	12
Carbon Pricing-based Scenario (CPRICE)		363	1065	14
Combined approach of REG and CPRICE scenarios (MIX)		370	1060	14
Regulatory-based measures scenario (REG)		363	1040	14
Scenario based on MIX and further intensified fuel mandates for the aviation and maritime sectors (ALLBNK)		374	1060	14

Proposals presenting financial management procedures for the Green Deal were presented in January 2020. The main aim is to assemble EUR 1 trillion worth of sustainable investments during the next ten years [3,23].

Additionally, European solar power companies are currently undergoing major sector changes. New and stricter rules required from supply chain management introduced by the European Union favor those firms that have implemented circularity procedures and therefore better life-cycle outcomes and reduced negative emissions. One of the major issues is the achievement of advanced sustainable solutions for used nonrenewable resources and the waste disposal of units.

The European Green Deal [69] was approved in 2020 and became a very important document where further development is concerned. The year 2021 brought the Fit for 55 Package, designed to realize the European Climate Law objectives: climate neutrality by 2050 and a 55% reduction of net greenhouse gas (GHG) emissions by 2030, compared with 1990 levels [70] and in response to the global energy market disruption taking place in 2022. This document mentions a double urgency to transform Europe's energy system: ending the EU's dependence on Russian fossil fuels before 2030 and addressing the climate crisis. There is also a section dedicated to the rapid installation of rooftop PV cells up to 15 TWh. Another important sector document is the EU Solar Strategy together with the Solar Rooftop Initiative, which includes the introduction of legislation requiring the installation of PV cells on all newly constructed buildings [71,72]. The changes within both the EU and national legislation are mainly administrative simplifications, which support PV systems. It is also possible to have a mixed use of agricultural lands called agroPV. The EU Commission postulates that countries should introduce incentives when developing strategic plans for farm policies.

5. Conclusions

The potential energy of a PV power generation system is long-lasting and may be used as a reliable and environmentally friendly medium to achieve renewable energy goals. The differences in yearly average solar irradiation do not exceed 5% throughout the Central European countries. The efficiency of the PV system has the highest value from May to August; the minimum value of efficiency occurs in December. Nevertheless, it is scientifically proven that its power output decreases with an increase in the temperature of the PV module. Such an important issue that proves to be a major barrier for further development of installations is controlled by adopting several cooling mechanisms for the PV module, which are currently under research in various countries. There are two types of cooling approaches: 1. active cooling using electricity energy and 2. passive cooling using natural external phenomena, such as wind and rain or physical phenomena, e.g., conduction [73].

It should also be mentioned that there are two potential solutions that may be used with the use of solar energy. The first one is the already analyzed photovoltaic installation where sunlight is directly converted into electricity. The second is concentrated solar power (CSP) technology where the approach is based on generating electricity through mirrors. The mirrors reflect and focus sunlight and convert it to heat that is then used to create steam driving a turbine to generate electrical power. PV cells can be used only during solar hours, whereas CSP can store the produced heat to be used when sunlight is not available. This paper includes data only from PV technology. Both technologies were in use already in 1980, and at the time, since PV relied on expensive solar modules, CSP was used more often. Presently, the market has evolved due to two factors: 1. Like all technical solutions, solar energy is also market-driven; PV cells can be installed everywhere, whereas current CSP technologies require higher levels of irradiance and access to water and usually are large-scale developments; hence, more stakeholder became interested in PV cells. 2. The PV system is a simple technology using solar cells, whereas CSP is a combination of various components and has allowed the PV industry to concentrate on lower costs of a simple manufacturing process. In contrast, the CSP industry had to make modifications to a variety of components. Nevertheless, CSP technology has one major advantage over PV, this being its dispatchability of renewable source electricity. Current CSP plants can store thermal energy for up to 16 h, which means that their production profile can match the demand profile. Current PV is not dispatchable, as a feasible commercial energy storage system still does not exist. Nevertheless, economic accessibility appears to have the advantage over the still-required storage where PV installations are concerned [74]. This is one of the problematic issues that will have to be considered during the next stages of development, namely that the solar power influx at peak demand time (noon) has a stabilizing effect on the grid but also reduces profit margins for power providers. Nevertheless, sunny weather and hot temperatures do not automatically lead to higher solar power output, as hot solar modules lose electric tension and have lower capacity. The high output during summer is offset by a lower or nonexistent output during the winter and at night. This highlights the need for reliable storage technology, which should expand during the next technology wave.

Data on the cooling methods in Central European countries are very limited. Such technologies, such as half-cut or HJT, reduce the heat build-up in the PV panels. Nevertheless, even for high-quality panels, the temperature coefficient of photovoltaic panels (Pmax) does not exceed 0.25–0.37%. Other traditional solutions for cooling PV panels include natural ventilation, which can be achieved through the adequate spacing of the modules and distance from the mounting plane. This solution proves to be sufficient in warm temperate countries; unfortunately, during extreme hot weather spells, an adequate distance proves to be an insufficient solution. Another idea is the development of floating PV installations, which can be found in many countries including Poland [75–77]. One of the methods leading to the introduction of an active cooling system is currently being analyzed by scientists from the University of Sheffield in the UK and PSG College of Technology in India. The solution uses a fully automated sprinkler system on the PV's front panel, which allows for a better efficiency of approximately 0.5%. Used, heated water may be then used for domestic purposes. The daily usage of water on the panel heated to more than 45 °C amounts to 15.6 L. Maximum cooling allowed a temperature drop of 20 °C, and the average drops were approximately 10 °C [78]. A different approach is presented by a team of scientists from the Institute of Science and Technology in Henan, China and two Egyptian universities. The solution the research team proposes is to combine photovoltaic panels with thermoelectric coolers that operate according to the Peltier effect (hence the coolers are called 'Peltier heat pumps'). This method is also fully automated and uses elements of artificial intelligence for better efficiency. Furthermore, this case solution is still undergoing research [79,80]. Water as a medium, for cooling PV panels has also been proposed by a French PV installation company boasting of using water from rain water placed into a closed loop where it is filtered and stored for future use. It is used when the ambient temperature around the panels exceeds 25 °C. Technology may be used both on rooftop and ground-level installations. This solution may be used presently but due to the high costs only in large commercial solar farms where this solution is also often supported by external financial grants. Due to rising global temperatures those technologies should possibly also be part of the future development.

There is very little research on the dust collection on PV surfaces for Central Europe, which in fact might prove to become an issue as seasonal winds whip up large amounts of sand into the atmosphere, which are then carried into Europe especially during springtime [81].

There also remains the requirement for better-managed waste issues and the development of circular management chains where PV cells are concerned. Where Extended Producer Responsibility (EPR) regarding PV panels is concerned, producers may use one of three options: 1. implementation a self-organized take-back, 2. participation in a compliance scheme on a voluntary basis, and 3. usage of the compliance scheme as a service provider. What has been found is that although legislation in all EU member states is based on the WEEE Directive, specific national characteristics do exist and influence the way EOL processes are established. The applied prognosis model shows a significant increase in PV panel waste for the upcoming years, which might become a problem [82]. Hence, possibly outside Austria as the leader of PC installations, other countries should also develop better management procedures.

Solar energy is one of the most sought-after energy forms for renewable technologies, but there are also many challenges where technical solutions are concerned. Availability in many regions is still one of the economic thresholds; there are also issues concerning the technical and economic viability of the used solutions. Solar radiation available on the ground level, which could be in its total spectrum utilized for electricity purposes or thermal applications, appears to be a key factor [83].

Some of the barriers for the development of solar PV plants are typical to most renewable-sourced energy resources, including nuclear power plants [84]. In the case of PV installations, the major issue is their high cost and insufficient national support for further development, issues concerning connection to the grid, and exploitation and fire safety procedures, nonexistent localization conditions in master plans. In the case of larger solar plants, many countries require special concessions, which require long procedures, additional expert opinions, acquirement of "green energy certificates", and a variety of permission payments. Public acceptance and knowledge are also an issue [85,86]. The connection of new sources of electricity to the system is conditioned by the grid's capacity, availability, and technical standard of the grid infrastructure. This means that the development of photovoltaic power plants is technically limited by the availability of the connection capacity. Another barrier, evident also in a warm moderate climate is the cooling issue, which has been described in the former paragraph, together with fire preventions issues [87].

Renewable energies may be the solutions creating a bond between sustaining climate parameters and implementing energy science. Mitigation strategies aimed at the de-escalation of climate change include a variety of renewable energies. Research also covers their possible effects on societies and a modified way of life. However, one of the key issues that still has not been solved is the abatement of technical solutions dependent on the weather and climate and therefore the impossibility to be fully recognized as a valuable management of renewable resources.

This dependency may affect the feasibility of future low-carbon energy supply systems. Photovoltaic (PV) electricity generation depends on solar irradiance, a shortwave with a wavelength interval of 0.2–4.0 mm, radiation (RSDS) by climate models, and other atmospheric variables. Climate change may therefore affect PV power generation and its temporal stability for a given panel fleet [88].

Figure 1 presents the electricity generation of Central European countries and clearly depicts the solar energy gap between Germany and other areas. As already discussed, solar PV energy was introduced in Germany very early, and this country has been the leading provider for several years.

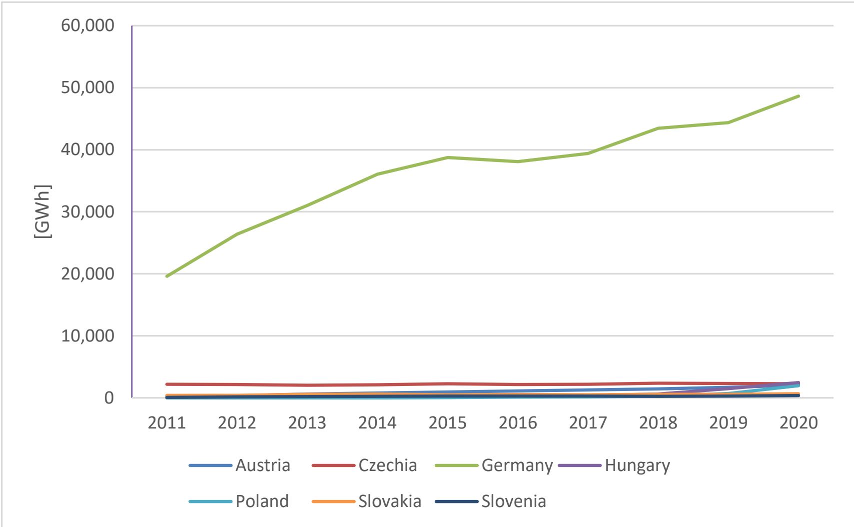

Figure 1. Electricity generation photovoltaics (PV) in Central European countries [30].

Figure 2 depicts PV growth in Central European countries except for Germany. Each country has its own characteristics. The Czech Republic, Slovakia, and Slovenia after initial growth before 2011, do not present a rapid development of PV technology. When comparing these countries during 2011–2020, the Czech Republic stayed as the leader where the implemented power is concerned. Austria showed a steady growth in the same period, whereas after 2017, Poland and Hungary were characterized as the most quickly developing Central Europe countries. It should be pointed out that the development of solar energy where PV technologies are concerned in warm moderate climates highly depends on the existing national incentives and financial support offered to large-scale and microstakeholders [42,89].

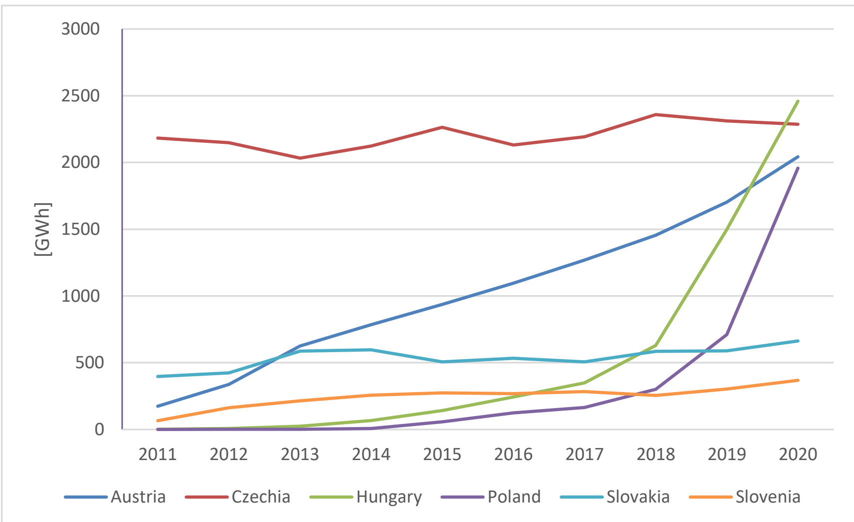

Figure 2. Electricity generation photovoltaics (PV) in Central European countries—without Germany [30].

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