Photovoltaic Systems: A Challenge or an Opportunity for the Polish Energy Sector During Its Transformation

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1 Introduction

To present the possibility of utilization of any renewable energy in any country, first it is necessary to describe the theoretical potential of such energy in specific geographical and local conditions [1]. When possible applications of photovoltaic systems are analyzed, it is necessary to present climatic conditions with a focus on the availability of solar energy. It should be underlined that analyzing only the average annual solar irradiation conditions, it may seem that the utilization of solar energy in Poland cannot be a very effective solution. However, relying only on averaged values does not reflect the dynamics of phenomena and does not show the real possibility of utilization of solar energy in various types of energy systems. Therefore, more detailed solar radiation data should be considered and analyzed to give clear recommendations for possible applications and modes of operation of the PV systems, and to predict the technical potential for these systems [2].

To answer a question formulated in the title of the chapter and decide if the application of photovoltaic systems is a challenge or an opportunity for the Polish energy sector during its transformation, it is good to describe the present state of the Polish energy sector. Then it is necessary to present briefly what is going in energy policy in the country. Different supporting mechanisms can always foster the introduction of new technologies into the energy market. In addition, a strong impulse for deployment of renewable energy technologies should be the need to comply with international legal regulations that strengthen the use of environmentally clean solutions, like photovoltaic technologies. In the case of European Union member states, the

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energy efficiency and clean environment policies have priority. As a result, the implementation of the set of quantitative and qualitative goals regarding the share of renewable energy in the energy consumption balance and the reduction of greenhouse gas emissions and other harmful compounds has got the highest importance.

The present state of application of the PV systems in Poland is presented in this chapter. At the beginning, most of the applications of PV systems have been seen on the micro-scale in single-family houses. However, recently the number of large PV power plants has been increasing continuously. The PV systems in the country are mainly on-grid systems without any storage. In the on-grid PV systems if electricity is not used at the same time when it is generated it has to be transferred to the grid. Such on-grid systems make up the vast majority of all operating PV systems in the country. This situation has been caused mainly by the national Act for the renewable energy systems [3], which was introduced several years ago and gave a support for such microsystems (theoretically with installed capacity less than 50 kW, but in reality of a few kW). According to this regulation the grid was used as a virtual storage. As a result the grid can be overloaded, when many micro-scale systems supply electricity at the same time. In the case of complex regional projects, when several dozen buildings are equipped with photovoltaic installations, the problem of overloading the old grids started to be quite serious. Consequently, their failure rate has increased. Outdated power grids are not able to accept a large amount of energy coming from many micro-installations at the same time. Therefore, there is an urgent need of upgrading not only the old inefficient power plants but also the grid.

2 Polish Climatic Conditions

The territory of the Republic of Poland is equal to 322,577 km^2, and the land area (including inland water) is 311,904 km^2. Poland is situated on the huge Northern European Plain, with the Baltic Sea in the north and Carpathian Mountains in the south. It lies open to the east and west. Poland is located between 49° and 54.5° N latitudes in a moderate climate zone influenced by both the Atlantic and Continental climate. Poland's location causes it to be affected by different atmospheric fronts that result in frequent heavy cloud formation. The averaged mean yearly temperature is equal to 7.9 °C, average annual global solar radiation is in range 950–1150 kWh/m^2. The annual solar hours are on average equal to 1600 that is about 18% of the total number of hours per year [4].

The climatic conditions of Poland are characterized by high variability over the time of the availability of solar radiation. The highest level of solar irradiation is in the northern part of the country, i.e., in Pomerania, and in the south-eastern part, i.e., the Lubelskie Region. The highest solar irradiation is in June when the night time is shortest and it lasts 7 hours and 14 minutes. The lowest irradiation is in December when the night time is longest and it lasts 16 hours and 20 minutes. In Warsaw (central Poland) solar insolation conditions are not very good and the average annual irradiation is about 962 kWh/m^2. The highest average monthly solar irradiation is in

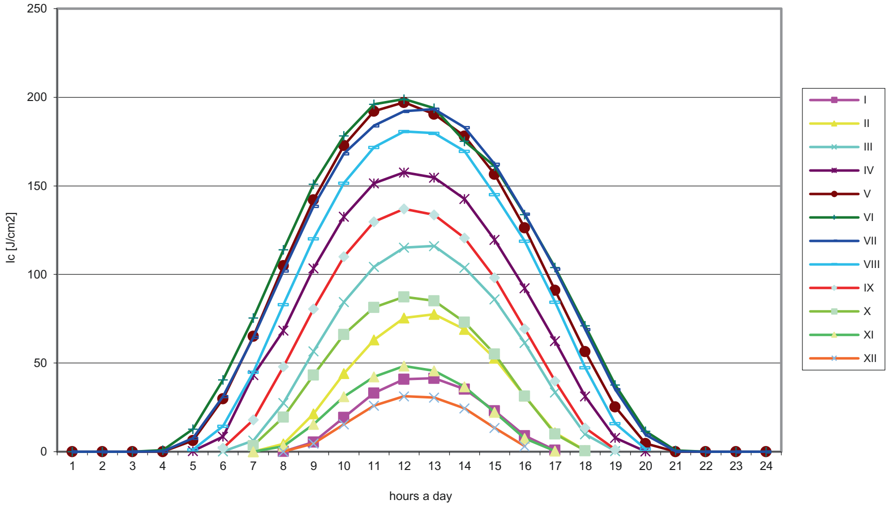

Fig. 1 Daily distribution of average hourly sums of global solar radiation for all months of an average year for Warsaw

June, like all over the country and equals to 160 kWh/m^2 and the lowest is in December and equals to 11 kWh/m^2 [5, 6]. Figure 1 presents daily distribution of average hourly sums of global solar radiation for all months of a year for Warsaw.

The huge difference in solar insolation conditions between winter and summer can be easily seen in Fig. 1. This very uneven distribution of solar radiation during a year is caused by the location of Poland, related to its latitude and location in the central-eastern Europe, where the moderate weather conditions are strongly influenced by the continental climate. Because of that, summers are relatively hot and winters cold. So large differences in daily distribution of solar radiation for all months of the averaged year indicate that inclination of a surface exposed to incident solar radiation is very important to assure the highest solar energy gains throughout a year.

The annual and diurnal course of solar radiation, as is well known, depends mainly on astronomical factors and atmosphere state [1, 7]. The most evident is the relation between the elevation of the Sun and the day length, the highest values being observed in summer, the lowest in winter months. Cloudiness and transparency of the atmosphere for the large dispersion of the diurnal and hourly values are mainly responsible. Figure 2 presents the Sun Charts for Warsaw and it is evident that the course of the charts is analogous to monthly distribution of average hourly sums of global solar radiation presented in Fig. 1.

The climatic conditions of Poland are characterized by high fluctuations of solar radiation availability in the time. About 80% of annual solar radiation is available from April to October and only 20% in the remaining 5 months. In winter, a day lasts 6–7 hours, while in summer it can be nearly 19 hours. Moreover, an average annual percentage of the direct solar radiation amounts only for 46%. In summer the

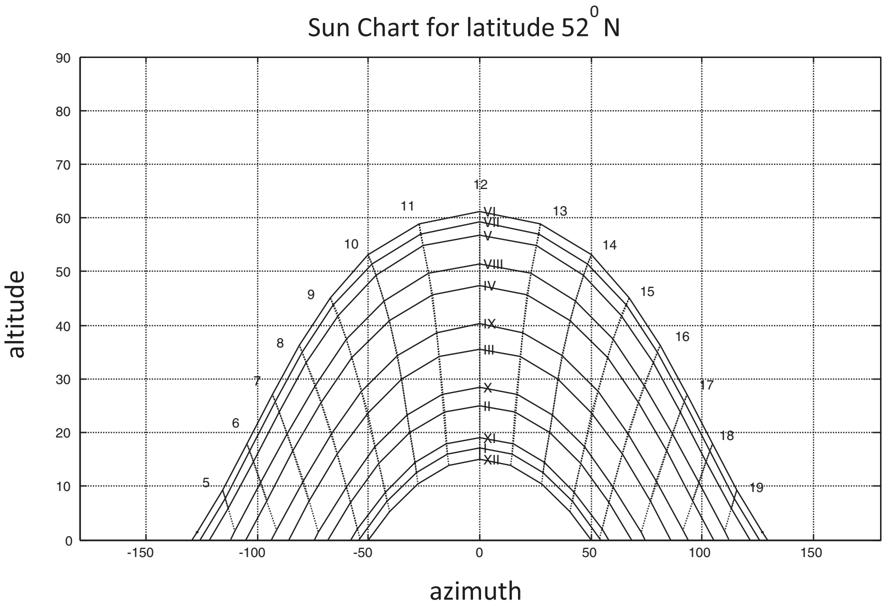

Fig. 2 Sun charts for Warsaw

share of direct radiation is higher and accounts for 56%, but in a period from November to January average diffuse radiation varies from 65% to 71%, and sometimes in December it can reach 80% [5].

Figure 3 shows daily distribution of average hourly sums of diffuse solar radiation on a horizontal surface for all months of a year for Warsaw. This figure can be compared with Fig. 1 to see how high is a share of diffuse solar radiation throughout the year and especially in winter months.

Figure 4 presents monthly distribution of mean monthly sums of global and diffuse solar radiation for an averaged year for Warsaw.

Generally, the surface orientation of any solar receiver normally corresponds to south in the southern hemisphere (and north in the southern hemisphere). However, with the increase in latitude describing the geographical location of a given place on the globe, the importance of the inclination of a surface receiving solar radiation increases. The position of the Sun relative to a surface exposed to incident solar radiation is described in terms of several spherical angles by appropriate relationships [1, 7]. The calculations of solar radiation incident on surfaces with different azimuth and inclination angles for Polish climatic conditions have been performed using such relationships and applying the average hourly solar radiation data for Warsaw [5].

In Poland the influence of inclination of the incident surface on solar irradiation level is evident for the whole year [8]. In summer the most irradiated surfaces have small inclination angles of 10–15°. If the slope is larger then the solar gains are smaller accordingly. Vertical surfaces (the maximum slope) experience a significant

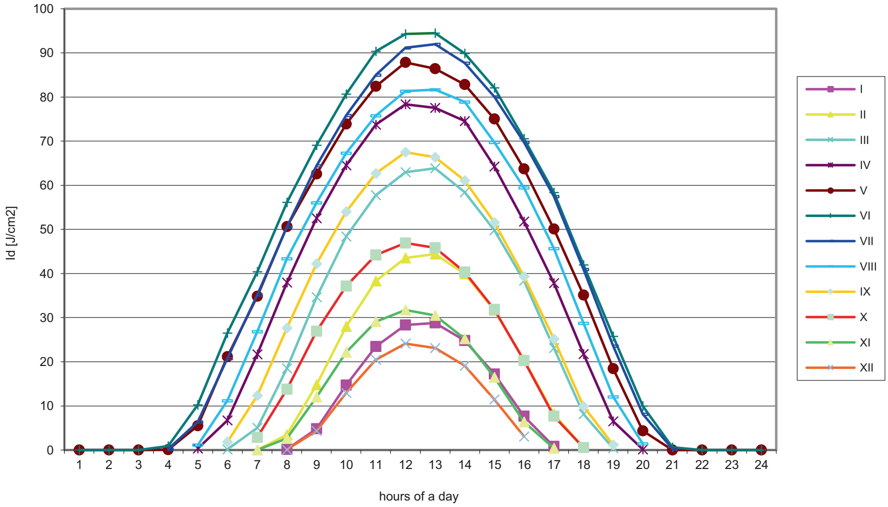

Fig. 3 Daily distribution of average hourly sums of diffuse solar radiation on a horizontal surface for months of a year for Warsaw

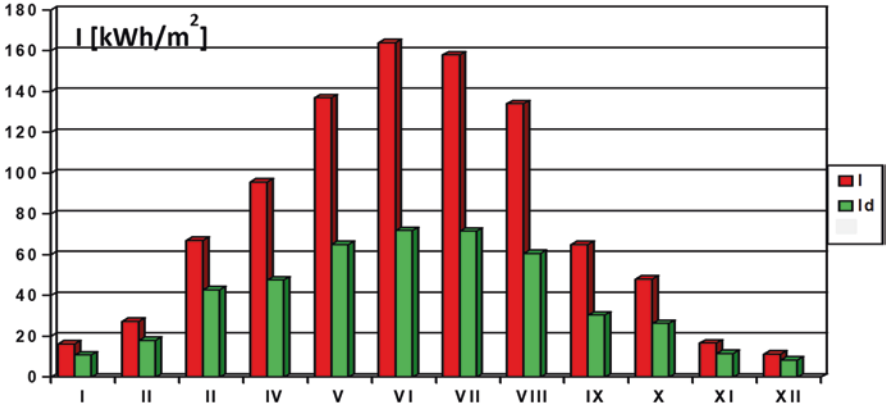

Fig. 4 Distribution of monthly sums of global solar radiation and diffuse radiation for Warsaw

reduction in received solar radiation and the summer solar energy peak, typical for horizontal surfaces, is reduced, especially for south-facing surfaces. In winter the situation is opposite and the best inclination is in the range 50°–70° directed to the south. In winter all surfaces facing south-east through north to south-west receive little solar irradiation, because they cannot see the direct component of solar radiation, what reduces a lot solar energy availability. Calculations carried out for the year-round solar radiation impact on any surface show that in the case of the isotropic solar radiation model the recommended inclination to receive maximum solar energy is equal to 30°, but in the case of using the anisotropic solar radiation model the inclination is 45°. The best orientation for the whole year operation of any solar receiver is for the azimuth angle of +15° (slightly to the west). This preferably for the West direction is particularly visible in the summer, when the most irradiated surfaces are directed to the south-west, and to a larger extent for azimuth angles from +30 to +90 degrees (the last one refers to the west direction). This phenomenon is caused by a larger share of direct radiation in the afternoon than the morning (in the morning there is often foggy, which weakens the global solar energy flux reaching the earth).

Thus knowing the structure of solar radiation in Poland, it is obvious that only the solar systems which use both direct and diffuse solar radiation can be effectively used in Polish solar radiation conditions. The PV modules use of course both forms of solar radiation, but insolation conditions create preferences for the use of PV installation connected directly to the grid or require the use of various forms and modes of energy storage.

Table 1 gives the mean monthly values of climatic parameters in Warsaw: ambient air temperature, wind velocity, rainfalls, solar radiation on horizontal surface with percentage of diffuse radiation [9]. It can be seen that the ambient air temperature during winter drops below zero, which forces the use of anti-freezing mixture instead of water in solar collector loops in solar thermal systems.

The availability of solar energy depends also on local conditions that can be influenced not only by the climatic parameters but also by local pollution conditions. Figure 5 presents the map of availability of solar energy in Poland that was prepared taking into account both climatic and environmental conditions connected mainly with pollution. The map in Fig. 5 was elaborated 30 years ago and presented in an expert evaluation report on availability of solar energy in the country [6]. That report was the first one official report on possible application of solar energy in the country. It dealt with solar thermal systems only, as photovoltaic technology was completely unknown in those days in the country (it was published 30 years ago). It was the first time when national energy report (solar energy namely) took into account environmental aspects presenting potential of utilization an energy technology. The report included a state of the environment, namely air pollution. The map in Fig. 5 was elaborated using the classification of country's regions regarding their environmental state. It is necessary to underline that this environmental situation has not been changed since then. Thus the best solar energy irradiation conditions

Table 1 The average climatic conditions in Warsaw

Month	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Ambient temperature [°C]	−3.5	−2.6	1.2	7.8	13.8	17.3	19.1	18.2	13.9	8.1	3.0	−0.6
Average wind speed [m/s]	3.5	3.5	3.5	3.25	2.8	2.4	2.45	2.45	2.7	2.82	3.2	3.3
Rainfall [mm]	22	18	29	28	59	82	57	60	41	26	35	36
Solar monthly irradiation [MJ/m^2]	62	102	253	357	494	577	558	475	308	161	60	41
Diffuse radiation ratio [%]	66	65	53	50	47	42	44	44	46	54	67	71

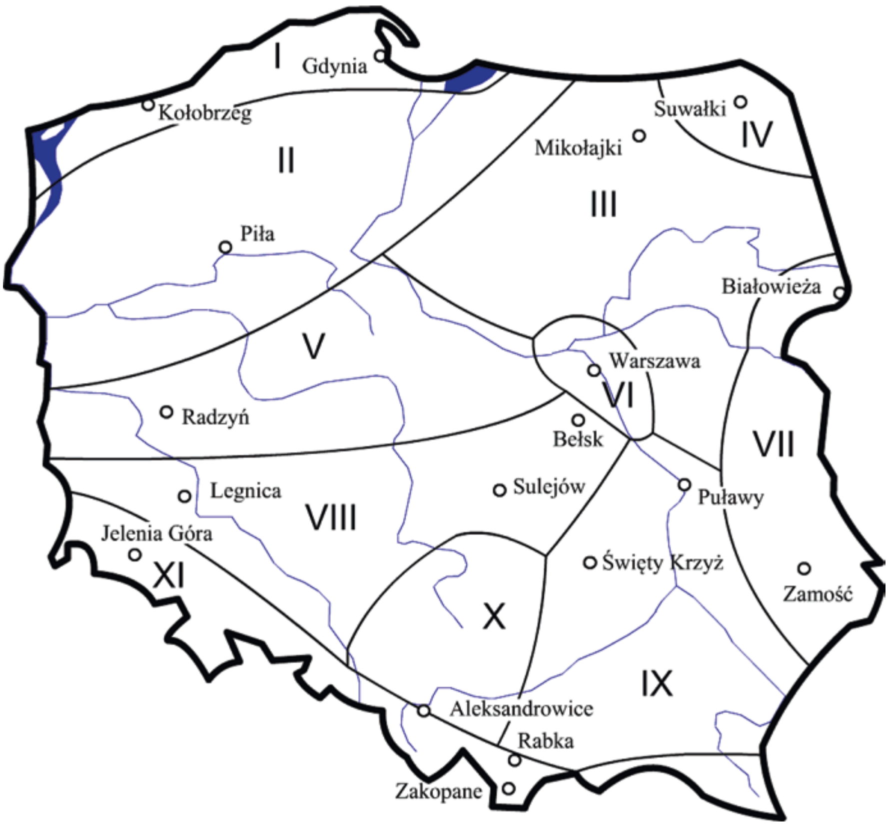

Fig. 5 Regions in Poland according to the availability of solar energy [6]

are in regions: Nadmorski (number I), Podlasko – Lubelski (number VII), Slasko – Mazowiecki (number VIII), and the worst in regions: Warszawski (number VI) and Gornoslaski (number X). The last one is an industrial region with mining and other heavy industry.

For many years not so much effort has been put to reduce environmental pollution. Fortunately, thanks to the accession to the European Union the environmental policy started being treated seriously. In the last years some strong actions have been undertaken, e.g., recently the Clean Air Program. Unluckily, the energy crises caused by the Russian war in Ukraine have stopped many of the important initiatives and actions for environment. Nowadays, the shortage of many fuels, mainly coal and gas can be seen. Due to the lack of these fuels, the government allowed to use traditional methods of burning solid fuels, including biomass of various origins and poor-quality coal, which until recently was forbidden to use at all.

The use of high-emission fuels is not only harmful to the environment and human health, but also significantly reduces the availability of solar radiation. High environmental pollution means the presence of dust in the atmosphere. Dust and pollution particles attach to other particles of the atmosphere, as a consequence, the number of large particles of highly polluted atmospheric aerosol increases. It can be added that traditionally atmospheric aerosol consists of liquid and solid substances, like pollen, bacteria, ashes, sea salt crystals, or soot. Photons of solar radiation, unable to penetrate directly to the earth's surface, are partly dispersed, but mainly absorbed by particles of polluted atmospheric aerosol. As a result of absorption, the internal energy of the molecules increases, which is then radiated as long-wave thermal radiation. As a consequence, the temperature of the atmosphere (hemisphere) increases, and the share of short-wave solar radiation decreases, so less solar radiation can be converted into a useful form of energy.

With reduced solar radiation flux, the ability of solar receivers to effectively gain solar energy is limited [10]. Useful energy gained by solar systems decreases, what is specially evident for photovoltaic modules. In case of solar thermal collectors their useful thermal energy does not drop so much, because apart from the short wave solar radiation they also utilize energy contained in the environment (solar collectors are not only solar receivers but heat exchangers as well). In case of photovoltaic modules, their electricity gains decrease significantly not only due to the lower level of short-wave solar radiation, but also because as the ambient air temperature increases, their efficiency decreases [11]. As a consequence, the power gained decreases and specific cooling methods are recommended to be used [12, 13]. Therefore, in many heavily polluted places on earth, mainly cities and industrialized areas, despite their geographical location (low latitudes), the energy gains of solar photovoltaic installations are not very high, often comparable to those obtained by PV installations operating at much higher latitudes.

3 The Background for Deployment of the PV Systems in the Country

The Past State of the Energy Sector and Its Main Energy Fuel Dependence

To present the background for application of photovoltaic technologies in any country it is necessary to analyze not only climatic conditions, but a state of the energy sector in the country and its main energy fuel dependence.

At the beginning of this chapter the past energy economy of Poland is briefly described to show how it is difficult to develop the energy transformation through the application of distributed energy sources based on renewables, like PV plants, if a country has used to be strongly dependent on one own fossil fuel and the use of which has been centralized for decades. Any changes to such a centralized system carry a high risk, mainly economic, but very often social, too, and not many politicians, decision decision-makers want to take the risk.

In Poland the prevailing view in the communistic energy policy in the last decades of the twentieth century was that the best form of development was to maintain the status quo when everything was planned and managed centrally. No actions, especially no energy transformation activities gave no risk. It was not thought at that time that the existing state of energy generation and transmission sector could not last forever. Maintenance and modernization activities were not a priority. The status quo situation led to the rapid aging of both the power generation blocks themselves and the power grids. What currently results in the lack of the possibility of their cooperation with modern renewable energy systems, when energy generation has a stochastic character, so it can change rapidly in time in unpredictable way, particularly when wind and solar energy are utilized.

The beginning of the economy transition started at the end of twentieth century in Poland, when Poland started to implement its accession plan to become a member of the European Union. In those days the stress was put on reduction of energy intensity of national product mainly through the ownership transformations in the national economy. Then to reduce energy consumption many energy-intensive industrial plants were simply closed down. In those years the economy showed a high dependence on coal (hard and brown), which came from its own domestic resources. The consumption of coal corresponded to 70% of the primary energy. The country was characterized by outstanding position of coal in the energy supply sector for decades. In the electricity generation sector it was especially evident. In those days in electricity production and supply Poland was practically self-sufficient. Coal (hard and brown) in 97% used to be a source of electricity (3% contribution was from hydro energy). The Polish power generation sector was and still is the largest in Central and Eastern Europe. About 97% of Polish electricity sector was generated in 55 coal power plants, of which 33 were combined heat and power (cogeneration CHP) plants [14]. So it is a huge challenge to transform such huge centralized energy sector based on one fossil fuel to distributed energy sources based on solar energy [15], which is widely recognized in the country as unstable and uncertain form of energy in meeting the needs of users.

The central heat supply played and still plays an important role in the Polish energy economy. Heat has been generated in the Combined Heat and Power stations and in Heat (only) Plants since decades. The fuel structure of direct consumption has not been changing significantly for many years. The large cities and factories have been supplied by thermal electric power stations using coal. However, in the new century, the new trends have been noticed, the slightly reduction of solid fuels share (hard and brown coal) to favor of liquid and gaseous fuels (gas, oil), which were imported ones.

District heating used to be and still is a major component of Poland's energy infrastructure. District heating networks supply more than half of Poland's residential heating needs, with 75% in urban areas. The largest district heating network in Europe and the second in the world is in Warsaw, where its total length is 1760 km [16].

It can be easily guessed, that in such economy based on coal, it was no interest in the application of renewables, especially that energy generation and supply sector was highly centralized and it was no place for energy-distributed systems like those based on renewables. However, the situation began to change with Poland's accession to the European Union in May 2004 and since then aspects of reconstruction of energy sector have become a must. As a result the energy efficiency and clean environment policies became more and more important and visible in the energy economy of the country.

And so the Polish government, willy-nilly, had to start creating conditions for the development of renewable energy technologies and their market. Initially, support for renewable energy was more theoretical than practical. Officially, it was declared necessary to increase the share of renewable energy in the country's fuel and primary energy balance, but no legal framework and financial support mechanisms were created to strengthen the role of renewable energy. In particular, there were great concerns about solar energy, as it was widely believed that economically viable energy investments were not possible under Polish climatic conditions. For many years, such a view resulted from the provisions of the National Strategy for the Development of RES, published in the late 1990s [17]. The strategy was adopted by the government and parliament of the country. This document, although it was supposed to promote the development of renewable energy, in fact only supported the use of biomass and contributed to a significant suspension of the development and use of other renewable energy sources for years. It was especially evident in case of photovoltaics. The document stated, among others, that in Polish conditions the use of photovoltaic systems would not be economically viable for at least the next 40 years. Unfortunately, often the lack of knowledge and purely vested interests can lead to create significant obstacles in the development of a given technology and its implementation in practice. It was just a case of photovoltaic technologies. The opinion that the use of PV technology is unprofitable is often visible in contemporary legal documents, such as the basic document for the development of the energy sector in the country, which is the Polish Energy Policy. Such an attitude of disbelief in the widespread effective use of solar energy through the use of photovoltaic technologies is still visible in new strategic government documents, for example, in the latest Polish Energy Policy – PEP until the year 2040 [18]. It can be said that photovoltaics has developed against all odds, and society itself has played an important role in the growth of PV applications.

Fortunately for utilization of solar photovoltaic systems, as well as other renewable energy technologies, in accordance with the European Union energy policy Polish energy sector had to change and move to environmentally friendly technologies. At the beginning, the best way to do that was seen mainly as to be focused on energy efficiency, what of course is always necessary and gives the base for effective utilization of modern renewable energy technologies. Luckily, after several years it turned out that without utilization of renewable energies, it is not possible to reduce energy consumption and environmental pollution highly enough.

4 The Transformation of the Energy Sector Thanks to Accession to European Union

The importance of energy conservation and necessity of using renewables have been indicated in the EU Directives, mainly *Directive of the European Parliament and of the Council on the energy performance of buildings* [19], *Directive of the European Parliament and of the Council on the Energy Efficiency* [20] and *Directive of the European Parliament and of the Council on the promotion of renewable energies* [21]. All those directives support the implementation of new, innovative technologies and modern options of energy conservation, enhancing the use of renewables. They have paid an important role for development of modern energy-saving distributed energy systems, including application of solar systems, and in such a way they help to intensify the pace of the energy transformation process.

Thanks to that legal framework introduced by the directives, reduction of energy consumption and in consequence the environmental pollution have become a priority of the Polish energy economy. However, as presented above, the transformation of large, centralized energy sector into distributed energy sector with energy systems of various sizes and based on different energy sources, mainly renewable energy sources, is not easy, and often seems to be practically impossible for many decision-makers. But thanks to the EU energy policy measures of rational use of energy, which combine energy efficiency from supply and demand sides the utilization of renewables, have been supported by financing mechanisms and regulative framework.

As mentioned before, the basic legal framework for the implementation of renewable energy in the country has been included in the Renewable Energy Act [4]. The Act went into force in the year 2015 and since then it has been amended dozens of times, the most of all national laws (the last change was in June 2022). This Act defines, among others: rules and conditions for conducting activities in the field of electricity generation from renewable energy sources, rules for the implementation of the national action plan in the field of energy from renewable sources or rules for international cooperation in the field of renewable energy sources and joint investment projects. The Act has created a good background for the development of micro-energy systems mainly photovoltaics. It defined the role of the prosumer and created the framework for his activity.

The Act formulated the modes of operation of the prosumer on the domestic energy market, giving huge regulatory support to micro-installations up to the installed capacity of 40 kW initially, and recently 50 kW. Consequently, the Act has given the background to introduce very beneficial financial mechanism for the end user, which is the prosumer. According to this Act till April 2022 the prosumers generating electricity in own PV systems could have used the grid as a virtual energy storage operating with 80% of efficiency. The Act introduced an energy billing system based on net metering and semi-annual billing, with the aforementioned treatment of the grid as an energy store. Such a legal situation caused a huge interest among inhabitants of small cities, villages, suburbs of the cities in investing in micro

Fig. 6 Examples of micro PV systems installed on a roof of a single-family house (right) and small hotel (left)

PV installations, which began to appear like mushrooms after the rain. Examples of such micro PV systems installed on a roof of a single-family house (right) and small hotel (left) are presented in Fig. 6. However, this scheme is not applied anymore. Currently, for new prosumers, the network is no longer treated as an energy store and individual prosumer contracts with energy distribution companies are concluded on the basis of a generally applicable price list.

The introduced regulatory scheme has been enhanced by specific energy–efficiency support mechanisms for renewables, like *Clean Air* or *My current,* which are national or regional projects managed by the National Fund for Environment Protection and Natural Resources or by appropriate regional Funds. They offer special grants and loans for investments in clean energy technologies. The highest share of such support is given to photovoltaics. Despite the fact that new contracts concluded by prosumers with energy distribution companies no longer have the option of using the grid as an energy storage, the number of new investments in photovoltaic micro-installations is still growing rapidly.

Ordinary inhabitants have started to invest in PV systems to be not only energy consumers but also the energy producers to have own energy source and to be responsible not only for the energy consumption, but also generation. The introduced support mechanisms helped to achieve significant benefits in energy consumption, and as a consequence, financial savings. This has contributed to the dissemination of photovoltaic technologies and the development of the domestic photovoltaic market in the country. Nowadays the name of prosumers has become popular and exists in the official regulation language, as has been mentioned before. It should be underlined that nowadays the photovoltaic systems are seen as a huge opportunity for Polish residents to be energy independent from the centralized energy systems and generate on their own the clean energy. It can be said that thanks to the Polish prosumers and their interest in application of the PV technologies, the energy sector has started undergoing its important transformation into decentralized decarbonized energy systems, mainly photovoltaic ones.

In case of large-scale photovoltaic systems the support has been stimulated by two mechanisms: certificates of origin and the auction system. Certificates of origin were introduced as a result of the implementation of the energy efficiency policy (and the EU Directive on energy efficiency [20]). However, they have not caused a huge deployment of the large Photovoltaic systems, even though the property rights of such green certificates could have been and still can be traded on the Polish Power Exchange stock. As a result of the introduction of the Renewable Energy Sources Act since 2016, the certificates have been gradually replaced by the auction systems. Significant changes to this support scheme were made through the amendments of the Act in the last years and development of a large-scale PV systems has been fostered a lot.

The Polish government has approved Poland's energy policy until 2040 (PEP2040) [18]. This document sets the framework for the energy transformation in the country, which is a priority if decarbonization of the Polish economy is to be achieved by the year 2050. It can be mentioned that there were a few years of delay in issuing this strategic document regarding the Polish energy sector, what is not good for the effective development of the energy sector. The document PEP 2040 presents solutions to meet EU climate and energy goals to assure the energy transition toward a zero-emissions economy. In the year 2030, a maximum 56% share of coal-fired power generation should be achieved and complete exit of such plants is expected in 2049. In the year 2030, a minimum 23% share of renewable energy in final energy consumption is planned.

According to PEP2040 by 2040, the heating needs of all households will be covered by district heat supply systems and zero- or low-emission individual energy systems. The latter are defined as systems using heat pumps or electricity. It can be seen that this is a turn toward the electrification of heating sector, where photovoltaics can play an important role. However, it is not mentioned in this strategic document.

It is expected that expansion of the new generation and network infrastructure will lead to the creation of an almost new power system by 2040, based largely on zero-emission sources. This is to be achieved thanks to the development of photovoltaics and offshore wind farms. However, the priority is given to the offshore wind farms due to "their greatest prospects for development". This last statement raises doubts among energy experts, especially those dealing with renewable energy, because the technology is relatively new in the world, and in Poland it has not been used at all so far. It is not good to rely only on imported technology, not to have own experts specialized in that field, and the logistic could be a huge challenge.

Decision-makers all the time do not believe in photovoltaics. According to the PEP2040, it is expected that in the year 2030 installed capacity of all PV plants will be 5–7 GW and in the year 2040 it will 10–16 GW. The document was published in April 2021. In that time the installed capacity of PV systems was already more than 5 GW, so it looks like the authors of that strategic document did not know what was going in the renewable energy sector in the country (they expected such capacity to be reached in 2030!).

Nowadays, the situation with the PV sector looks much better than it was ever expected by any creators of the Polish energy policy. The installed capacity of the PV systems has nearly fully reached the goal declared by the PEP2040 to be in 2040. At the end of 2022 it was at level of 12 GW, while the installed capacity in all generation sources in Poland reached 60 GW. Renewable energy sources accounted for almost 38% (22.6 GW). In the RES sector, photovoltaics ranks first with approximately 54% of the installed capacity [22]. A decade ago, at the end of 2012 the installed capacity in photovoltaics in Poland was 1.5 MW. At the end of 2019 it increased up to 1.6 GW (more than 10 times). Forecasts indicate that the closest milestone of 20 GW installed in PV in Poland will be reached by 2025 [23] (so it is much higher than the goal indicated by the PEP2040 to be reached in 2040).

The last 10 years of deployment of the PV technology are called "the golden decade of Polish photovoltaics". In recent years, the prices of PV installations have changed significantly and have become widely available on the domestic market. Nowadays, PV systems are one of the most acceptable new energy technologies. Solar thermal collectors take the first place, even if they are not so popular nowadays. Quite often new photovoltaic installations next to the previously installed solar thermal collectors can be seen, as it is presented in Fig. 7. Solar thermal collectors are located on a roof of the building, which belongs to the ski lift station. A light roofing structure is attached to the building and photovoltaic modules are

Fig. 7 New photovoltaic installations next to the previously installed solar thermal collectors on a building of the ski lift center

installed on it. The PV installation also represents the micro-system and operates on works on the principles of a prosumer installation.

Renewable energy market in Poland is dominated by photovoltaics. And photovoltaics is dominated by micro-scale systems, thanks to the investment boom that has been going on for several recent years, which was helped by support mechanisms for prosumers. At the end of August 2022, there were 1,132,259 renewable energy prosumers in Poland, of which almost 1,132,000 had photovoltaic installations. The installed capacity in RES micro-installations amounted to 8262.49 MW and was dominated by photovoltaic installations, whose capacity amounted to as much as 8259.43 MW [23]. Prosumers account for 80% of the installed capacity in photovoltaics and their role on the renewable energy market is undeniable in Poland.

5 Application of PV Systems in Poland

As mentioned before, the support mechanisms for micro-installations and individual solar energy prosumers were introduced in recent years and they have led to a huge increase in the number of photovoltaic installations with power from a few to a dozen or so kW, which were and are installed mainly in single-family houses. Photovoltaic systems at the micro scale are relatively easy to be installed, operate, and maintain. Their costs have been reduced significantly, while their efficiencies have been increased. Currently, there are many different technologies available on the market. However, the majority belongs to mono and polycrystalline silicon technologies. The photovoltaic market is currently dominated by micro-installations in the form of BAPV – Building Attached Photovoltaic systems (see Fig. 8).

Figure 8 presents Building Attached Photovoltaic system during its installation on the roof of the building. There are some PV modules already installed on the left side of the roof, while on the right side of the roof there is only the metal construction for further mounting PV modules on the roof. Quite often photovoltaic modules cannot be directly installed on a roof as BAPV systems and then they can be settled on the ground as the detached structures, see Fig. 9, or in the case of horizontal roofs can be placed on them on support mounting constructions, as shown in Fig. 10.

The concept of utilization of renewables in households is mostly based on the implementation of solar energy and heat pumps. This concept refers to new buildings, as well as old buildings under refurbishment. In such buildings the demand for heating (eventually for cooling) and lighting is reduced substantially. The energy is supplied to a building or it is generated in a building with high efficiency with high share of utilization of renewable energy sources. Then the final use of energy by residents is accomplished in effective way. As a result of the application of high thermal standards of the building envelope and its complementarity with the surrounding, and effective operation of energy devices, systems and receivers and smart energy management systems in a building, the final and primary energy consumption in buildings has been significantly reduced. Prosumers using the support system in which the grid is treated as a virtual storage of electrical energy can be

Fig. 8 Single-family house with BAPV system during its installation on the roof of the building

Fig. 9 PV modules settled on the ground as detached structures

practically self-sufficient. This is possible when the PV system is well dimensioned for the solar radiation conditions and the use of the solar energy gained. The best result in being energy self-sufficient is to use heat pump coupled with the PV system operation.

Fig. 10 PV modules placed on horizontal roof on support constructions

In the beginning of this century the solar energy applications in residential and tertiary sectors were connected only with the solar thermal active systems. Those systems were mostly used in the form of low-temperature heating systems with flat plate solar collectors, and later also with vacuum tube collectors. They supplied heat to Domestic Hot Water systems. Later the solar heating systems have been coupled with heat pumps to accomplish total heating needs for DHW and space heating. In those days application of solar thermal systems and heat pumps was not supported by any official regulations and supporting mechanisms. It was just a will of people to have own energy systems. In those years photovoltaic systems were rather completely unknown in the country and in addition they were very expensive.

It is necessary to underline that inclination of a surface exposed to incident solar radiation is very important to assure the high solar energy gains, what has been presented in the first part of this chapter, when climatic conditions were described. The large slope is especially recommended for the application of solar receivers operating in mountains in winter. Usually, the best slope for the annual operation of PV modules or solar collectors is in range 30–45°. In mountains it can be even more because of the snow, which can easily melt on a surface of larger inclination (see Fig. 11) than on a surface of small slope (see Fig. 12). It is necessary to mention, that both pictures were made at the same time in January in Polish mountains and two places are located in a distance of 100 m.

The support mechanisms for micro-installations and individual solar energy prosumers were introduced in recent years and they have led to a huge increase in the number of photovoltaic installations with power from a few to a dozen or so kW, which were and are installed mainly in single-family houses, as already presented. However, the interest in investing in PV systems in multifamily buildings is increasing [24]. This is mainly caused by the increase of electricity prices and new support mechanism for such buildings. Nowadays, grants are available for renewable energy projects (RES projects). They offer the support in the amount of 50% costs of purchase, assembly, construction, or modernization of a RES installation in a

Fig. 11 PV system located on a high slope of the hill in January in Polish mountains

Fig. 12 PV system located on a small slope of the hill in January in Polish mountains

multi-family building, with the upper limit of the support granted not specified. The PV systems are mainly mounted on roofs as the Building Attached Photovoltaic systems, when a roof is inclined, or they are attached to the supporting structures on horizontal roofs.

Up to now rather very rarely the BIPV – Building Integrated PhotoVoltaic systems are used. Some of them can be met in public buildings, as shown in Fig. 13. Sometimes the BIPV systems apply the PV technology called glass–to-glass, where they play an important role not only as electrical energy generator but also are main elements of a daylighting system and have a function of solar shading devices, as presented in Fig. 14.

Large-scale systems are usually built as photovoltaic farms with power from one to hundreds megawatts in the countryside. Nowadays, the largest photovoltaic farm with a capacity of 204 MW is located in Zwartów in Pomerania. It was commissioned in September 2022. The second place is occupied by the PV farm in Brudzewo with power of 70 MW. The third largest farm is in Witnica and has a capacity of

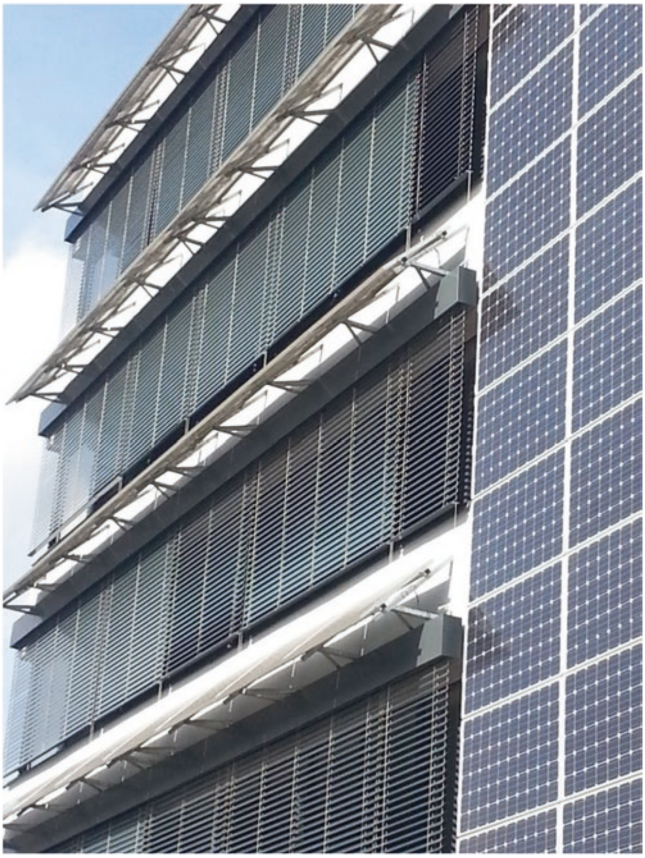

Fig. 13 BIPV – Building Integrated PV systems as cladding and solar shading devices

Fig. 14 BIPV system in a form of glass–to-glass technology

64 MW. All of them belong to different energy groups. Throughout the last year (2022) 362,159 new photovoltaic plants with a total capacity of 4269.8 MW were built. According to the Polish Power Grid company data the last year record was broken on September 7, when at 1 p.m. the photovoltaic plants operated with a capacity of 6711.3 MW. In August, 14,147 GWh of electricity was produced in Poland, of which 11,575 GWh (81%) was provided by conventional power plants, and 2477 GWh (17%) by RES [22]. Photovoltaics covered approximately 8% of energy demand in that months, which was characterized by the best solar irradiation conditions in the last year.

There are many plans for new investments in large-scale PV plants. New investments in photovoltaic installations with a capacity of several megawatts in areas that must undergo intensive reclamation process are characteristic. These include areas of former garbage dumps, mine heaps, areas after opencast lignite mining, etc. Here is great potential for such an environmental transformation of areas related to the extraction of fossil fuels and the place of their storage, into new environmentally clean areas intended for generating energy in a zero-emission way thanks to investments in PV installations constructed and operated in these areas. Nowadays, energy generation and distribution company implementing a photovoltaic farm in Mysłowice with a target capacity of 100 MW can be an example of such a modern ecological energy transition. Over 60,000 PV modules have already been installed in the reclaimed coal combustion waste landfill area, which is 73% planned installations. As a result, the farm is expected to provide 39,000 MWh of green energy annually, which will help reduce carbon dioxide (CO_2) emissions by 30,000 tons compared to generation in coal-fired plants [25].

6 Summary and Final Remarks

After the communist political system, the country underwent a systemic transformation. However, the transformation of energy sector goes very slowly. After many years of centralized energy economy based on using coal as basic raw material and lack of concern for the energy and environment conservation, the transition to distributed energy systems based on renewable energy sources presents a huge challenge for the energy sector. The situation of urban heating networks and centralized energy systems is especially difficult in large cities. Therefore, the energy transformation in big urban areas should be implemented gradually. The easiest way should be to develop distributed small renewable energy systems cooperating with the national power grid and step by step substitute the central district heating systems by such small RES systems where the photovoltaics can pay the basic role of energy generation system.

It should be underlined that utilization of renewables is well perceived by society. It is the previous monopolistic energy economy that causes the society to want to liberate itself from these old centrally controlled and managed energy structures. People strive to have their own independent energy systems and sources. And it is renewable energy that gives them such an opportunity. Therefore, from the beginning of the implementation of the new energy policy focused on energy efficiency and taking into account the possibility of using new renewable energy sources, it is the role of the inhabitants of cities and villages in the pursuit of energy independence and the use of their own renewable energy resources. Thus the regular energy consumers have become the main initiators to implement the renewable energy technologies.

Poland declared and confirmed in the national Energy Policy till 2040 [3] that the share of renewable energy for the heating and cooling will increase by 1.1% annually. For several dozen years, the central heating system provided easy and cheap access to heat for the entire city. This advantage of a very centralized operation of the heating system is now becoming the main obstacle in the fast, and energy and economic efficient transition to a modern low-temperature heating system of the fourth or fifth generation, where the heat pumps will be the main heating devices and they will be powered by the electricity generated by the photovoltaic and wind farms, as the process of electrification of the heat supply system is developing.

Concluding it can be said, that application of photovoltaic systems is for sure a challenge for the Polish energy sector, but the same time it is huge opportunity for its green transformation, going to zero-emission economy of the country so much experienced for many years by centralized energy sector based on utilization of fossil fuels applied with low efficiency of their conversion into final energy. It must be underlined, that any transition of economy of a country cannot go without acceptance of the society. The role of society in their support for investment in environmentally clean energy technologies can be seen, especially among young people. This is particularly reflected in small investments in own micro PV systems. The will of ordinary people to buy and use the PV systems is of course also related to the financial benefits that they can achieve thanks to the reduction in consumption of conventional energy based on fossil fuels, which costs a lot nowadays.

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